Evaluation of the relationship between NDVI and LAI in cool-temperate deciduous forest

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Abstract: Leaf area index (LAI) is a key biophysical variable influencing land surface processes such as photosynthesis, transpiration and it is a required input for various ecological models. A cool-temperate deciduous forest in Takayama, central Japan was selected as experimental site for this study. The dominant tree species at the study site are birch *(Betula ermanii, Betula platyphylla*) and oak (*Quercus crispula*). In addition, the dominant species of understory is evergreen dwarf bamboo (*Sasa senanensis*). The moderate resolution imaging spectroradiometer (MODIS) LAI products (MOD15) and ground-measured LAI was compared. Because more than half of MODIS LAI data used in this study was derived from Normalized Difference Vegetation Index (NDVI)-LAI relationship, MODIS NDVI derived from MOD9 reflectance data and ground-measured LAI was also compared. As results of comparison between NDVI derived from MOD9 and ground-measured LAI, the date of beginning of increase in NDVI value is earlier than the date of beginning of leaf expansion detected by ground-measured LAI. Furthermore, the date of beginning of decrease in NDVI value is earlier than the date of beginning of leaf fall detected by ground-measured LAI. In order to understand the relationship between NDVI and LAI in this study area, the relationship between NDVI calculated by scattering from arbitrarily inclined leaves (SAIL) radiative transfer model and LAI was evaluated. This led to two results: (a) understory plant (*Sasa senanensis*) affected canopy level NDVI during leaf expansion and leaf senescent periods, and (b) the relationships between NDVI and LAI of summer and that of autumn are different because of discoloration of the leaf during leaf senescent period. These results indicate that it is necessary to take into account the influence of understory plant for estimating canopy LAI from NDVI during leaf expansion and leaf senescent periods, and it is also necessary to consider discoloration of the leaf during leaf senescent period.
Keywords: Cool-temperate deciduous forest, LAI, NDVI.

1. Introduction

Leaf area index (LAI) is defined as the total one-side area of all leaves per unit ground area (m^2/m^2). LAI is a key biophysical variable influencing land surface processes such as photosynthesis, respiration, transpiration, carbon and nutrient cycle, and rainfall interception. LAI is a required input for various ecological models [1], [2].

Satellite remote sensing provides a unique way to obtain the distribution of LAI over large scale. Several studies were conducted to retrieve LAI value. Almost these studies were based on the relationship between LAI and vegetation indices [3]-[6]. In recent year, advances in satellite remote sensing technology and radiative transfer modeling have improved the possibility of accurate estimation of LAI. The launch of TERRA with Moderate Resolution Imaging Spectroradiometer (MODIS) onboard began a new era in remote sensing of the Earth system. MODIS LAI products (MOD15) have been released to public. MOD15 algorithm is based on three-dimensional radiative transfer theory [7], and developed for inversion using a look-up table (LUT) approach [8]. 1 km land cover map of six major biomes produced from MODIS is used to this algorithm. When this method fails to identify a solution, a back-up method based on relationship between the normalized difference vegetation index (NDVI) and LAI [9] were utilized together with a land cover map. Several studies about validation of MODIS LAI product using ground-measured data were published [10]-[12]. These studies reported that MODIS LAI values were not corresponding to ground-measured values by the influence of misclassification of biome type, the uncertainty included in satellite data and model, and so on. Influence of understory plants was not assessed in almost these studies. Because large amount of understory plants exist in this study area, the influence of understory has to be

considered for comparison between MODIS LAI and ground-measured LAI.

The objective of this study is evaluation of the relationship between the MODIS LAI and ground-measured LAI data in cool-temperate deciduous forest with large amount of understory plants in Japan.

2. Methodology

In this study, MODIS LAI product (MOD15) and ground-measured LAI were compared. Furthermore, as a result of checking MOD15 quality control (QC) flags, more than half of MODIS LAI used in this study were derived from NDVI-LAI relationship [9]. Therefore, NDVI derived from 250m surface reflectance data (MOD9) and ground-measured LAI were also compared. Finally, in order to understand NDVI-LAI relationship in this study area, relationship between NDVI calculated by scattering from arbitrarily inclined leaves (SAIL) radiative transfer model [13] and LAI was evaluated. In this study, because the spatial resolution of MODIS products and ground-measured LAI is very different, it was difficult to compare these absolute values directly. Therefore, this study focuses on pattern comparison.

