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PHENOLOGICAL STAGE MONITORING IN SIBERIA BY USING NOAA/AVHRR DATA

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ABSTRACT: Phenology describes the seasonal cycle of vegetation functioning. This is essential concept in order to understand the interactions between biosphere, climate, and biogeochemical cycles. This paper proposed a method to derive the start, the maximum, the end, and the length of the vegetation cycle in a year, based on the analysis of time-series of 10-day composite NDVI, NOAA/AVHRR Pathfinder Land Dataset at a resolution of 4 minutes for the year 1982 - 2000. The map of spatial patterns of each phenological stage are presented, and their zonal distribution is selected in Siberia region, Russia. This paper focuses on the start of vegetation growth cycle that is called "onset" date has been related to air temperature summations, which are derived from thermal-time model. A good agreement was found between satellite derived onset and climate predicted onset date and it is expected that onset is used as the indicator to monitor the effects of climate effects. The comprehensive relationship between the NDVI, topography, climate variables and interannual onset date are discussed in terms of major vegetation types.

1. INTRODUCTION

Phenology is the study of timing of recurrent biological events and the causes of timing with regard to biotic and abiotic forces (Lieth, 1975). Vegetation phenology depends primarily on the climatic conditions for given biome and affects the terrestrial carbon cycle. Myneni et al. (1997) and Menzel & Fabian (1999) have recently highlighted the importance of ongoing large-scale changes of phenology. Leaf onset models based on plant physiological principles developed at the stand level have been extrapolated for the United States by White et al. (1997).

Climate effects are expected as one of the factors of interannual variations in vegetation activities, and relationships between NDVI and climate data have been investigated on regional (Li and Kafatos, 2000) and global (Schultz et al. 1995) scales. In this study, mainly focused on the onset date derived from NOAA/AVHRR with climatic data, the DISCover landcover map and elevation data were combined to investigate interannually regarding to the interactions of these variables. Purpose of this study is to investigate the characteristics of satellite derived phenology and their interannual variations related to climate variables.

2. DATA DESCRIPTION

2.1 Land-cover Map

DISCover global land-cover dataset (Loveland and Belward, 1997) are chosen in order to establish a land-cover map consistent with the satellite dataset used to obtain the date of phenological stage. This dataset was derived using monthly NDVI 1-km NOAA/AVHRR from 1992 to 1993. It distinguishes 14 vegetation types and two types of bare soil with 1-km resolution. DISCover map was then spatially aggregated to the equal 8-km resolution as Pathfinder dataset by taking the dominant vegetation type, which has maximum number of pixel (maximum is 8 × 8 = 64 pixel) within each 4-minutes grid.

2.2 Satellite Dataset

NOAA/AVHRR Pathfinder Land Dataset with a 10-day composite time-series NDVI at an 8-km spatial resolution for the year 1982 - 2000 is used in this study. The NDVI is the difference between near-infrared and visible reflectance of land-surface normalized by their sum. The NDVI data were corrected by using the Best Index Slope Extraction (BISE) algorithm, in order to reduce the effect of cloud contamination, atmospheric interference, and bi-directional reflectance (Viovy et al, 1992). The BISE algorithm contains two main assumptions: NDVI is depressed by cloud and atmospheric contamination, and rapid, no persistent increases or decreases in NDVI are inconsistent with natural vegetation.

2.3 Climate Dataset

Many climatic factors influence vegetation growth and development. Among these parameters, temperature and precipitation are most important in triggering the vegetation growth. Air temperature affects plant mechanisms such as respiration, transpiration and photosynthesis. Climate Research Unit (CRU) 1901-1995 monthly climate dataset (New, 1998) with 0.5-degree resolution are used and temporal interpolations (linear) were applied to obtain a 10-day time intervals. National Climate Data Center (NCDC) 1995-1999 Global Surface Summary of Day (http://www.ncdc.noaa.gov/, 2000) with daily meteorological station observation data is also used.

