The Relationship between NDVI and Forest Leaf Area Index in MODIS Land Product

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Abstract: NDVI has been used to estimate several ecological variables including leaf area index (LAI). Global MODIS LAI data are partially produced by empirical model that is based on the assumption of high correlation between NDVI and LAI. This study attempts to evaluate the MODIS empirical model by comparing with the result obtained from field LAI measurement and Landsat ETM+ reflectance. MODIS LAI product and ancillary data were analyzed over a small forest watershed near the Seoul metropolitan area. The relationship between NDVI of ETM+ and field measured LAI did not correspond to MODIS LAI estimation. Since the study area is mostly covered by very dense and fully closed forest, the correlation between NDVI and LAI might not be high. Although MODIS LAI product has great potential for global environment studies, it needs to be cautious to use them in regional and local area in particular for the forest of dense canopy situation.

Keywords: NDVI, forest LAI, ETM+, MODIS LAI backup algorithm

1. Introduction

Normalized difference vegetation index (NDVI) has been widely used to assess or estimate such ecological variables as canopy closure, leaf area index (LAI), and biomass across diverse ecosystems. The high correlation between NDVI and LAI could be found numerous studies related to agricultural crop, semiarid grassland, and forests. However, large portion of such studies were dealing with vegetation system where the percent vegetation cover is far from fully closed condition. Recent studies showed that the NDVI may not be very sensitive to LAI in particular at the forest ecosystem having the close canopy condition [2, 7].

Remote sensing estimation of LAI has been based on two methods of 1) empirical relationship between the field-measured LAI and sensor observed spectral responses and 2) inversion of canopy reflectance model. Long before the launch of EOS Terra satellite in late 1999, global scale LAI estimation algorithms were developed. Moderate Resolution Imaging Spectro radiometer (MODIS) LAI product is such global-scale LAI map produced by MODIS reflectance data and other ancillary data. Although MODIS LAI data (supplied since early 2000) have a great potential for global scale climate, hydrology, and ecology studies, their validity has not been fully verified yet. The objectives of this study are to analyze the relationship between NDVI and LAI, which is the MODIS empirical model, and to evaluate whether such relationship is valid for regional scale LAI estimation using better spatial resolution remote sensor data.

2. MODIS LAI Algorithm

The MODIS LAI products are now being produced as 8-day maximum value composite (MOD15A2) and distributed to the public by the USGS Eros Data Center. The LAI product file contains another ecological variable (fraction of photosynthetically active radiation – FPAR) and other ancillary data that can be used to assess the quality of the product [5]. LAI value is estimated by two algorithms of 1) a physical and mathematical model of canopy radiative transfer (R-T) model and 2) empirical model of using NDVI as a backup algorithm when the RT model fails.

1) Canopy radiative transfer (RT) algorithm

The RT algorithm uses two basic variables of atmospherically corrected reflectance and land cover map of six biomes, which are also part of other MODIS Land products. The structural characters among these biomes, such as the horizontal (homogeneous vs. heterogeneous) and vertical (single vs. multistory) dimensions, canopy height, leaf type, soil brightness and climate (precipitation and temperature), are used to define unique model configurations, including some fixed parameter values appropriate for the biome characteristics [5, 6]. Look up tables are then generated for each biome by running the model for various combinations of LAI and soil type. It compares the observed reflectance to comparable values evaluated from model based entries stored in look up table (LUT) and derives the distribution of all possible solutions, LAI distribution functions [8].

2) Backup algorithm

When the RT algorithm fails for those pixels of cloudy or heavy atmospheric effect, the backup algorithm is triggered to estimate LAI using NDVI. Empirical MODIS specific NDVI-LAI relationships are derived from the RT-based LAI and the NDVI calculated from the MODIS surface reflectance product. Since the MODIS specific NDVI-LAI relationship is not derived by any field verified LAI values, its validity has not been confirmed yet. Currently, the backup algorithm for forest biomes uses relationships derived from SeaWiFS reflectance data [8]. For the remaining biomes, the backup algorithm was derived from MODIS surface reflectance product [5].

3. Methods

1) Study area and satellite data used

The study site is the Kyongan Watershed ($561km^2$) located in southeast of the Seoul in Korea. Two third of the area is covered by forest (1/3 coniferous, 2/3 mixed deciduous), in which most stands have very dense canopy closure and average tree age ranges from 20 to 50 years. Table 1 shows the satellite dataset used for this study.

