Global Vegetation Phenology Derived from a Long Term AVHRR and MODIS Data Record

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Outline

1. Satellite phenological metrics and detection
2. Reconstruction of time series vegetative greenness trajectory for the past 30 years
3. Spatial and temporal shift of global vegetation phenology
4. Quality assessment of long-term phenology detection
5. Summary
Phenological Metrics from Long-Term Satellite Data

- Day of Year (DOY)
- Vegetation Index

- Greenup Phase
- Greenup Onset
- VI increase rate
- Maturity Phase
- Maturity Onset
- Magnitude VI
- Growing season length
- VI at greenup on set
- Senescent Phase
- Senescence Onset
- VI decrease rate
- Dormancy Onset
- Dormant Phase
- Dormancy Onset
Simulating Temporal Vegetative Trajectory Using Piecewise Logistic Model

Greenup Phase

\[ VI(t) = \frac{c}{1 + e^{a+bt}} + VI_b \]

Maturity and Senescence Phase

\[ VI(t) = \begin{cases} 
\frac{c}{1 + e^{a+bt}} + VI_b \\
\frac{c + dt}{1 + e^{a+bt}} + VI_b 
\end{cases} \]

- Greenup Phase
  - **VI** is the VI value at time *t*
  - **VI** is the VI value in vegetation growth
  - **d** is water stress parameter
  - **c+VI** is the maximum VI value
  - **VI** is the background VI value

- Maturity and Senescence Phase
  - **t** is time in days
  - **VI** is the VI value at time *t*
  - **VI** is the VI value in vegetation growth
  - **a** and **b** are vegetation growth parameters
  - **c+VI** is the maximum VI value
  - **VI** is the background VI value

Diagram:
- **Optimal water supply**
- **Summer water stress**

Vegetation Index vs Day of year (DOY)
Identifying Phenological Transition Dates Using the Rate of Curvature Change

Curvature $K$:

$$K = \frac{d\alpha}{ds} = \frac{d^2 \text{vi}}{dt^2} \left[ 1 + \left( \frac{d\text{vi}}{dt} \right)^2 \right]^{\frac{3}{2}}$$

$\alpha$ is the tangential angle
$s$ is the arc length

Curvature Change Rate $K'$:

$$K' = \frac{dK}{dt}$$
Types of Temporal Trajectories in Vegetation Index Across Globe
Reconstruction of Time Series Vegetative Greenness (VI) Trajectory
-- Determination of Background VI Value

Background EVI2:
Average maximum EVI2 during two winters (LST <278K)
Reconstruction of Time Series Vegetative Greenness (VI)
Trajectory --Removal of Pseudo Plant Cycles

Ecosystem rules:
Forests: Span between peaks >4 month
Shrubland/grassland: Span between peaks >2 months
Cropland: Span between peaks > 1.5 months
Reconstructed Time Series Vegetative Greenness Trajectory - Model Simulated Trajectory

![Graph showing reconstructed time series vegetation greenness trajectory with model simulated trajectory. The x-axis represents days from January 1, 1995, and the y-axis represents AVHRR EVI2 (x10000). The graph includes different quality data points: EVI2 with good quality, EVI2 with other quality, and EVI2 with cloud. The years 1995 to 1998 are highlighted with dotted lines indicating summer water stress.]
Reconstructed Time Series Vegetative Greenness Trajectory

January 1

April 1

July 1

October 1
Spatial and Temporal Shift of Vegetation Phenology
Greenup Onset from AVHRR in 1996

a) Recorded in the first cycle
b) Recorded in the second cycle
c) The first greenup onset for the year 1996 (combined from the first and the second cycles)
Dormancy Onset from AVHRR in 1996

a) Recorded in first cycle
b) Recorded in second cycle
c) The first dormancy onset for the year 1996 (combined from the first and the second cycles)
Spatial and Temporal Shift in Greenup Onset

Days from January 1, 2001

EVI2

2001  2002  2003  2004  2005

Days: 0 366 732 1098 1464 1830

EVI2:

0  1000  2000  3000  4000  5000

2001  2002  2003  2004  2005

North America

p1

p2

p3

p1

p2

p3
Inter-annual variation (standard variation) in the timing of greenup onset
a) The difference between the 1990s and 1980s

b) the difference between the 2000s and 1990s

The green color indicates the number of advanced days, while the red color shows delayed days.
Growing Season Length

2000s
Inter-annual Variation (Standard Variation) in Growing Season Length
Long-Term Record of Global Crop Calendar

2000s
Onset of crop greenup

2000s
Beginning of flowering

2000s
Onset of milky ripe

Double Cycles of Crop growth
• Crop suffered drought impact this summer, which reduced crop greenness as much as 30%. The spatial pattern of greenness reduction matched well with exceptionally-severely dry areas identified by SPI in March-August, 2012.
• Drought could advance the timing of milky ripe
• Warm spring in 2012 advanced the timing of crop turning green.
Assessment of MEASURES Global LSVP Quality
--Precision and Confidence of Phenological Product
(for both AVHRR and MODIS)

During a plant growing season:
• Number of good quality observations
• Maximum period of consecutive missing observations
• Goodness of temporal EVI2 curve fitting
Assessment of Good Quality Observations in the Time Series

Proportion of good quality observations \((P_{qa0})\) during a growing season:

\[ P_{qa0} = \frac{N_{qa0}}{T} \]

\(T\)—is the total number of 3-day VI during a growing season

\(N_{qa0}\)—is the number of good quality observation within a growing season. If there is one good value within a moving window of 3 3-day VI, it is counts as one good observation. This is due to the fact that the error in phenology detection is lowest at temporal resolution of 6 or 8 days (Zhang et al., 2009).

Zhang et al., 2009
Maximum Consecutive Gap in the Time Series

If there were no satellite observations for more than one month, a flag value 254 is assigned.
Assessment of Fitted Temporal Vegetative VI Trajectory

Determining the quality of curve fitting using Willmott’s index of agreement (Willmott, 1982):

\[
d = 1 - \frac{\sum_{i=1}^{n} \left( P(i) - O(i) \right)^2}{\sum_{i=1}^{n} \left( |P(i) - \bar{O}| + |O(i) - \bar{O}| \right)^2}
\]

where \( n \) is number of observations with good (or better) quality during vegetation growing season

\( P(i) \) are the fitted values

\( O(i) \) are the observations with good quality

\( \bar{O} \) is the mean observed value.

This index of agreement provides a measure of relative error in model estimates.
Determination of Quality in Phenology Detection by Combining the Willmott’s Index of Agreement and the Proportion of Good Quality Data in Satellite Observations

QA=0 (processed, good quality) if $P_{qa0} > 0.6$ and $d > 0.8$
QA=1 (processed, other quality) if $P_{qa0} > 0.3$ and $d > 0.8$
QA=2 (not processed, clod) if $P_{qa0} < 0.3$
QA=4 (not processed, other) if growing season amplitude in VI < 0.08 in forests and < 0.02 in other ecosystems
Quality of Temporal Data and Curve Fitness
<table>
<thead>
<tr>
<th>DataField</th>
<th>Name</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>DataField_1</td>
<td>Onset_Greenness_Increase</td>
<td>UINT16</td>
</tr>
<tr>
<td>DataField_2</td>
<td>Onset_Greenness_Maximum</td>
<td>UINT16</td>
</tr>
<tr>
<td>DataField_3</td>
<td>Onset_Greenness_Decrease</td>
<td>UINT16</td>
</tr>
<tr>
<td>DataField_4</td>
<td>Onset_Greenness_Minimum</td>
<td>UINT16</td>
</tr>
<tr>
<td>DataField_5</td>
<td>VI_Onset_Greenness_Minimum</td>
<td>UINT16</td>
</tr>
<tr>
<td>DataField_6</td>
<td>VI_Onset_Greenness_Maximum</td>
<td>UINT16</td>
</tr>
<tr>
<td>DataField_7</td>
<td>VI_Area</td>
<td>UINT16</td>
</tr>
<tr>
<td>DataField_8</td>
<td>Growing_Season_Length</td>
<td>UINT16</td>
</tr>
<tr>
<td>DataField_9</td>
<td>Rate_Greenness_Increase</td>
<td>UINT16</td>
</tr>
<tr>
<td>DataField_10</td>
<td>Rate_Greenness_Decrease</td>
<td>UINT16</td>
</tr>
<tr>
<td>DataField_11</td>
<td>Dynamics_QC</td>
<td>UINT16</td>
</tr>
</tbody>
</table>
Product name convention
LSP12C2.A1982001_1982365.001.2010266161623.hdf