3. METHOD: DETERMINATION OF PHENOLOGICAL STAGES

Three main phenological stages (onset, peak, offset) and referential two stages (beginning of high magnitude, senescence) are defined as parameter to investigate the relationships between climate effects and the interanual vegetation growth cycle. The state of the vegetation growth is assessed with a transformation of the NDVI to Relative Greenness (Burgan and Hartford, 1993):

$$RG_i = \frac{NDVI_i - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \times 100 \qquad (1)$$

where i is the number of 10-day composite from 1 January raging from 1 to 36, RG_i is the output Relative Greenness raging from 0 - 100 for date i, $NDVI_i$ is the 10-day composite NDVI for date i, $NDVI_{\max}$ is the annual maximum NDVI, $NDVI_{\min}$ is the annual minimum NDVI and if $NDVI_{\min} < 0$, $NDVI_{\min}$ is replaced to 0. This transformation is attractive because it is consistent. An RG_i of 45 states that a vegetation has attained 45% of its maximum greenness regardless of landcover types.

Onset and offset date are defined as timing of rapid NDVI increase (onset) and decrease (offset), because of the leaf expansion, grass green-up and leaf abscission, grass brown-off. These date are detected by simply finding the inflection point in a year, time-series Relative Greenness profile. Firstly, calculating the forward moving average through the year 1982-2000 for each 10-day interval. Secondly, selecting the date for each year when it has maximum value after taking differentials of Relative Greenness profile. Offset date is detected by calculating profile inversely (December 2000 to January 1982). Figure 1 shows the zonal distributions of onset date after computation of temporal average over the entire 1982-2000 periods.

Peak date is defined as date of the maximum magnitude in a year cycle. The determination of peak date corresponds to the date (i) of maximum P_i in a year, such that:

$$P_i = (RG_{i-1} + RG_i + RG_{i+1}) / 3 \qquad (2)$$

Start of senescence date is determined when RG_i falls 92, and this threshold value was decided from ground observation in Siberia when it starts leaf coloration for birch forest. Start of high magnitude date in a year growth cycle is simply defined by using same threshold value as senescence, and it is when RG_i exceed 92.

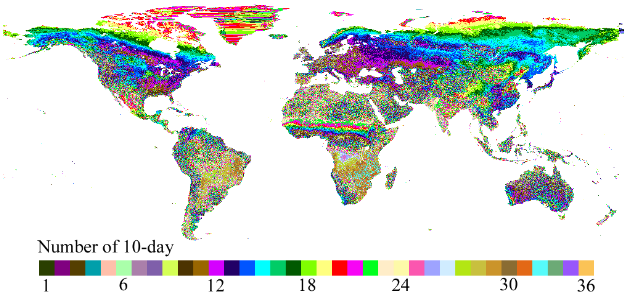


Figure 1. Onset date of vegetation growth derived from satellite data (1982-2000 mean)

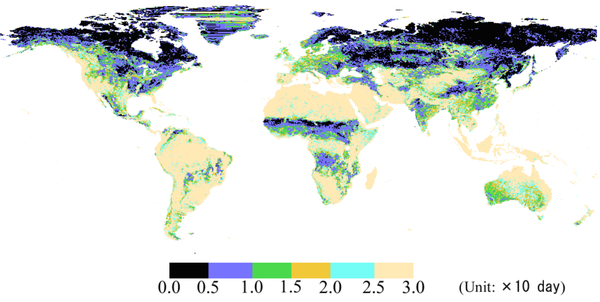


Figure 2. Spatiotemporal uncertainty of onset date derived from satellite data

4. RESULTS AND DISCUSSION

The spatiotemporal uncertainty of onset date derived from satellite data is shown in figure 2. Uncertainty image was made by computing standard deviation of annual onset image within 7× 7 pixel spatial moving matrix and temporally over studying period. Large values of uncertainty are obtained in the several dry areas and with rapid transition zones between different landcover such as mountainous area. In such areas, the heterogeneity of climate is great or no vegetation growth cycle, and it is inappropriate to discuss phenology for these regions. From these point of view, Siberia was chosen as study area, because vast areas of low uncertainty from figure 2 and it has consistent vegetation growth and less human interactions. Geographical coordinates of study area are from $90^{o}00'$N to $50^{o}00'$N in latitude and from $25^{o}00'$E to $170^{o}00'$W in longitude.

