Validation of MODIS LAI Product Over Temperate Forest

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Abstract

MODIS LAI has been one of key products for analyzing the quantitative aspects of terrestrial ecology. This study was designed to validate MODIS LAI product by using the reference LAI map that was derived from both ground measurements and ETM+ surface reflectance. The study area, the Kwangneung Experiment Forest in Korea, covers mixed species of deciduous and conifers of temperate forest. Throughout the growing season of 2002, we have measured LAI at the 30 sample plots using an optical device. Ground measured LAI data were then correlated to the ETM+ reflectance to produce a continuous map of LAI over the study area. Preliminary comparison between MODIS LAI and the reference LAI map showed the lower LAI values from the MODIS product.

Keyword : LAI, MODIS product validation, effective LAI, ground measurement, ETM+ reflectance

INTRODUCTION

Leaf Area Index (LAI), defined as projected leaf area per units ground surface area, is an important structural variable of vegetation because it is directly related to the exchange of energy, CO_2, and water from vegetation canopies (Sellers, 1996). The estimation of LAI using remote sensor data has been a primary interest for many ecological applications from landscape to global scales.

During the last three decades, there has been continuing interests of the development of empirical algorithms to related LAI to surface reflectance or to spectral vegetation indices (Turner, 1999). Numerous spectral vegetation indices have been used in LAI empirical algorithms, in which the normalized difference vegetation index (NDVI) was the most commonly used (Chen, 1996; Calson, 1997). Several factors have certain influence on the LAI-SVI relationships and may include vegetation type, canopy structure, and background (soil and litter), atmospheric effects, and topographic effects (Panferov, 2001; Tian,2000; Chen,1996;Turner,1999; Fassnacht;1997).

With the launch of EOS Terra satellite in 1999, the Moderate Resolution Imaging Spectrometer (MODIS) has begun to deliver 1km global scale LAI products. MODIS LAI product is processed with more refined and enhanced algorithms and will be used as a key variable in several fields of global environment and terrestrial ecology. Validation of the MODIS LAI algorithm is important part of the EOS program. One of such validations approach is inverting local and empirical relationship between LAI and spectral reflectance relationship (Turner, 1999).

Since MODIS LAI data has relatively short history, there are not enough studies of validating the product. MODIS LAI algorithm is dependent on six cover types of different biomes and the misclassification of biome can fatally influence the quality of LAI value (Tian, 2000; Wang, 2001).

This study is designed to validate MODIS LAI product over temperate forest region where the temporal variation of LAI is very high. As a reference map of LAI surface to be compared with MODIS LAI, we used ground-measured LAI data and Landsat ETM+ data.

METHODS

Study area and ground LAI measurement

The study area, Kwangneung Experiment Forest, is located about 30km northeast from Seoul, Korea and covers about 4x4km^2 area (Figure 1). The Kwangneng Experiment Forest includes diverse ground of mixed temperature species of deciduous and conifers. We have selected 30 ground plots for LAI measurement and assigned 10 plots per each of deciduous, coniferous, and mixed forest type. The exact coordinates of every ground plot was determined by Global Positioning System (GPS) and field survey and matched with image data.

Each plot is at least 100m apart from each other. Within each plot, LAI was measured at three subplots and the mean value of three LAI was used for the plot. The LAI measurement was carried out periodically from May to September 2002. Table 1 shows the date and LAI values for every measurement. LAI was measured by using a photo-optical device (Delta-T) that captures the amount the light penetrating tree canopy. This device is placed 1m above the ground and takes digital photos of vertical canopy view using sky using fish eye lens. The hemispherical view of canopy image was then processed to calculate LAI.

LAI value calculated from the image is often referred to 'effective LAI', which does not account for non-random distribution of foliage (Chen and Chilar, 1996). In practice, LAI and effective LAI are nearly identical in broadleaf canopies having relatively ordinary distribution without certain clumping. However, leaf clumping is quite obvious in coniferous stands and it is necessary to correct for the clumping factor (Chen and Chilar, 1996).

