Jan. 23, 2013

Arizona

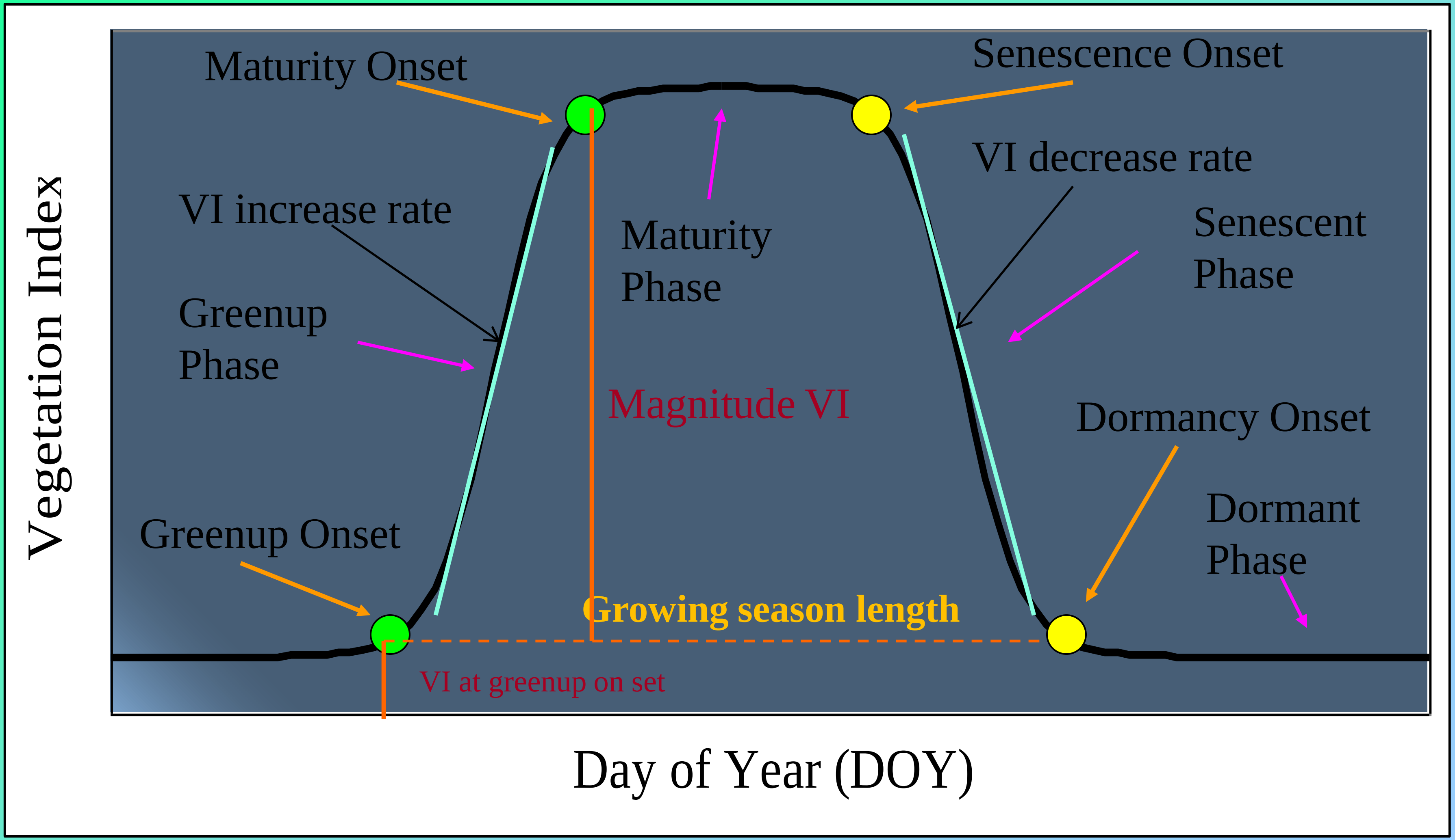
Global Vegetation Phenology Derived from a Long Term AVHRR and MODIS Data Record

Xiaoyang Zhang, Mark Friedl

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



Simulating Temporal Vegetative Trajectory Using Piecewise Logistic Model

Greenup Phase

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

Maturity and Senescence Phase

$$VI(t) = \begin{cases} \frac{c}{1+e^{a+bt}} + VI_b & \text{Optimal water supply} \\ \frac{c+dt}{1+e^{a+bt}} + VI_b & \text{Summer water stress} \end{cases}$$

t is time in days

$VI_{(t)}$ is the VI value at time *t*

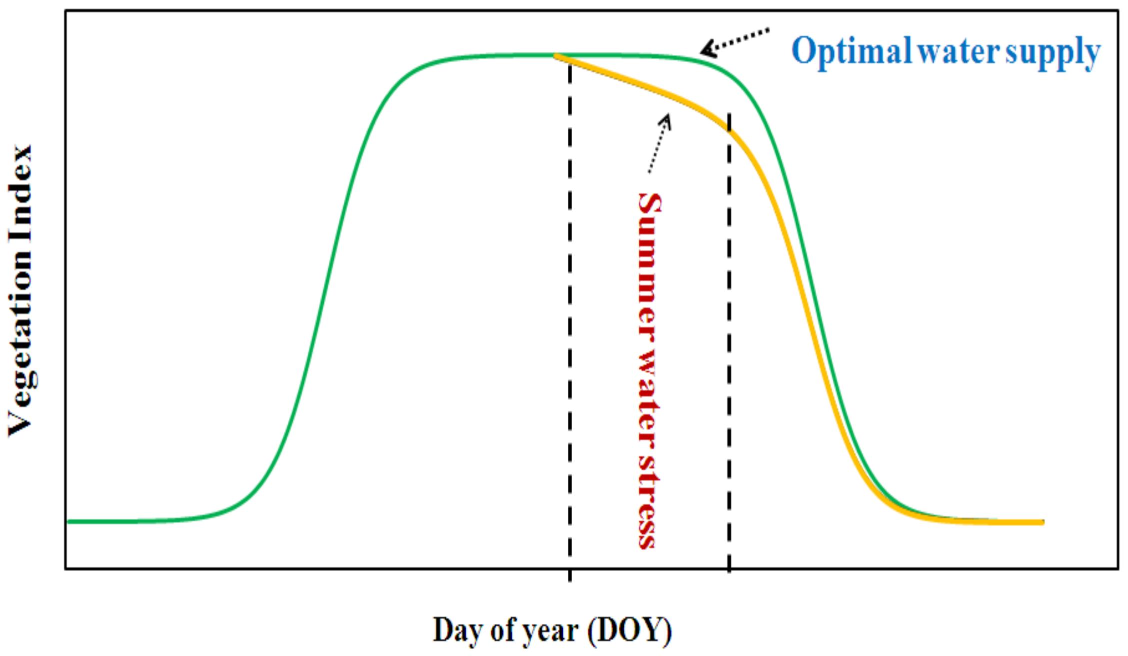
VI_v is the VI value in vegetation growth

a and ***b*** are vegetation growth parameters

d water stress parameter

$c+VI_b$ is the maximum VI value

VI_b is the background VI value

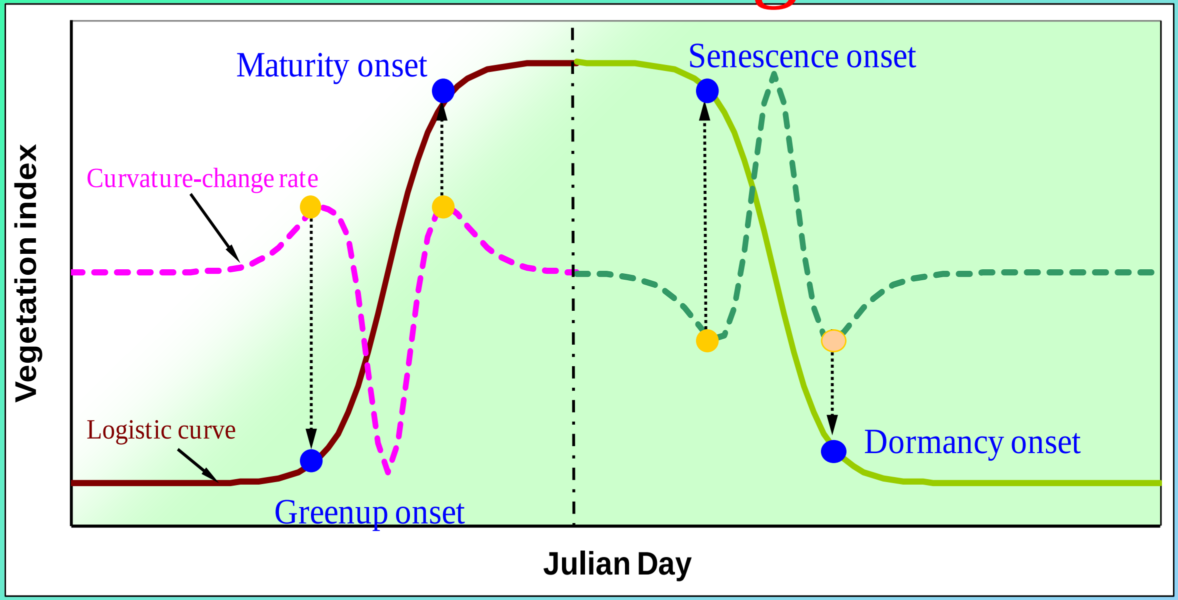


Identifying Phenological Transition Dates Using the Rate of Curvature Change

Curvature K:

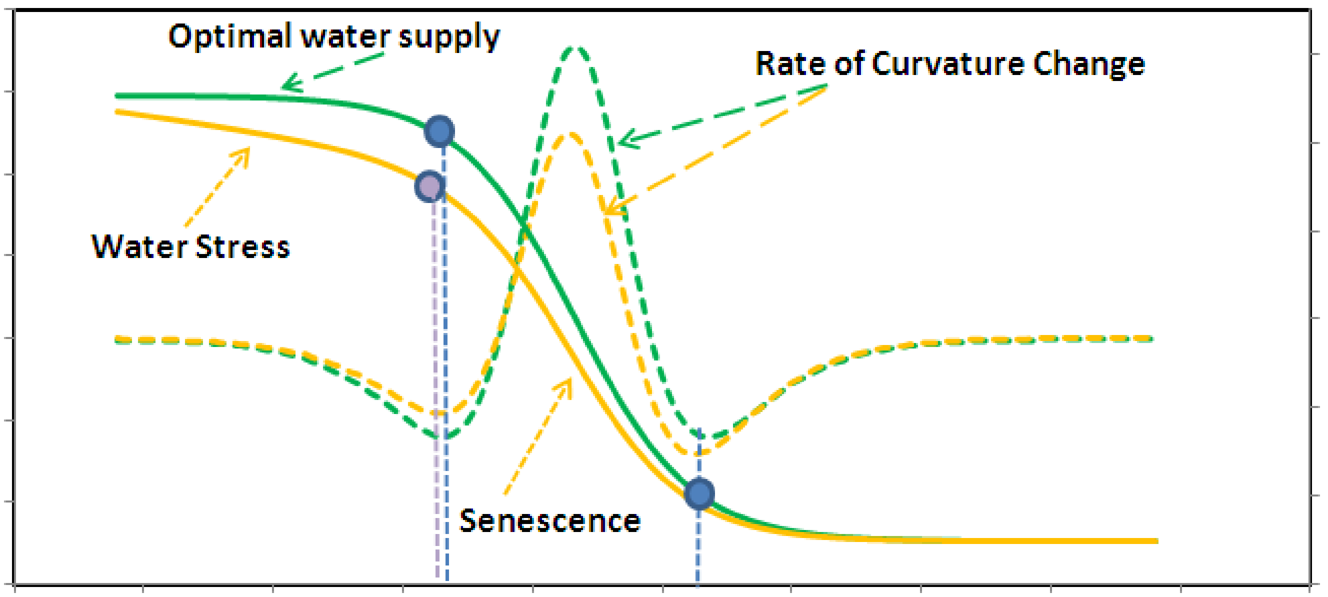
$$K = \frac{d\alpha}{ds} = \frac{\frac{d^2 vi}{dt^2}}{\left[1 + \left(\frac{dvi}{dt}\right)^2\right]^{\frac{3}{2}}}$$

α is the tangential angle
***s* is the arc length**

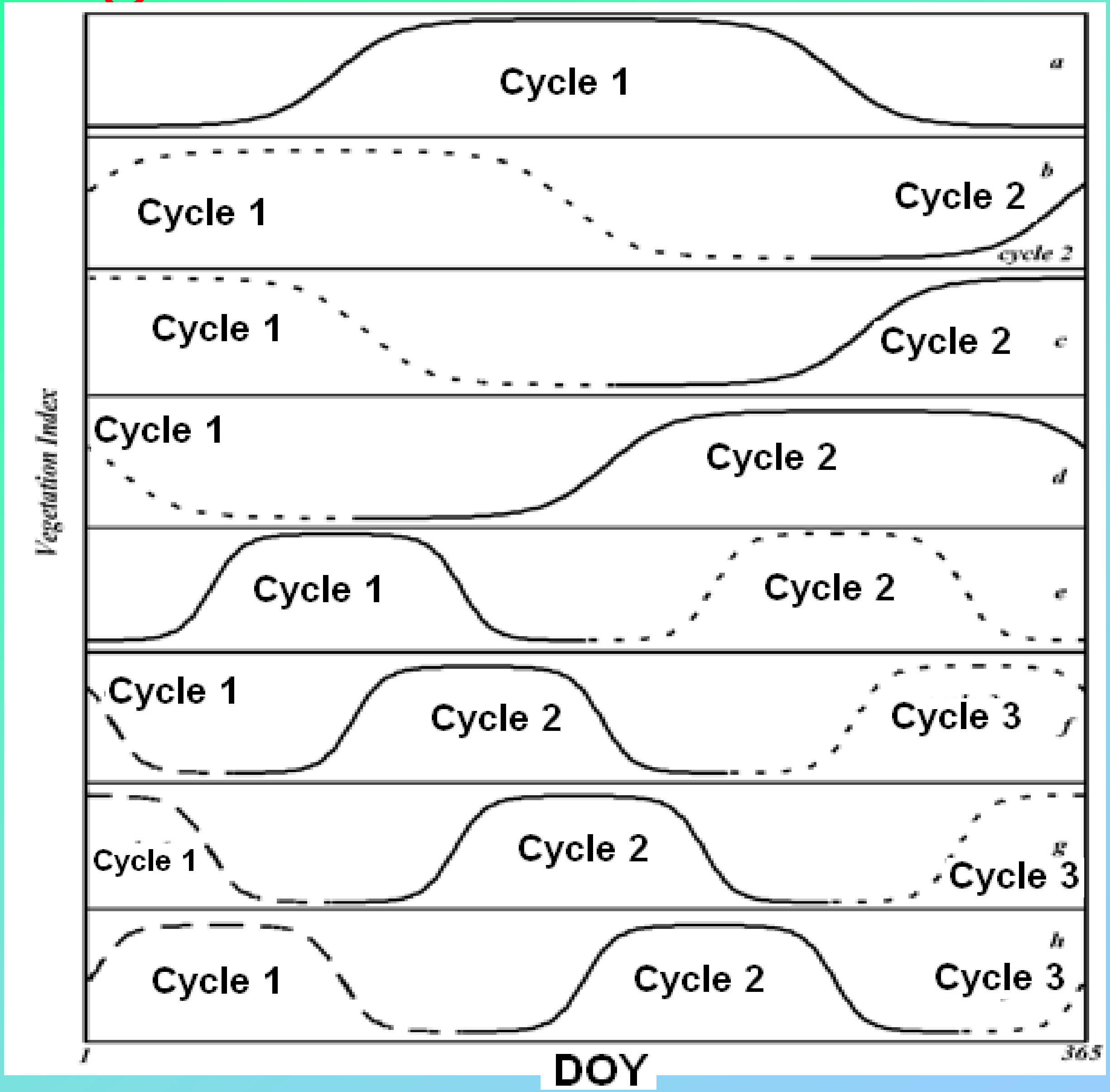


Curvature Change Rate K’:

