

VIIRS Global Land Surface Phenology Product User Guide

Version 1.0

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VIIRS LSP User Guide

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VIIRS LSP User Guide

TABLE OF CONTENTS

| | <u>Page</u> |
|--|-------------|
| LIST OF TABLES AND FIGURES | 4 |
| 1. Products | 5 |
| 1.1. Product Overview | 5 |
| 1.2. Product History | 6 |
| 1.3. Product Access..... | 6 |
| 2. Detailed Product Descriptions | 7 |
| 2.1. Vegetation growing cycle and data cycle in the output GLSP product..... | 10 |
| 2.2. Metadata information | 12 |
| 2.3. Data groups and datasets..... | 19 |
| 3. Algorithm Description | 20 |
| 3.1. Detection of phenological metrics..... | 20 |
| 3.2. Confidence of phenological metrics..... | 21 |
| 4. Related Web Sites..... | 22 |
| 5. References..... | 22 |

VIIRS LSP User Guide

LIST OF TABLES AND FIGURES

| | <u>Page</u> |
|--|-------------|
| Table 1. Scientific data sets in the VIIRS GLSP product. | 8 |
| Table 2. Values of GLSP_QC (8-bit) | 9 |
| Figure 1. VIIRS Sinusoidal “10-degree” tile system. GLSP distributes in 286 tiles with vegetated pixels located between 60°S to 80°N. | 5 |
| Figure 2. Characteristics of vegetation growing cycles during a 12-month period (current year). | 10 |
| Figure 3. Data cycles recorded in GLSP product during a calendar year. Solid line represents data cycle 1 while dashed line represents data cycle 2. The solid dots are the four phenological dates in the data cycle 1 (first data layer) and solid triangles are the four phenological dates in the data cycle 2 (second data layer). | 11 |
| Figure 4. An example of recording metrics related to growing season length if a growing season spans parts of preceding year and current year. Cycle 1 refers to the first data cycle (layer) and Cycle 2 refers to the second one in the product. GO - greenup onset and DO - dormancy onset.. | 12 |
| Figure 5. The structure of data groups and datasets..... | 19 |
| Figure 6. Schematic illustrating how transition dates are estimated from HPLM-LSPD algorithm. . | 21 |

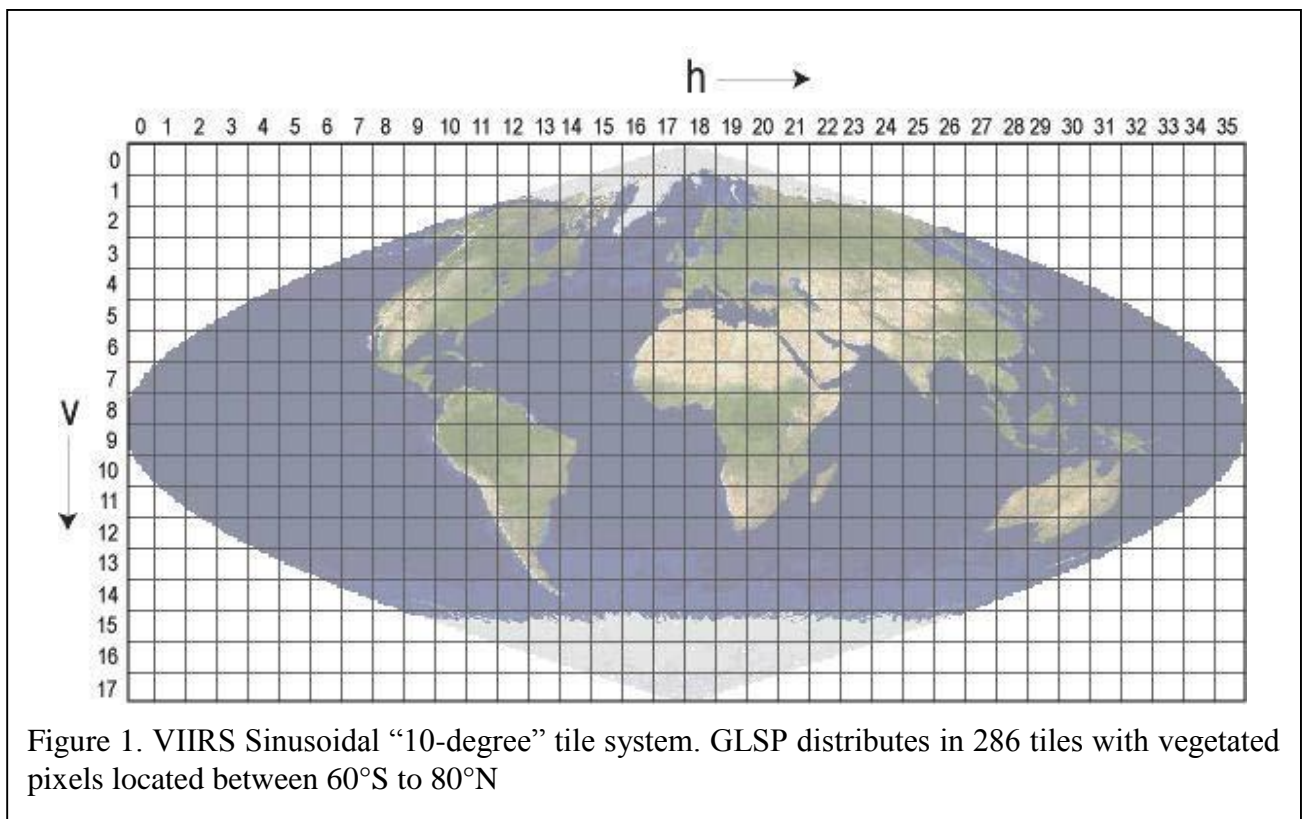
VIIRS LSP User Guide

1. Products

This is an external user guide document describing the NASA Visible Infrared Imaging Radiometer Suite (VIIRS) Global Land Surface Phenology (GLSP) product and output format. The VIIRS LSP product algorithm was developed at South Dakota State University and Boston University and the product is operationally produced and distributed in NASA.

1.1. Product Overview

The VIIRS GLSP produces phenological metrics in individual vegetation growing cycles on the vegetated land surface at a spatial resolution of 500 m across the globe. The product is generated using daily VIIRS Nadir BRDF (bidirectional reflectance distribution function)-Adjusted reflectance (NBAR) and ancillary data of VIIRS land surface temperature (LST), snow cover, and land cover type at each pixel as inputs. The VIIRS NBAR is used to generate time series of two band enhanced vegetation index (EVI2) that characterizes temporal vegetation phenology development. The product contains seven metrics describing the occurrence timings of vegetation phenological events. As a supplement to the phenological timings, it also includes five metrics related to the range, change rate, and summation of vegetation greenness (EVI2) calculated from VIIRS surface reflectance data. Moreover, the GLSP product also provides seven metrics to quantify the quality of phenological timing and greenness measurements in each pixel.