Table 1. Satellite datasets used for the study.

dataset	Acquistion date	resolution
MODIS LAI	Sep. 14-21, 2003	1 km
MODIS NDVI	Sep. 14-29, 2003	
MODIS Landcover	Oct.2000 - Oct. 2001	
Landsat ETM+	Sep. 10, 2002	30m

MODIS product are provided as a tiled segment on the Sinusoidal map projection, which covers an area of approximately 1,200 by 1,200 km^2. The MODIS data we used contains the whole area of southern part of the Korean Penisular and parts of China and Japan. Initially, we separated only those pixels (in both LAI and NDVI) corresponding to forest (biome type 5 and 6) using MODIS land cover product. After that, LAI map was further separated by the estimation algorithm using the ancillary data that comes with the LAI product. Using only those pixels estimated by the backup algorithm for the forest area, we were able to construct the MODIS specific NDVI-LAI relationship.

2) Field measurement of LAI and ETM+ NDVI

To evaluate the MODIS specific NDVI-LAI relationship, we compared the relationship between the field-measured LAI and NDVI calculated from ETM+ reflectance. Cloud-free Landsat ETM+ data were acquired on September 10, 2002, which is about the same date with the field measurement in early September, 2003. Although the ETM+ data was acquired one year earlier than the field measurement, we believe that it is not problematic since the leaf growth and canopy condition between 2002 and 2003 were not much different. The ETM+ data were geo-referenced using a set of GCPs obtained from the 1:5,000 scale topographic maps. ETM+ image was radiometrically corrected to reduce the effects of atmosphere and topography and converted to surface reflectance [3].

About 30 ground plots were selected to measure LAI directly on the ground. 30 ground plots were selected to include both coniferous and mixed deciduous species. Field measurements were conducted during the three days from September 15 to September 17, 2003. We used the Li-Cor LAI 2000 plant canopy analyzer to measure LAI value. Each plot has an area 20 x $20m^2$ and includes five subplots for the LAI measurement within it. LAI was measured three times at each subplot and total of 15 measurements were averaged to obtain the LAI value at each sample plot [3].

4. Results and Discussions

The NDVI-LAI relationship used for the backup algorithm is basically a linear function for each biome. Figure 1 shows the NDVI-LAI relationship for each of two forest biomes (coniferous and deciduous forest), in which the relationship is more like a exponential function. At lower NDVI (under 0.6), corresponding LAI values are less than 1. On the other hand, LAI increases rapidly at high NDVI value (0.6 to 0.8). Such exponential relationship between NDVI-LAI is somewhat contradict to several studies that presented the saturation problem in which NDVI is no longer correlated with high NDVI values [7].

Figure 2 shows the relationship between the field-measured LAI and NDVI value that was derived from the ETM+ reflectance of red and near infrared bands. In general, there is no significant relationship between NDVI and field-measure LAI and NDVI for the study area. The forest stands were almost close canopy and their LAI values were larger than three. This general low correlation between NDVI and LAI at high LAI vegetation has been noted in several studies [7][11].

(a) Biome 5 (Deciduous)