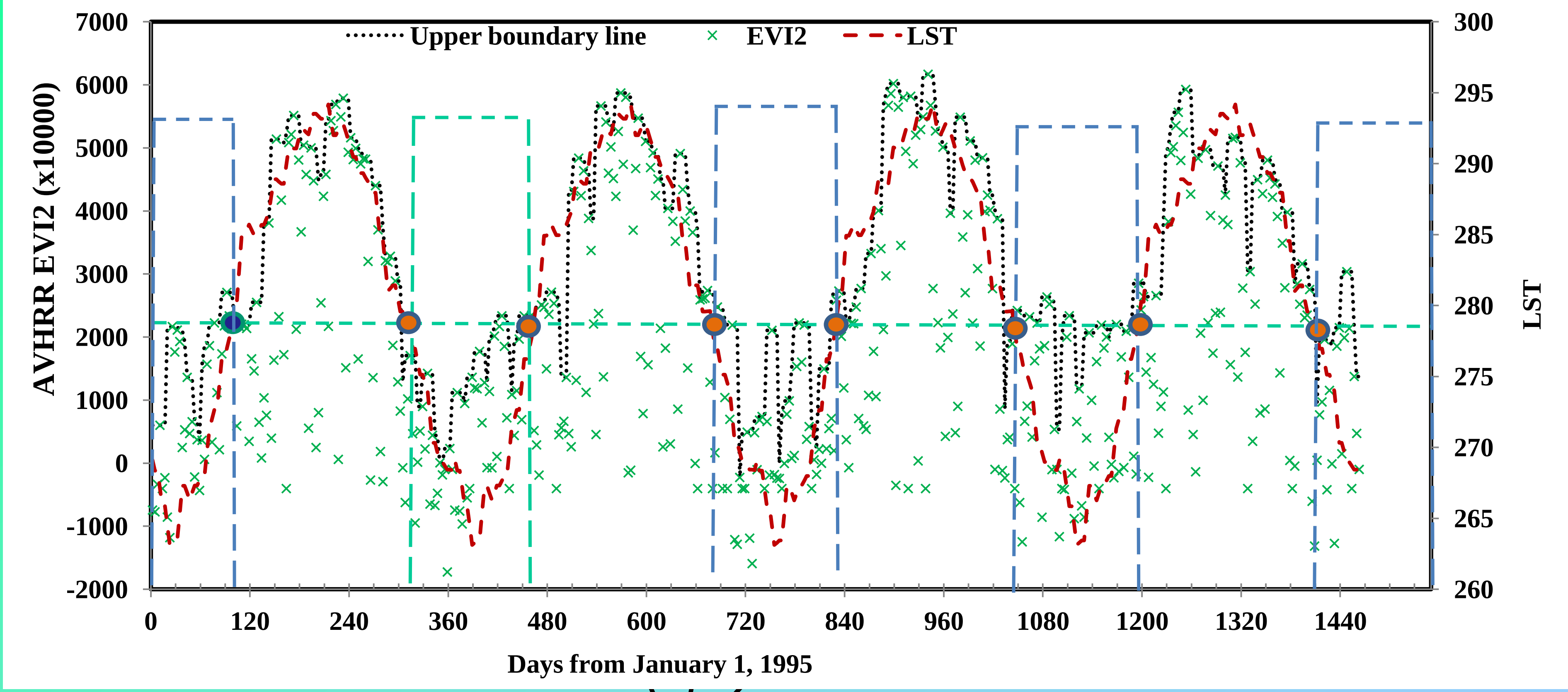
$$K' = \frac{dK}{dt}$$



Types of Temporal Trajectories in Vegetation Index Across Globe



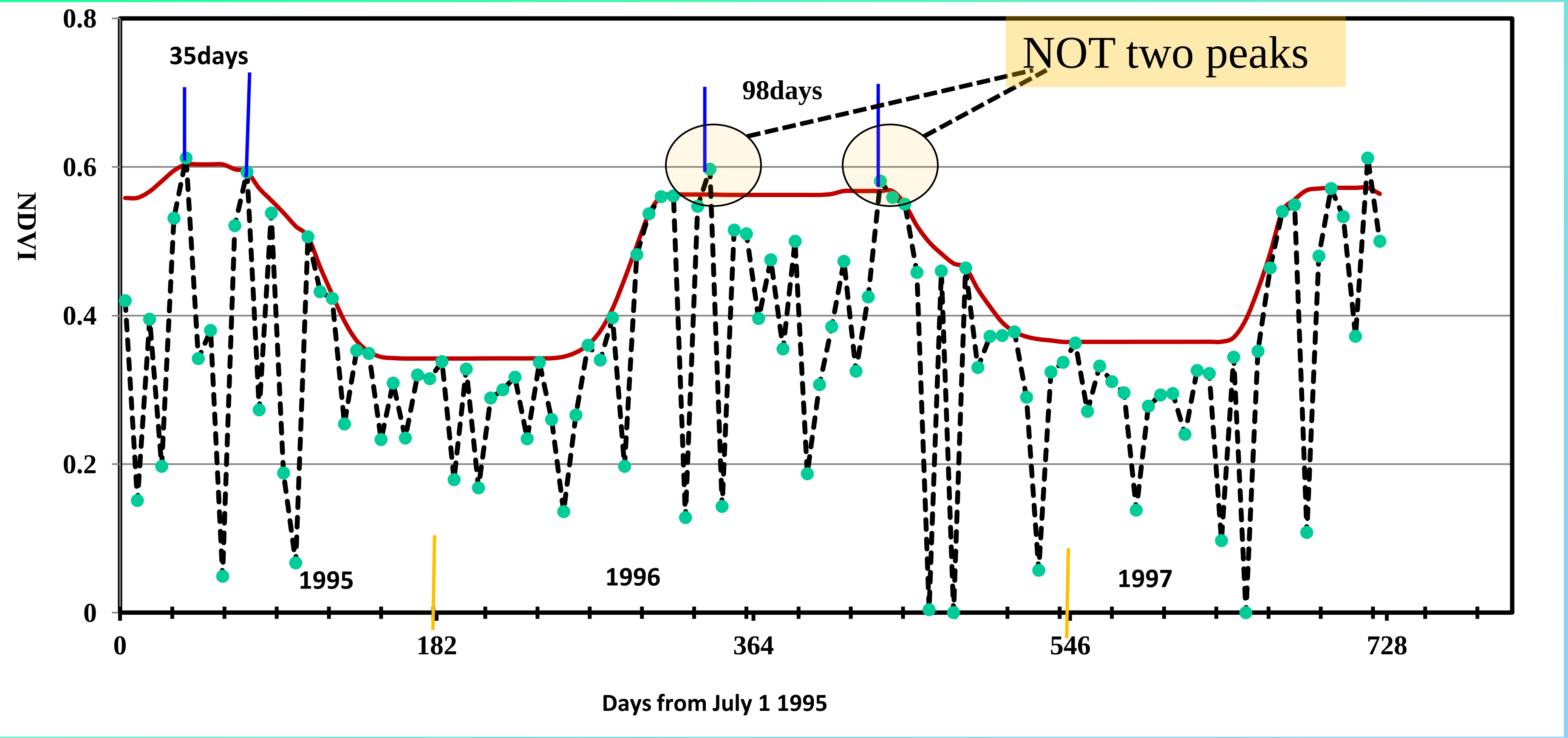
Reconstruction of Time Series Vegetative Greenness (VI) Trajectory
-- Determination of Background VI Value



Background EVI2:

Average maximum EVI2 during two winters (LST <278K)

Reconstruction of Time Series Vegetative Greenness (VI) Trajectory --Removal of Pseudo Plant Cycles



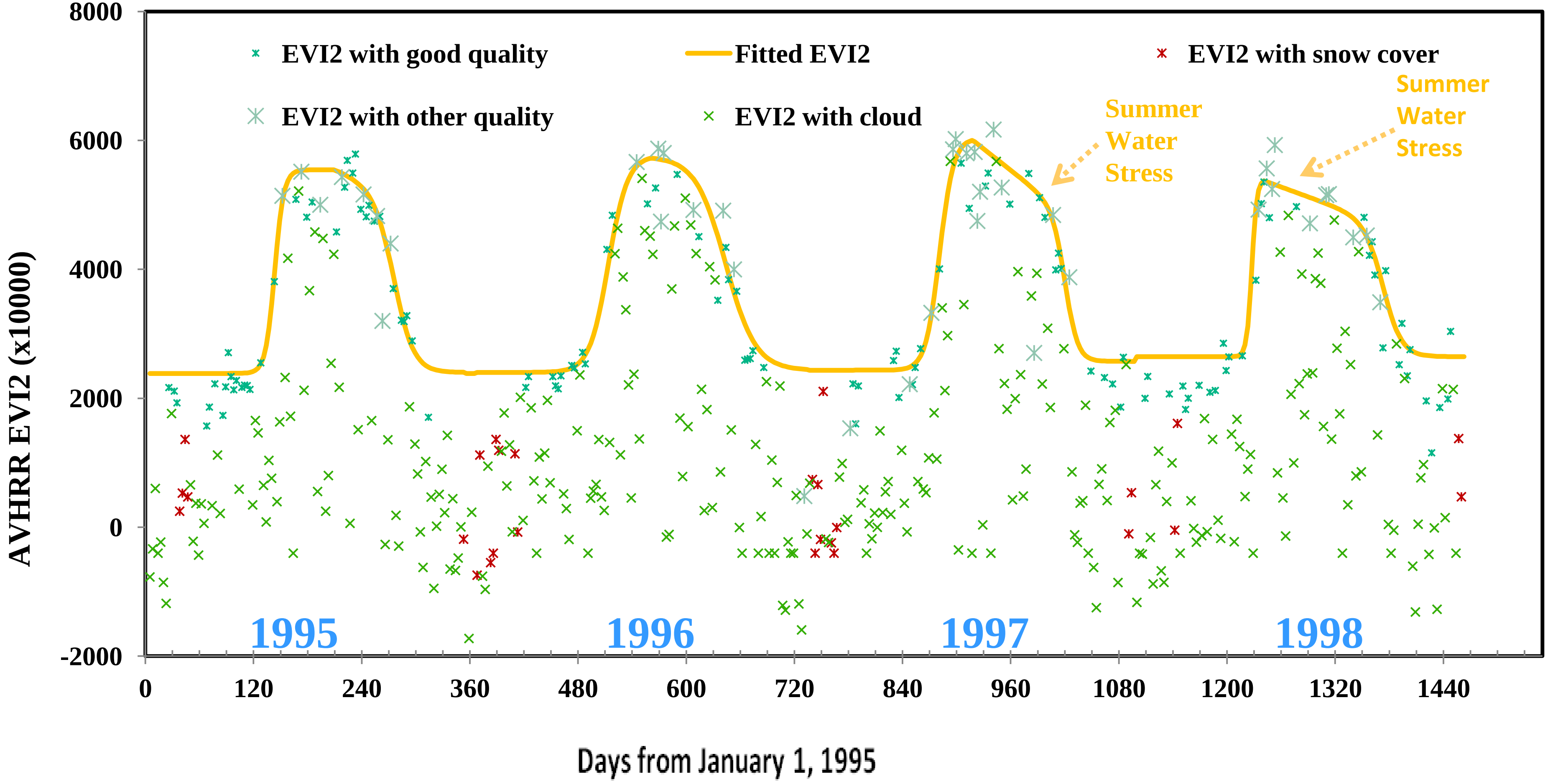
Ecosystem rules:

Forests: Span between peaks >4 month

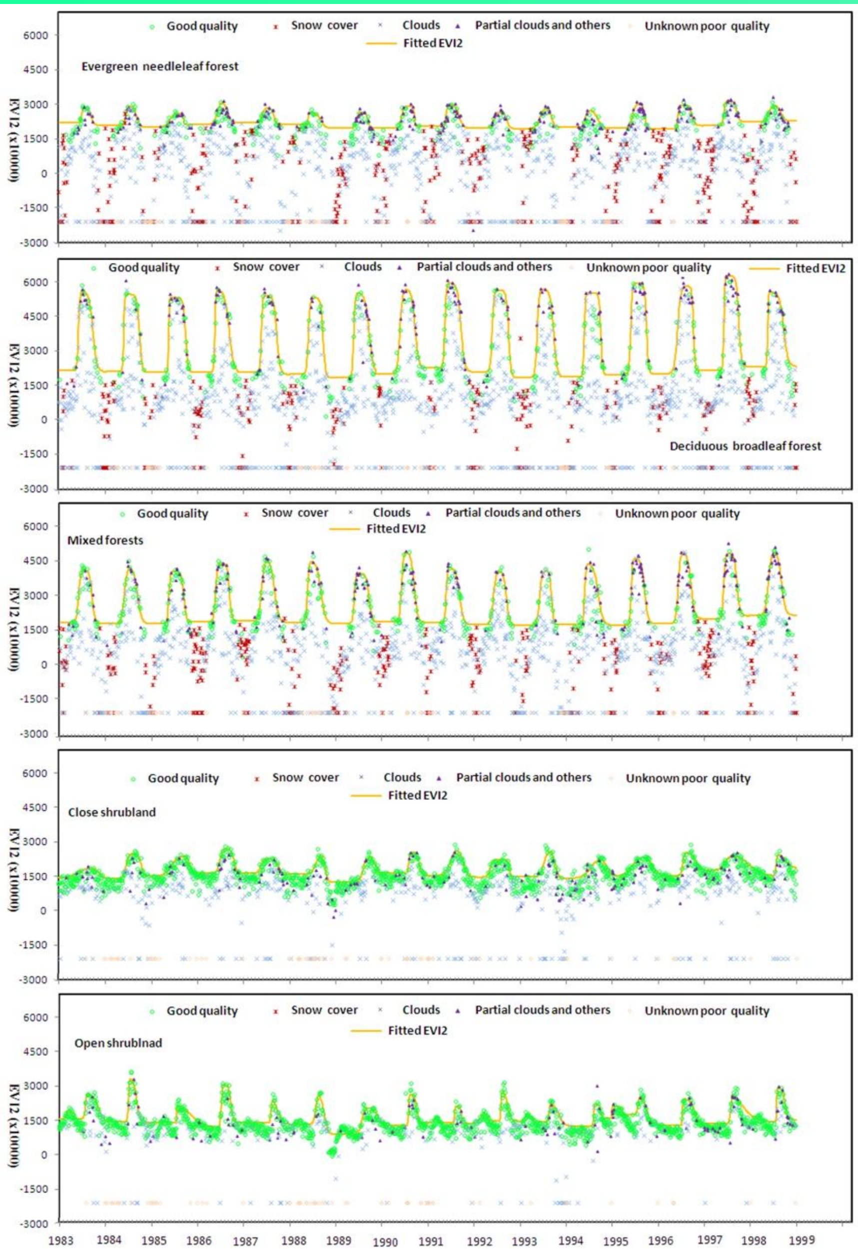
Shrubland/grassland: Span between peaks >2 months