VIIRS LSP User Guide

The VIIRS GLSP product is a level 3 product and follows the structure and file format in the high level of global VIIRS data. The data are saved in HDF-EOS5 (Hierarchical Data Format - Earth Observing System) file format with Sinusoidal map projection. Based on this project, the GLSP product is recorded in tiles that is approximately $10^{\circ} \times 10^{\circ}$ in size on the earth surface. Each tile is assigned a horizontal (H) and vertical (V) coordinate, ranging from 0 to 35 and 0 to 17, respectively (Figure 1). The tile in the upper left (i.e. northernmost and westernmost) corner is numbered (0,0). The GLSP product is distributed in 286 land tiles located between 60°S to 80°N . At a spatial resolution of 500 m GLSP, each tile is composed of 2400 columns and 2400 rows. It produces one file of phenological metrics for each tile once a year.

1.2. Product History

VIIRS GLSP is a continuous phenology product to replace the MODerate-resolution Imaging Spectroradiometer (MODIS) product. MODIS GLSP is called MODIS Land Cover Dynamics, (MOD12Q2) at a spatial resolution of 500 m. MOD12Q2 has been produced using algorithms developed at Boston University since 2001 based on the observations from both Terra and Aqua MODIS, in which surface is observed twice a day in daytime with more chances to obtain cloud-free data than VIIRS observations. In MOD12Q2 product, the phenological metrics are stored in a HDF4 file for each tile. Because MODIS is aging, VIIRS GLSP will replace MOD12Q2 to continue monitoring global phenology variation. VIIRS GLSP is produced using time series of daily VIIRS observations and contains well qualified confidence of phenology detections. The output files are written in a HDF-EOS5 format.

1.3. Product Access

VIIRS GLSP output files will be made available to users free of charge. Like most of the VIIRS land products, VIIRS GLSP can be obtained from the Land Processes Distributed Active Archive Center (LP-DAAC) using a Web-based interface known as *Reverb*, a replacement for the *Warehouse Inventory Search Tool* (WIST), and before that the older *EOS Data Gateway*. Thus the product can be found at the following URL:

Earth data Search Client: <https://search.earthdata.nasa.gov/>

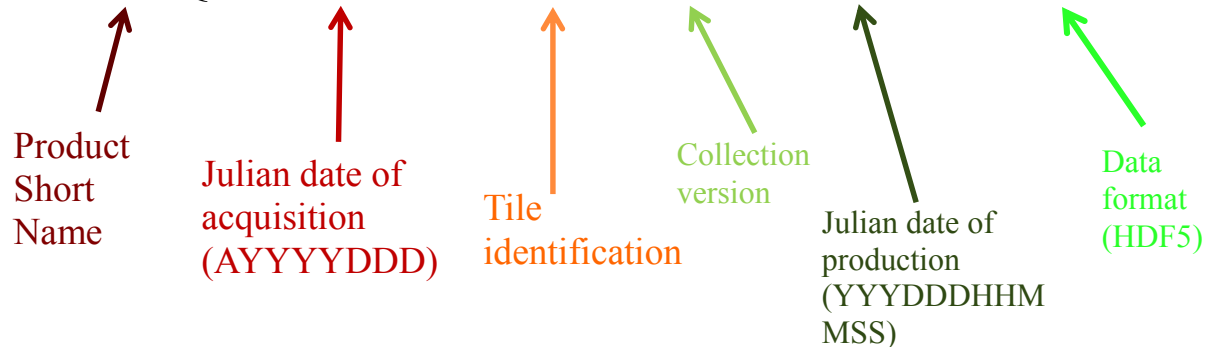
Reverb: <http://reverb.echo.nasa.gov/>

LP DAAC FTP: <https://e4ftl01.cr.usgs.gov/VIIRS/>

VIIRS GLSP at a 500m resolution is named as following:

File name format:

VNP12Q2.A2015001.h11v04.001.2017120122020.h5



2. Detailed Product Descriptions

The standard VIIRS GLSP product is produced yearly at a spatial resolution of 500 m. This product contains six phenological transition dates that are (Table 1):

- **Onset_Greenness_Increase:** the date of onset of greenness increase (greenup onset, start of growing season, or start of spring);
- **Onset_Greenness_Maximum:** the date at which canopy greenness approaches its seasonal maximum (maturity onset or end of spring);
- **Onset_Greenness_Decrease:** the date at which canopy greenness begins to decrease (senescence onset or start of fall);
- **Onset_Greenness_Minimum:** the date at which canopy greenness reaches a minimum (dormancy onset, end of growing season, or end of fall);
- **Date_Mid_Greenup_Phase:** the date at a mid-greenup phase (mid-greenup phase or middle of spring);
- **Date_Mid_Senescence_Phase:** the date at a mid-senescence phase (mid-senescent phase or middle of fall).

The product also includes another timing metrics that is the growing season length (**Growing_season_length**), which quantifies the time period between the dates of greenup onset and dormancy onset. The greenness related metrics in the GLSP product are:

- **EVI2_Onset_Greenness_Increase:** the EVI2 value at greenup onset, which is close to the minimum greenness during a growing season;
- **EVI2_Onset_Greenness_Maximum:** the EVI2 value at maturity onset, which is close to the maximum greenness during a growing season;
- **EVI2_Growing_Season_Area:** the integrated EVI2 during a growing season (from greenup onset to dormancy onset);
- **Rate_Greenness_Increase:** the rates of change in EVI2 values during a greenup phase;
- **Rate_Greenness_Decrease:** the rates of change in EVI2 values during a senesce phase.

VIIRS LSP User Guide

Table 1. Scientific data sets in the VIIRS GLSP product.

| Scientific Data Sets | Units | Bit Type | Fill Value | Valid Range | Scale Factor |
|---|----------------|-------------------------|------------|-------------|---------------------------------------|
| <u>Onset Greenness Increase</u> | Day | 16-bit unsigned integer | 32767 | 1-32766 | DOY=file data - (given year-2000)*366 |
| <u>Onset Greenness Maximum</u> | | | | | |
| <u>Onset Greenness Decrease</u> | | | | | |
| <u>Onset Greenness Minimum</u> | | | | | |
| <u>Date Mid Greenup Phase</u> | | | | | |
| <u>Date Mid Senescence Phase</u> | | | | | |
| <u>Growing Season Length</u> | Number of days | 16-bit unsigned integer | 32767 | 1-366 | N/A |
| <u>EVI2 Onset Greenness Increase</u> | EVI2 | 16-bit unsigned integer | 32767 | 1-10000 | EVI2=file data*0.0001 |
| <u>EVI2_Onset_Greenness_Maximum</u> | EVI2 | | | | |
| <u>EVI2_Growing_Season_Area</u> | EVI2 | 16-bit unsigned integer | 32767 | 1-32766 | EVI2=file data*0.01 |
| <u>Rate Greenness Increase</u> | EVI2 per day | 16-bit unsigned integer | 32767 | 1-32766 | EVI2/day=file data*0.0001 |
| <u>Rate Greenness Decrease</u> | | | | | |
| <u>Greenness Agreement Growing Season</u> | Dimensionless | 8-bit unsigned integer | 255 | 0-100 | N/A |
| <u>PGQ Growing Season</u> | | | | | |
| <u>PGQ Onset Greenness Increase</u> | | | | | |
| <u>PGQ Onset Greenness Maximum</u> | | | | | |
| <u>PGQ Onset Greenness Decrease</u> | | | | | |
| <u>PGQ Onset Greenness Minimum</u> | | | | | |
| <u>GLSP_QC</u> | | | | | |