1) Study area

Takayama AsiaFlux site was selected as our experimental site. The location of this site (36°08’43”N, 137°25’24”E; 1420m a.s.l.) is a mountainous region in the central part of the main island of Japan. The dominant tree species at the experimental site are birch (*Betula ermanii*, *Betula platyphylla* ver. japonica) and oak (*Quercus crispula*). The dominant species of understory is evergreen dwarf bamboo (*Sasa senanensis*). Leaf expansion and leaf fall in this area typically start from the middle of May and the beginning of October, respectively. Snowfall period in this area is usually four and a half month from the middle of December to the beginning of May.

2) MODIS data products

MODIS LAI (MOD15) algorithm is based on three-dimensional radiative transfer theory [7], and developed for inversion using a look-up table (LUT) approach [8]. 1 km land cover map of six major biomes produced from MODIS is used to this algorithm. When this method fails to identify a solution, a back-up method based on relationship between NDVI and LAI [9] were utilized together with land cover map. MODIS surface reflectances (MOD9) for the visible red (band1) and near infrared (band 2) wavelengths are corrected for atmospheric effects (molecular scattering, ozone, and aerosols) and adjusted for anisotropy using a bidirectional reflectance distribution function (BRDF). The spatial resolution of MOD15 and MOD9 are 1km and 250m, respectively. In this study, MOD15 and MOD9 acquired from September 2003 to August 2004 were used. These data were 8-days composite data.

3) Ground-measured LAI

Ground-measured LAI values used in this study were calculated by the attenuation of photosynthetic active radiation (PAR) in the canopy. PAR was measured by quantum sensors (model IKS27, KOITO, Japan) at 19.5m (above the canopy) and 2.0m (below the canopy and above the understory plant). LAI was calculated by the following function [14]:

$$LAI = -\frac{1}{K_p} \ln \frac{PAR_{2m} \downarrow}{PAR_{19.5m} \downarrow} \qquad (1)$$

where K_p is a constant expressing the attenuation of PAR in the canopy. In this study, K_p = 0.83 [14] was used and LAI was calculated only for cloudy days, because the presence of direct solar radiation increase the calculation error of LAI. $PAR_{19.5m} \downarrow$ and $PAR_{2m} \downarrow$ are the downward PAR measured at 19.5 m and 2 m, respectively. Therefore, ground-measured LAI value indicates only canopy LAI. After calculating LAI for each day, 8-days maximum composite LAI data sets were made for comparison with MOD15 and MOD9.

3. Results and Discussion

1) Comparison between MODIS LAI (MOD15) and ground-measured LAI

MOD15 time series data were reconstructed because few high quality (SFC_QC value=0) data of MOD15 were acquired for this study. The reconstructing method used in this study was based on the Savitzky–Golay filter [15]. Fig. 1 represents the result of the comparison between reconstructed MOD15 time series data and ground-measured

LAI time series data from September 2003 to August 2004. The periods of leaf expansion, leaf fall, and snowfall were detected by ground-measured LAI and photographs. This led to the following results: (a) the date of beginning of increase in MODIS LAI value is earlier than the date of beginning of leaf expansion detected by ground-measured LAI, (b) the date of beginning of decrease in MODIS LAI value is earlier than the date of beginning of leaf fall detected by ground-measured LAI, (c) the date to reach the leaf constant period of MOD15 time series data is earlier than ground-measured LAI, (d) because ground-measured LAI values were calculated by the attenuation of PAR in the canopy, LAI values in winter become more than zero by influence of stems and branches.

Because more than half of MOD15 data used in this study were retrieved from the NDVI-LAI relationship, it is also necessary to compare ground-measured LAI with NDVI derived from MOD9 in order to evaluate the relationship between MODIS LAI and ground-measured LAI.