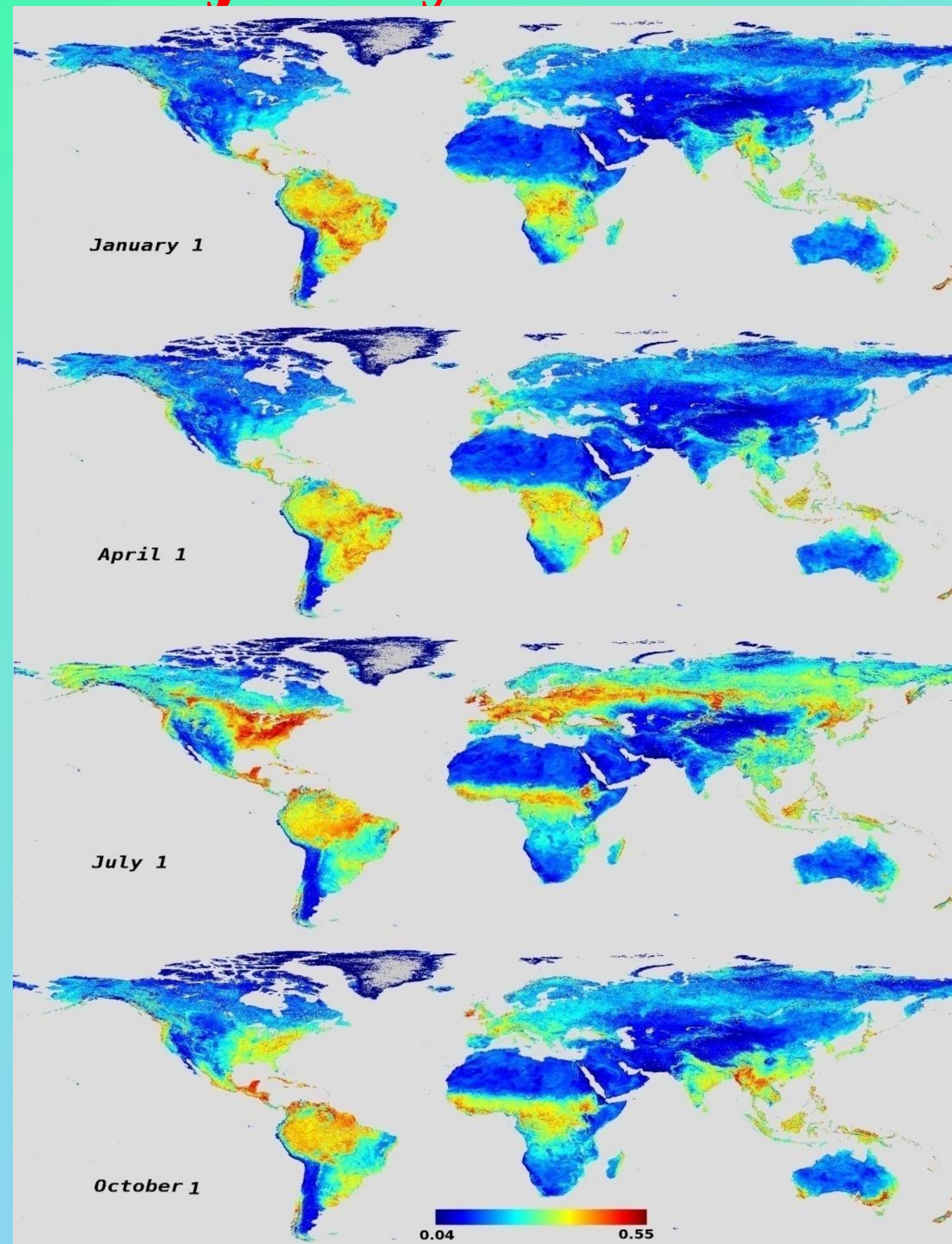
Cropland: Span between peaks > 1.5 months

Reconstructed Time Series Vegetative Greenness Trajectory--- Model Simulated Trajectory



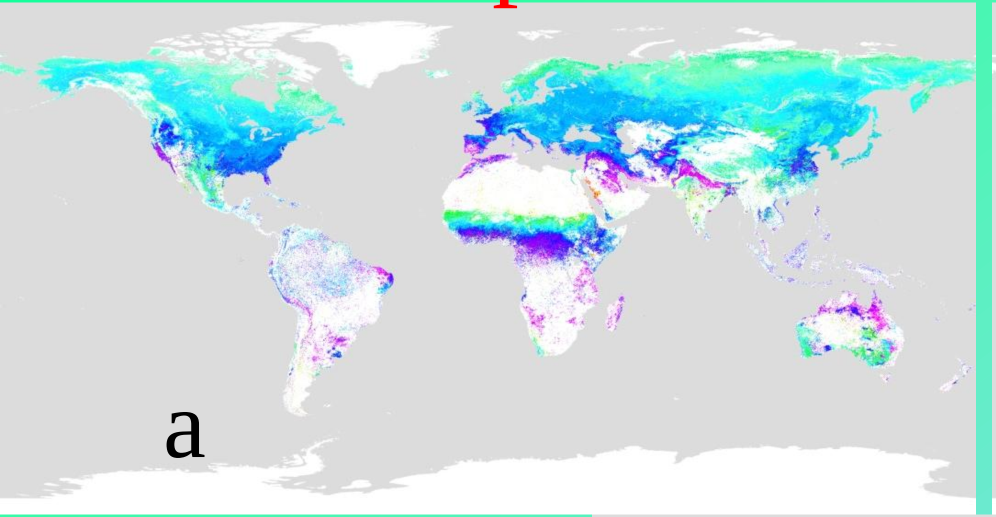
Reconstructed Time Series Vegetative Greenness Trajectory

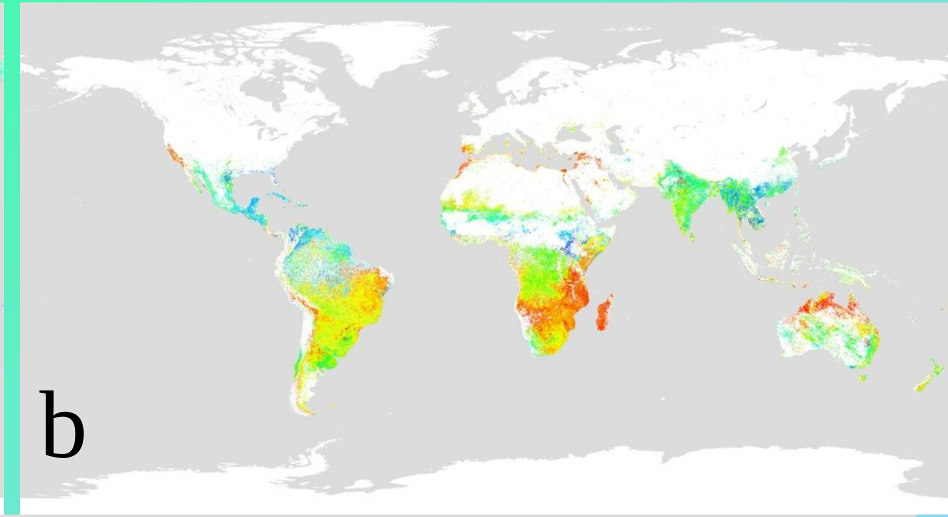




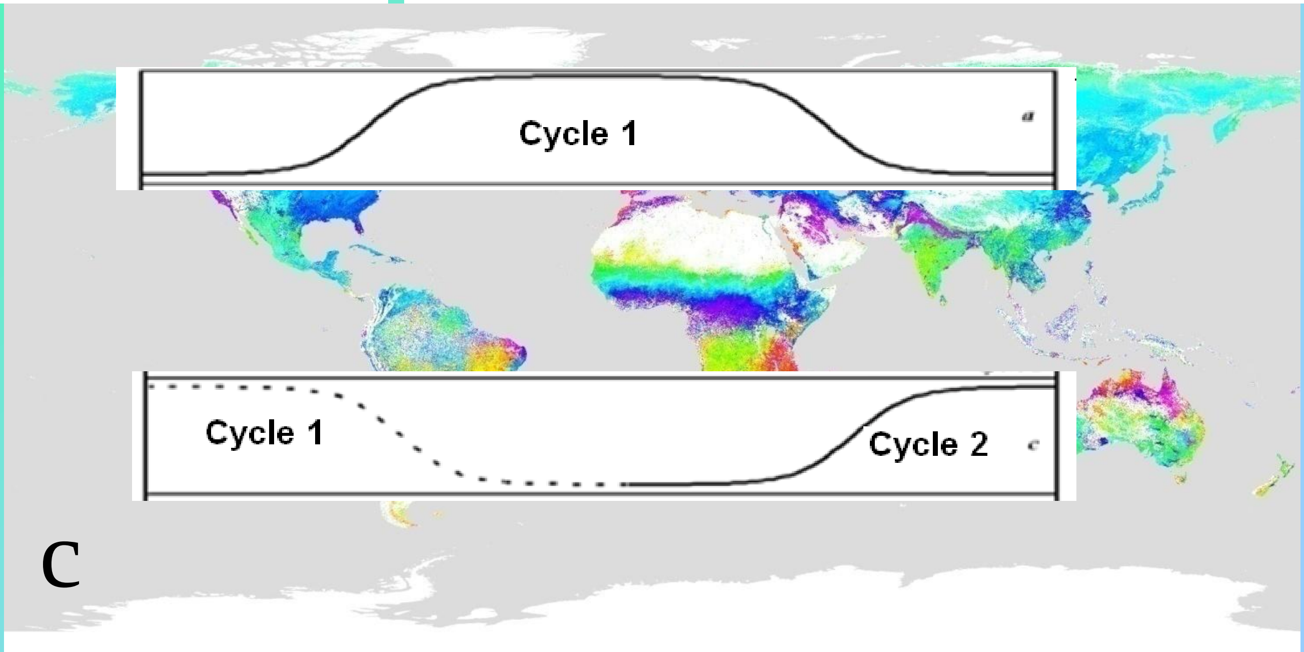
Spatial and Temporal Shift of Vegetation Phenology

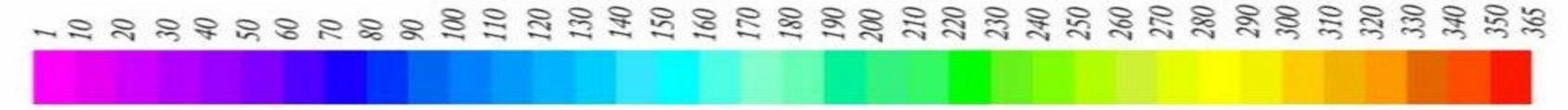
Greenup Onset from AVHRR in 1996



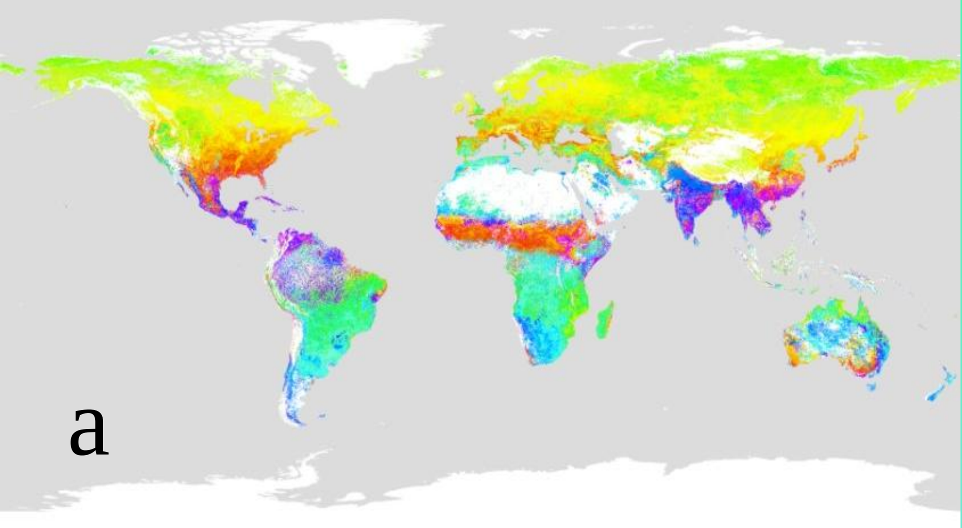


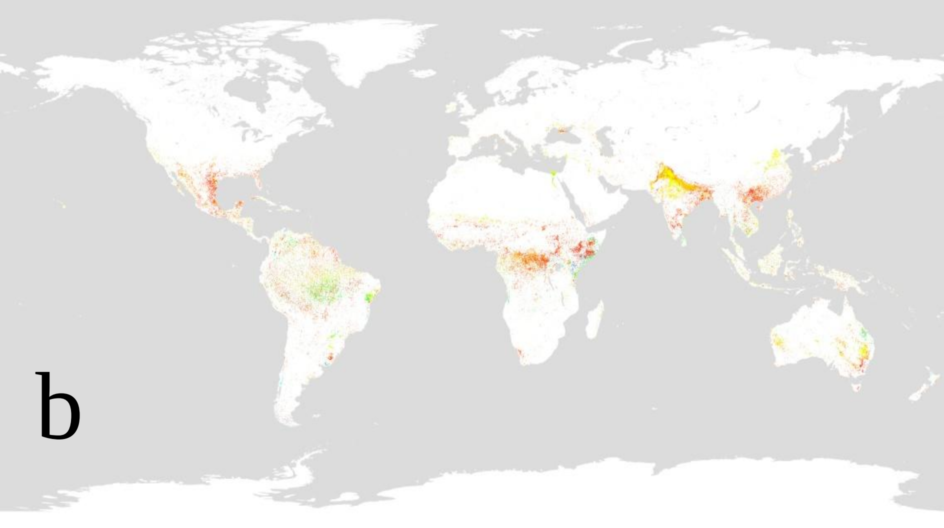
a) Recorded in the first cycle
b) Recorded in the second cycle
c) The first greenup onset for the year 1996 (combined from the first and the second cycles)