The confidence of phenology detections is provided in six data sets (Table 1). They are:

- Greenness_Agreement_Growing_Season: the EVI2 agreement between modeled values and raw observations with good quality (cloud free observations) during a vegetation growing season;
- PGQ_Growing_Season: the proportion of good quality (PGQ) of VIIRS observations during a vegetation growing season, in which the good quality observations are counted as the number of three 3-day moving windows that contain good quality observations;
- PGQ_Onset_Greenness_Increase: PGQ around greenup onset, which is calculated as the proportion of 3-day good observations during the periods of 3 3-day EVI2 composite before and after the greenup onset;

VIIRS LSP User Guide

- **PGQ_Onset_Greenness_Maximum:** PGQ around maturity onset, which is calculated as the proportion of 3-day good observations during the periods of 3 3-day EVI2 composite before and after the maturity onset;
- **PGQ_Onset_Greenness_Decrease:** PGQ around senescence onset, which is calculated as the proportion of 3-day good observations during the periods of 3 3-day EVI2 composite before and after the senescence onset;
- **PGQ_Onset_Greenness_Minimum:** PGQ around dormancy onset, which is calculated as the proportion of 3-day good observations during the periods of 3 3-day EVI2 composite before and after the dormancy onset.

The last data set is quality control (QC, GLSP_QC). QC is produced at each pixel based on overall quality assurance (QA), which specifies the overall quality of the product. Several bit fields are passed through from the corresponding VIIRS Albedo/NBAR (VNP43I4 and VNP43I2) products, particularly the land/water mask. The bit patterns are parsed from right to left and the interpretation of bit-strings is presented in Table 2.

Table 2. Values of GLSP_QC (8-bit)

| <i><u>Bit No.</u></i> | Parameter Name | Bit Comb | GLSP_QC |
|-----------------------|-------------------|----------|--|
| 0-2 | Mandatory Quality | 000 | 0=processed, good quality |
| | | 001 | 1= processed, other quality |
| | | 010 | 2=processed, backup algorithm |
| | | 011 | 3= not processed, bad quality |
| | | 100 | 4=not processed, other |
| 3-4 | TBD | TBD | TBD |
| 5-7 | Land/water mask | 000 | 0 = Shallow ocean |
| | | 001 | 1 = Land (Nothing else but land) |
| | | 010 | 2 = Ocean coastlines and lake shorelines |
| | | 011 | 3 = Shallow inland water |
| | | 100 | 4 = Ephemeral water |
| | | 101 | 5 = Deep inland water |
| | | 110 | 6 = Moderate or continental ocean |
| | | 111 | 7 = Deep ocean |

VIIRS LSP User Guide

2.1. Vegetation growing cycle and data cycle in the output GLSP product

The cycle of the vegetation growing season differs geographically, especially between Northern and Southern Hemispheres (Figure 2). Further, vegetation growth can have one or more growing cycles (or parts of growing cycles) during a 12-month period (calendar). Each full vegetation growing cycle starts from greenup onset and ends at dormancy onset. To record possible multiple growing cycles, the algorithm used for this product allows to record a maximum of two data layers for each phenological event in a given calendar year. If the product data are recorded based on vegetation growing cycles, which are the first and second data layers for the first and second growing cycles, separately, any phenological events in the third vegetation growing cycle are unable to be recorded in the given year (such as Figure 2f-h). To fully record the vegetation growing cycles without increasing the data size of output file, the VIIRS GLSP product records data cycles that are different from the

