QUALITY ASSESSMENT OF GLOBAL MODIS LAI PRODUCT FOR THE REGIONAL SCALE APPLICATIONS

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KEY WORDS: Remote Sensing, Ecology, Forestry, Accuracy, Quality, Algorithm

ABSTRACT:

MODIS LAI product has been increasingly important for analyzing the process and productivity of terrestrial ecosystems at global scale. This study was aimed to assess the quality of global MODIS LAI product for applications in regional and even in local scales. To examine the quality of MODIS LAI data, we produced a reference LAI map that was derived by relating the ground-measured LAI to Landsat ETM+ reflectance over the forest of the Kyongan watershed in central Korean peninsula. After the reference LAI map was rescaled at 1km spatial resolution, it was compared with the MODIS LAI product that was generated about the same time with the reference data. From the comparison between the MODIS LAI and the reference LAI, it was found that MODIS LAI values were slightly higher at the forestland than the reference map and they were generally lower in grasslands and croplands. Specially, MODIS LAI pixels estimated by the backup algorithm by using NDVI were obviously under-estimated comparing with the reference LAI value. The MODIS LAI pixels that were attenuated by cloud cover also showed large difference from the reference LAI value. The discrepancy between the MODIS LAI and the reference LAI can be also caused by the misclassification of MODIS land cover product that is one of the input variable to create MODIS LAI. The quality of MODIS LAI product was largely dependent on the estimation algorithm, cloud cover, and the accuracy of MODIS land cover product.

INTRODUCTION

Although it has been relatively new since we are able to get MODIS LAI product, the estimation algorithm development started since the early 1990's. After launching the EOS terra satellite in 1999, the Moderate Resolution Imaging Spectrometer (MODIS) has begun to deliver 1km global scale LAI products. EOS program progressed the validation of MODIS products with production of MODIS data. After 2003, the papers about validation of provisional MODIS products were began to introduce. Main products of validation were MODIS land cover and LAI products. The cases of validation of MODIS LAI product have two parts, which are the validation of LAI Radiative Transfer algorithm itself and the accuracy of LAI product by using empirical methods (Tian *et al.,* 2002; Cohen *et al*., 2003). Since MODIS LAI product was primarily designed at global and continental scales, the validation of various geographic areas must be continued in local or global scale. The validity of MODIS global LAI product is being analyzed at several sites over the world, but it is rare to find any studies of analyzing at temperate forest in northeast Asia.

Leaf Area Index (LAI) has been an important parameter that is directly related to the photosynthesis, evapotranspiration, and the productivity of plant ecosystem (Bonan, 1993). Measurement of LAI in the field is very difficult, and requires a great amount of time and efforts (Gower *et al*., 1999). The mapping of LAI in large geographic area may be impossible when we rely on the field measurement. To solve this problem, there have been continuing efforts to develop methodologies to estimate LAI using remote sensor data (Turner *et al*., 1999). The normalized difference vegetation index (NDVI) was the most commonly used, however, showed the saturation phenomenon in high LAI value (Chen and Cihlar, 1996; Carlson and Reley, 1997). Although empirical modeling is relatively easy and useful method for relating field measured LAI to remote sensor data, several factors have certain influence empirical model (Cohen *et al*., 2003). The vegetation type, canopy structure, background, atmospheric conditions, and topographic conditions were affects the empirical model (Tian *et al.,* 2000; Panferov *et al.,* 2001).

In this study, we are attempted to determine the validity of MODIS global LAI product at temperate forest in northeast Asia. Terrestrial ecosystem in this region is vulnerable to several factors of environmental perturbations. MODIS LAI product can be an invaluable source of information for analyzing the status and activity of vegetation at regional and local scale.

METHODS

Study area

The study area, the Kyongan Watershed, is located near the Seoul metropolitan area in central Korean peninsula. The study area covered about 1,070km^2 area and 67% of them is forest. Two third of the forest is natural forest of mixed deciduous species, in which the dominant species are oaks (*Quercus mongolica*) mixed with natural pine species. The remaining one third of the forest is coniferous plantation stands of Korea pine (*Pinus karaiensis*), Pitch pine (*Pinus rigida*), and Larch (*Larix leptolepis*). Except for a few plantation forest stands, most forests have very dense canopy closure over 80% and average tree age ranges from 20 to 50 years. The study area has been an experimental watershed for many years to study local-scale runoff and water quality monitoring, in which site-specific LAI estimate can be a variable of interest for the hydrological studies (Lee et al., 2003).