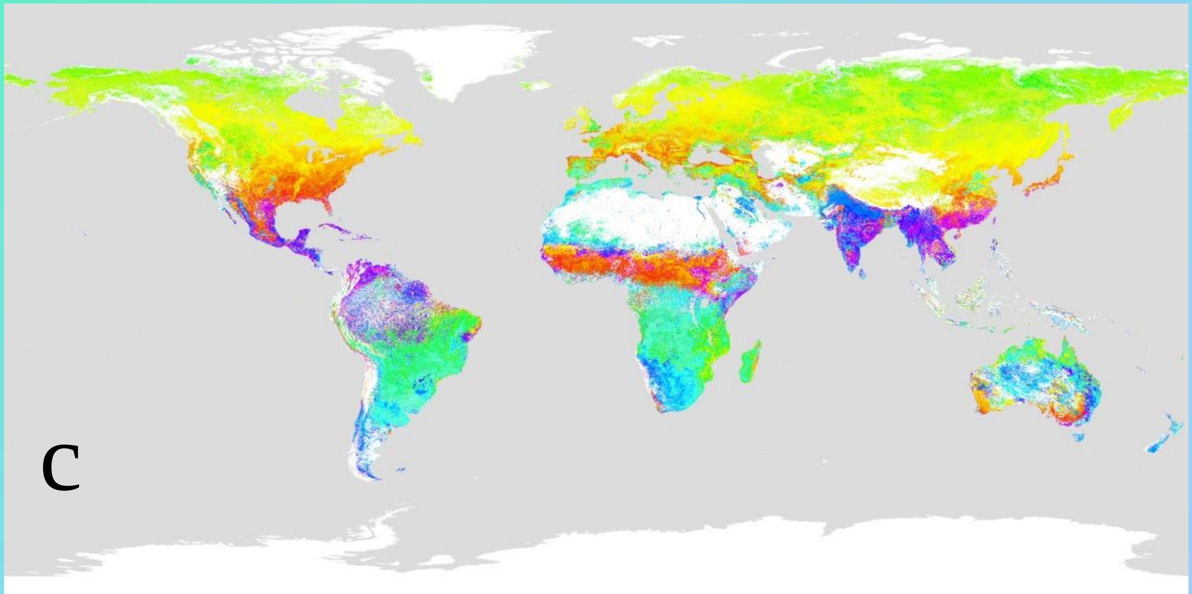


Dormancy Onset from AVHRR in 1996

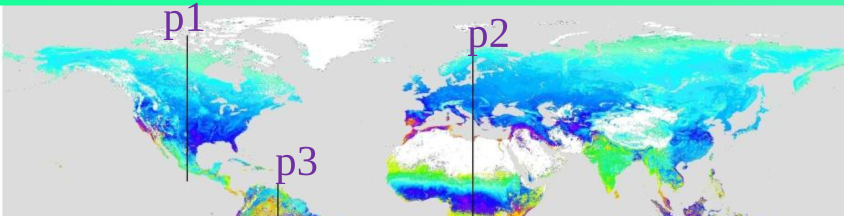


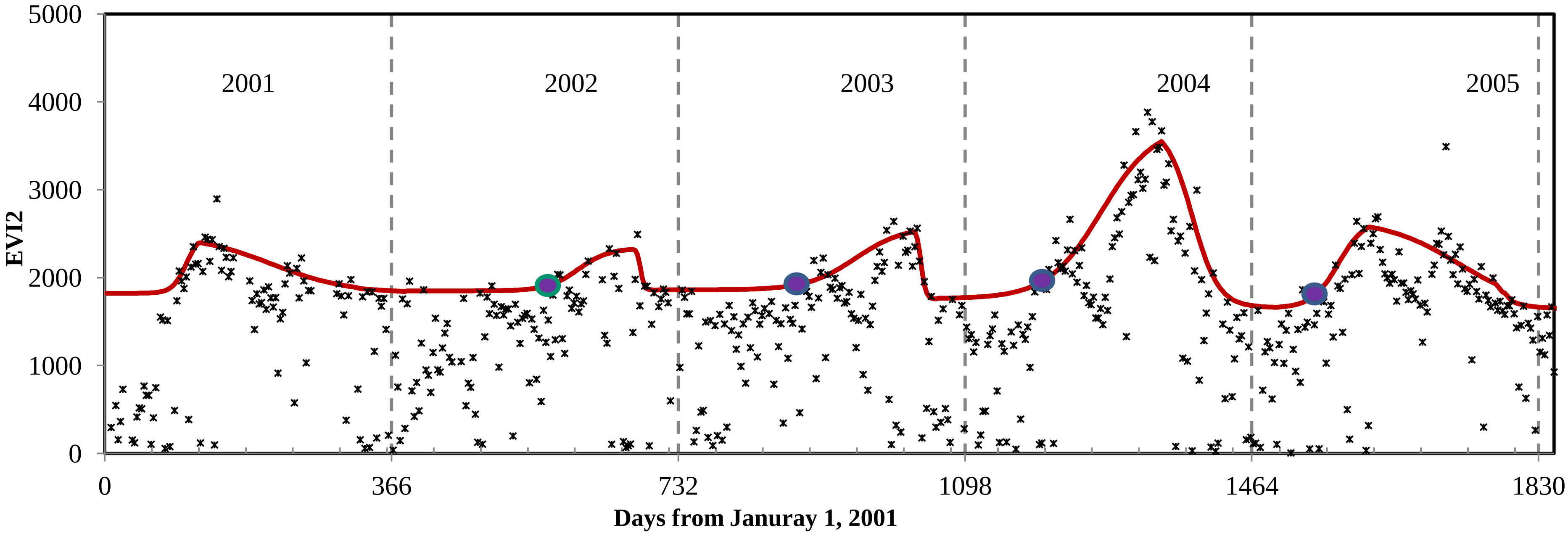


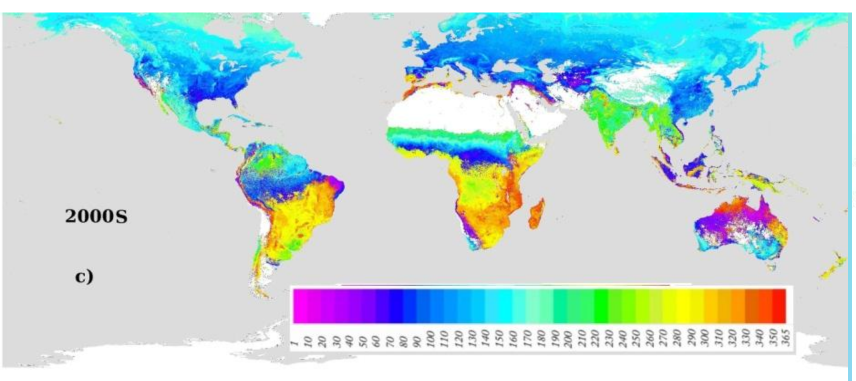
a) Recorded in first cycle
b) Recorded in second cycle
c) The first dormancy onset for the year 1996 (combined from the first and the second cycles)

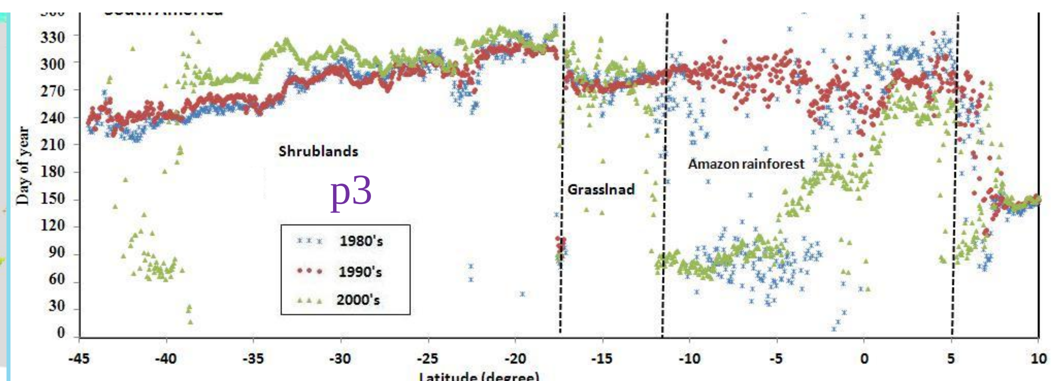


Spatial and Temporal Shift in Greenup Onset

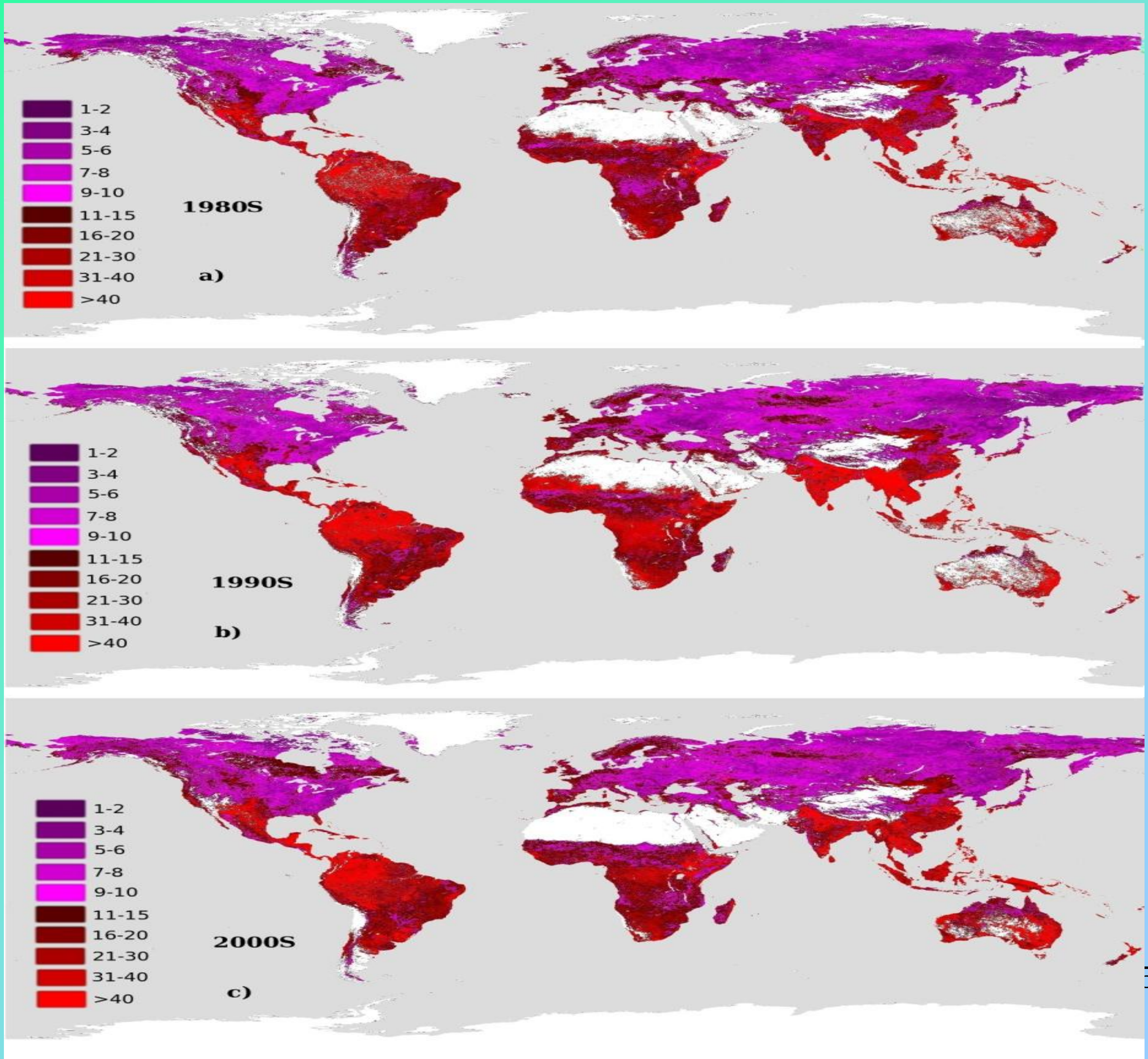








Inter-annual variation (standard variation) in the timing of greenup onset

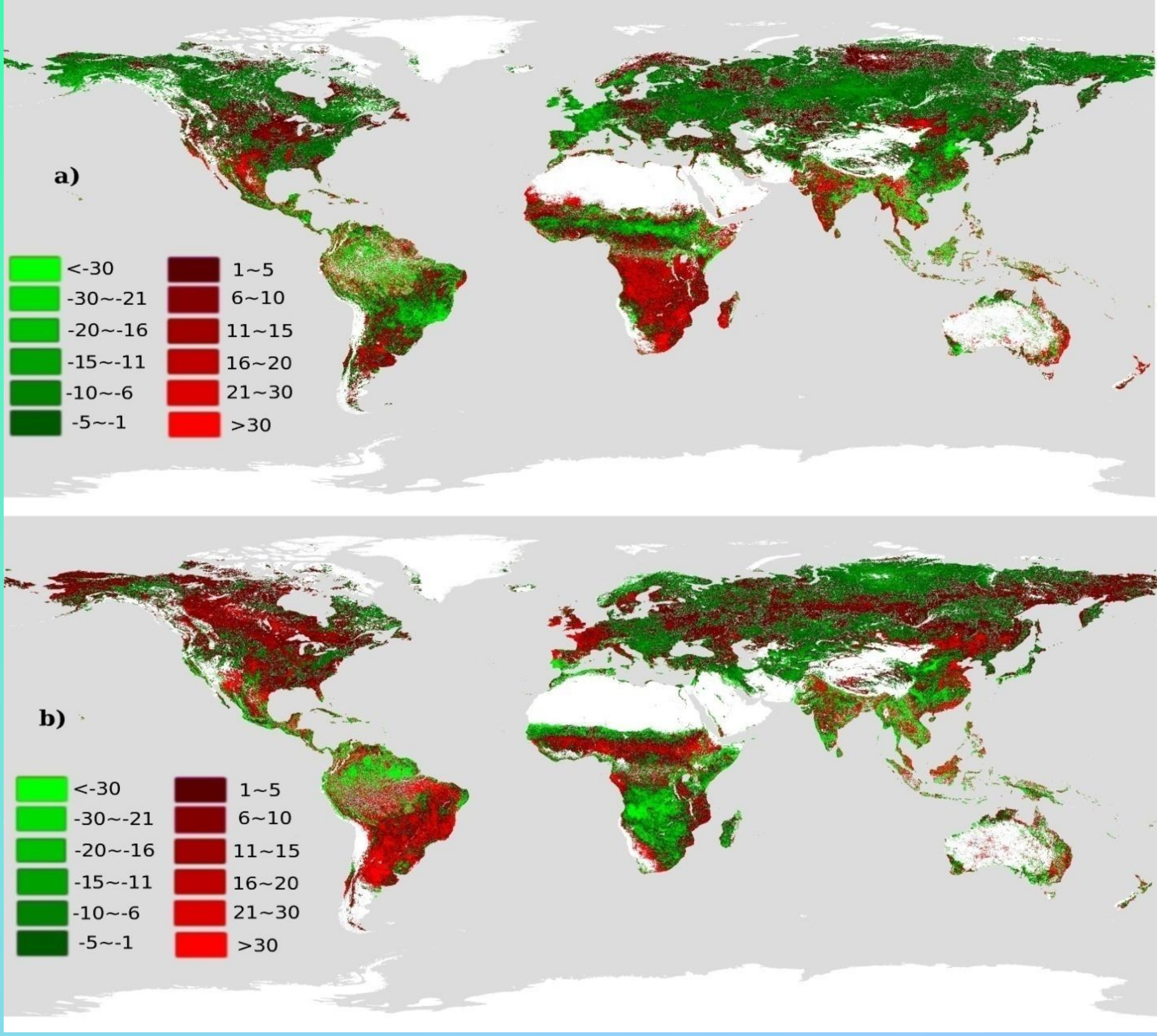


Shift in Greenup Onset

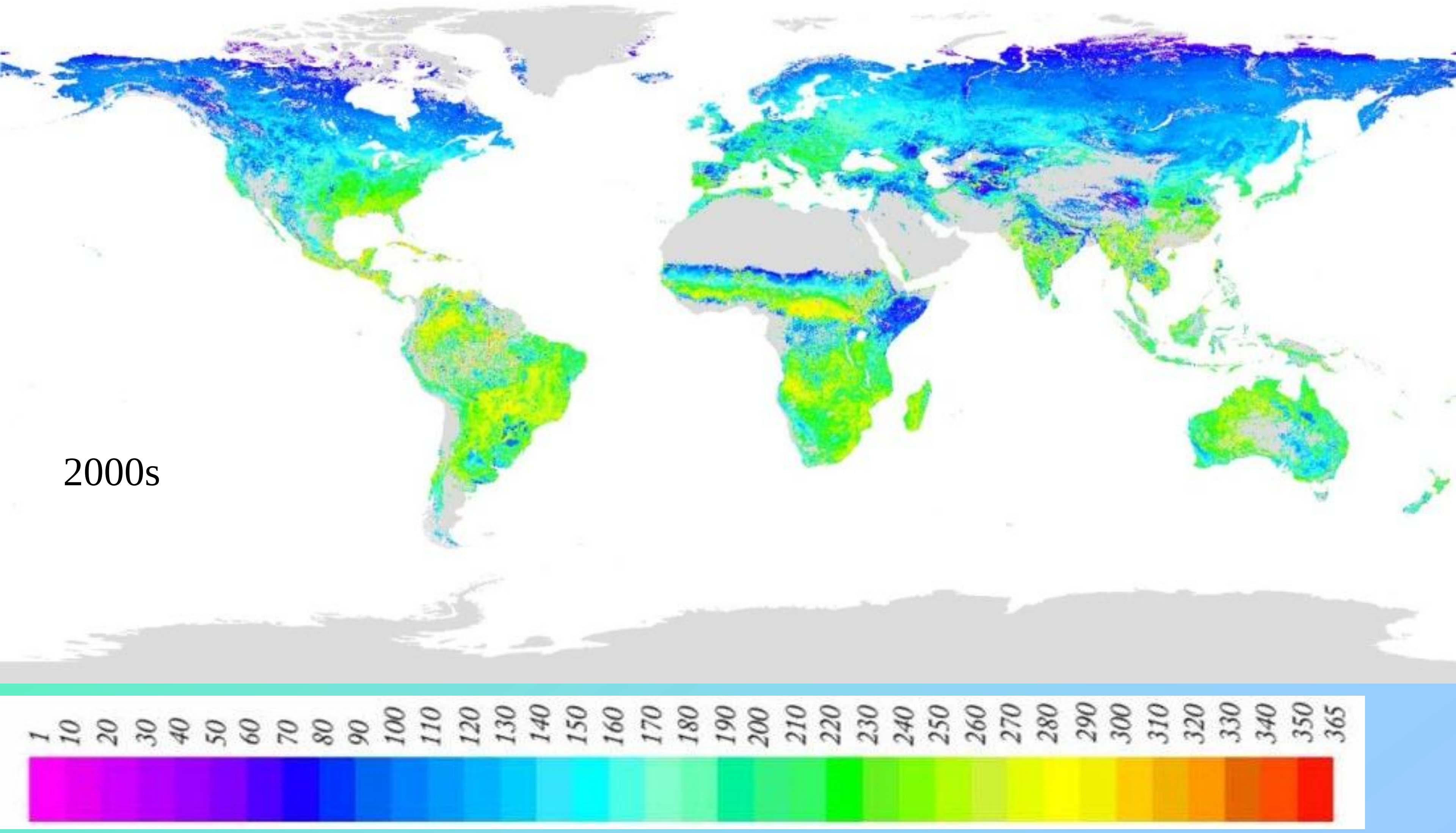
a) The difference between the 1990s and 1980s