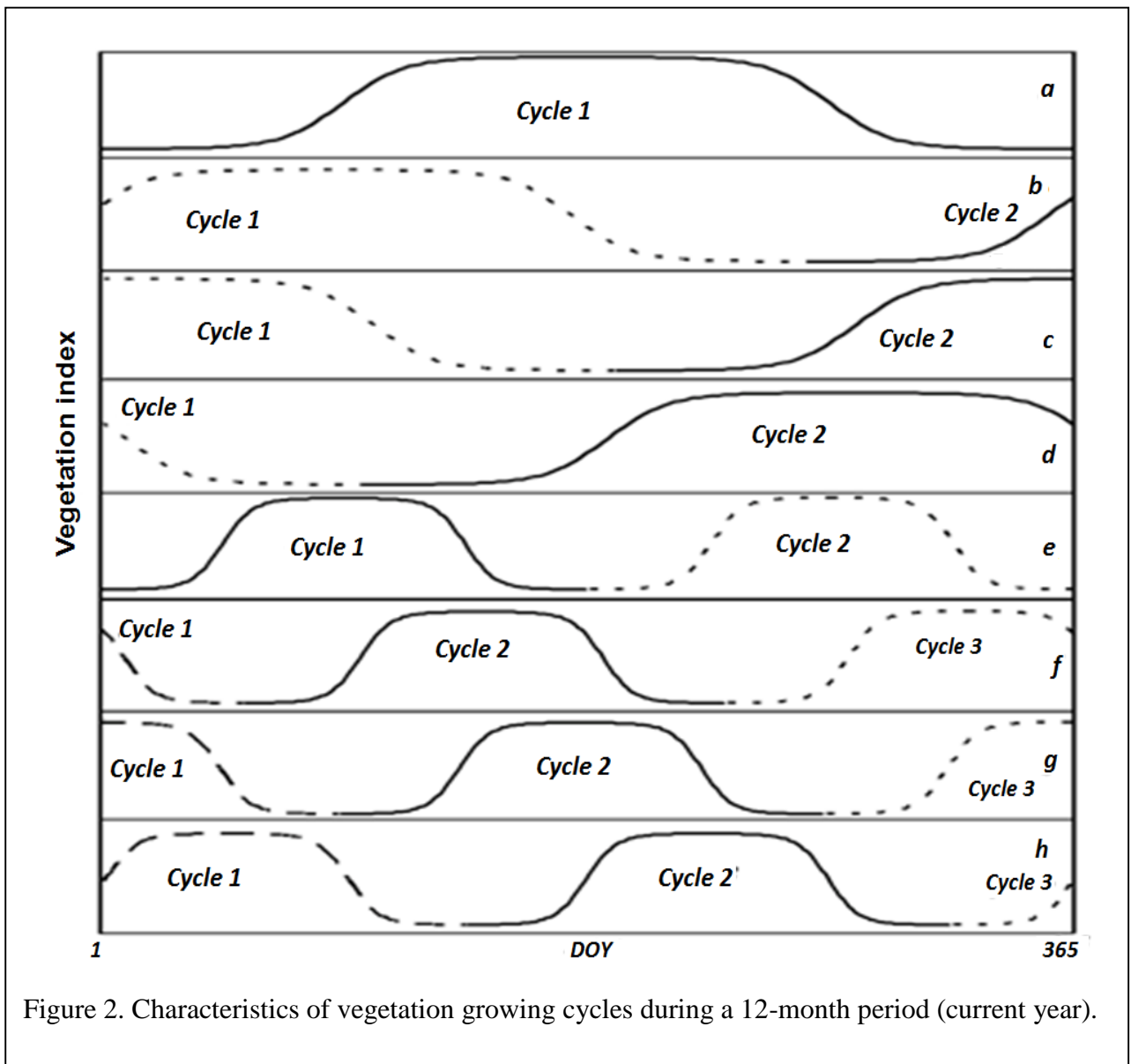
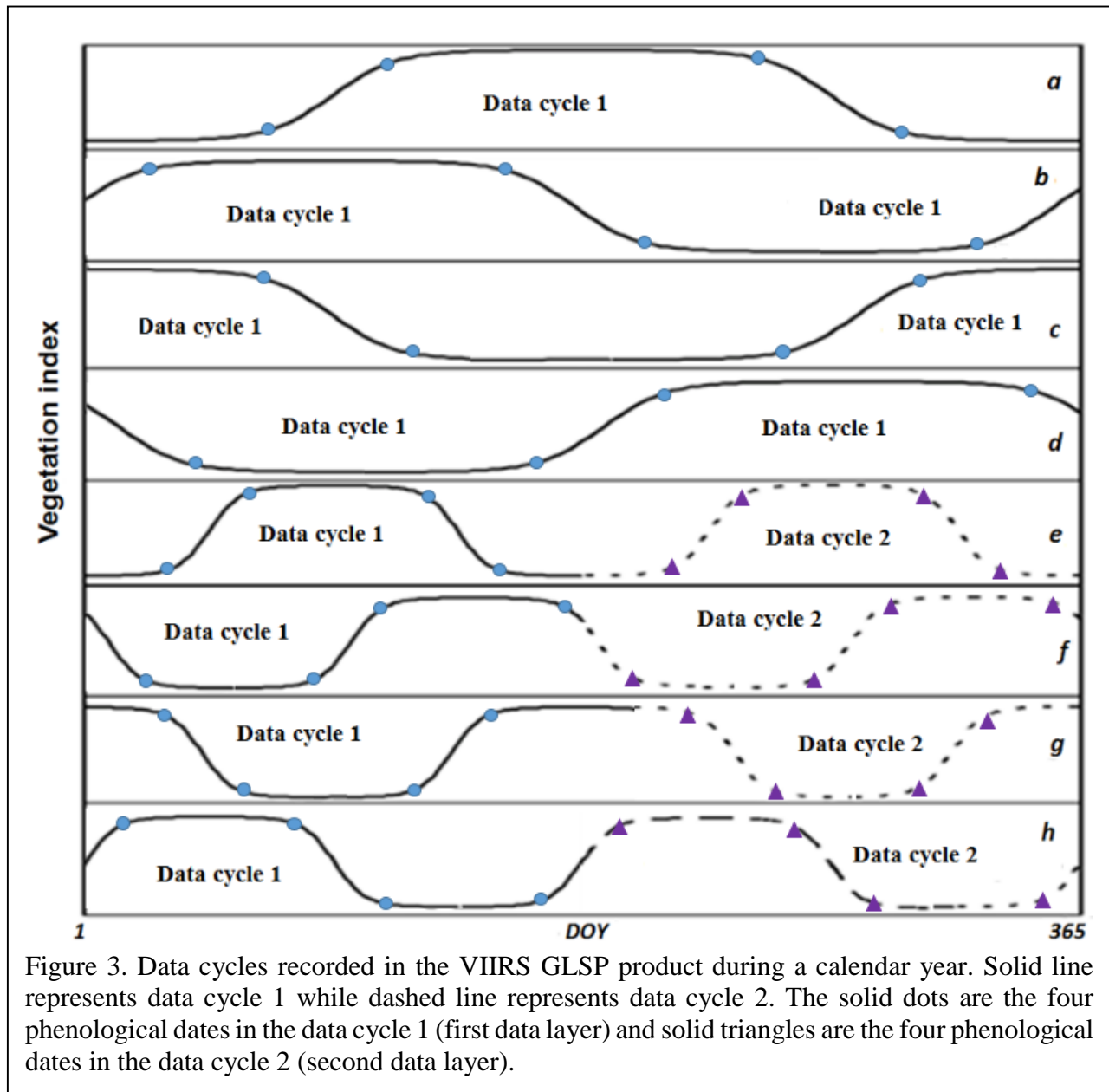


Figure 2. Characteristics of vegetation growing cycles during a 12-month period (current year).