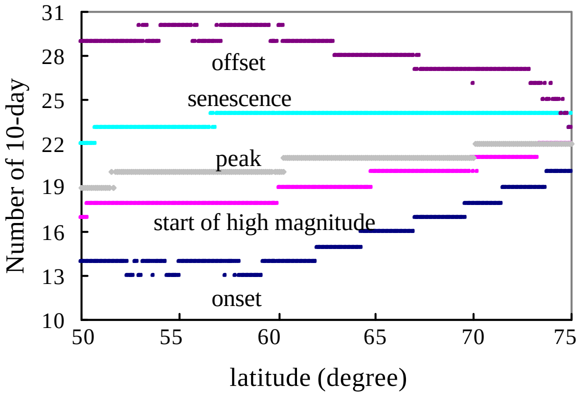


Figure 3. Zonal average date of each phenological stage

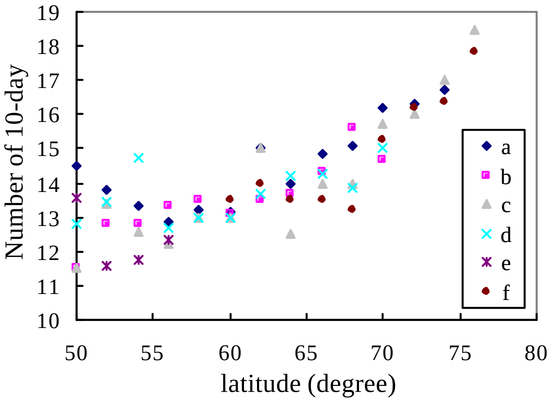


Figure 4. Zonal average date of onset for each landcover

Figure 3 shows a zonal average date of each phenological stage for each latitude that date values were averaged over longitude. Because of lack of the data, year 1994 was excluded from this study. Pixels with insufficient NDVI dynamics (barren or sparsely vegetated) were not considered. Over the study area, the length of the vegetation growth cycle that is from onset to offset date regularly decreases when latitude increases from temperate to boreal regions. The spring green-wave arrives in May to June over most of the area. Peak date varies for latitude much less than the other phenological stages. The zonal average of onset date for each major landcover type is shown in figure 4, where a: Deciduous broadleaf forest, b: Deciduous needleleaf forest, c: Evergreen broadleaf forest, d: Grassland, e: Mixed forest, f: Open shrubland. Transition of onset date for latitude can be seen for all landcover types.

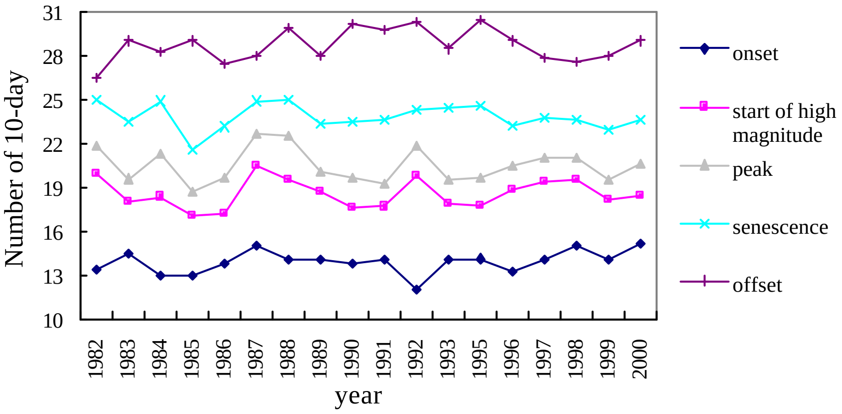
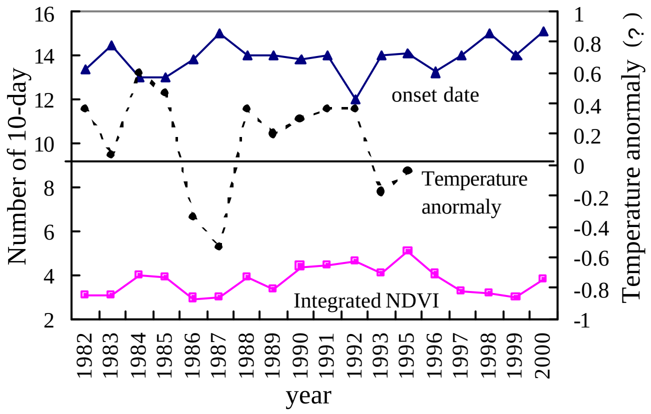