b) the difference between the 2000s and 1990s

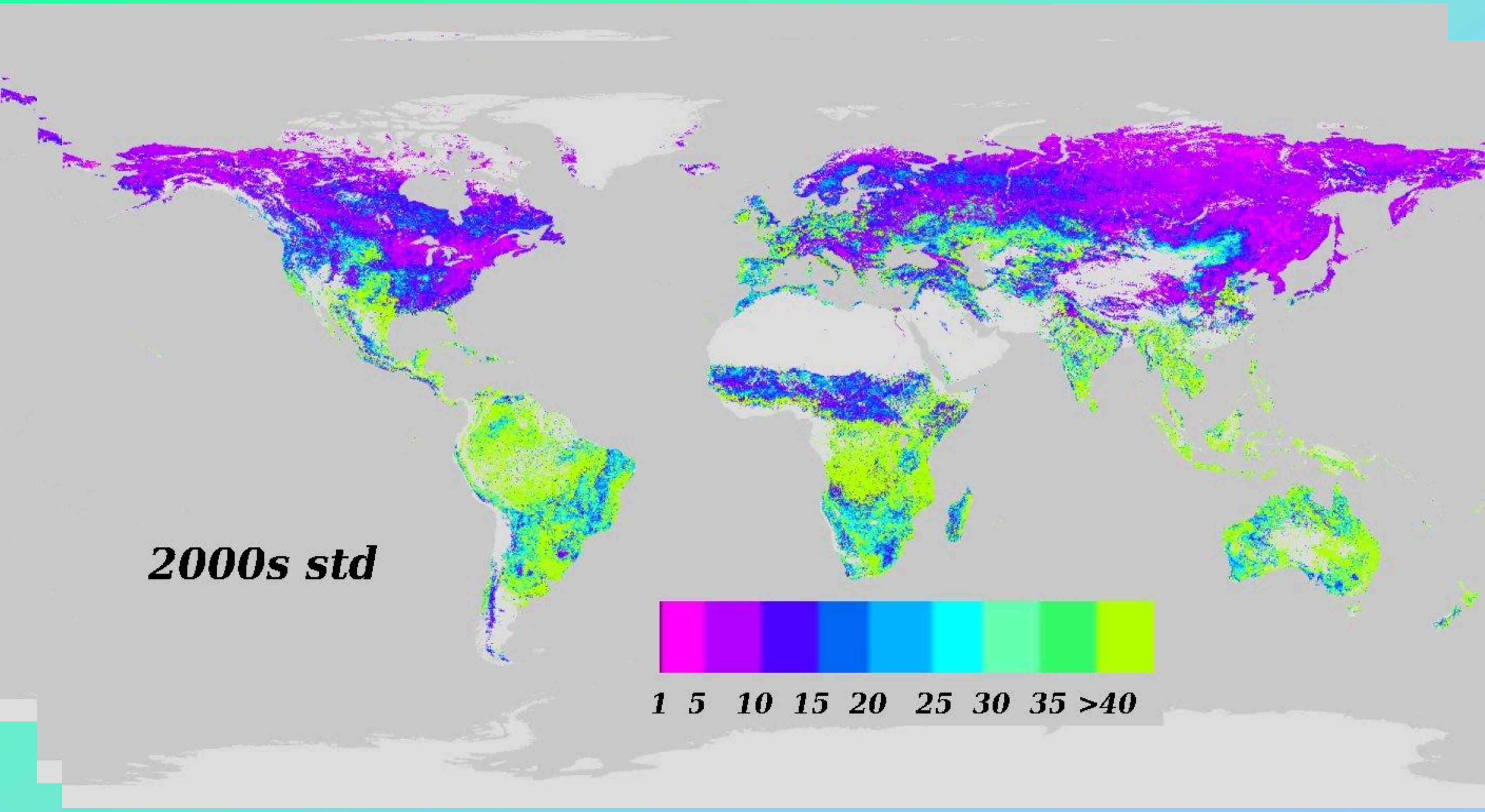
The green color indicates the number of advanced days, while the red color shows delayed days.



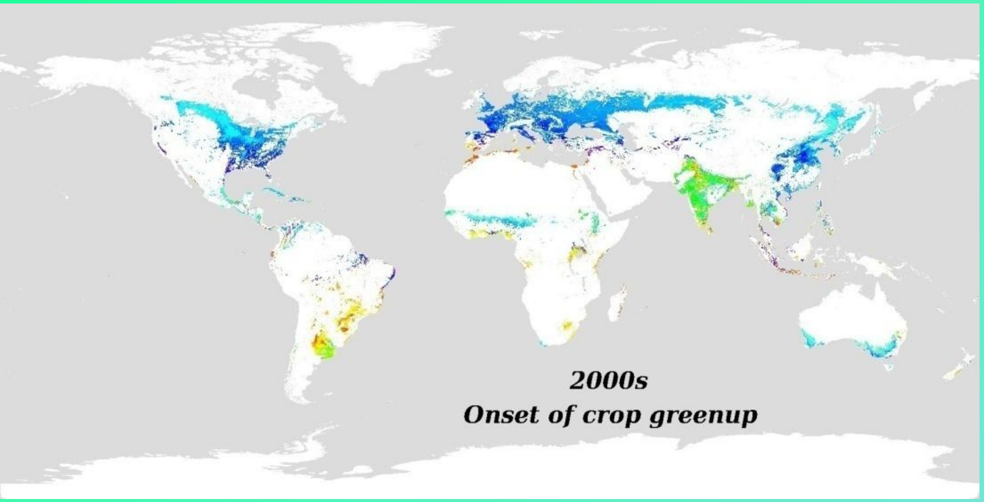
Growing Season Length

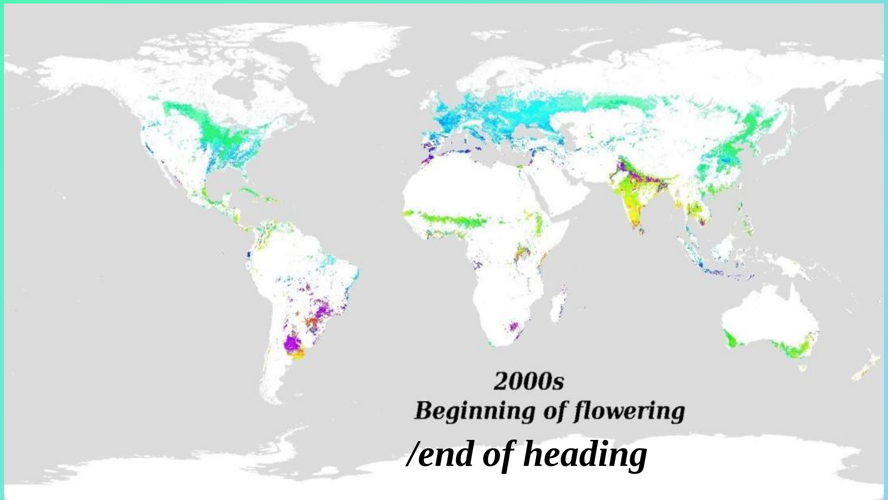


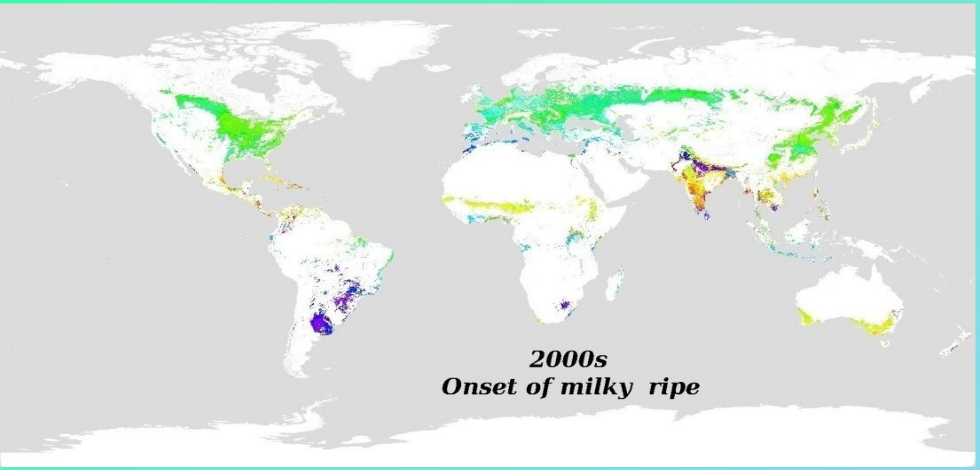
Inter-annual Variation (Standard Variation) in Growing Season Length

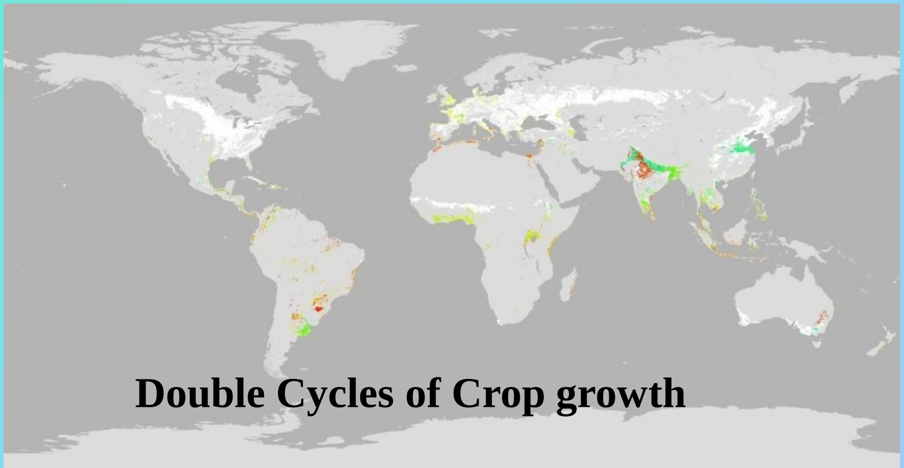


Long-Term Record of Global Crop Calendar

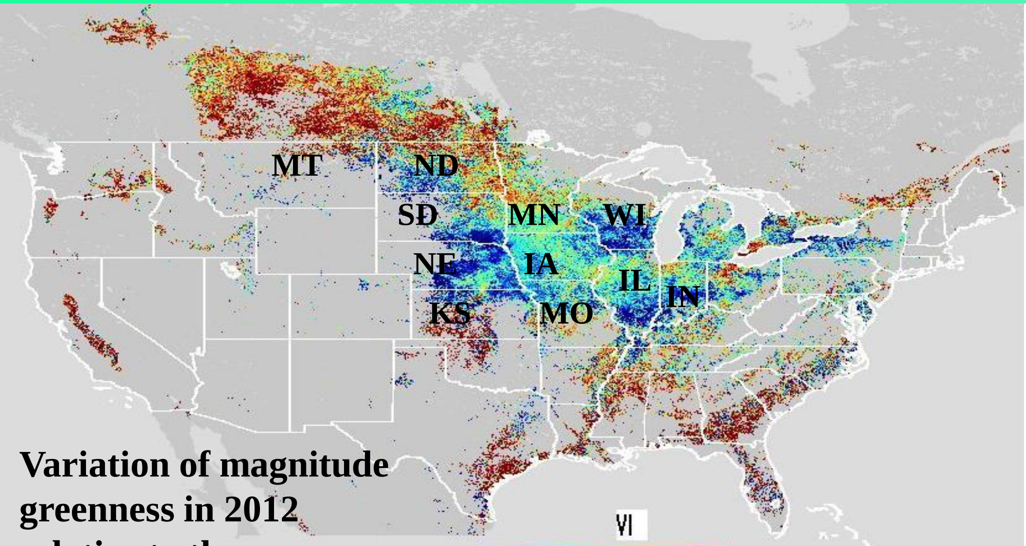




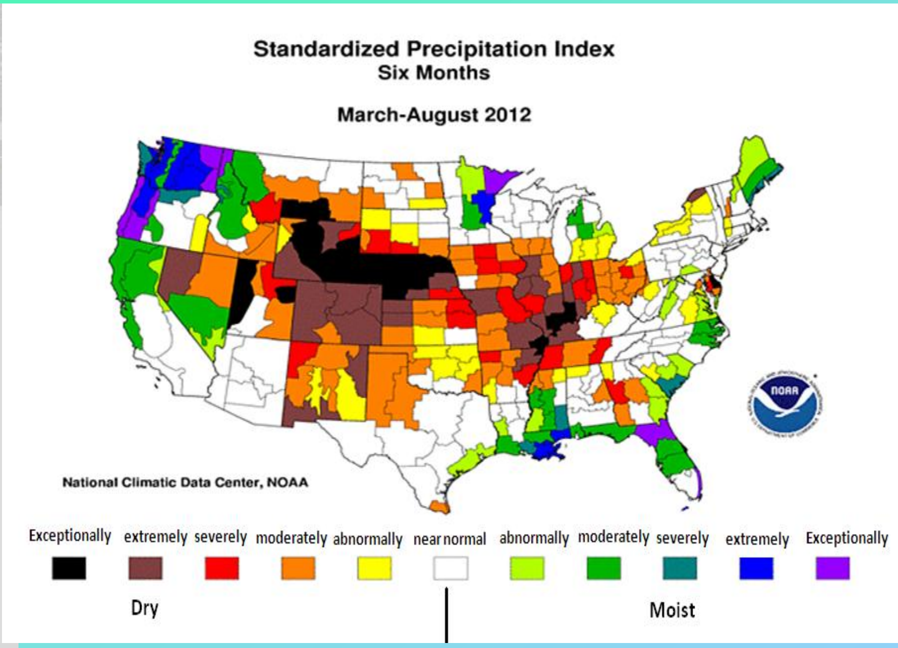


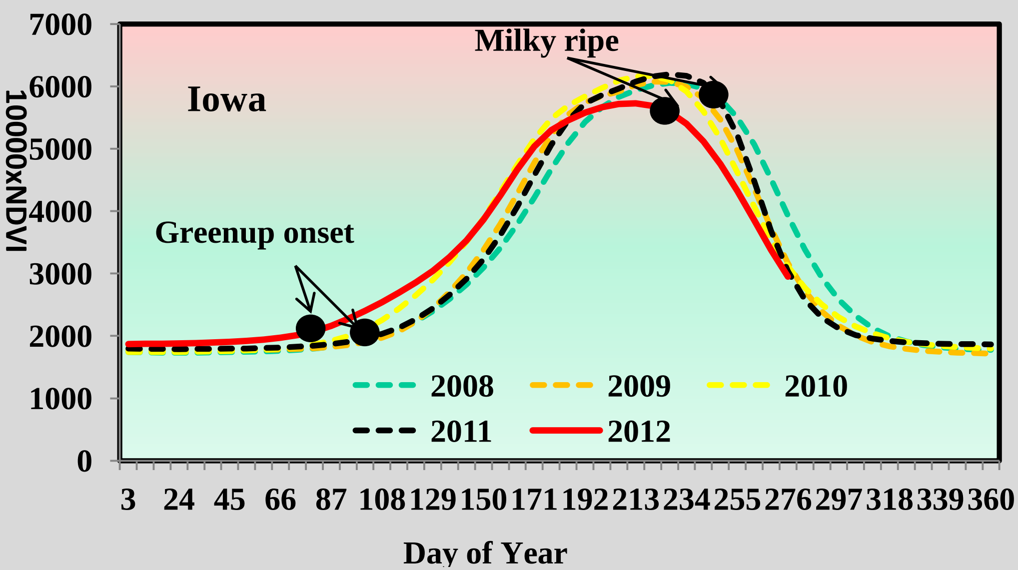


Drought Impacts on Crop Phenology



Variation of magnitude greenness in 2012 relative to the average value during 2008-2011





- **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:

$P_{qa0}=N_{qa0}/T$

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).