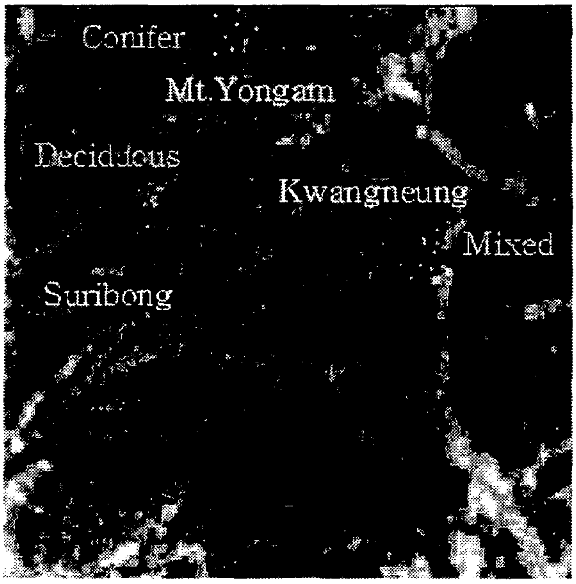

Figure 1. The ETM+ image of Kwangneung forest

Table 1. LAI measurements during the growning season of 2002.

Date	Type	# plot	LAI Range
2002. 05.24	Conifer	9	2.56-3.52
	Deciduous	10	2.93-4.18
2002. 06.26	Conifer	10	4.08-5.4
	Deciduous	10	3.91-5.16
	Mixed	10	3.3-5.0
2002. 08.14	Conifer	10	3.02-3.82
	Deciduous	10	2.84-3.59
	Mixed	10	2.68-3.61
2002. 09.11	Conifer	10	3.32-4.16
	Deciduous	10	3.08-4.58
	Mixed	10	2.62-3.79

Generating a reference LAI surface map

In order to evaluate MODIS LAI product, we decided to create a reference LAI surface by relating the ground measured LAI to Landsat ETM+ reflectance.

For this purpose, two ETM+ scenes were used. As can seen in Table 2, the acquisition date of ETM+ data was very close to the ground LAI measurement.

ETM+ images of the study area were initially registered to a plane rectangular coordinate using 20 ground control points that were obtained from 1:5,000 scale topographic maps. To extract the surface reflectance of pixels corresponding to the ground plot, ETM+ data were further processed for reducing topographic and atmospheric effects. Digital number (DN) value of the original image was converted to radiance by applying sensor gain, sensor bias, sun elevation, and sun azimuth values that were obtained from image headers (Markham and Barker, 1986). Since the study area is mountainous terrain, the topographic effect of illumination difference is very clear. To reduce the topographic effect, we used an empirical method that normalizes the illumination difference by applying the Minnaert's constant calculated from digital elevation model (DEM) and digital map of forest stand.

Table 2. Used ETM+ Images properties

Using ETM+	30 June,1999	4 Sept.,2000
Field Measure	26 June, 2002	11 Sept,2002
Sun Zenith Ang.	24.543°	36.61°
Sun Azimuth Ang.	118.92°	140.06°
Row/Col	145/144	
Path/Row	116/34	

Although the atmospheric correction of Landsat TM data has been frequently attempted, it has a certain limitation of obtaining the atmospheric parameters at the time of image capture. In this study, we used a modified dark object subtraction method, which corrects for path radiance and sun angle effects. After topographic and atmospheric corrections, the radiance values were converted to surface reflectance. Mean spectral reflectance value was extracted from the 2x2 pixel window that spans each of the 30 ground plots.

The reference LAI surface was created by relating the ground measured LAI to ETM+ reflectance. ETM+ reflectance of six spectral bands was compared with ground LAI value. Since the ground LAI values were obtained from the three different forest types of coniferous, deciduous, and mixed, the correlation between spectral reflectance and ground LAI were not significant when the 30 plot data were combined. Instead, we analyzed the statistical relationship between ETM+ reflectance and ground LAI by forest type. To build the optimal statistical regression model to estimate LAI for entire study area, we compared several sets of independent variables that are subset of a few spectral bands and/or vegetation indices. The best regression model was obtained when we used all six bands.