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Field LAI measurements

Although the accurate measurement of LAI is crucial to relate the satellite observed surface reflectance, it is often difficult to obtain reliable ground-truth of LAI. Field measurement of LAI can be divided into two major approaches of direct and indirect methods (Chen *et al.*, 1997; Gower *et al.*, 1999). The direct method includes destructive harvest, litterfall collection, and application of allometric equations. In recently years, several optical devices become available for the indirect measurement of LAI. The basic concept of optical LAI measurement is to invert a radiation model that describes the amount of light penetrating tree canopy as a function of leaf area and distribution. In this study, we used the Li-Cor LAI 2000 plant canopy analyzer, which is a commercial instrument to indirectly measure LAI. This device estimates LAI by measuring light transmittance under the forest canopy like as other optical devices.

The 30 ground plots were selected to include diverse forest types of both coniferous and natural deciduous species. Field measurements were conducted from September 15 to 17, 2003. Each plot has an area of 20×20m^2 and includes five subplots for LAI measurements within it. LAI was measured three times at each subplot and total of 15 measurements were averaged to obtain the LAI value for each plot. The exact locations of the 30 ground plots were obtained using a differential global positioning system (GPS). Figure 1 shows the distribution of the 30 plots within the boundary of the Kyongan River basin.

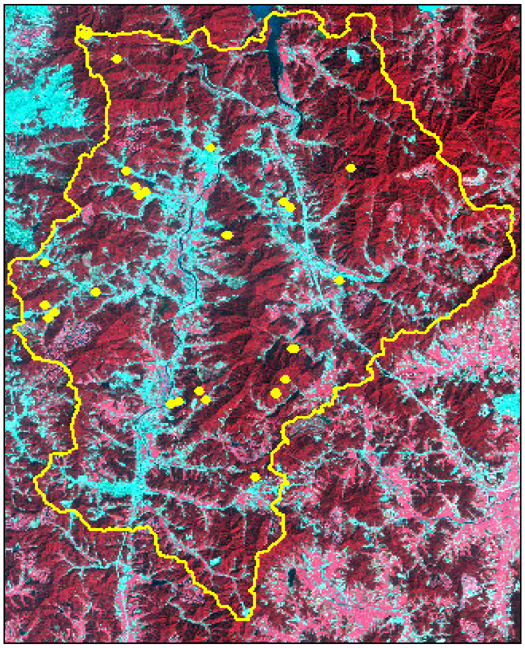

Figure 1. Distribution of 30 ground plots for the field LAI measurement over Kyongan River basin

Generation of reference LAI and land cover map

In an attempt to validate MODIS LAI product, we have constructed a reference map of LAI surface by relating the field-measured LAI to Landsat ETM+ spectral reflectance and spectral vegetation indices. To minimize any discrepancies due to the phenological variation of leaf development, the ETM+ data was captured on September 10, 2002 for this study. Although the ETM+ data acquisition was one year earlier than the field measurement, we believe that it did not cause any problem since the leaf development and the actual canopy condition between 2002 and 2003 were not much different.

Figure 2 showed the overall procedure of ETM+ data to construct reference LAI surfaces using the field-measured LAI. The ETM+ data were initially geo-referenced to plane rectangular coordinate system by using a set of ground control points (GCP) obtained from the 1:5,000 scale topographic maps. To extract the surface reflectance of pixels, rather than raw digital number (DN) value, ETM+ data were further processed to reduce topographic and atmospheric effects. DN value of the original image was converted to radiance by applying sensor's gain and bias coefficients that were obtained from image headers. We used the MODTRAN radiative transfer model for the atmospheric correction using a standard atmosphere model and atmospheric humidity and visibility that were obtained from local weather stations.

