Improvement of the phenology module for summer green tree in Community Land Model 3.5-Dynamic Global Vegetation Model (CLM3.5-DGVM) using MODIS LAI

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Abstract

Several phenology modules have been evaluated using MODIS land products in temperate mixed or deciduous forests in Korea for the purpose of improving the phenology model of CLM3.5-DGVM. Plant phenology plays an important role in simulating energy and mass exchange in model. The phenology module of CLM3.5-DGVM for summer green tree has deficiency in that the model simulates too short leaf expansion period in spring and the time of leaf fall is late by one month, resulting in an overestimation of growing days. To improve the phenology module for summer green tree, we used 1-km resolution 8-day MODIS LAI data, surface air temperature data at Korean Meteorological stations, and 1-km resolution land use data. The phenological dates have been determined using MODIS LAI following the detection algorithm of Zhang et al. (2003). To examine if MODIS LAI captures the observed seasonal variation of LAI, we compared the seasonal variation of MODIS LAI with the observed plant area index of a temperate deciduous forest at Gwangnung. The comparison results showed that MODIS LAI captured the seasonal variation of plant area index such as leaf-out, leaf-maturity and an end of leaf fall but showed difference for the beginning of leaf senescence. MODIS LAI decreases from early September due to leaf coloring while the observed plant area index does not decrease significantly until late October. This may be due that plant area index includes both green leaf and colored leaf. Several methods for leaf out and leaf fall conditions have been evaluated using MODIS land products at 22 meteorological stations in Korea. The results show that the M1 method to use the 20 year-mean coldest month air temperature shows overall good performance for leaf out condition and the F1 method to use both critical temperature and day length show overall good performance for leaf fall condition.

Key words: Community land model, Leaf Area Index, MODIS, Phenology, Summer green tree

1. Introduction

Plant phenology is timing of onset and offset of vegetation greenness. Because vegetation controls partitioning of available energy into sensible and latent heat fluxes, accurate determination of phenological dates is important part in good simulation of surface fluxes. The phenology module of CLM3.5-DGVM (Levis et al., 2004) for summer green tree has deficiency in that the model simulates too short leaf expansion period in spring and the time of leaf fall is late by one month, resulting in an overestimation of growing days.

The objective of this study is to evaluate several methods for leaf out and leaf fall conditions using the MODIS land products over South Korea for the purpose of improving phenology module of CLM3.5-DGVM for summer green trees.

2. Material and method

2.1. Data

Surface phenological data used in this study have been compiled at Gwangneung in temperate deciduous forest by Yonsei University using plant analyzer (Park et al. (2007). MODIS 8-day composite LAI data at the resolution of 0.008928 (about 1km) and meteorological data at 21 Korean Meteorological stations over South Korea were used in order to examine the relationship between phenology date and meteorological variables. Land use data of Kongju Land Cover V (KLCV) which is based on MODIS product were used to identify the deciduous forest pixel.

2.2. Determination of phenological dates

To detect the onset of greening up from LAI data, we used method developed by Zhang et al. (2003). We applied it to the LAI time series. It consists in fitting logistic functions $y(t)$ to the MODIS LAI time series. y(t) is defined by

$$y(t) = \frac{c}{1 + e^{a+bt}} + d \quad (1)$$

where a and b are fitted coefficients linked to temporal variations of LAI, $c + d$ is the maximum LAI value and d is the minimum LAI value. Two distinct functions are fitted for the greening up and leaf coloring. The onset of the LAI increase and senescence are then taken as the date of maximum positive curvature of the ascending function and minimum curvature of the descending function, respectively. The greening -up and senescence dates derived from remote sensing data are compared with in situ data at Gwangneung.

2.3. Phenology model

We have evaluated four methods including default M0 method for GDD_{crit} of leaf out condition. The GDD_{crit} is accumulated growing degree-days above 0°C. Table 1 summarizes the methods with references.