Three multiple regression models were built for each of the three forest types. To apply these LAI models, we had to categorize the entire study area into three layers of forest types by using the digital map of forest stand. Reference map of LAI surface was made after combining the three layers of LAI estimate for each forest type. Two sets of reference LAI map were created for the June and September.

Comparison between MODIS LAI and Reference LAI

MODIS LAI data are being produced from the other MODIS land products such as the surface reflectance products (MOD09) and land cover product (MOD12). 1m resolution MODIS LAI products are distributed every 8 days, which corresponds to the maximum value composition interval to remove cloud cover. LAI values are calculated by the inversion of a rather sophisticated canopy reflectance model that uses MODIS reflectance. If the main algorithm fails, a backup algorithm based on the empirical relationship with vegetation index is triggered to estimate LAI.

In this study, the two MODIS LAI images of similar data capture date with ETM+ were used (Table 3). MODIS LAI data can be directly obtained through the internet. MODIS LAI data of the study area were reprojected and georeferenced by using the MRT reprojection program provided by NASA. To compare the reference LAI surface with MODIS LAI product, the reference LAI map having the 28.5m resolution was resampled to 1km resolution.

Table 3. Used MODIS LAI images

	June	September
MODIS LAI	18 June, 2002	6 Sept, 2002
ETM+ Image	30 June, 2002	4 Sept, 2002

RESULTS AND DISCUSSIONS

Interpretation of the reference LAI from ETM+

Ground measured LAI values ranged from 3.58 to 9.099 in June and decreased to the range of 2.73 and 5.774 in September. Fig 2 shows the reference LAI surface maps of June and September. Comparing with existing forest stand map, the bright area of high LAI is corresponding with natural stands of deciduous species. Non-forest areas were mostly road, residential, and bare soil and masked out with zero LAI value.

Comparison between MODIS LAI and reference LAI

Figure 3 and Table 4 shows the comparison between MODIS LAI and reference LAI derived from ETM+ for the entire study area of $4x4km^2$. Although the mean LAI values of whole study area are very similar in June between MODIS LAI and reference LAI, the spatial pattern does not correspond each other. Since MODIS LAI data is 1km resolution, there might be a problem of mis-registration to reference LAI. In September data, MODIS LAI is significantly lower than the reference LAI map in all area.