VIIRS LSP User Guide

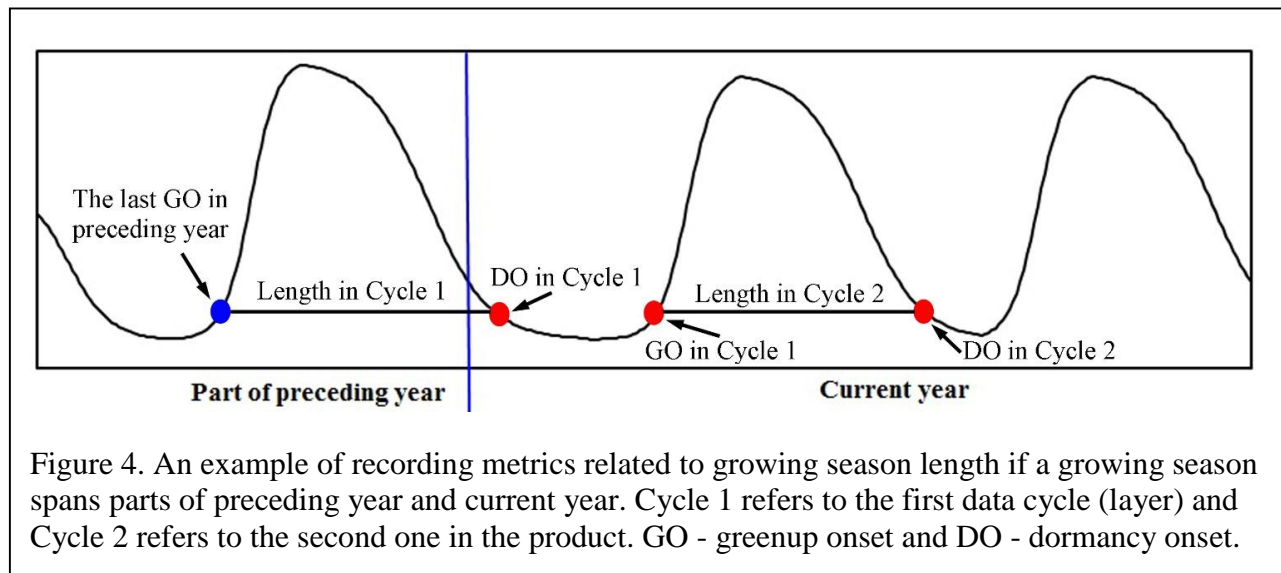
vegetation growing cycles. The data cycles are defined based on the four key phenological transition dates (greenup onset, maturity onset, senescence onset, and dormancy onset). In other words, starting from January 1, the part of EVI2 curve contains the first four key phenological transition dates as the first data cycle no matter which phenological event appears first (Figure 3). As a result, the two data layers (data cycles: Cycle 1 and Cycle 2 in the GLSP product) can record phenological information in parts of the third vegetation growing cycle, which are common in Southern Hemisphere. All other phenological metrics related to phenological dates are recorded in the same way as the four key phenological dates. Fill values are used for data cycle 2 if no vegetation phenological events occur (such as Figure 3a-d). It should be note that the rate of change in EVI2 during the greenup phase is



VIIRS LSP User Guide

recorded only accompanying with the appearance of greenup onset, and the rate of change in EVI2 during the senescence phase is recorded with the appearance of senescence onset.

However, the phenological metrics related to the entire vegetation growing cycle are more complex. These metrics include growing season length, growing season integrated EVI2, EVI2 model agreement, proportion of good quality (PGQ) VIIRS observations, and quality control (QC). They are recorded in the first data cycle if the dormancy onset occurs in the current year but the corresponding greenup onset in the growing cycle appears in the preceding year (Figure 4). If an entire growing season occurs in the current year, the phenological metrics associated with the vegetation growing season are simply recoded in the first data cycle or the second data cycle.



2.2. Metadata information

An example of VNP12Q2.A2015001.h11v04.001.2017120122020.h5:

```
GROUP=SwathStructure
END_GROUP=SwathStructure
GROUP=GridStructure
  GROUP=GRID_1
    GridName="Cycle 1"
    XDim=2400
    YDim=2400
    UpperLeftPointMtrs=(-7783653.637667,5559752.598333)
    LowerRightMtrs=(-6671703.118000,4447802.078667)
    Projection=HE5_GCTP_SNSOID
    ProjParams=(6371007.181000,0,0,0,0,0,0,0,0,0,0)
    SphereCode=-1
  GROUP=Dimension
    OBJECT=Dimension_1
```

VIIRS LSP User Guide

```
        DimensionName="YDim"
        Size=2400
    END_OBJECT=Dimension_1
    OBJECT=Dimension_2
        DimensionName="XDim"
        Size=2400
    END_OBJECT=Dimension_2
END_GROUP=Dimension
GROUP=DataField
    OBJECT=DataField_1
        DataFieldName="Onset_Greenness_Increase"
        DataType=H5T_NATIVE_USHORT
        DimList=("YDim","XDim")
        MaxdimList=("YDim","XDim")
    END_OBJECT=DataField_1
    OBJECT=DataField_2
        DataFieldName="Onset_Greenness_Maximum"
        DataType=H5T_NATIVE_USHORT
        DimList=("YDim","XDim")
        MaxdimList=("YDim","XDim")
    END_OBJECT=DataField_2
    OBJECT=DataField_3
        DataFieldName="Onset_Greenness_Decrease"
        DataType=H5T_NATIVE_USHORT
        DimList=("YDim","XDim")
        MaxdimList=("YDim","XDim")
    END_OBJECT=DataField_3
    OBJECT=DataField_4
        DataFieldName="Onset_Greenness_Minimum"
        DataType=H5T_NATIVE_USHORT
        DimList=("YDim","XDim")
        MaxdimList=("YDim","XDim")
    END_OBJECT=DataField_4
    OBJECT=DataField_5
        DataFieldName="Date_Mid_Greenup_Phase"
        DataType=H5T_NATIVE_USHORT
        DimList=("YDim","XDim")
        MaxdimList=("YDim","XDim")
    END_OBJECT=DataField_5
    OBJECT=DataField_6
        DataFieldName="Date_Mid_Senescence_Phase"
        DataType=H5T_NATIVE_USHORT
        DimList=("YDim","XDim")
        MaxdimList=("YDim","XDim")
    END_OBJECT=DataField_6
    OBJECT=DataField_7
```

VIIRS LSP User Guide

```
DataFieldName="Growing_Season_Length"  
DataType=H5T_NATIVE_USHORT  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")  
END_OBJECT=DataField_7  
OBJECT=DataField_8  
DataFieldName="EVI2_Onset_Greenness_Increase"  
DataType=H5T_NATIVE_USHORT  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")  
END_OBJECT=DataField_8  
OBJECT=DataField_9  
DataFieldName="EVI2_Onset_Greenness_Maximum"  
DataType=H5T_NATIVE_USHORT  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")  
END_OBJECT=DataField_9  
OBJECT=DataField_10  
DataFieldName="EVI2_Growing_Season_Area"  
DataType=H5T_NATIVE_USHORT  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")  
END_OBJECT=DataField_10  
OBJECT=DataField_11  
DataFieldName="Rate_Greenness_Increase"  
DataType=H5T_NATIVE_USHORT  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")  
END_OBJECT=DataField_11  
OBJECT=DataField_12  
DataFieldName="Rate_Greenness_Decrease"  
DataType=H5T_NATIVE_USHORT  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")  
END_OBJECT=DataField_12  
OBJECT=DataField_13  
DataFieldName="Greenness_Agreement_Growing_Season"  
DataType=H5T_NATIVE_UCHAR  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")  
END_OBJECT=DataField_13  
OBJECT=DataField_14  
DataFieldName="PGQ_Growing_Season"  
DataType=H5T_NATIVE_UCHAR  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")
```