LSP12C2.A: product identification
1982001_1982365: time period of vegetation phenology detection
001: the data product version
2010266161623: time of product processing
.hdf: the output file is in HDF
Grid Structure: LSP_Grid_LSP

Dimensions:

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Dimension Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension_1</td>
<td>Ydim:MGLSP_Grid_LSP</td>
<td>Data Rows</td>
</tr>
<tr>
<td>Dimension_2</td>
<td>Xdim:MGLSP_Grid_LSP</td>
<td>Data Columns</td>
</tr>
<tr>
<td>Dimension_3</td>
<td>Num_QC_Words:MGLSP_Grid_LSP</td>
<td>Num_QC_Words</td>
</tr>
<tr>
<td>Dimension_4</td>
<td>Num_Modes:MGLSP_Grid_LSP</td>
<td>Num_Modes</td>
</tr>
</tbody>
</table>

global attributes:

:WestBoundingCoordinate = -180.0 ;
:EastBoundingCoordinate = 180.0 ;
:NorthBoundingCoordinate = 90.0 ;
:SouthBoundingCoordinate = -90.0 ;
:PixelSize = 0.05deg ;
Land Surface Vegetation Phenology
Product Specification (continue)

Format for SDS of Onset Greenness Increase, Onset Greenness Maximum, Onset Greenness Decrease, and Onset Greenness Minimum

<table>
<thead>
<tr>
<th>DataField</th>
<th>Name</th>
<th>Data Type</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>DataField_1</td>
<td>Onset_Greenness_Increase</td>
<td>UINT16</td>
<td>Dimension_1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dimension_2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dimension_3</td>
</tr>
</tbody>
</table>

**Description:**
Onset of greenness Increase
---
Days starting from January 1, 1980

Note: Word 1 is first mode of the year, Word 2 is second mode of the year (other possible modes are not reported)

**Data conversions:**
DOY=file data − (given year−1979)∗366

**DataField_1 HDF Attributes:**

- `long_name` STRING 1 PGE "Onset_Greenness_Increase"
- `units` STRING 1 PGE "day"
- `valid_range` uint16 2 PGE 1, 32766
- `_FillValue` uint16 1 PGE 32767
- `scale_factor` float64 1 PGE 1
- `add_offset` float64 1 PGE 0
DataField_5  VI_Onset_Greenness_Increase  UINT16  Dimension_1
              Dimension_2
              Dimension_3

Description:  VI value at onset of greenness increase during a growth cycle
Note: Word 1 is first Mode of year, Word 2
      is second mode of year (other possible
      modes are not reported)

DataField_5 HDF Attributes:
  long_name      STRING  1   PGE     "VI_Onset_Greenness_Increase"
  units          STRING  1   PGE     "VI value"
  valid_range    uint16   2   PGE    0, 10000
  _FillValue     uint16   1   PGE     32767
  scale_factor   float64 1   PGE       0.0001
  add_offset     float64 1   PGE       0
Description: Number of days in a growing cycle

Note: Word 1 is first mode of year, Word 2 is second mode of year (other possible modes are not reported)

HDF Attributes:
- long_name: STRING 1 PGE "Growing_Season_Length"
- units: STRING 1 PGE "day"
- valid_range: uint16 2 PGE 0, 32766
- _FillValue: uint16 1 PGE 32767
- scale_factor: float64 1 PGE 1
- add_offset: float64 1 PGE 0
DataField_9 Rate_Greenness_Increase UINT16 Dimension_1
Dimension_2
Dimension_3

Description: Average rate of VI increase during a greenup phase

Note: Word 1 is first Mode of year, Word 2 is second mode of year (other possible modes are not reported

DataField_7 HDF Attributes:

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Type</th>
<th>Dimensions</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>long_name</td>
<td>STRING</td>
<td>1</td>
<td>PGE</td>
<td>&quot;Rate_Greenness_Increase&quot;</td>
</tr>
<tr>
<td>units</td>
<td>STRING</td>
<td>1</td>
<td>PGE</td>
<td>&quot;VI/day&quot;</td>
</tr>
<tr>
<td>valid_range</td>
<td>uint16</td>
<td>2</td>
<td>PGE</td>
<td>0, 32766</td>
</tr>
<tr>
<td>_FillValue</td>
<td>uint16</td>
<td>1</td>
<td>PGE</td>
<td>32767</td>
</tr>
<tr>
<td>scale_factor</td>
<td>float64</td>
<td>1</td>
<td>PGE</td>
<td>0.0001</td>
</tr>
<tr>
<td>add_offset</td>
<td>float64</td>
<td>1</td>
<td>PGE</td>
<td>0</td>
</tr>
</tbody>
</table>
DataField_11 Dynamics_QC UINT16 Dimension_1
Dimension_2

Description: Quality flags for vegetation phenology

DataField_8 HDF Attributes:
Note: First Word:
the first two bits are Mandatory QA
  0=processed, good qual
  1=processed, other qual
  2=not processed, cloud
  3=not processed, other
the next two bits are TBD
the 5-8 bits are Land Water mask
  (as passed down from NBARS)
  0 = Shallow ocean
  1 = Land (Nothing else but land)
  2 = Ocean coastlines and lake shorelines
  3 = Shallow inland water
  4 = Ephemeral water
  5 = Deep inland water
  6 = Moderate or continental ocean
  7 = Deep ocean
  the 9-16 bits are Phenology__Assessment
0-100 = Assessment values
255= FillValue
Conclusions

• Reconstruction of \textit{vegetative} seasonal trajectory is the most important part in phenology detection.
• Pieceswise logistical models could present different formats during greenup and senescent phases, but curvature change rate is robust in detecting phenological transition dates.
• The quality of phenological detection could be assessed using the combination of good quality satellite observations during a vegetation growing season and the quality of curve fitting.
• The pattern of long-term phenology variation is complex globally.
Thanks
Maturity Onset from AVHRR in 1996

a) Recorded in the first cycle
b) Recorded in the second cycle
c) The first maturity onset for the year (combined from the first and the second cycles)
Senescent Onset from AVHRR in 1996

a) Recorded in the first cycle
b) Recorded in the second cycle
c) The first senescent onset for the year (combined from the first and the second cycles)
Long-term Daily AVHRR and MODIS Data

• AVHRR Long-Term Data Record (LTDR) : 0.05 degrees (1981–1999) (http://ltdr.nascom.nasa.gov/).

• MODIS CMG dataset provides Terra and Aqua MODIS daily CMG surface reflectance (Collection 5.0): 0.05 degrees (2000 to 2011) (http://edcdaac.usgs.gov/main.asp).

• Continued long-term daily EVI2: 0.05 degrees (1981 to 2011) (http://vip.arizona.edu/viplab_data_expplorer).

(Courtesy to Kamal Didan)
LTDR AVHRR QA in NA

Proportion of QA (%)

Month from January 1982 to December 1999

- Good quality
- Partially cloudy
- Cloudy
- Unknown poor quality and not processed
- Others
Biophysically Understanding Temporal Trajectory of Satellite Vegetation Index (VI) in Greenup Phase – an example

Plant growing
\[ \text{EVI2} = \text{EVI2}_g + \text{EVI2}_b + \text{EVI2}_a \]

Partly snow cover
\[ \text{EVI2} = \text{EVI2}_s + \text{EVI2}_b + \text{EVI2}_a \]

Full snow cover
\[ \text{EVI2} \approx \text{EVI2}_s + \text{EVI2}_a \]

Time (Day of year)
Physically-Based Algorithms for the MEASURES LSVP Product

LDRT AVHRR+MODIS

LST
Snow cover

Background LTVI determination

LTVI

Gap filling and outlier removing

Phenological phase detection

Temporal curve fitting

Phenology detection

Model precision and confidence
Phenological metrics

MEASURES phenology product