Table 1. The model for growing degree days on leaf out date

Method	GDD_{crit}	References
M0	100	CLM-DGVM (Levis et al., 2004)
M1	$\alpha\exp(\beta T_c)$	This study
M2	$\alpha\exp(\beta T_a)$	CLM-CN
M3	$\alpha\exp(\beta D_c)$	Chiang and Brown(2007)

In Table 1, T_c is the 20-year running mean of the minimum monthly temperature (K), T_a is annual mean air temperature and D_c is the number of chilling days since 1 November the previous year. α and β are the parameter estimates determined by non-linear fitting procedure.

Three methods have been evaluated for leaf fall condition. Table 2 summarizes the methods.

Table 2: The models for leaf fall condition. P indicates day length of each day in minute.

Method	Leaf fall condition	References
F0	$T_{10d} \geq T_c+5$	CLM-DGVM (Levis et al., 2004)
F1	$T_{10d} \geq T_c+12$ or $P(d) \leq 655$min	White et al. (1997), CLM-CN
F2	if $P(d)<P_{st}$ and $T(d)<T_b$ $R_{sen} = \sum (T_b - T(d))^2 \left(\frac{p(d)}{p_{st}}\right)^2$ $R_{sen} \geq Y_{crit}$	Delpierre et al. (2009)

In Table 2 P indicates day length of each day in minute and Y_{crit} is the parameter estimate determined by averaging the value of R_{sen} at leaf fall date during fitting period.

2.4. Evaluation method

Dates of leaf-out and end of leaf fall are derived from the used methods and then the dates are compared with dates obtained from MODIS LAI data. The root mean square error (RMSE), mean bias error (MBE) and index of agreement (d) are calculated using data during fitting period, validation period and whole period for each method. Formulations of RMSE, MBE and d are given in Willmott (1982):

$$MBE = \sqrt{\frac{\sum_{i=1}^{N}(x_{mi} - x_{oi})}{N}} \tag{2}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(x_{mi} - x_{oi})^2}{N}} \tag{3}$$

$$d = 1 - \left[\frac{\sum_{i=1}^{N}(x_{mi} - x_{oi})^2}{\sum_{i=1}^{N}(|x'_{mi}| - |x'_{oi}|)^2}\right] \tag{4}$$

where x_m is the date obtained from tested methods, x_o is the date obtained from remote sensing data, N is the total number of data and $x'_{mi} = x_m - \overline{x_o}$ and $x'_{0i} = x_o - \overline{x_o}$

3. Results

3.1. Comparison of surface-based and MODIS LAI at Gwangneung Deciduous forest

Fig. 1 shows the comparison of seasonal variation of surface-based and MODIS LAI. The surface-based LAI was calculated as measured plant area index (PAI) minus winter PAI. The major phenological dates, such as leaf out, mature and end of leaf fall of MODIS LAI corresponds well to those of observed one. However, MODIS LAI shows difference in the beginning date of leaf senescence. MODIS LAI begins to decrease from late September while surface-based LAI does not show significant decreases until late October. The difference can be due that surface observation measured PAI which include both LAI and stem area index (SAI) and hence they do not differentiate green leaf from colored leaf.

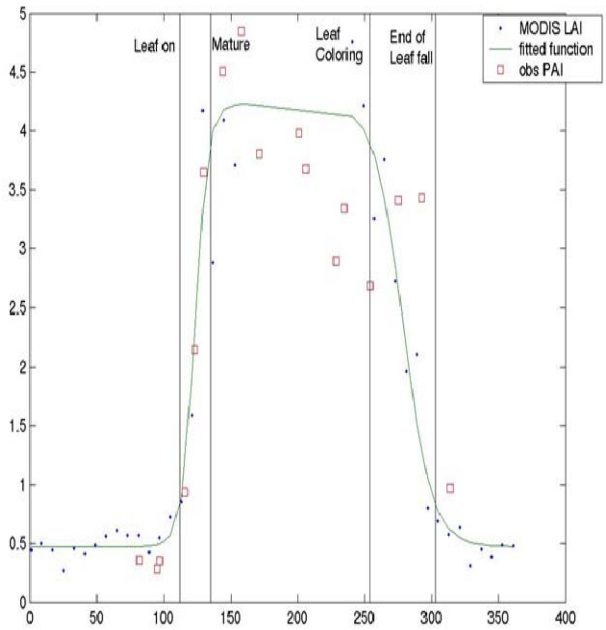

Figure 1: The comparison of seasonal variation of MODIS LAI with surface based measurements.