Sensitivity of vegetation phenology detection 2069

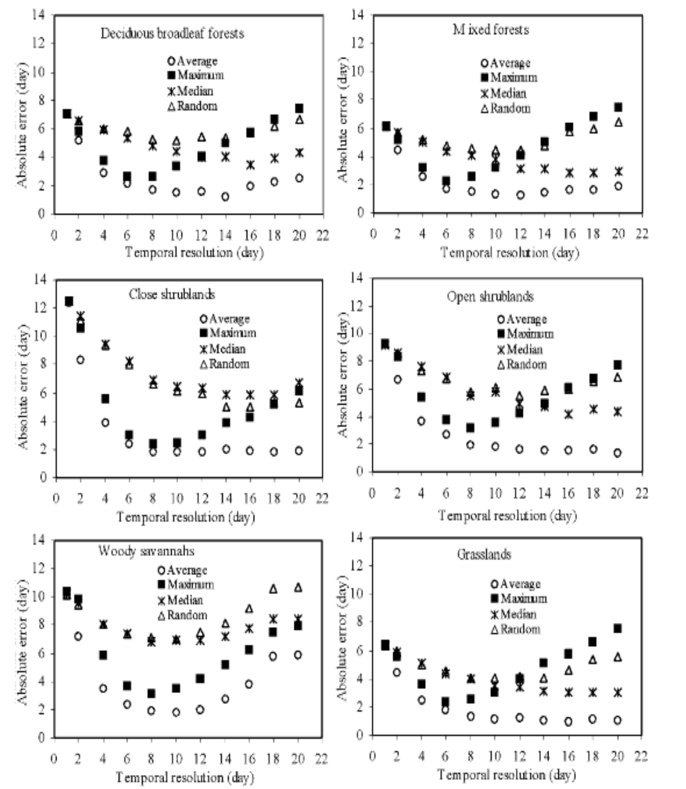
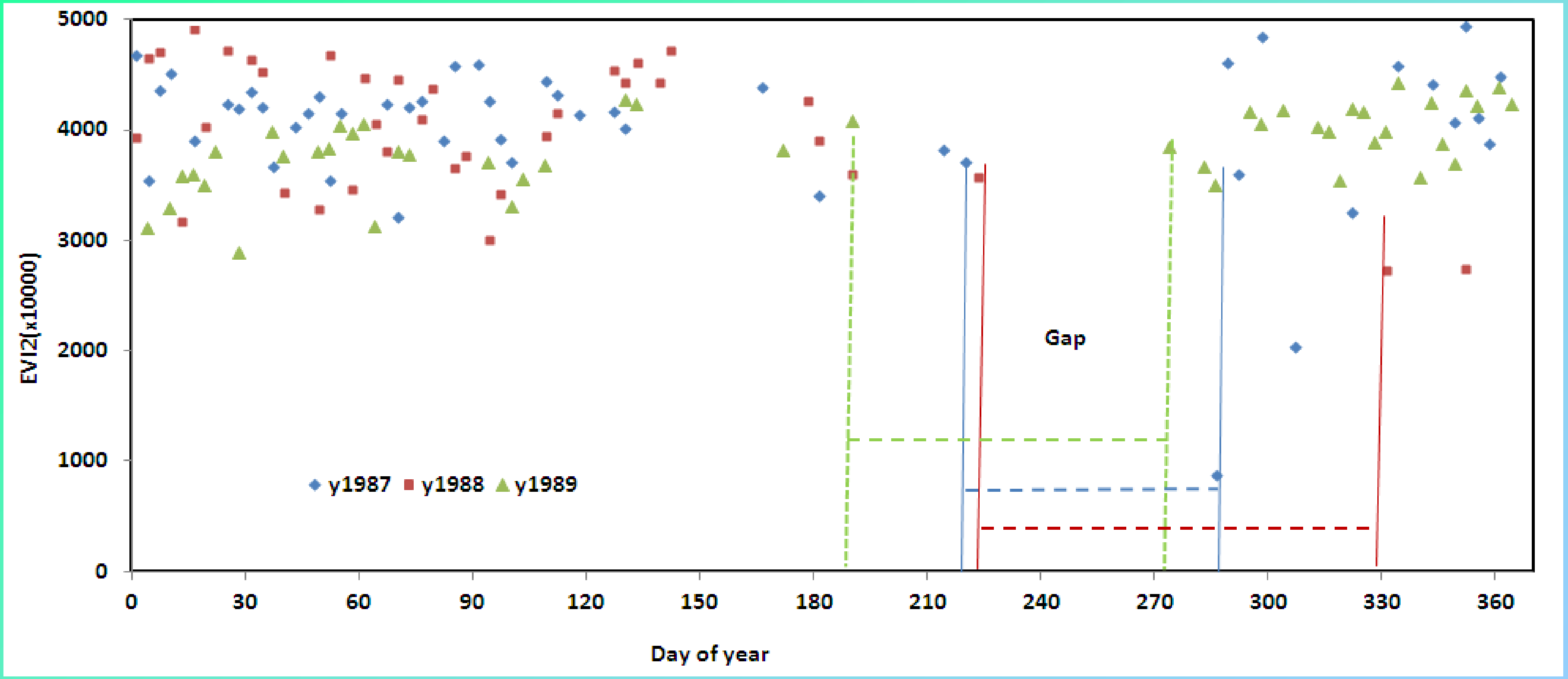


Figure 4. Average of absolute errors derived from four phenological transition dates using simulated daily data.

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):

$$d = 1 - \frac{\sum_{i=1}^{n}\left(P_{(i)} - O_{(i)}\right)^2}{\sum_{i=1}^{n}\left(\left|P_{(i)} - \bar{O}\right| + \left|O_{(i)} - \bar{O}\right|\right)^2}$$

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

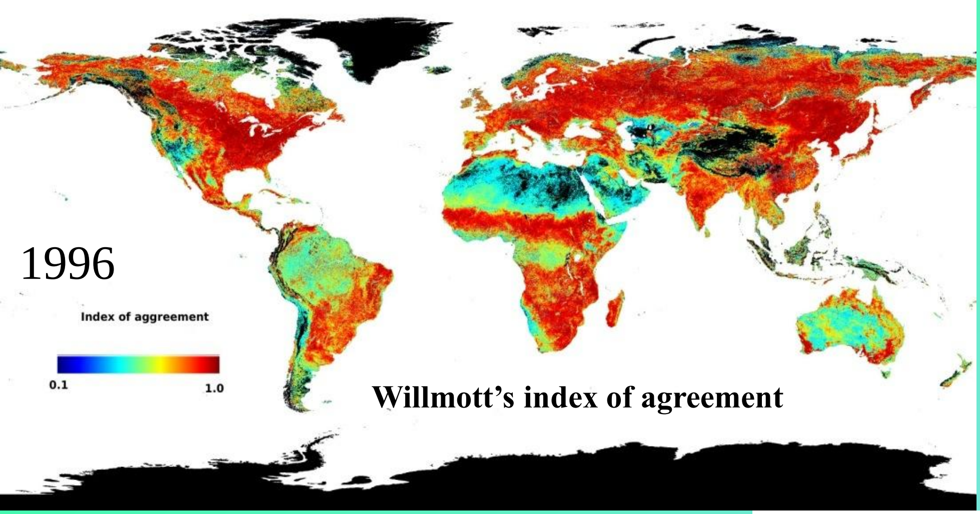
$P_{(i)}$ are the fitted values

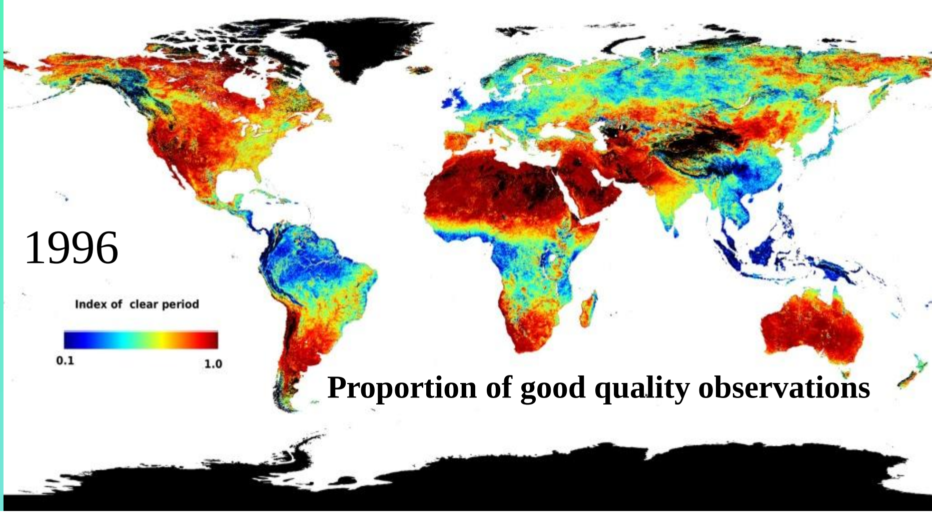
$O_{(i)}$ are the observations with good quality

$\bar{O}$ is the mean observed value.

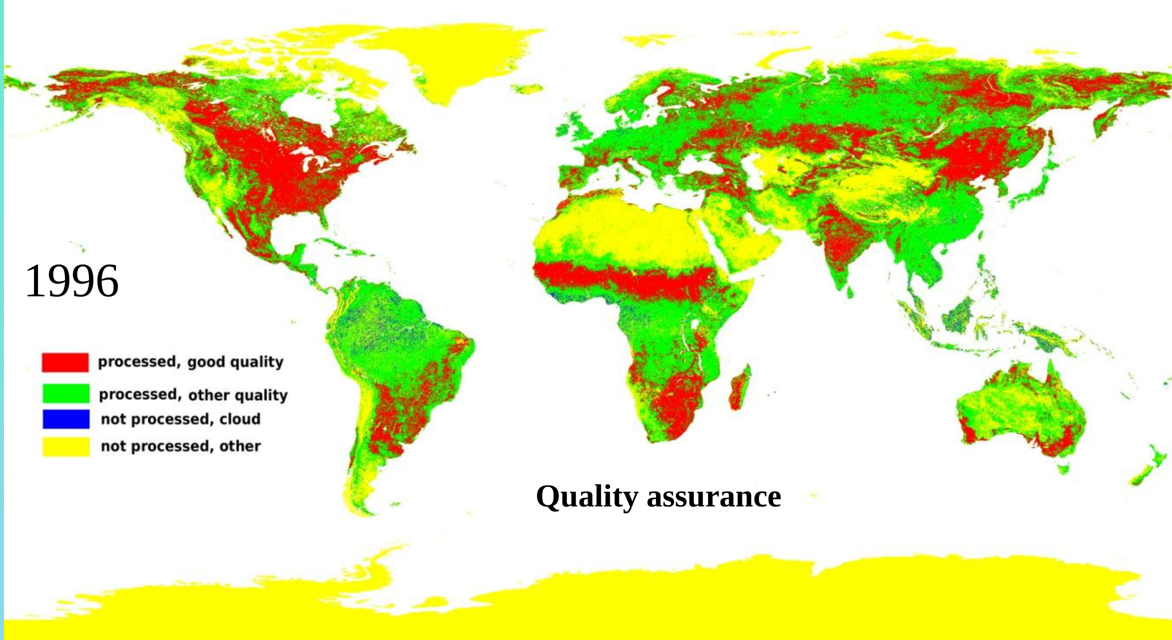
This index of agreement provides a measure of relative error in model estimates

Determination of Quality in Phenology Detection by Combining the Willmott's Index of Agreement and the Proportion of Good Quality Data in Satellite Observations

