

User Guide for MOD09GFS and MOD15GFS

Version 1.0

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Note:

This Guide is a living document that describes the smoothed and gap-filled MODIS VIs (LAI/FPAR from MOD15A2, and EVI/NDVI calculated from MOD09A2 and MOD09Q2). It is revised as progress is made in the development of these products. The purpose of the document is to give the potential user an understanding of the MOD09GFS and MOD15GFS products and the current state of the data in those products.

Introduction:

The Moderate Resolution Imaging Spectroradiometer (MODIS) is a key instrument aboard NASA's Terra and Aqua satellites. Both Terra and Aqua image the entire Earth's surface every 1 to 2 days, and provide vital information for global change research. MODIS land products are critical inputs to parameterize, calibrate, and validate climate and ecosystem process models [1]-[3].

MODIS land products have been validated with independent field measurements [4] but generally under clear-sky conditions (see MODIS land validation web site landval.gsfc.nasa.gov). However, cloud contamination and other sub-optimal atmospheric or illumination conditions not only reduce data quality but also result in missing data in

multi-day land products. Although MODIS LAI/FPAR and EVI/NDVI products will produce results even under cloudy or sub-optimal condition, care is taken to use the MODIS quality assessment (QA) data layers to flag these values as lower or poor quality [1], [3]. Such a scenario is not acceptable for those ecosystem or climate models that require realistic, high quality, temporally and spatially continuous measurements.

Algorithm and Methodology:

1. Calculating EVI/NDVI

EVI and NDVI are calculated from MODIS surface reflectances as following:

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

$$EVI = G \frac{NIR - RED}{NIR + C_1 \cdot RED - C_2 \cdot BLUE + L} \quad (2)$$

Where

$$L = 1, C_1 = 6, C_2 = 7.5 \text{ and } G = 2.5 \text{ [3].}$$

500-m EVI/NDVI are calculated from 500-m resolution MODIS surface reflectance (MOD09A1). 250-m NDVI is calculated from 250-m resolution red and NIR reflectances (MOD09Q1). The 250-m blue reflectance is not available. Therefore, 500-m data from MOD09A1 is interpolated to 250-m for calculating 250-m EVI.

2. Smoothing with TIMESAT

Jonsson and Eklundh developed the TIMESAT program (2004) for smoothing time-series satellite sensor data [5]. This program provides three different smoothing functions to fit time-series data: asymmetric Gaussian, double logistic, and adaptive Savitzky-Golay filtering. The adaptive Savitzky-Golay filtering approach uses local polynomial functions in fitting. It can capture subtle and rapid changes in the time-series but is also sensitive to noise. Both asymmetric Gaussian and double logistic approaches use semi-local methods. They are less sensitive to the noise and can give better description on the beginnings and endings of the seasons. We found that both asymmetric Gaussian and double logistic approaches in the TIMESAT program produced similar results with the exception that asymmetric Gaussian approach is less sensitive to the incomplete time-series data. This is a significant advantage considering many data gaps existing in satellite observations due to cloud etc. Therefore, the asymmetric Gaussian method was selected for temporally smoothing the data.

The base function of Asymmetric Gaussian is:

$$g(t, x_1, x_2, \dots, x_5) = \begin{cases} \exp\left[-\left(\frac{t - x_1}{x_2}\right)^{x_3}\right] & \text{if } t > x_1 \\ \exp\left[-\left(\frac{x_1 - t}{x_4}\right)^{x_5}\right] & \text{if } t < x_1 \end{cases} \quad (3)$$

For this function x_1 determines the position of the maximum or minimum with respect to the independent time variable t , while x_2 and x_3 determine the width and flatness (kurtosis) of the right function half. Similarly, x_4 and x_5 determine the width and flatness of the left half. The details of the algorithm could be found at [5].

3. Second smoothing with adjusted weight

After applying the TIMESAT fitting with the initial weights, the weights are adjusted based on the fitted results from first iteration [6]. The original data weights for the second run through TIMESAT are based on the difference between the original data and the fitted value, scaled by the standard deviation. Specifically, the new weights are:

$$w' = w \left[1 / \left(1 + \frac{|dy|}{S\sigma} \right) \right], \text{ if } dy \leq 0 \text{ (MODIS value is below TIMESAT curve)} \quad (4)$$

$$w' = w \left(1 + \frac{|dy|}{S\sigma} \right), \text{ if } dy > 0 \text{ (MODIS value is above TIMESAT curve)} \quad (5)$$

where dy is the difference between the original MODIS value and the TIMESAT fitted values, σ is the standard deviation of $\{dy_i\}$ (standard deviation of residuals from first fitting, where i represents all high quality data), and S is a constant parameter for the weight adjustment.