3.2. Phenological dates at 22 sites

We only used data from January to May for greening up and from September to December for leaf senescence. The fitted logistic function captured the seasonal variation of MODIS LAI reasonably well. Table 3 shows calculated mean phenological date and the range at 22 sites for four phenological dates. The mean phenological dates are Day of year (DOY) 104 for leaf out, DOY 141 for leaf maturity, DOY 250 for leaf coloring and DOY 309 for an end of leaf fall. Large range is shown for leaf coloring.

Table 3: Calculated phenological dates at 22 sites.

Phenology	Average	Minimum	Maximum
Leaf out	104	80	118
Leaf maturity	141	124	160
Leaf coloring	250	225	311
End of leaf fall	309	292	320

3.3. Evaluation statistics of each method

We divided data into fitting group (2002, 2004, and 2006) and validation group (2001, 2003, and 2005). Parameters in each method were calibrated using fitting subset data and then the methods were evaluated using validation subset data and also whole data. Tables 4 and 5 show evaluation statistics for phenological dates for leaf out and leaf fall, respectively. All tested methods show better performance than default method (M0 and F0) for both leaf out and leaf fall conditions. For leaf out condition, each method shows different performance depending on the year. For example, M3 method shows good performance in validation period but not in fitting period. On the other hand, M1 method shows opposite. It is necessary to understand the inter-annual variation of leaf out date derived from MODIS LAI. Based on current overall evaluation statistics, we suggest M1 method for the improvement of the performance to simulate leaf out in CLM-DGVM.

For the methods of leaf fall condition, both F1 and F2 methods show similar performance but Y_{crit} in F2 method varies a lot depending on site. Therefore, to get a general value which is applied to other areas is not easy. On the other hand, critical day length in F1 method is more general and critical temperature can be determined depending on forest type such as temperature and Boreal forest. And also F1 method show low MBE and RMSE. Therefore, we suggest F1 method for the improvement of the performance to simulate leaf fall in CLM-DGVM.

Table 4: Evaluation statistics for phenological dates for leafout

	Fitting subset (N=64)			Validation subset (N=65)			Overall (N=129)		
	MBE	RMSE	d	MBE	RMSE	d	MBE	RMSE	d
M0	-28.72	35.22	0.17	-16.55	19.75	0.23	-22.59	28.38	0.18
M1	-0.13	7.86	0.64	5.23	8.11	0.54	2.57	7.95	0.60
M2	-0.94	10.45	0.36	4.78	7.51	0.46	1.95	9.05	0.40
M3	-0.47	9.84	0.38	1.83	6.12	0.57	0.69	8.15	0.45

Table 5: Evaluation statistics for phenological dates for leaf fall

	Fitting subset (N=65)			Validation subset (N=61)			Overall (N=126)		
	MBE	RMSE	d	MBE	RMSE	d	MBE	RMSE	d
F0	59.06	57.80	0.13	41.98	51.13	0.18	53.12	54.46	0.16
F1	1.11	5.03	0.57	-1.97	6.83	0.45	-0.38	5.95	0.44
F2	-1.43	8.42	0.48	-4.02	8.53	0.53	-2.68	8.44	0.50

4. Summary

We have evaluated several methods for leaf out and leaf fall conditions using the MODIS land products over South Korea for the purpose of improving the phenology model of CLM3.5-DGVM for summer green trees.

The comparison between MODIS LAI and surface-based LAI showed that MODIS LAI captured the seasonal variation of plant area index such as leaf-out, leaf-maturity and an end of leaf fall but showed difference for the beginning of leaf senescence. MODIS LAI decreases from early September due to leaf coloring while the observed plant area index does not decrease significantly until late October. This may be due that plant area index includes both green leaf and colored leaf.

The several phenology methods for leaf out and leaf fall have been evaluated. The results suggest that the M1 method using the coldest month mean air temperature shows overall good performance for leaf out condition and the F1 method to use both critical temperature and day length shows overall good performance for leaf fall condition.

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