VIIRS LSP User Guide

```
END_OBJECT=DataField_14
OBJECT=DataField_15
  DataFieldName="PGQ_Onset_Greenness_Increase"
  DataType=H5T_NATIVE_UCHAR
  DimList=("YDim","XDim")
  MaxdimList=("YDim","XDim")
END_OBJECT=DataField_15
OBJECT=DataField_16
  DataFieldName="PGQ_Onset_Greenness_Maximum"
  DataType=H5T_NATIVE_UCHAR
  DimList=("YDim","XDim")
  MaxdimList=("YDim","XDim")
END_OBJECT=DataField_16
OBJECT=DataField_17
  DataFieldName="PGQ_Onset_Greenness_Decrease"
  DataType=H5T_NATIVE_UCHAR
  DimList=("YDim","XDim")
  MaxdimList=("YDim","XDim")
END_OBJECT=DataField_17
OBJECT=DataField_18
  DataFieldName="PGQ_Onset_Greenness_Minimum"
  DataType=H5T_NATIVE_UCHAR
  DimList=("YDim","XDim")
  MaxdimList=("YDim","XDim")
END_OBJECT=DataField_18
OBJECT=DataField_19
  DataFieldName="GLSP_QC"
  DataType=H5T_NATIVE_UCHAR
  DimList=("YDim","XDim")
  MaxdimList=("YDim","XDim")
END_OBJECT=DataField_19
END_GROUP=DataField
GROUP=MergedFields
END_GROUP=MergedFields
END_GROUP=GRID_1
GROUP=GRID_2
  GridName="Cycle 2"
  XDim=2400
  YDim=2400
  UpperLeftPointMtrs=(-7783653.637667,5559752.598333)
  LowerRightMtrs=(-6671703.118000,4447802.078667)
  Projection=HE5_GCTP_SNSOID
  ProjParams=(6371007.181000,0,0,0,0,0,0,0,0,0,0)
  SphereCode=-1
GROUP=Dimension
  OBJECT=Dimension_1
```

VIIRS LSP User Guide

```
        DimensionName="YDim"
        Size=2400
    END_OBJECT=Dimension_1
    OBJECT=Dimension_2
        DimensionName="XDim"
        Size=2400
    END_OBJECT=Dimension_2
END_GROUP=Dimension
GROUP=DataField
    OBJECT=DataField_1
        DataFieldName="Onset_Greenness_Increase"
        DataType=H5T_NATIVE_USHORT
        DimList=("YDim","XDim")
        MaxdimList=("YDim","XDim")
    END_OBJECT=DataField_1
    OBJECT=DataField_2
        DataFieldName="Onset_Greenness_Maximum"
        DataType=H5T_NATIVE_USHORT
        DimList=("YDim","XDim")
        MaxdimList=("YDim","XDim")
    END_OBJECT=DataField_2
    OBJECT=DataField_3
        DataFieldName="Onset_Greenness_Decrease"
        DataType=H5T_NATIVE_USHORT
        DimList=("YDim","XDim")
        MaxdimList=("YDim","XDim")
    END_OBJECT=DataField_3
    OBJECT=DataField_4
        DataFieldName="Onset_Greenness_Minimum"
        DataType=H5T_NATIVE_USHORT
        DimList=("YDim","XDim")
        MaxdimList=("YDim","XDim")
    END_OBJECT=DataField_4
    OBJECT=DataField_5
        DataFieldName="Date_Mid_Greenup_Phase"
        DataType=H5T_NATIVE_USHORT
        DimList=("YDim","XDim")
        MaxdimList=("YDim","XDim")
    END_OBJECT=DataField_5
    OBJECT=DataField_6
        DataFieldName="Date_Mid_Senescence_Phase"
        DataType=H5T_NATIVE_USHORT
        DimList=("YDim","XDim")
        MaxdimList=("YDim","XDim")
    END_OBJECT=DataField_6
    OBJECT=DataField_7
```


VIIRS LSP User Guide

```
DataFieldName="Growing_Season_Length"  
DataType=H5T_NATIVE_USHORT  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")  
END_OBJECT=DataField_7  
OBJECT=DataField_8  
DataFieldName="EVI2_Onset_Greenness_Increase"  
DataType=H5T_NATIVE_USHORT  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")  
END_OBJECT=DataField_8  
OBJECT=DataField_9  
DataFieldName="EVI2_Onset_Greenness_Maximum"  
DataType=H5T_NATIVE_USHORT  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")  
END_OBJECT=DataField_9  
OBJECT=DataField_10  
DataFieldName="EVI2_Growing_Season_Area"  
DataType=H5T_NATIVE_USHORT  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")  
END_OBJECT=DataField_10  
OBJECT=DataField_11  
DataFieldName="Rate_Greenness_Increase"  
DataType=H5T_NATIVE_USHORT  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")  
END_OBJECT=DataField_11  
OBJECT=DataField_12  
DataFieldName="Rate_Greenness_Decrease"  
DataType=H5T_NATIVE_USHORT  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")  
END_OBJECT=DataField_12  
OBJECT=DataField_13  
DataFieldName="Greenness_Agreement_Growing_Season"  
DataType=H5T_NATIVE_UCHAR  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")  
END_OBJECT=DataField_13  
OBJECT=DataField_14  
DataFieldName="PGQ_Growing_Season"  
DataType=H5T_NATIVE_UCHAR  
DimList=("YDim","XDim")  
MaxdimList=("YDim","XDim")
```

VIIRS LSP User Guide

```
END_OBJECT=DataField_14
OBJECT=DataField_15
  DataFieldName="PGQ_Onset_Greenness_Increase"
  DataType=H5T_NATIVE_UCHAR
  DimList=("YDim","XDim")
  MaxdimList=("YDim","XDim")
END_OBJECT=DataField_15
OBJECT=DataField_16
  DataFieldName="PGQ_Onset_Greenness_Maximum"
  DataType=H5T_NATIVE_UCHAR
  DimList=("YDim","XDim")
  MaxdimList=("YDim","XDim")
END_OBJECT=DataField_16
OBJECT=DataField_17
  DataFieldName="PGQ_Onset_Greenness_Decrease"
  DataType=H5T_NATIVE_UCHAR
  DimList=("YDim","XDim")
  MaxdimList=("YDim","XDim")
END_OBJECT=DataField_17
OBJECT=DataField_18
  DataFieldName="PGQ_Onset_Greenness_Minimum"
  DataType=H5T_NATIVE_UCHAR
  DimList=("YDim","XDim")
  MaxdimList=("YDim","XDim")
END_OBJECT=DataField_18
OBJECT=DataField_19
  DataFieldName="GLSP_QC"
  DataType=H5T_NATIVE_UCHAR
  DimList=("YDim","XDim")
  MaxdimList=("YDim","XDim")
END_OBJECT=DataField_19
END_GROUP=DataField
GROUP=MergedFields
END_GROUP=MergedFields
  END_GROUP=GRID_2
END_GROUP=GridStructure
GROUP=PointStructure
END_GROUP=PointStructure
GROUP=ZaStructure
END_GROUP=ZaStructure
END
```

VIIRS LSP User Guide

2.3. Data groups and datasets

There are two root groups in the GLSP output file. The “GRIDS” in the “HDFEOS” group contain all Scientific Data Sets. Data Cycle 1 and Cycle 2 are two members of “GRIDS”. “HDFEOS INFORMATION” include metadata information (Figure 5).