This process is similar to the upper envelope-weighting scheme in the TIMESAT software [5] that forces the curve to fit upper values more closely. The upper envelope option has been tested for VIs and is very effective because high parameter values normally represent clear sky conditions or better viewing or illumination geometry [6].

4. Spatial Gap-filling

The TIMESAT program can only produce fitted values if there are enough high quality data in the time-series. Values will not be produced if there are too many missing values because the fitting function becomes unreliable if it is forced to do so. Also, some fits may be unrealistic (e.g., out of the data range) due to noise or limitations of the fitting function. In these cases, instead of trying to fit a curve to the smaller number of high quality data points, we use a separate gap filling process [6].

All pixels with the same landcover type falling into an adaptive window are used to calculate an ‘‘ancillary seasonal curve’’. The size of the window increases from 5 x 5 to 100 x 100 until a mean value is available. If the mean value is not available, all pixels with the same landcover type within the processing tile are used to calculate the seasonal curve.

Once the ancillary seasonal curve, $f_n(t, c)$ is found, a regression transform function $r(x)$ is computed such that the temporal variation curve of the gap pixel can be computed using $r(f_n(t, c))$. The parameters of this transform function are determined strictly by the high quality data pairs between the case 2 pixel with gaps and the ancillary seasonal curves using least square approach with cost function

$$M_g(t_i, c) = r(f_n(t_i, c)) + \varepsilon \quad (6)$$

where subscript n represents neighbor pixel, subscript g represents current gap pixel, t_i represent the i^{th} production date, c represents land cover type, ε are the errors between gap values and curve values, $M_g(t_i, c)$ represents all available high quality MODIS data of the gap pixel, and $f_n(t_i, c)$ is the TIMESAT seasonal variation curve from neighbor pixel (strategy 1) or tile-level average (strategy 2). We use the 2nd order polynomial function for the computation, i.e., $r(x) = ax^2 + bx + c$. The seasonal variation curve $f_g(t, c)$ of the gap pixel is computed using

$$f_g(t, c) = r(f_n(t, c)) \quad (7)$$

The algorithm allows flexibility in the time window used to compute the transfer function. In the extreme, the function can be fit with all high quality data pairs from the entire time series being considered. Alternatively, the algorithm can use a local window of high quality data pairs within a subset period, centered on the date of the gap being filled. There is a trade-off between having enough observations to fit the transfer function vs. a small enough window to capture inter-annual data variations. In this paper, we used one year period as local moving time window in a way that a gap pixel at each production date is computed from the two half year periods before and after [6].

The data flow of the smoothing/gap-filling algorithm is as the following chart:

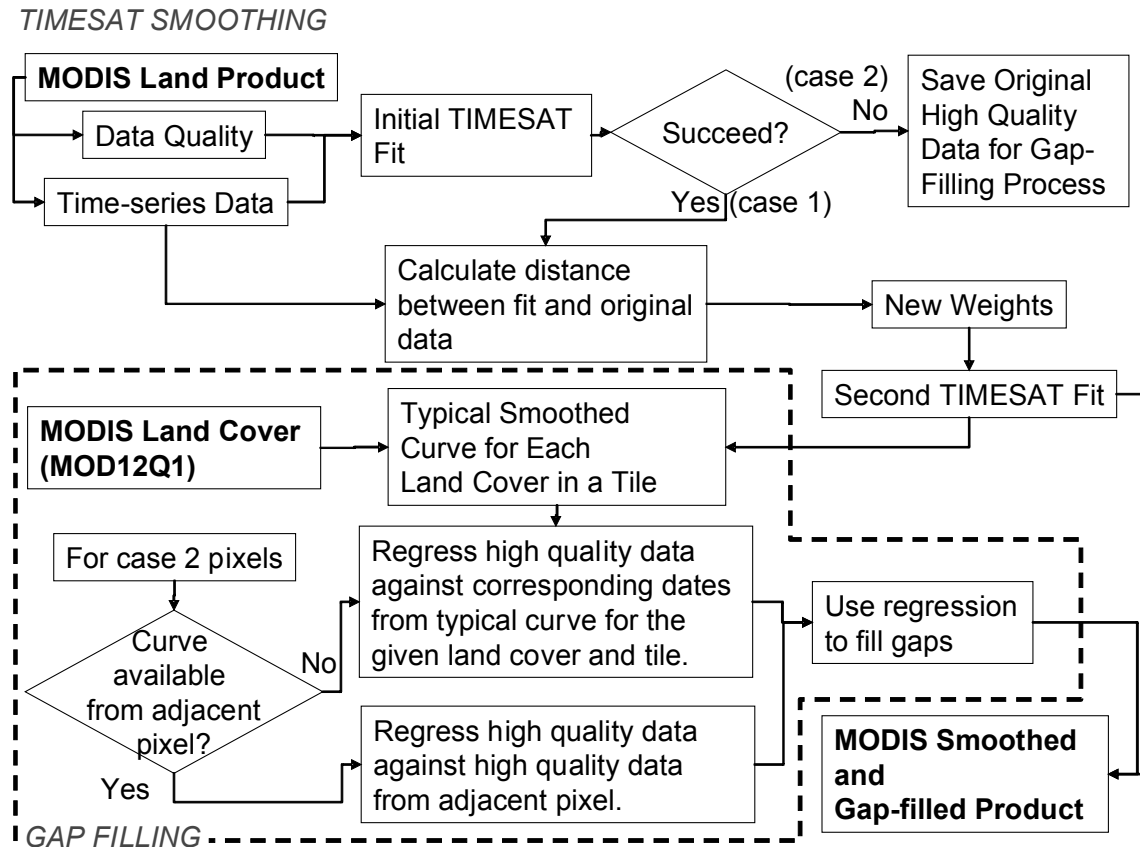


Figure 1: Flow diagram of the TIMESAT temporal fitting and gap-filling (dashed box) procedure. (This figure is copied from the Figure 1 in [6]).

Scientific data set:

MOD09GFS refers to four data sets – MOD09A1_EVI, MOD09A1_NDVI, MOD09Q1_EVI, and MOD09Q1_NDVI. NDVI and EVI are calculated from MODIS surface reflectance products (MOD09). “A1” products are in 500-m resolutions, and “Q1” products are in 250-m resolutions. MOD15GFS is generated from MOD15A2 8-day LAI products. The spatial resolution is 1-km. MOD09GFS and MOD15GFS are stored in Hierarchical Data Format (HDF) with sinusoidal projection, same as other standard MODIS land products.

The details of the SDS for smoothed/gap-filled products estimated from the NDVI is outlined as an example:

```

Layer-1 MODIS_NDVI(short 16-bits):
long_name = "MODIS NDVI Computed from MOD09A1" ;
scale_factor = 0.0001 ;
valid_range = -2000s, 10000s ;
FillValue = 32767s ;
  
```

Layer-2 Smoothed_NDVI(short 16-bits):

long_name = "Gap-Filled and Timesat-Smoothed NDVI" ;
scale_factor = 0.0001 ;
valid_range = -2000s, 10000s ;
FillValue = -3000s ;

Layer-3 Composed_NDVI(short 16-bits):

long_name = "Composed NDVI from MODIS and Timesat" ;
scale_factor = 0.0001 ;
valid_range = -2000s, 10000s ;
FillValue = -3000s ;

Layer-4 MODIS_NDVI_QC(unsigned char 8-bits):

long_name = "MODIS NDVI Retrieval Quality" ;
description =
 "1 = MODIS high quality, timesat good fit\n",
 "2 = MODIS high quality, timesat moderate fit\n",
 "3 = MODIS low quality\n",
 "4 = not produced" ;

Layer-5 Smoothed_NDVI_QC(unsigned char 8-bits):

long_name = "Gap-Filled and Timesat-Smoothed NDVI Quality" ;
description =
 "1 = timesat\n",
 "2 = gap-filled\n",
 "3 = rounded\n",
 "4 = fill value" ;

Layer-6 Composed_NDVI_QC(unsigned char 8-bits):

long_name = "Composed NDVI Quality" ;
description =
 "1 = high quality MODIS NDVI\n",
 "2 = smoothed NDVI\n",
 "3 = fill value from MODIS" ;

The detail SDS information for smoothed/gap-filled LAI/FPAR products is

Layer-1 MODIS_LAI(unsigned char 8-bits):

long_name = "Original MODIS LAI" ;
scale_factor = 0.1 ;
valid_range = '0', '100' ;
FillValue = '255' ;
fill_value_legend = "MOD15A1 FILL VALUE LEGEND\n",
 "255 : _Fillvalue: not-computed or outside projection...\n",
 "254 : water (ocean or inland)\n",
 "253 : barren, very sparsely vegetated\n",
 "252 : perennial snow,ice on pixel\n",
 "251 : permanant wetlands,marshes\n",
 "250 : urban,built-up \n",
 "249 : unclassified\n",

Layer-2 Smoothed_LAI(unsigned char 8-bits):

long_name = "Gap-Filled and Timesat-Smoothed LAI" ;

scale_factor = 0.1 ;

valid_range = '0', '100' ;

FillValue = '255' ;