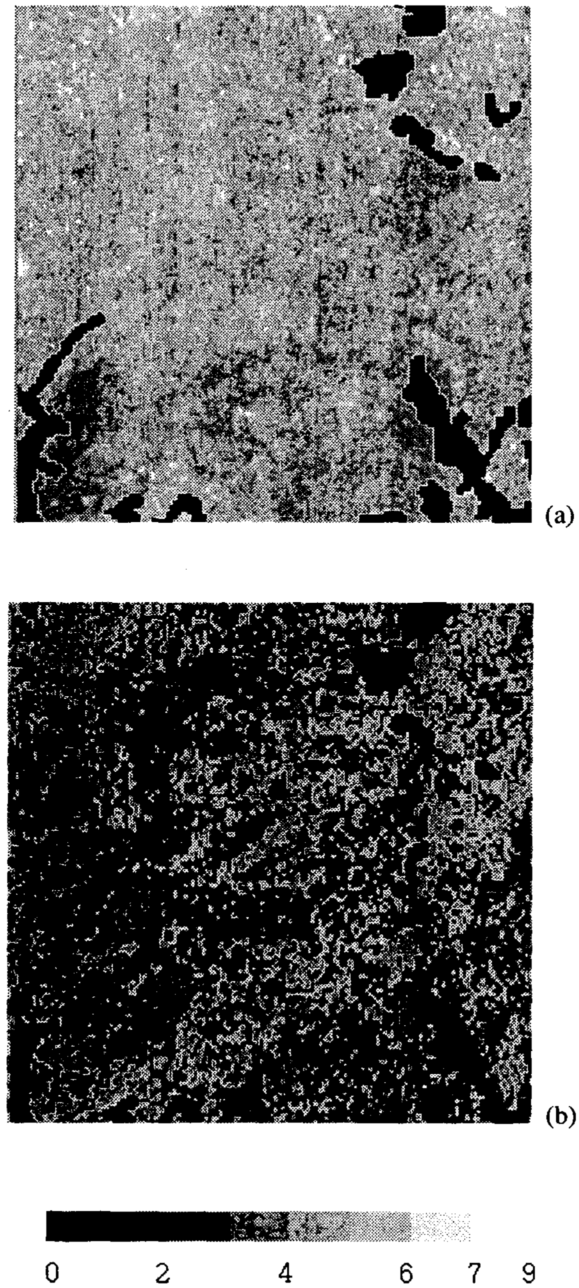

Figure 2. Reference LAI map generated by using ETM+ for June (a) and September (b).

In this study, the reference LAI map is actually showing the 'effective LAI' value, which tends to have lower than the real LAI value on MODIS product. Considering such discrepancy between effective LAI and real LAI, the MODIS LAI estimates might be even further lower than the true LAI.

The evaluation of MODIS LAI is only carried out over relatively small area of temperate forest cover. Since the collection of reliable and accurate ground measure of LAI is very difficult and time-consuming, the validation of MODIS LAI was restricted to such small scale. The relationship between ground measured LAI and ETM+ reflectance should not be applied to large scale area.

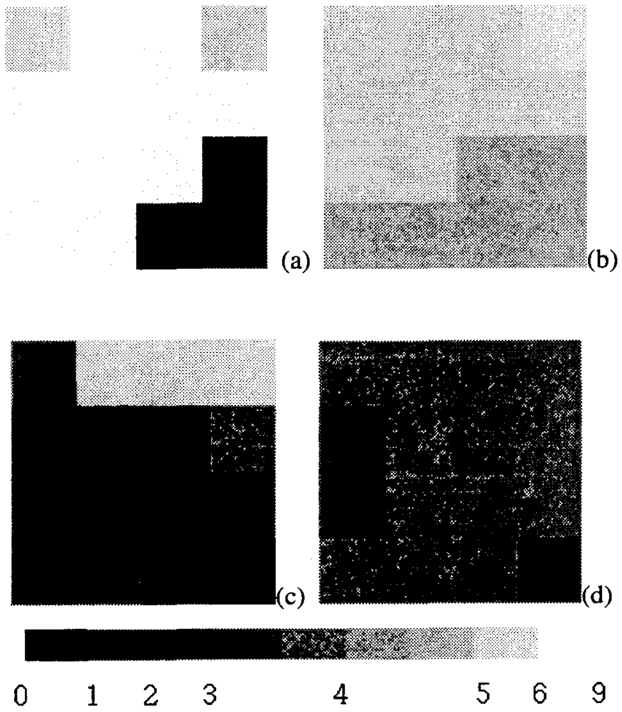

Figure 3. Comparison between MODIS LAI (a) (c) and reference LAI (b) (d) for June (top) and September (bottom).

Table 4. Simple statistics of MODIS LAI and reference LAI map using ETM+.

Date	Data	Mean	S.D.	Min	Max
June	28.5kmETM+	5.124	0.728	3.58	9.099
	1km ETM+	5.125	0.301	4.61	5.656
	MODIS	5.008	2.17	1	6.63.
Sept.	28.5kmETM+	3.695	0.652	1.47	5.774
	1km EMT+	3.694	0.143	3.37	3.923
	MODIS	3.336	1.495	0.3	5.6

CONCLUSIONS

Based on the results obtained from an empirical approach to directly compare the MODIS LAI with reference LAI surface, we can conclude as follow:

- MODIS LAI values are under estimated than the reference LAI for the temperate forest
- The discrepancy between MODIS LAI and reference LAI may be caused by the uncertainties in image registration and input variable of MODIS cover type, reflectance, and algorithm itself.
- Ground measured LAI values were better explained when we used all six bands of ETM+ reflectance rather than using subset of a few band or vegetation indices.

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