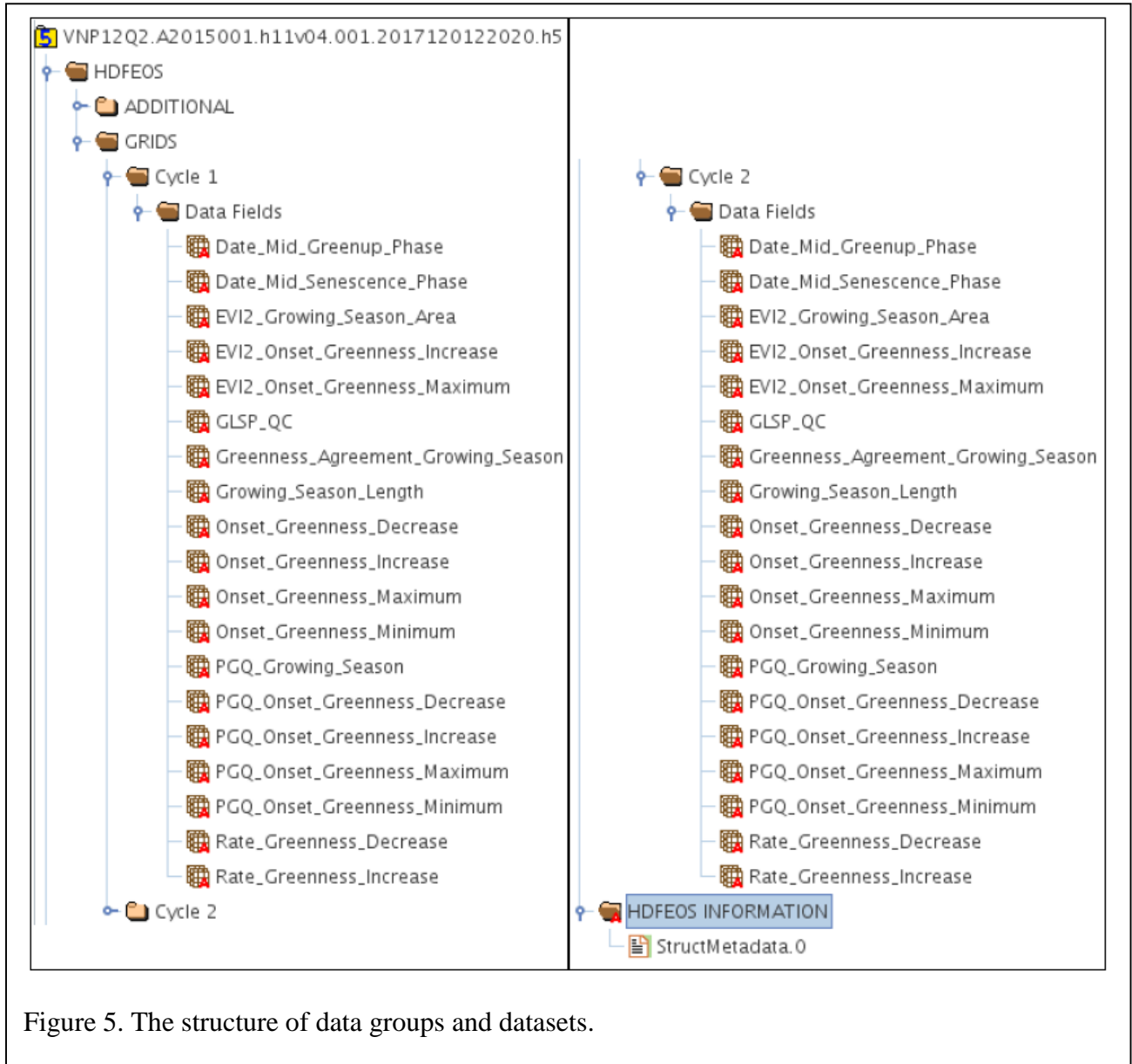


Figure 5. The structure of data groups and datasets.

3. Algorithm Description

3.1. Detection of phenological metrics

VIIRS GLSP is produced using an algorithm of Hybrid Piecewise Logistic Model (HPLM) based Land Surface Phenology Detection (LSPD) (Zhang 2015; Zhang et al. 2003). The technical details can be found in the Algorithm Theoretical Basis Document (ATBD). The HPLM-LSPD is briefly described here. Inputs of the HPLM-LSPD algorithm are VIIRS NBAR (with data quality), snow cover, land surface temperature (LST), and land cover type. Specifically, daily VIIRS NBAR is used to calculate daily EVI2. The background EVI2 value at each pixel (i.e., the minimum snow-free value) is identified using the EVI2 values that are not contaminated by snow and cloud during the winter period defined from $LST < 278K$. The data points associated with snow-covered surfaces are removed from the input time series and replaced with snow-free “background EVI2” values.

The annual temporal EVI2 trajectory is then reconstructed using the HPLM that describes biophysical progress of vegetation growth (Zhang 2015). To do this, raw EVI2 time series is smoothed using background EVI2 to remove snow contamination and using moving average, moving median and Savitzky-Golay filters to reduce cloud and atmospheric impacts. The vegetation greenup phases and senescence phases are further separated using a moving slope algorithm along the smoothed EVI2 temporal trajectory. Transitions from the periods of ascending EVI2 to the periods of descending EVI2 are identified using changes from positive to negative slope, and vice versa. The HPLM is finally applied for fitting the EVI2 time series. By combining both favorable condition and stress condition in vegetation growth, the HPLM describes the temporal EVI2 trajectory using the following formula (Figure 6):

$$VI(t) = \begin{cases} \frac{c_1}{1 + e^{a_1 + b_1 t}} + VI_b & \text{Favorable growth condition} & (1) \\ \frac{c_2 + dt}{1 + e^{a_2 + b_2 t}} + VI_b & \text{Vegetation stress condition} & (2) \end{cases}$$

where t is time in the day of year (DOY), a is related to the vegetation growth time, b is associated with the rate of plant leaf development, c is the amplitude of EVI2 variation, d is a vegetation stress factor, and VI_b is the background EVI2 value. In order to determine whether the plant suffers from stress or not, the equations 1 and 2 are compared in fitting the temporal EVI2 observations and the function with better fitting is chosen.

From the reconstructed temporal trajectory, the timing of phenological transitions during the vegetation growing season are then extracted based on curvature change rate (Zhang et al. 2006; Zhang et al. 2003). Other phenological timing metrics and vegetation growth metrics are further calculated, which are listed in Table 1.