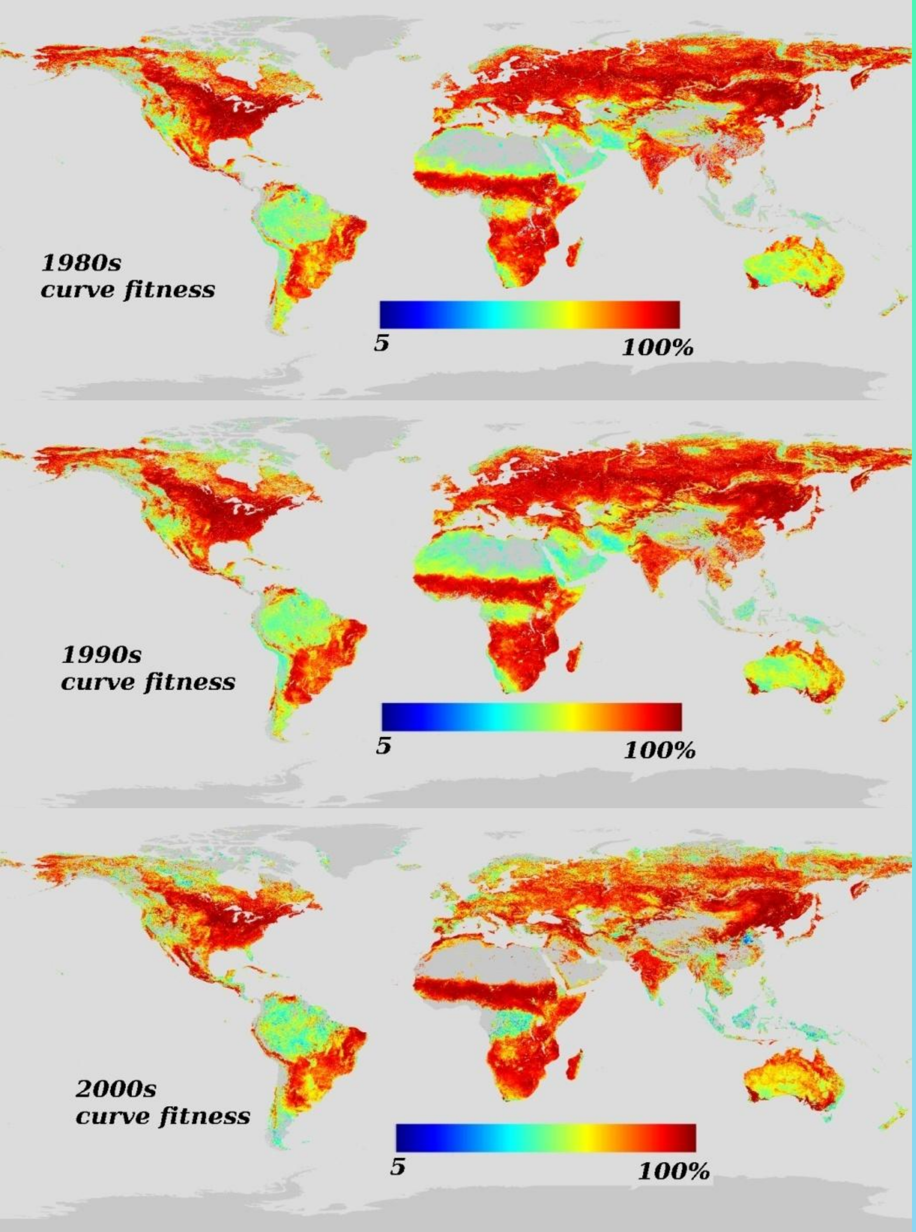


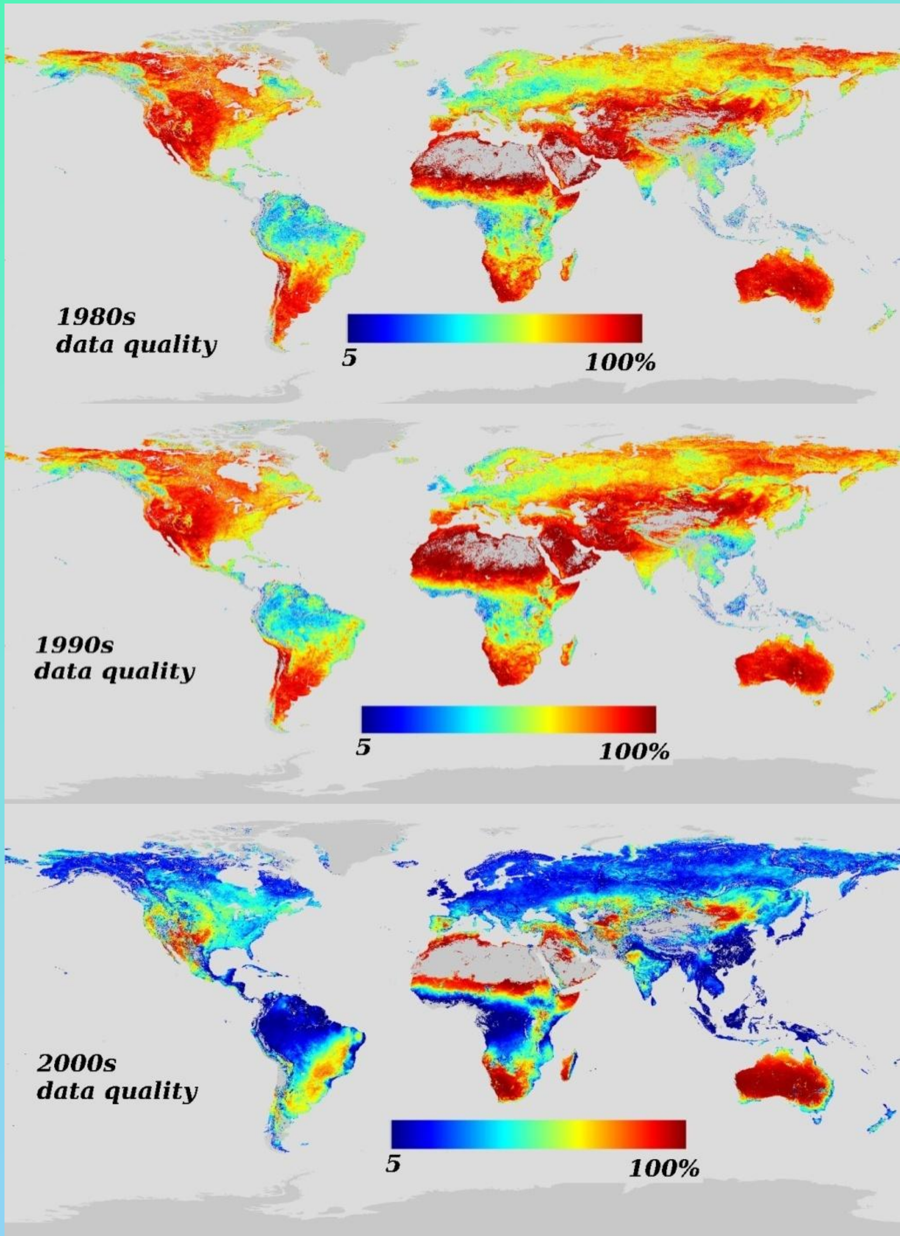


QA=0 (processed, good quality) if P_{qa0} >0.6 and d>0.8
QA=1 (processed, other quality) if P_{qa0} >0.3 and d>0.8
QA=2 (not processed, clod) if P_{qa0} <0.3
QA=4 (not processed, other) if growing season amplitude in VI<0. 08 in forests and <0.02 in other ecosystems



Quality of Temporal Data and Curve Fitness





Land Surface Vegetation Phenology

Science Data Sets (SDS)

DataField	Name	Format
DataField_1	Onset_Greenness_Increase	UINT16
DataField_2	Onset_Greenness_Maximum	UINT16
DataField_3	Onset_Greenness_Decrease	UINT16
DataField_4	Onset_Greenness_Minimum	UINT16
DataField_5	VI_Onset_Greenness_Minimum	UINT16
DataField_6	VI_Onset_Greenness_Maximum	UINT16
DataField_7	VI_Area	UINT16
DataField_8	Growing_Season_Length	UINT16
DataField_9	Rate_Greenness_Increase	UINT16
DataField_10	Rate_Greenness_Decrease	UINT16
DataField_11	Dynamics_QC	UINT16

Land Surface Vegetation Phenology Product Specification

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

Land Surface Vegetation Phenology Product Specification (continue)

```
Grid Structure:  LSP_Grid_LSP
    Dimensions:
Dimension       Dimension Name                      Value
Dimension_1  Ydim:MGLSP_Grid_LSP                    Data Rows
Dimension_2  Xdim:MGLSP_Grid_LSP                    Data Columns
Dimension_3  Num_QC_Words:MGLSP_Grid_LSP            Num_QC_Words
Dimension_4  Num_Modes:MGLSP_Grid_LSP               Num_Modes

 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

DataField	Name	Data Type	Dimensions
DataField_1	Onset_Greenness_Increase	UINT16	Dimension_1 Dimension_2 Dimension_3

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

Land Surface Vegetation Phenology Product Specification (continue)

Format for SDS of **VI Onset Greenness Increase and VI Onset Greenness Maximum**

```
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
```

```
DataField_8 Growing_Season_Length        UINT16                Dimension_1
                                                               Dimension_2
                                                                                                     Dimension_3
       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
       DataField_7 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:
         long_name      STRING  1   PGE     "Rate_Greenness_Increase"
         units          STRING  1   PGE     "VI/day"
         valid_range    uint16    2   PGE    0, 32766
         _FillValue     uint16    1   PGE     32767
         scale_factor   float64 1   PGE       0.0001
         add_offset     float64 1   PGE       0
```

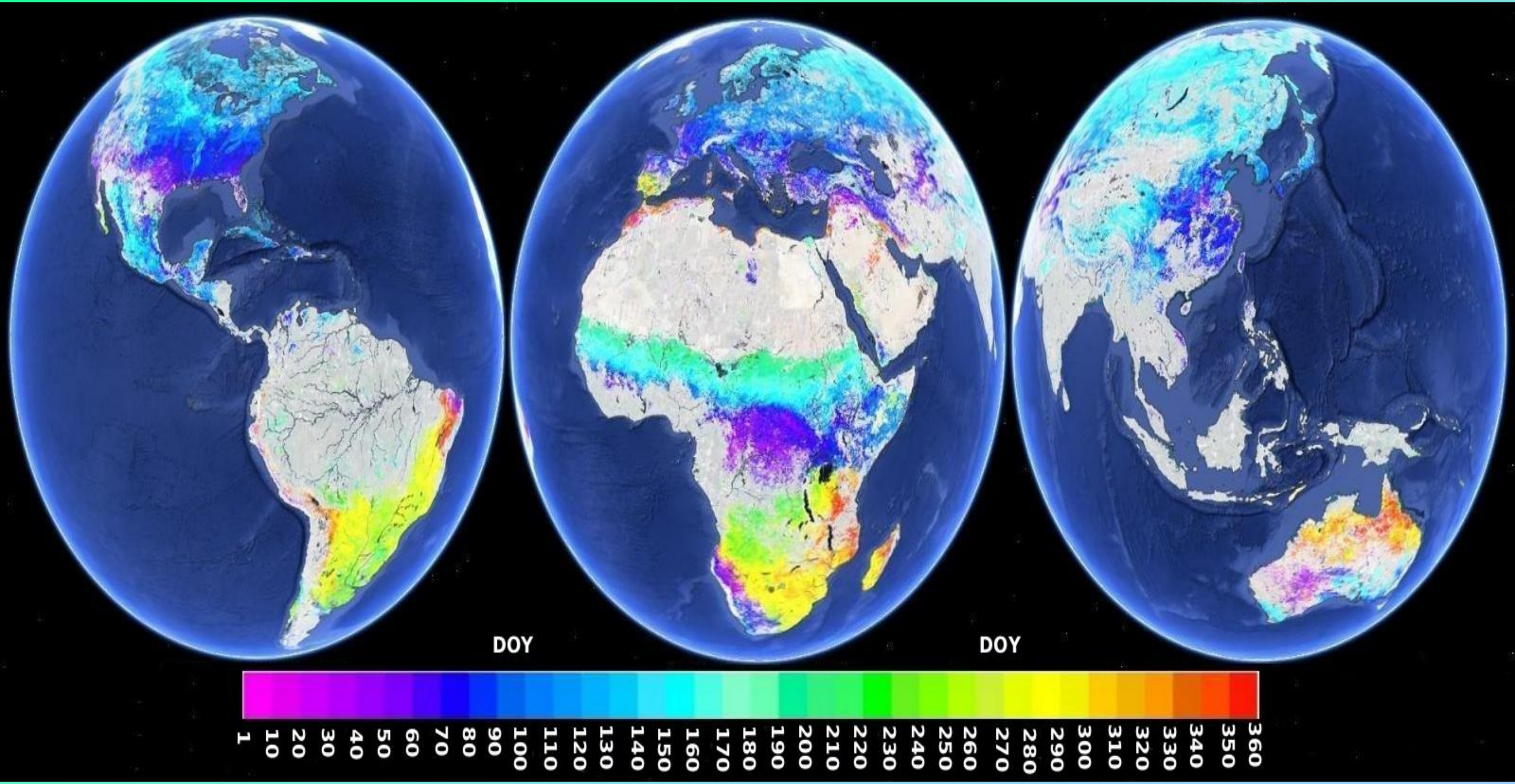
```
DataField_11  Dynamics_QC     UINT16           Dimension_1
                                              Dimension_2

        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 **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


DOY
DOY
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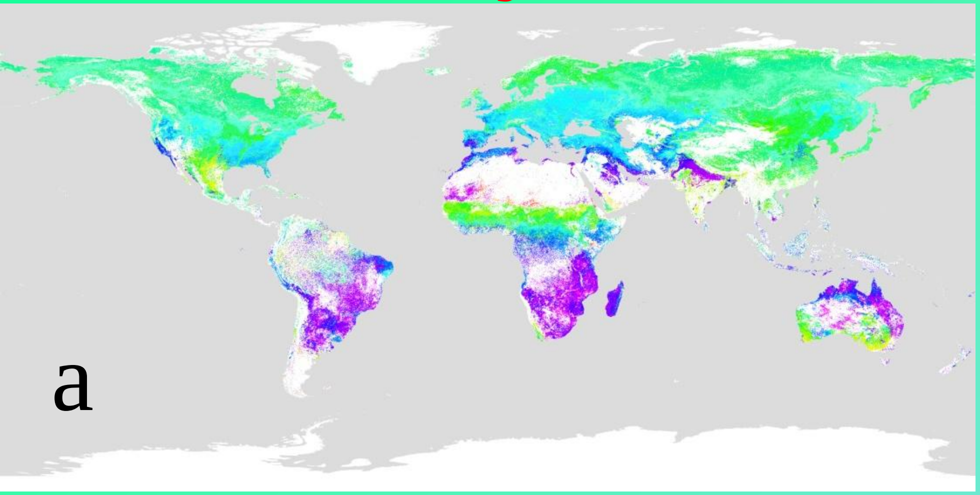
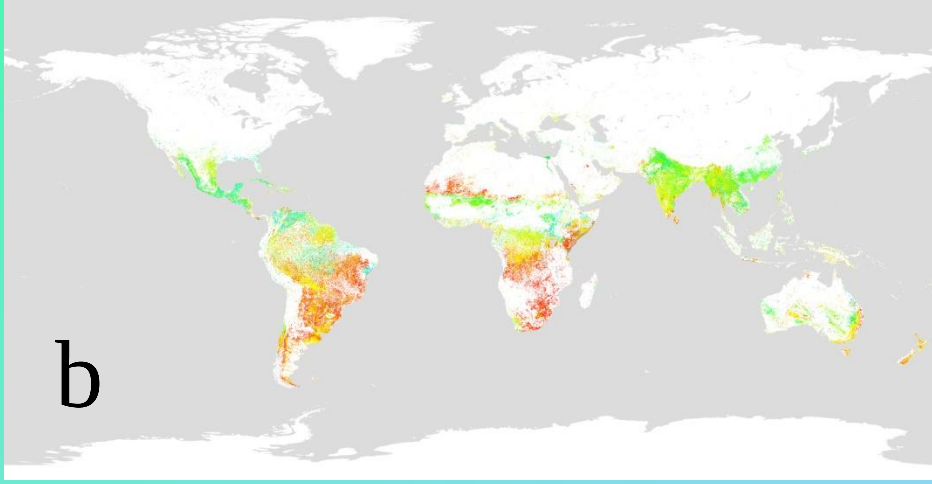
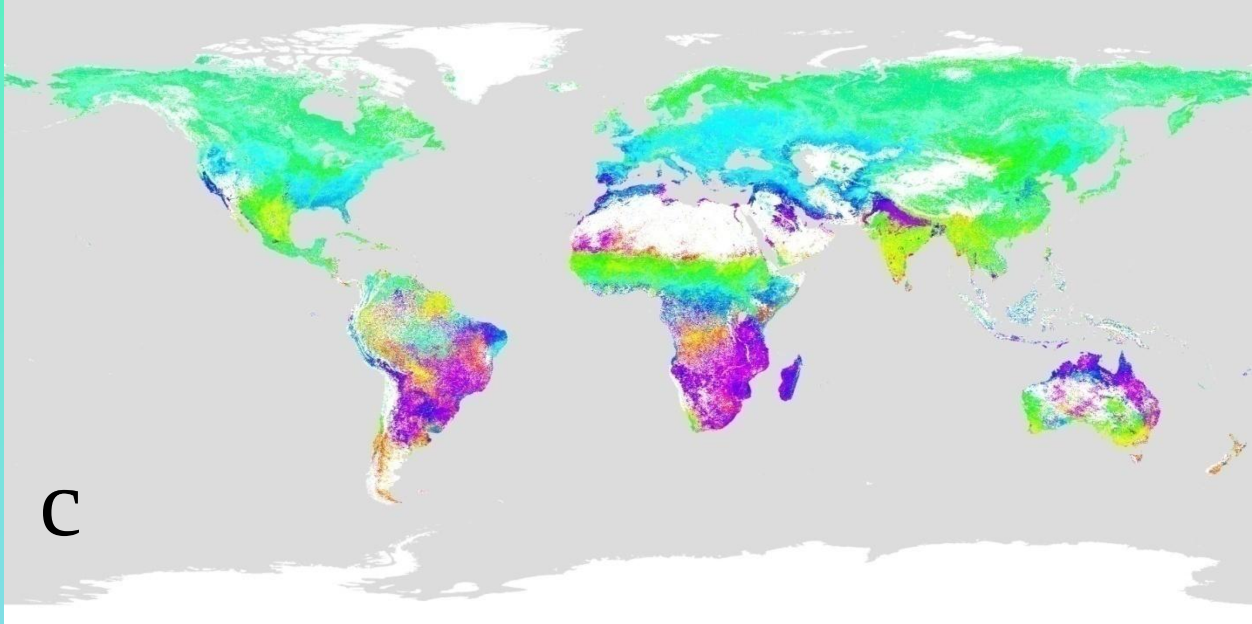
360