Figure 5. Interannual variations of each phenological stage (60^{0}N, 130^{0} E)

Interannual variations of each phenological stage, spatially averaged for 3 × 3 pixel, central pixel with geographical coordinate of 60^{o}N, 130^{o} E were shown in figure 5. This pixel was selected, because of low uncertainty in figure 2 and vast distribution of single biome (Deciduous needleleaf forest) referred to the DISCover map. Annual offset dates are spatially speckled than the onset date, because the rapid increase slope of NDVI profile is usually very steep, whereas decrease NDVI slope is not. The offset date is very sensitive to little NDVI changes. Compared with the meteorological data, an interannual variation of offset date is mainly related to the starting period of snowfall, whereas onset date is dependent on temperature in boreal region. We can assume that interannual variations of offset date are changes of snowfall time and it is one factor to change the length of growing season.



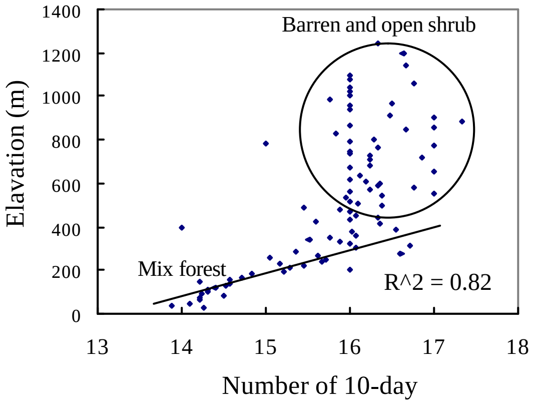


Figure 6. Interannual variations of onset date, integrated NDVI, temperature anomaly (60^{0}N, 130^{0}E)

Figure 7. Correlation between onset date and elevation (63^{0}N-65^{0}N, 55^{0}E -65^{0}E)

Figure 6 shows intreannual variations of onset date, integrated NDVI over onset to offset date, temperature anomaly. Temperature data was expressed as anomalies, annually averaged (10-day from 11 to 14), of year 1966 to 1995 from CRU climatic data. At the selected point, it shows the integrated NDVI is gradually increasing from year 1982 to 1995, but decreasing from year 1996 to present. Correlations between integrated NDVI and length of growing season (onset to offset) was R^2 = 0.63. This indicates that lengthened growing season during year 1980's. Correlations between interannual onset date and temperature anomaly is negatively correlated (R^2 = 0.51). The year with negative temperature anomaly, onset date will be late (year 1987); whereas the year with positive anomaly, onset will be earlier (year 1984-85).

To examine the relationship with onset and topography, figure 7 shows the correlation between onset date and elevation with geographical coordinates from 63^{o}N to 65^{o}N in latitude and from 55^{o}E to 65^{o}E in longitude. Refer to the DISCover map, barren and open shrubs are distributed higher than about 500m levels, and mix forest are distributed below this level in this extracted area. There were strong correlations with onset date (R^2=0.82) below 500m levels, but it seems no correlations over this level arises from high onset uncertainty, less consistent phenology for barren and open shrubs.

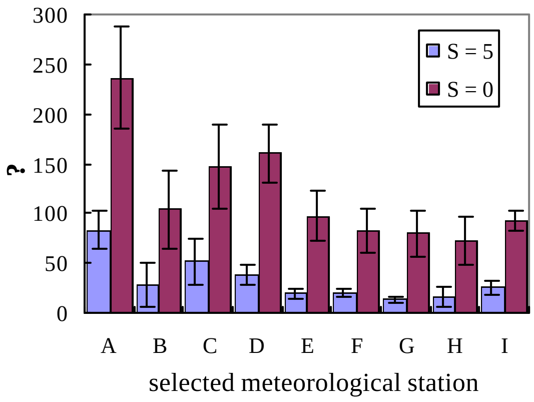


Figure 8. Mean cumulated air temperature until satellite derived onset date for year 1995-1998