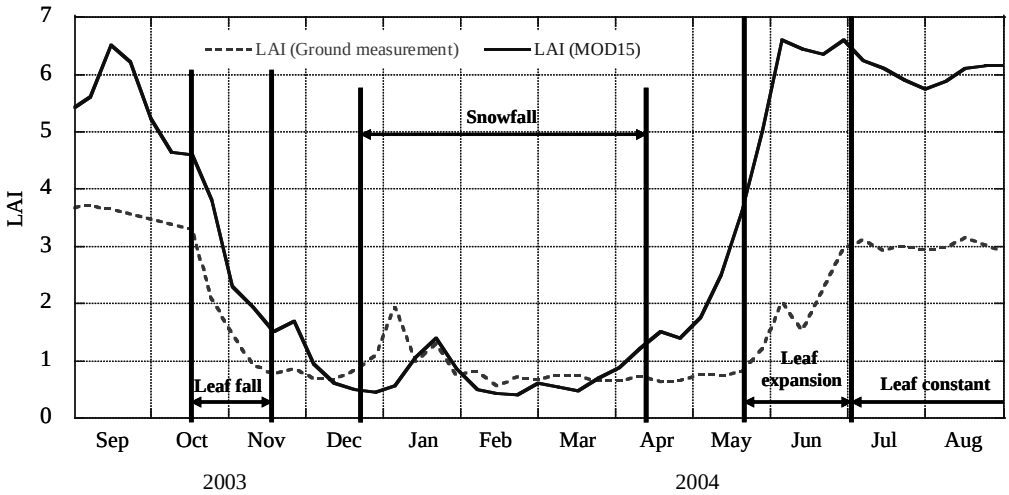

Fig. 1 Comparison between MODIS LAI (MOD15) and ground-measured LAI

2) Comparison between NDVI derived from MOD9 and ground-measured LAI

NDVI time series data were reconstructed using the method for reconstructing high-quality NDVI time series data set [16], because more than half of MODIS NDVI data used in this study were cloudy day's data. Fig. 2 represents the result of a comparison between reconstructed NDVI time series data derived from MOD9 and ground-measured LAI time series data from September 2003 to August 2004. This led to the following results: (a) the dates of beginning of increase in and decrease in NDVI value derived from MOD9 are earlier than the dates of beginning of leaf expansion and leaf fall detected by ground-measured LAI as well as MOD15, (b) the date to reach the leaf constant period of MOD9 is approximately same as ground-measured LAI, Moreover, (c) after falling leaves (the middle of November), NDVI value derived from MOD9 are approximately constant up to the middle of December, (d) NDVI value then rapidly decreases.

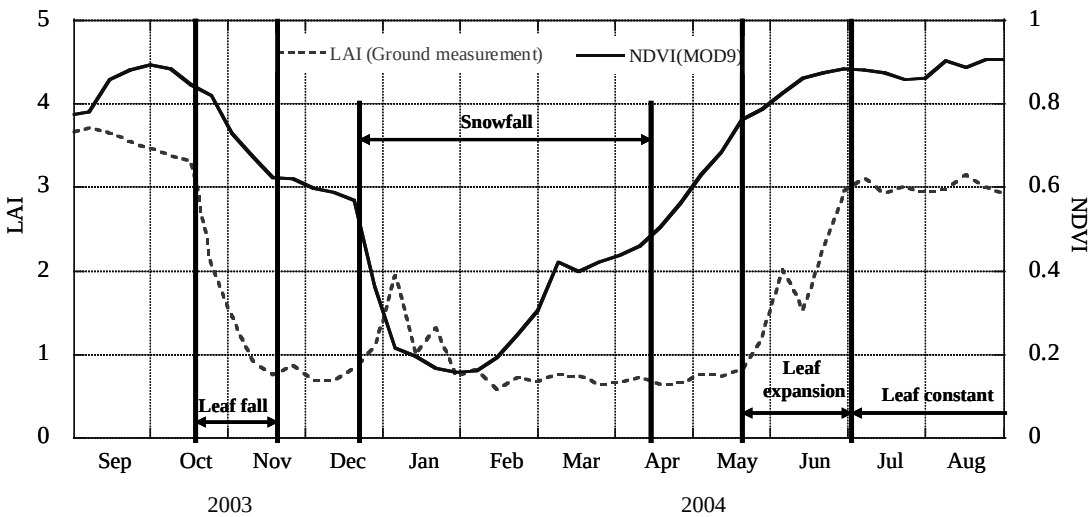

Fig. 2 Comparison between NDVI derived from MOD9 and ground-measured LAI

3) Evaluation of relationships between NDVI and LAI with SAIL model

In order to understand the relationship between NDVI derived from MOD9 and ground-measured LAI, several relationships between NDVI calculated by scattering from arbitrarily inclined leaves (SAIL) radiative transfer model and LAI were evaluated. Because SAIL model is not taken into account influence of stems and branches, evaluation of NDVI-LAI relationship focused on absolute value is difficult. However, it is considered that SAIL model is able to evaluate relative relationships between NDVI and LAI under various ground conditions. Table 1 represents the input data used in this study for SAIL model. These data were measured at the study area. Fig. 3 represents relationships between NDVI and LAI under various ground conditions with SAIL model. This led to the following results: (a) when canopy LAI is low value (spring, autumn, and winter), understory plant (*Sasa senanensis*) affect canopy LAI value, (b) when canopy LAI is high value (summer), understory plant does not affect canopy LAI value, (c) NDVI-LAI relationship of summer and that of autumn are different because optical property of leaf changes in autumn (leaf color turns red).