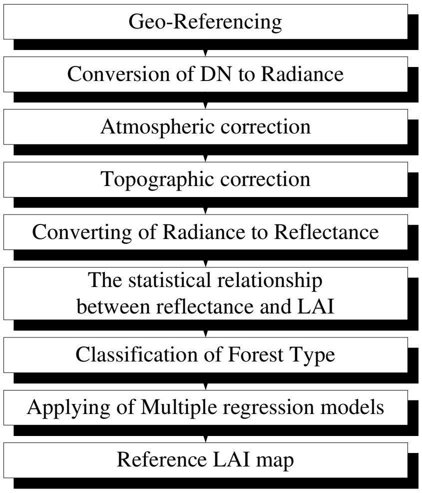

Figure 2. Procedure of constructing a reference LAI map using Landsat ETM+ and ground measured LAI

Further radiometric correction was applied to reduce the illumination variation caused by topographic slope and aspect. 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. Minnert's method have shown its effectiveness to correct the topographically induced radiometric distortions over the forests in Korea (Lee and Yoon, 1997). The detailed information on estimating of Minnaert constant k can be found in Lee *et al.* (2003).

A vector map of 30 sample stands of the field LAI measurement was overlaid to the geo-referenced ETM+ reflectance data and the pixels corresponding to each plot were extracted. Due to the high spatial autocorrelation, the variation of adjacent pixels was very low to overcome the problem of the sub-pixel error distance of the geometric registration.

Initial approach to compare the field measured-LAI and the image spectral reflectance was a simple correlation analysis.

The empirical models to link the spectral reflectance to the field measured LAI were developed separately for each forest type as well as for all forest types. In this study, we tried to use several vegetation indices (SVI) as independent variables to the multiple regression model. Three other spectral indices of brightness (BR), greenness (GN), and wetness (WT) were also created by the tasseled cap (TC) transformation.

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 vegetation indices. Two multiple regression models were built for each of two forest types. In addition to the forest cover map, we also need a land cover map to validate the empirical LAI estimation algorithm. A land cover map, in which the class categorization is comparable to the MODIS Land cover type 3-scheme (9 classes), was obtained by ordinary maximum likelihood classification method. Although the major portion of the study area is forest, it also includes small and segmented agricultural areas. The LAI values for the grass and croplands (mostly rice paddy) were adapted from the previous study by Hong *et al*. (1998).

Quality assessments of MODIS LAI product

As shown in Figure 3, the operational algorithm for producing MODIS LAI uses two MODIS land products of the surface reflectance (MOD09) and land cover (MOD14). The 1km resolution MODIS LAI products are produced every 8 days, which corresponds to the maximum value composition interval to remove cloud cover. LAI values are calculated by mathematical inversion of a rather sophisticated canopy reflectance (CR) model that uses MOD09 and MOD14. If the CR model-based main algorithm fails, a backup algorithm based on the empirical relationship with vegetation index is triggered to estimate LAI.

The MODIS LAI image that corresponded to the date of the reference LAI map was obtained. Since the MODIS LAI value is separately calculated by cover type, the MODIS land cover products of were also acquired. MODIS land products can be directly obtained from the Earth Observing System Data Gateway (EOS, 2003). The MODIS LAI and land cover products supplied by the EOSDG is originally referenced by the sinusoidal map projection. To compare with the reference LAI map of the study site, the MODIS products were geo-referenced to the Transverse Mercator map projection by using the MODIS reprojection tool (MRT) software provided by NASA. To compare the reference LAI surface with MODIS LAI product, the reference LAI map having 28.5m pixel size was rescaled to 1km pixel size.

For the quality assessment of MODIS LAI data, we applied three phases of 1) quality of input datasets, 2) the MODIS LAI estimation algorithms, and 3) LAI value by land cover type (Figure 3). The accuracy of the MODIS land cover product was assessed by the reference land cover map. We also analyzed the effects of cloud cover at each pixel location for the MODIS reflectance data. After the validation of input datasets, we compared the reference LAI map with the MODIS LAI data by the estimation algorithms. Within the scene, some pixels had LAI value from the main CR-based algorithm and the other pixels had LAI value from the NDVI-based backup algorithm. As LAI value is also very sensitive to vegetation types, we tried to analyze the MODIS LAI value by different vegetation type (forest vegetation and grass /cropland).