Layer-3 Composed_LAI(unsigned char 8-bits):

long_name = "Composed LAI from MODIS and Timesat" ;

scale_factor = 0.1 ;

valid_range = '0', '100' ;

FillValue = '255' ;

fill_value_legend =

"255 : _Fillvalue: not-computed or outside projection...\n",

"254 : water (ocean or inland)\n",

"253 : barren, very sparsely vegetated\n",

"252 : perennial snow,ice on pixel\n",

"251 : permanant wetlands,marshes\n",

"250 : urban,built-up \n",

"249 : unclassified\n",

Layer-4 MODIS_FPAR(unsigned char 8-bits):

long_name = "Original MODIS FPAR" ;

scale_factor = 0.01 ;

valid_range = '0', '100' ;

FillValue = '255' ;

fill_value_legend =

"255 : _Fillvalue: not-computed or outside projection...\n",

"254 : water (ocean or inland)\n",

"253 : barren, very sparsely vegetated\n",

"252 : perennial snow,ice on pixel\n",

"251 : permanant wetlands,marshes\n",

"250 : urban,built-up \n",

"249 : unclassified\n",

Layer-5 Converted_FPAR(unsigned char 8-bits):

long_name = "Converted FPAR from LAI-FPAR LUT" ;

scale_factor = 0.01 ;

valid_range = '0', '100' ;

FillValue = '255' ;

Layer-6 Composed_FPAR(unsigned char 8-bits):

long_name = "Composed FPAR from MODIS and Converted FPAR" ;

scale_factor = 0.01 ;

valid_range = '0', '100' ;

FillValue = '255' ;

fill_value_legend =

"255 : _Fillvalue: not-computed or outside projection...\n",

"254 : water (ocean or inland)\n",
"253 : barren, very sparsely vegetated\n",
"252 : perennial snow,ice on pixel\n",
"251 : permanant wetlands,marshes\n",
"250 : urban,built-up \n",
"249 : unclassified\n",

Layer-7 MODIS_LAI_FPAR_QC(unsigned char 8-bits):

long_name = "MODIS LAI/FPAR Retrieval Quality" ;

description =

"1 = MODIS high quality, timesat good fit\n",
"2 = MODIS high quality, timesat moderate fit\n",
"3 = MODIS low quality empirical model\n",
"4 = not produced due to cloud etc." ;
"255 : _Fillvalue: not-computed or outside projection...\n",
"254 : water (ocean or inland)\n",
"253 : barren, very sparsely vegetated\n",
"252 : perennial snow,ice on pixel\n",
"251 : permanant wetlands,marshes\n",
"250 : urban,built-up \n",
"249 : unclassified\n",

Layer-8 Smoothed_LAI_FPAR_QC(unsigned char 8-bits):

long_name = "Gap-Filled and Timesat-Smoothed LAI/FPAR Quality" ;

description =

"1 = timesat\n",
"2 = gap-filled\n",
"3 = rounded\n",
"4 = fill value" ;

Layer-9 Composed_LAI_FPAR_QC(unsigned char 8-bits):

long_name = "Composed LAI/FPAR Quality" ;

description =

"1 = high quality MODIS data\n",
"2 = smoothed data\n",
"3 = fill value from MODIS" ;

Reference

[1] R. B. Myneni, S. Hoffman, Y. Knyazikhin et al., "Global products of vegetation leaf area and fraction absorbed PAR from year one of MODIS data," Remote Sens. Environ., vol. 83, pp. 214-231, 2002.

[2] C. B. Schaaf, F. Gao, A. H. Strahler et al., "First operational BRDF, albedo and nadir reflectance products from MODIS," Remote Sens. Environ., vol. 83, pp. 135-148, 2002.

[3] A. Huete, K. Didan, T. Miura et al., "Overview of the radiometric and biophysical performance of the MODIS vegetation indices," *Remote Sens. Environ.*, vol. 83, pp. 195-213, 2002.

[4] J. T. Morisette, J. L. Privette, et al., "A framework for the validation of MODIS Land products," *Remote Sens. Environ.*, vol. 83, pp. 77-96, 2002.

[5] P. Jonsson and L. Eklundh, "TIMESAT - a program for analyzing time-series of satellite sensor data," *Computers & Geosci.*, vol. 30, pp. 833-845, 2004.

[6] F. Gao, J. T. Morisette, R. E. Wolfe, G. Ederer, J. Pedelty, E. Masuoka, R. Myneni, B. Tan, and J. Nightingale. An algorithm to produce temporally and spatially continuous MODIS-LAI time series. *IEEE Geosci. Remote Sens. Lett.*, vol. 5, 2008