Maturity Onset from AVHRR in 1996

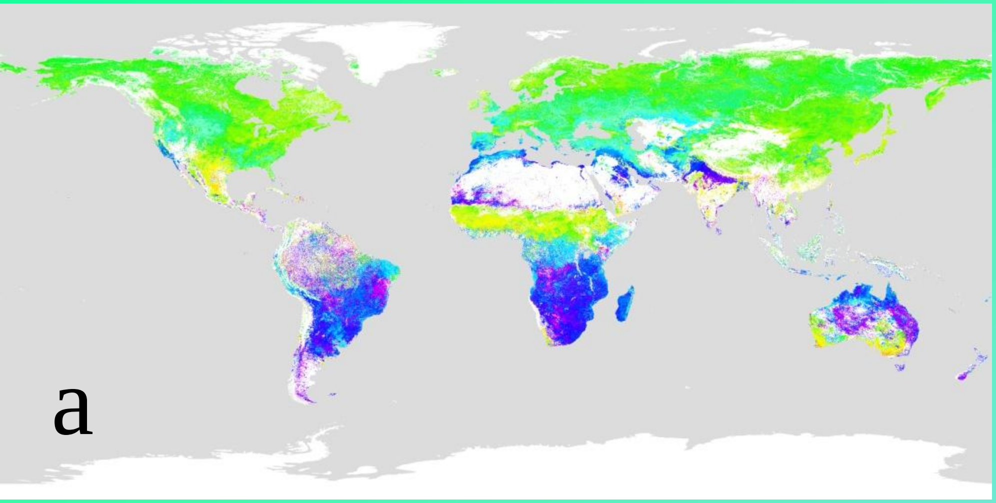


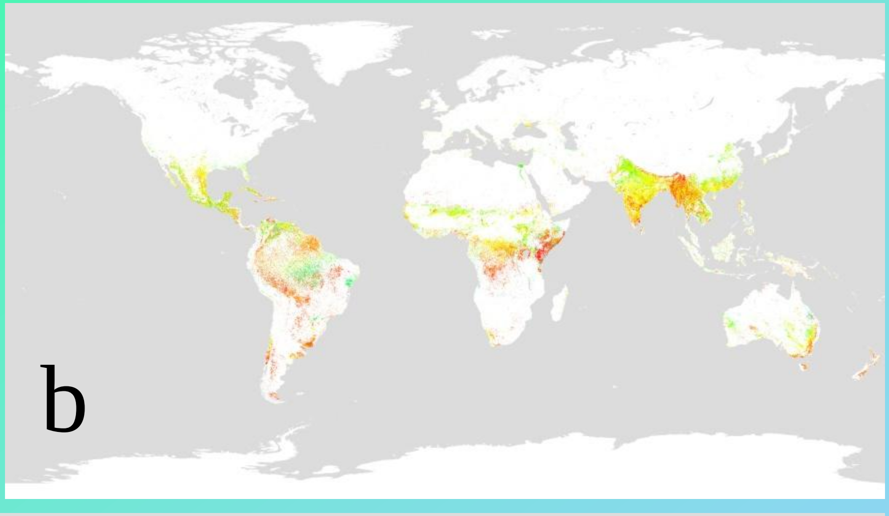


a) Recorded in the first cycle
b) Recorded in the second cycle
c) The first maturity onset for the year (combined from the first and the second cycles)

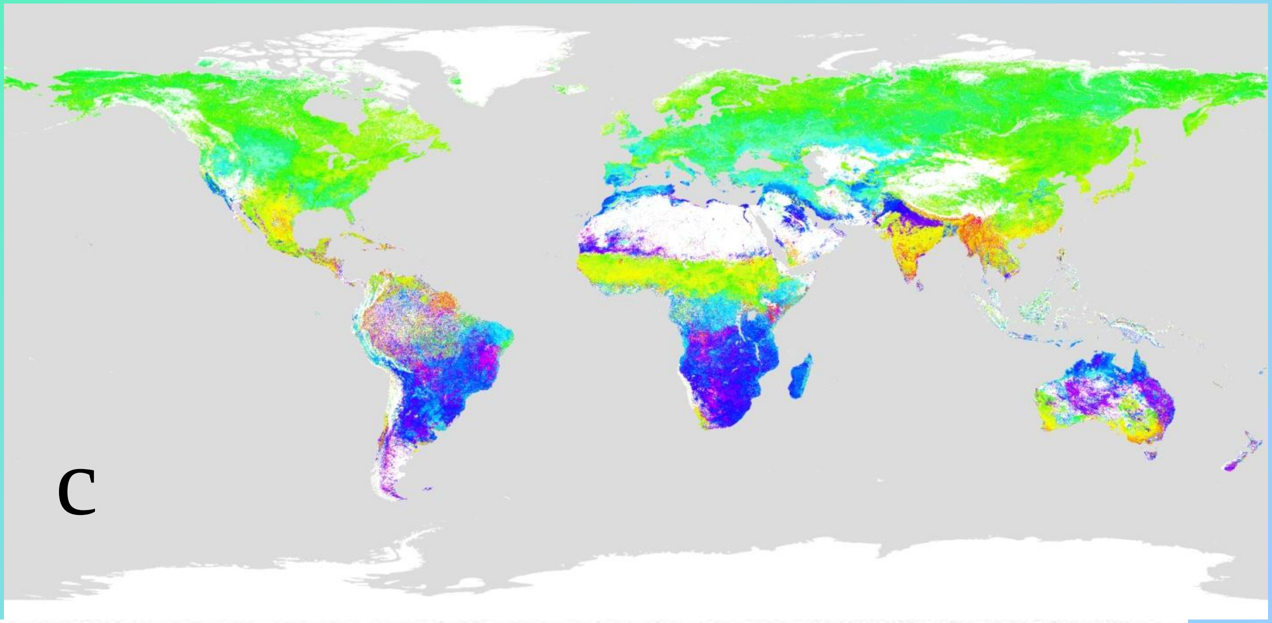


Senescent Onset from AVHRR in 1996





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/).**

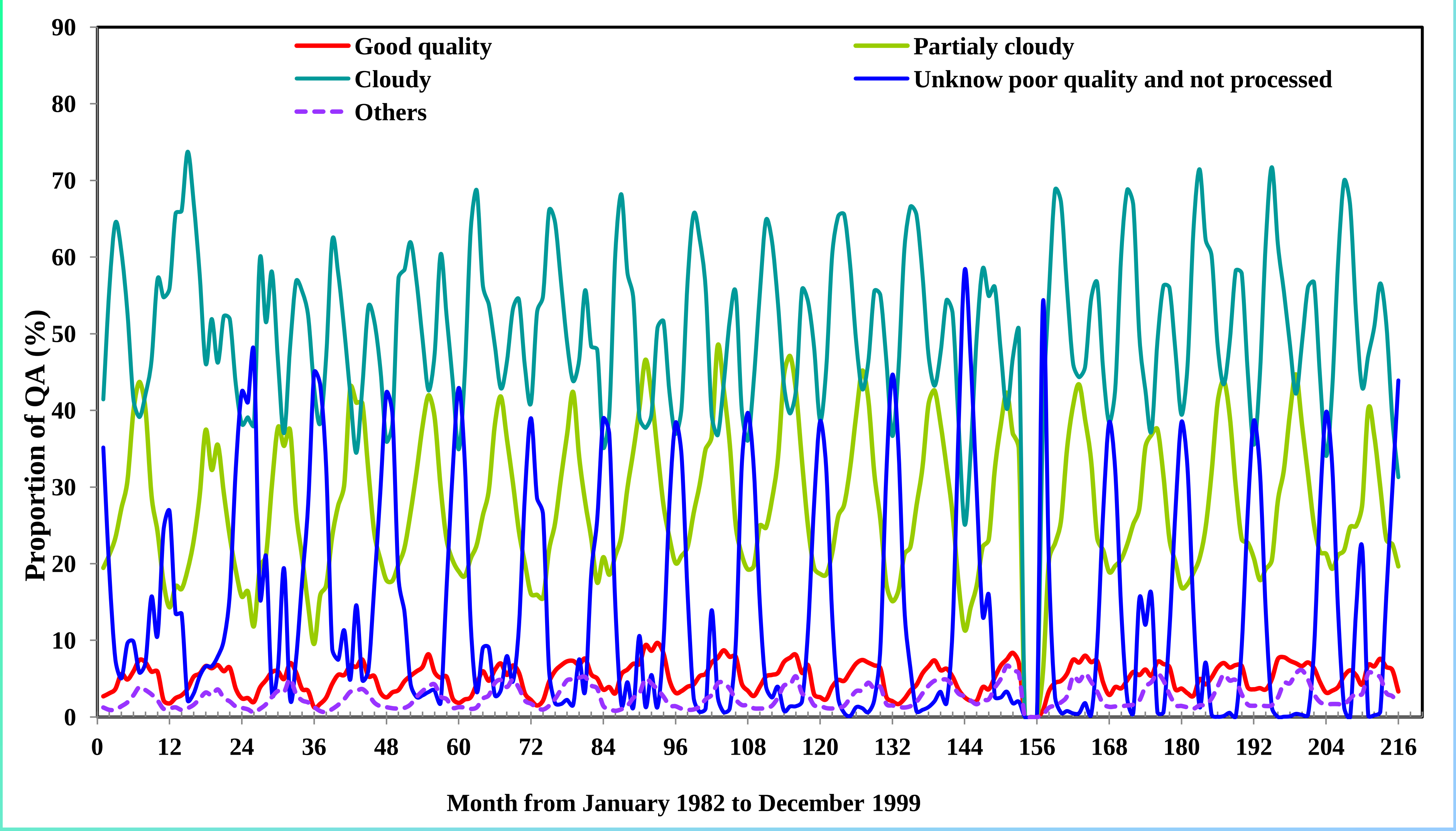
- **MODIS CMG dataset provides Terra and Aqua MODIS daily CMG surface reflectance (Collection 5.0): 0.05 degrees (2000 to 2011) (http://edcdaac.usgs.gov/main.asp).**

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

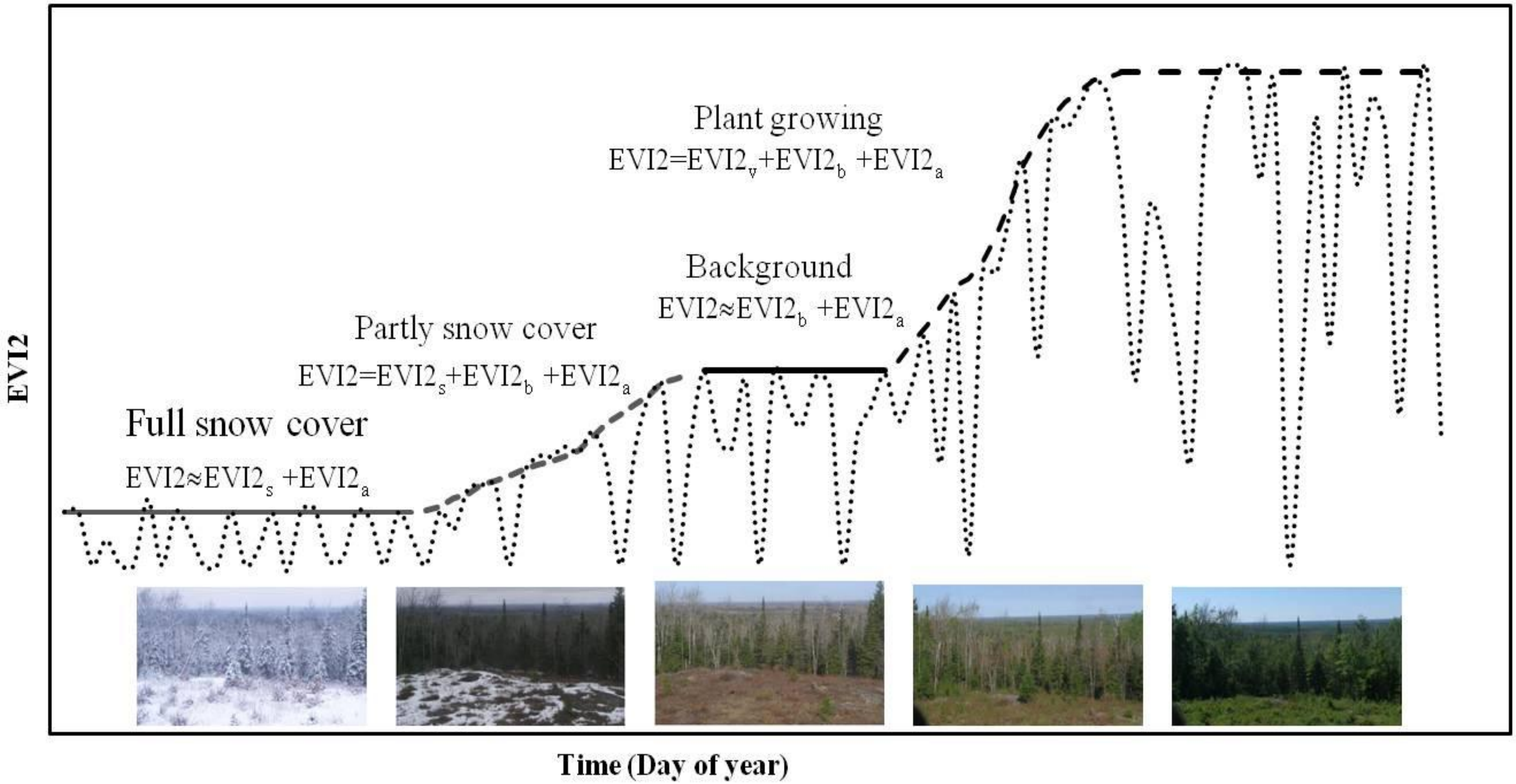
$$EVI2 = 2.5\frac{\rho_{NIR}-\rho_{RED}}{\rho_{NIR}+2.4\rho_{RED}+1}$$

(Courtesy to Kamal Didan)

LTDR AVHRR QA in NA



Biophysically Understanding Temporal Trajectory of Satellite Vegetation Index (VI) in Greenup Phase – an example



Physically-Based Algorithms for the MEASURES LSVP Product