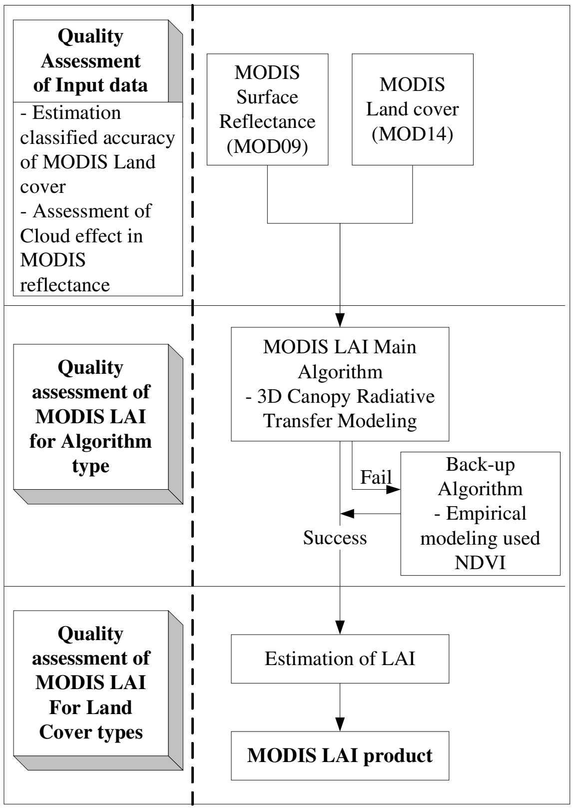

Figure 3. Flowchart of producing MODIS LAI and schemes of quality assessment of MODIS LAI

RESULTS AND DISCUSSIONS

Two separate multiple regression models to predict LAI for the reference map were developed for each of coniferous and deciduous forest. To avoid over-fitting problem of too many independent variables (five SVIs), we imposed the rule that only three variables can be selected for each model. Table 1 shows the selected independent variables, R^2 value, and root mean squared error of each of two models developed. Although the use of two separate estimation models requires additional effort of classifying the forest into two species groups, it should be a better approach to obtain more reliable LAI map. We generated the high-resolution reference LAI map by applying the best regression models to the radiometrically corrected reflectance data. Using the reference land cover type map, the coniferous and deciduous forests were extracted prior to applying the models and the grass and croplands were given the same LAI value that was measured in September.

Table 1. Regression models to estimate LAI over the study area

Type	Selected independent variables (SVI)	R^2	RMSE
Coniferous	RSR, BR, GN	0.8018	0.6289
Deciduous	NDVI, RSR, WT	0.3413	0.4504

Rather high spatial resolution map of the reference LAI surface was rescaled to 1km cell size to compare with the 1km MODIS LAI map. Figure 4 compares the MODIS LAI and the reference LAI maps for the whole study area of 28 x 38km^2. It appears that the MODIS LAI estimates are higher than the reference LAI surface. From our fieldwork and experience, the LAI over the study area showed little variation, at least within the forest. The MODIS LAI map shows highly variable spatial pattern of LAI.

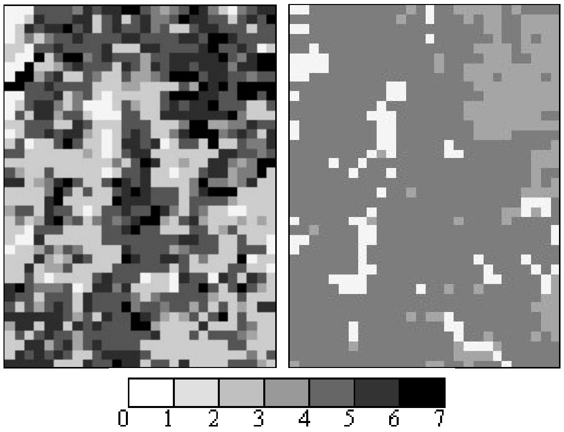

Figure 4. Comparison between the MODIS LAI (left) and the reference LAI (right) maps.