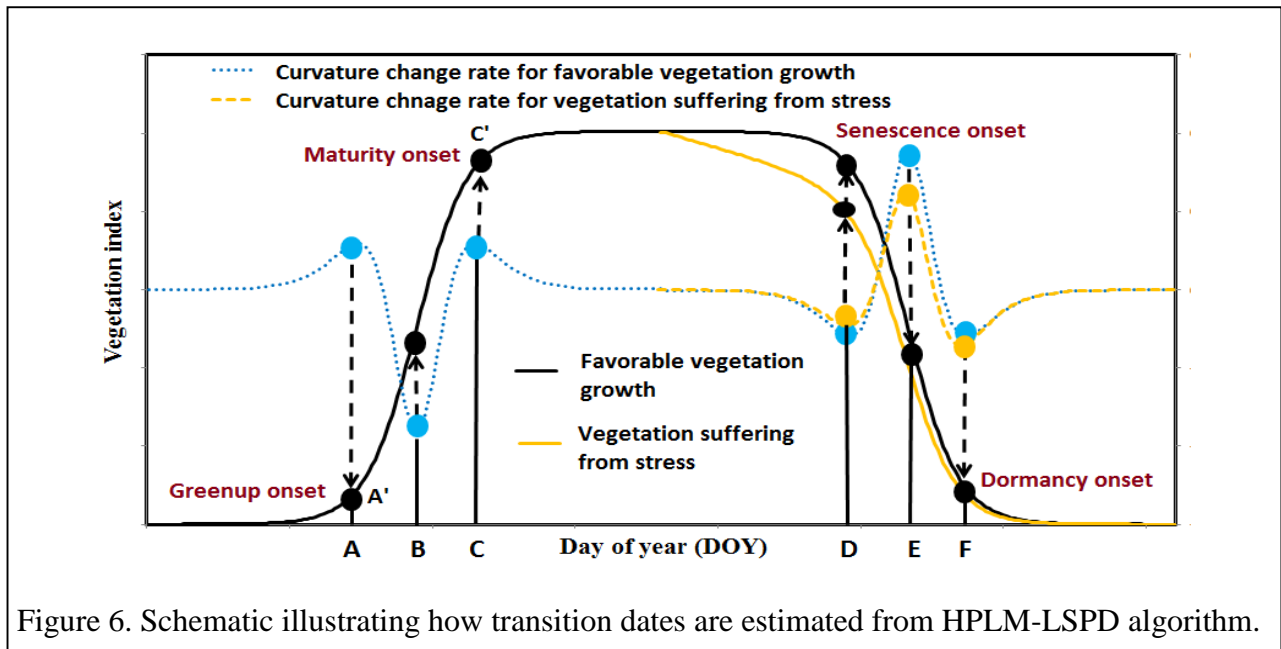


Figure 6. Schematic illustrating how transition dates are estimated from HPLM-LSPD algorithm.

3.2. Confidence of phenological metrics

The quality and confidence of GLSP metrics are strongly controlled by the quality of time series of EVI2 observations. They are qualified using the model fit and the proportion of high quality data at each pixel. Goodness of model fit or agreement index (AI) is described using an index of model agreement (*Greenness_Agreement_Growing_Season* in Table 1) that is calculated from the differences between modeled values and satellite measurements with “good” quality during a growing season at each pixel (Willmott 1981; Zhang 2015). The quality of satellite observations is inherited from VIIRS NABR product.

Because the quality of the simulated EVI2 model at each pixel is strongly dependent on the number of good quality observations during a vegetation growing season (Zhang et al. 2009), the proportion of good quality (PGQ) EVI2 values for a given pixel is calculated for an entire growing season and around phenological phase transitions. “*PGQ_Growing_Season*” in Table 1 quantifies the quality of the simulated temporal trajectory within a growing season. In the calculation, a good observation is counted if there is one good value within a moving window of three 3-day EVI2 composites. It is because vegetation greenness temporal trajectory could be properly reconstructed if there is a good EVI2 observation within an 8-day period (Zhang et al. 2009).

The local EVI2 quality around the four key phenological dates that divide a vegetation growing season into four growing phases is also quantified to describe the confidence of the corresponding detections of phenological events. Simply, the local confidence is the proportion of good EVI2 during the three 3-day periods before and after the detected phenological timing. These four confidence

VIIRS LSP User Guide

parameters in Table 1 are *PGQ_Onset_Greenness_Increase*, *PGQ_Onset_Greenness_Maximum*, *PGQ_Onset_Greenness_Decrease*, and *PGQ_Onset_Greenness_Minimum*. Note that the low local confidence does not necessarily indicate the detected phenological timing is incorrect.

The overall mandatory quality (GLSP_QC in Table 1) in a specified growing season is controlled by both the proportion of good quality data (PGQ) and the agreement index (AI) of the EVI2 model, both of which scale from 0 to 100. From these two indices during a growing season, the overall quality assurance (QA) of phenological detections in VIIRS GLSP product is defined as:

- QA=0 (processed, good quality), if $PGQ \geq 60$ and $AI \geq 60$
- QA=1 (processed, other quality), if $20 \leq PGQ < 60$ or $AI < 60$
- QA=2 (processed, backup algorithm), if the length of consecutive missing EVI2 > 30 days
- QA=3 (not processed, bad quality), if $PGQ < 20\%$
- QA=4 (not processed, other), if growing season amplitude in EVI2 < 0.08 in forests and $EVI2 < 0.02$ in other ecosystems

4. Related Web Sites

Suomi-NPP

<http://npp.gsfc.nasa.gov/suomi.html>

VIIRS

VIIRS Land: <http://viirsland.gsfc.nasa.gov/>

HDF5

The HDF Group: <https://www.hdfgroup.org/HDF5/>

5. References

- Willmott, C.J. (1981). On the validation of models. *Physical Geography*, 2, 184-194
- Zhang, X. (2015). Reconstruction of a complete global time series of daily vegetation index trajectory from long-term AVHRR data. *Remote Sensing Of Environment*, 156, 457-472
- Zhang, X., Friedl, M., & Schaaf, C. (2009). Sensitivity of vegetation phenology detection to the temporal resolution of satellite data. *International Journal of Remote Sensing*, 30, 2061-2074
- Zhang, X.Y., Friedl, M.A., & Schaaf, C.B. (2006). Global vegetation phenology from Moderate Resolution Imaging Spectroradiometer (MODIS): Evaluation of global patterns and comparison with in situ measurements. *Journal of Geophysical Research-Biogeosciences*, 111
- Zhang, X.Y., Friedl, M.A., Schaaf, C.B., Strahler, A.H., Hodges, J.C.F., Gao, F., Reed, B.C., & Huete, A. (2003). Monitoring vegetation phenology using MODIS. *Remote Sensing Of Environment*, 84, 471-475