Table 1 Input data for SAIL model

Input parameters	*Input values*
Conopy LAI	0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0
Leaf reflectance/transmittance	**Spring to summer (LAI: 0-3.0)**
	Quercus crispula Red: 0.06/0.12, NIR: 0.35/0.62
	Betula ermanii Red: 0.07/0.11, NIR: 0.42/0.56
	Summer (LAI: 3.0-4.0)
	Quercus crispula Red: 0.04/0.05, NIR: 0.42/0.55
	Betula ermanii Red: 0.05/0.06, NIR: 0.47/0.53
	Autumn to winter (LAI: 0.0-4.0)
	Quercus crispula Red: 0.28/0.32, NIR: 0.43/0.51
	Betula ermanii Red: 0.26/0.31, NIR: 0.47/0.51
Ground reflectance	LAI of *Sasa senanensis*
	1.22 Red: 0.07, NIR: 0.32
	0.55 Red: 0.09, NIR: 0.25
	0.00 Red: 0.09, NIR: 0.22
View zenith angle	0 degrees (nadir)
Sun zenith angle	40 degrees
Fraction of direct incoming radiation	0.8

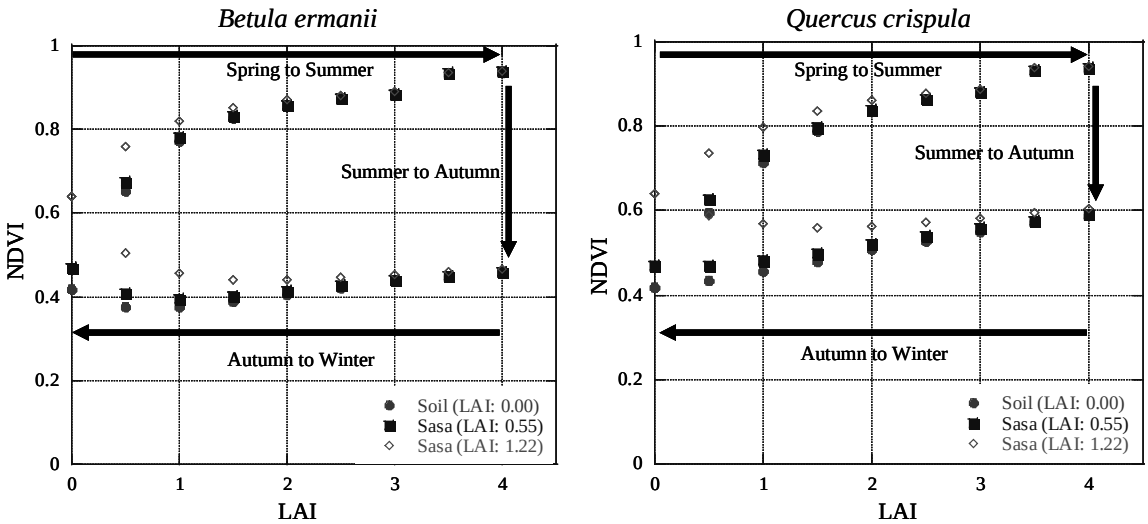

Fig. 3 Relationships between NDVI and LAI with SAIL model

These results are useful to interpret the behavior of NDVI value in Fig. 2. Interpretations of NDVI behavior are as follows.

a) Gradual decrease in NDVI value in the beginning of October is mainly due to discoloration of the leaves.

b) Rapid decrease in NDVI value from the middle of October to the middle of November is mainly due to leaf fall at canopy level.
c) Rapid decrease in NDVI value from the middle of December to the beginning of January is mainly due to decrease in fraction of understory plant (*Sasa senanensis*) per unit area by snowfall.
d) Rapid increase in NDVI value from the middle of April to the middle of May is mainly due to increase in fraction of understory plant (*Sasa senanensis*) per unit area by snow melting.

4. Conclusion

In this study, comparison between MODIS products (MOD9 and MOD15) and ground-measured LAI, and evaluation of relationships between NDVI and LAI under various ground conditions with SAIL model were performed. These analyses produced the following conclusions: (a) there is a possibility that NDVI derived from MOD9 is able to detect the date to reach the leaf constant period, (b) understory plant (*Sasa senanensis*) affected canopy level NDVI during leaf expansion and leaf senescent periods, (c) the relationship between NDVI and LAI of summer and that of autumn are different because of discoloration of the leaf during leaf senescent period, therefore (d) it is necessary to take into account the influence of understory plants for estimating canopy LAI from NDVI during leaf expansion and leaf senescent periods, and (e) it is also necessary to consider discoloration of the leaves during leaf senescent period.

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