Table 2. Simple statistics of MODIS LAI and reference LAI

Factor	Class	Reference		MODIS	
		Mean	Std.	Mean	Std.
Land cover type	Whole area	3.26	0.24	3.52	1.81
	Forest	3.28	0.24	3.74	1.76
	Grass & Cropland	3.10	0.17	2.30	1.53
Model	RT model	3.27	0.24	3.40	1.77
	Empirical model	3.13	0.26	5.94	0.30
Cloud	Non-cloud	3.25	0.22	3.41	1.67
	Cloud	3.29	0.28	3.81	2.10

The mean LAI value of the MODIS product is about 0.38 higher than the reference map (Table 2). Although the mean LAI values of whole study area are similar between MODIS LAI and reference LAI, the spatial variation and pattern of the LAI values are quite different between two maps. When the two LAI maps are compared by vegetation type, the MODIS LAI values were larger than the reference value in forest. On the other hands, grass and cropland showed the under-estimation in which the MODIS LAI value was lower than reference LAI value.

The discrepancy between the MODIS LAI and the reference LAI could be explained by several factors that were the accuracy of the input datasets, estimating algorithms and land cover types. Since the MODIS LAI values are estimated by the seven cover types of different biomes, it is worthwhile to examine the MODIS land cover map used for the production of the MODIS LAI. Figure 5 compares the MODIS land cover product and the reference land cover map. The classification accuracy of the MODIS land cover product is 44.72% as assessed by the reference land cover map (Table 3).

The study area includes large forest area. The MODIS land cover product didn't show well the small water-body, needleleaf forest, and urban. It was obvious that some portion of forests were misclassified into grass and cropland on the MODIS land cover product. Water-body was misclassified to needleforest and the urban area was misclassified into grass and cropland. These misclassifications were caused by low spatial resolution of MODIS land cover product and might be the causes of the difference between two LAI maps.

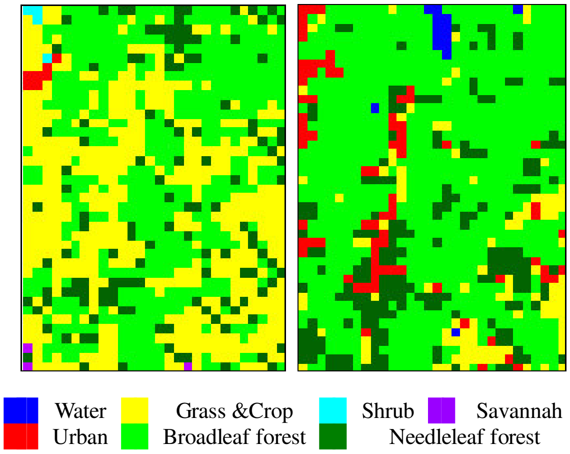

Figure 5. Land cover map of the MODIS product (left) and the reference data (b)

Another factors influenced on the MODIS LAI estimation were the cloud effect. Although the MODIS LAI product is based on the eight-day maximum value composite to remove/reduce the

Table 3. Classification accuracy of the MODIS land cover assessed by the ETM+ classification (Overall accuracy = 44.72%)

Reference \ MODIS	Water	Grasses & all Crop	Shrubs	Savannah	Broadleaf forest	Needleleaf forest	Urban	Total
Water	0	4	0	0	6	4	0	14
Grasses & Crop	0	71	0	2	16	16	0	105
Shrubs	0	0	0	0	0	0	0	0
Savannah	0	0	0	0	0	0	0	0
Broadleaf forest	0	311	2	0	438	85	2	838
Needleleaf forest	0	98	0	1	60	36	0	195
Urban	0	53	2	0	14	4	5	78
Total	0	537	4	3	534	145	7	1230

cloud covers, some pixels certainly has continuing cloud cover during the eight days. Fortunately, such cloud cover information is supplied with the MODIS LAI product. Figure 6 showed the cloud coverage at every pixel location and the LAI estimation algorithm used. As seen in Figure 6, about 30% pixels of the MODIS LAI image were affected by cloud cover. The 5% pixels of this MODIS LAI image were produced by the backup algorithm based on NDVI. In particular, most of the pixels corresponding to the backup algorithm were forest. Although the MODIS LAI product at this study area was mainly estimated by main RT algorithm and not affected by cloud, the effects of the backup algorithm and cloud should be considered at the quality assessment of MODIS LAI over other sites.