Table 1. Result of climate predicted onset date

Meteorological station		AVHRR	Climate predicted Julian day	
point	coordinate	10-day	Th[0?]	Th[5?]
A	N53.13, E112.46	14	145	145
B	N56.35, E121.29	14	137	138
C	N58.37, E125.22	13	156	157
D	N59.27, E112.35	14	141	138
E	N62.09, E117.39	14	138	136
F	N62.32, E111.14	14	139	138
G	N63.58, E127.28	14	138	135
H	N63.46, E121.37	14	137	136
I	N68.30, E112.26	15	153	148

In this paragraph, we will try to predict the onset date from climate data. Thermal time model (Hunter and Lechowicz, 1992) was used to predict the onset date from climatic data alone, in order to validate the relationships between satellite derived onset and climate variables. This is degree-day approach, that daily air temperature are cumulated when daily air temperature exceeds certain value S on air temperature with following formula:

$$Th = \frac{1}{2}\sum_{D=S_D}^{D=B_D}((T_{X_D} - S) + (T_{N_D} - S)) \qquad (3)$$

with,

$$T_{X_D} - S = 0 \text{ if } T_{X_D} < S, \text{ and } T_{N_D} - S = 0 \text{ if } T_{N_D} < S$$

where T_{X_D} and T_{N_D} are day D maximum and minimum air temperature, B_D is the onset date, S_D is the starting date for cumulating and 1 January was chosen in this study. Two threshold value, 0 and 5? were chosen for *S*.

For these purposes, NCDC climate data was used during 1995 to 1999 and nine meteorological stations were selected. Climate predicted onset date is done in two steps. Firstly: air temperature was cumulated until satellite derived onset date for selected stations, and figure 8 shows the result of four years mean (1995-1998) cumulated air temperature with error bars (standard deviation) for each stations. Secondly: onset date is predicted for year 1999 just from climate data. It is determined when it reaches the mean cumulated air temperature from the first step. These processes are done independently for each station. Results of climate predicted onset date for year 1999 is shown with satellite derived onset date in table 1. Table 2 shows the error matrix of the results for (a) $S = 0$, (b) $S = 5$. There were good agreement between the climate predicted and satellite derived onset date. Threshold with S = 5 had a better agreement than S = 0.

Table 2. Error matrix of climate predicted and satellite derived onset date (year 1999)

Climate predicted

Satellite derived (Number of 10-day)	Julian day				
	121~ 129	130~ 140	140~ 151	152~ 160	161~ 171
13	▨				
14		B, E F, G, H	D		
15		A	▨	I	
16				C	
17					▨

(a) S = 0

Climate predicted

Satellite derived (Number of 10-day)	Julian day				
	121~ 129	130~ 140	140~ 151	152~ 160	161~ 171
13	▨	A			
14		B, D, E F, G, H			
15			I		
16				C	
17					▨

(b) S = 5

5. CONCLUSION AND REMARKS

This article showed that NOAA/AVHRR NDVI was useful to monitor the phenological stages and its interannual variations, especially focused on the onset date. Spatiotemporal uncertainty of onset date is presented and high values were found in several dry areas or mountainous area where the heterogeneity of climate is great or no vegetation growth cycle. Siberia was chosen for the study area and the length of the growing season decreases as latitude increases. The onset date also varies with elevation shift. Air temperature data was used during the study year to investigate the interactions between satellite derived phenology and climate variable on its interannual variations. A good agreement was found between the satellite derived onset and onset date predicted from climatic data using thermal time model. This agreement indicates that the cumulated air temperature drives vegetation onset date and it is expected to be a good indicator to monitor where it had a climatic effect or changes on a global scale especially in temperate, boreal regions.

In the future studies, correlations for different climatic variables and each phenological stages should be examined precisely. The time of snowmelt and snowfall should be interannually extracted by using satellite data, then compared with interactions to each phenological stages or vegetation growth. Finally, present and future study will lead to observe decadal trends in the NDVI, vegetation growth itself, and part of the response to El Nino events.

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