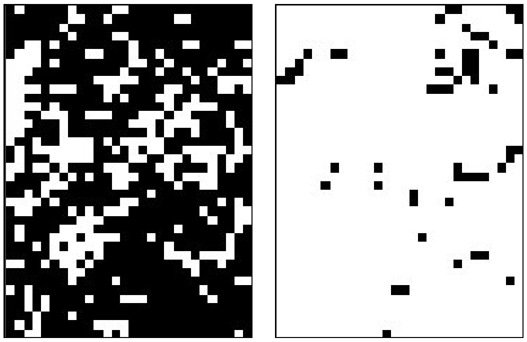

Figure 6. MODIS LAI QA images of cloud effect (left: white- cloud, black- no cloud) and estimation algorithm (right: white- RT model, black-backup model).

As seen in Table 2 and Figure 7, the MODIS LAI values, which were estimated by the backup algorithm and affected by cloud cover, showed large difference as compared to the reference LAI map. In these pixels, the MODIS LAI is lower than the reference LAI value. Since the portion of area of the backup algorithm and the cloud cover was relatively small, they might have not affected the overall statistics of MODIS LAI. However, since the more than two third of the study area is occupied by forest, the over-estimation of MODIS LAI in forest shows great influence on the total image (Figure 7). In grass and cropland, although they were small portion, the MODIS LAI values were lower than the reference LAI value.

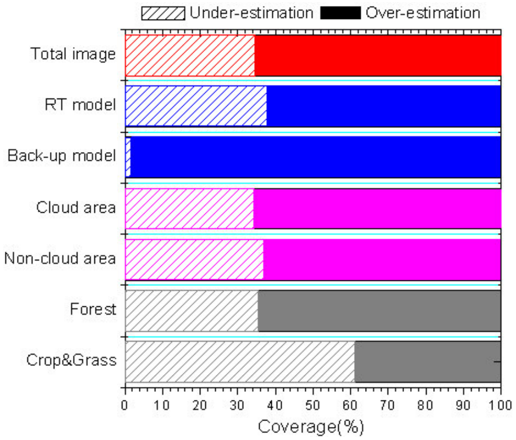

Figure 7. Estimation patterns of MODIS LAI for each schemes (Under-estimation means MODIS LAI was lower than reference LAI, Over-estimation means MODIS LAI was higher than reference LAI)

4. CONCLUSIONS

During the last decades, there was a great amount of time and efforts to develop the global ecological variables by the earth observing system (EOS) program. The MODIS global LAI product is one of such variables that are now being provided. To use such valuable information at regional and local scales, it is crucial to validate the quality of the product. In this study, we made a simple and direct comparison between the MODIS LAI data and the reference LAI surface that was derived by an empirical approach to relate the field-measured LAI to Landsat ETM+ reflectance.

Although the validation can be further expanded into larger areas, the preliminary results obtained from this study indicate that the MODIS LAI product is different from the reference data. At the temperate forest, the MODIS LAI estimates were higher than the reference LAI values during the leaf-on season of September. The discrepancy between the MODIS LAI and the reference LAI may be caused by the uncertainties in the input variables of MODIS LAI algorithm, effects of cloud at each pixels, estimation algorithm, and land cover type. In general, MODIS LAI values were higher than the reference LAI in forest and they were lower than in grass and cropland. Additionally, MODIS LAI data affected by backup algorithm and cloud showed higher value as compared RT algorithm and no-cloud condition.

The validations of MODIS LAI product are being carried out at the several study sites throughout the world. Due to the 1km spatial resolution of the data, the validation is often restricted by the size of test area and the collection of accurate ground-truth data. Temperate forest is even more complicated than any other ecosystems, which include a variety of species and stand structure. Further study is planned to assess the quality of the MODIS LAI estimate for local and regional applications.

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