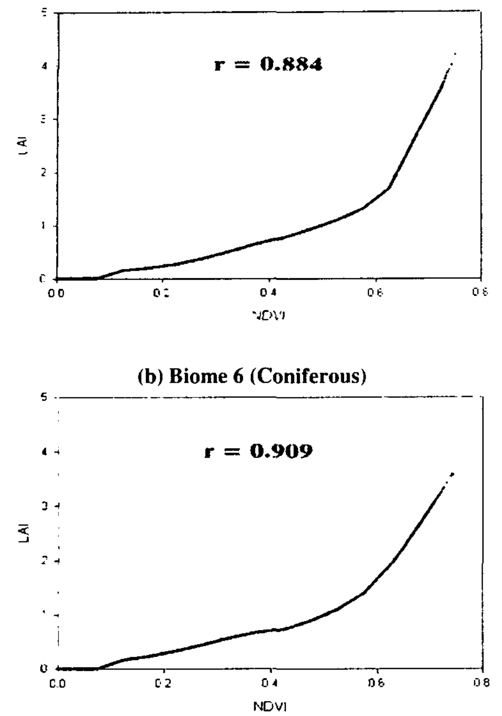

Fig 1. MODIS specific relationship between NDVI and LAI used in backup algorithm

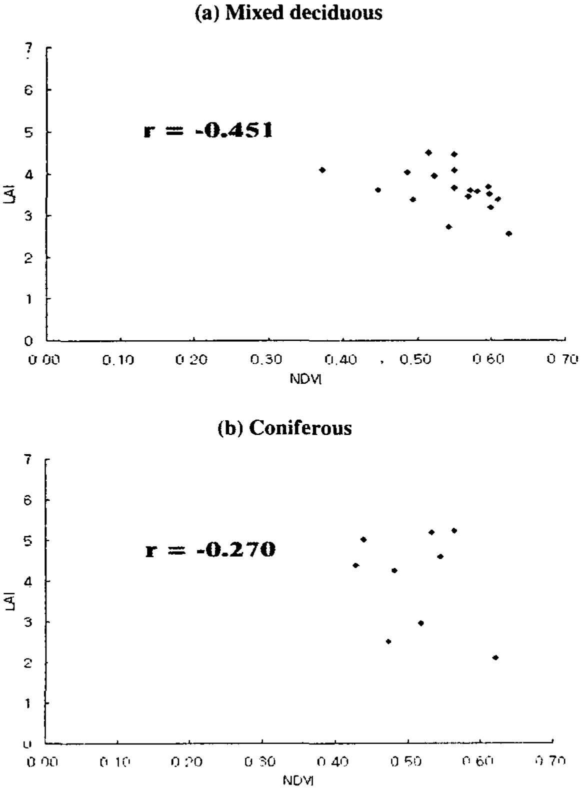

Fig 2. Relationship between field-measured LAI and ETM+ NDVI over the study area.

For over two decades, NDVI has been a popular index with which to estimate LAI across diverse systems but these results suggest that other indices may be more appropriate. Fortunately, numerous recent studies have noted a strong contribution of middle infrared bands to the strength of relationships between reflectance and LAI [10][12].

Figure 3 shows the relationship between NDVI and LAI, where both of them were extracted from MODIS product. Since the MODIS LAI basically estimated from the backup algorithm, the relationship is essentially the same as the functions seen in Figure 1. Since the 16-day composite NDVI value shown in Figure 3 is not exactly the same one used for the backup algorithm, the graph does not show the one-to-one relationship. The 8-day MODIS LAI composite is produced by selecting the maximum LAI value among eight daily LAI calculated from the corresponding daily NDVI value.

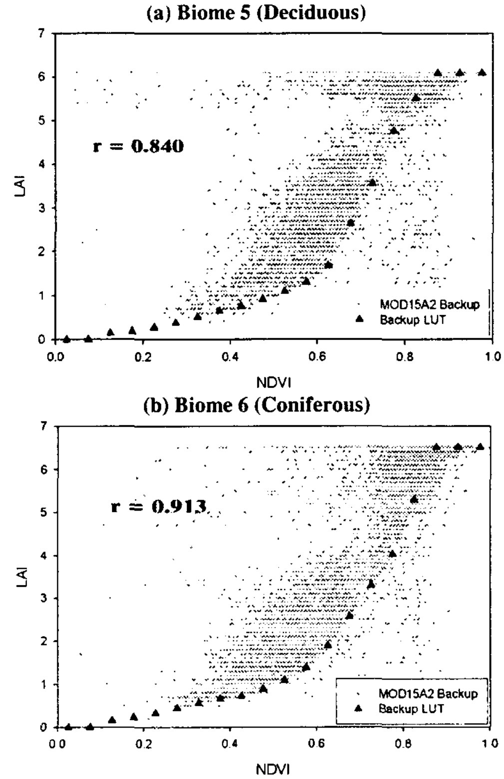

Fig 3. Relationship between MODIS NDVI and MODIS LAI values extracted for those pixels corresponding to the backup algorithm.

When we need to generate LAI map using higher resolution satellite image (such as ETM+ or SPOT) using the MODIS backup algorithm, the outcome would be somewhat biased LAI values considering the relationship seen in Figure 1. Figure 4 shows the LAI map generated by applying the MODIS backup algorithm to the ETM+ NDVI data.

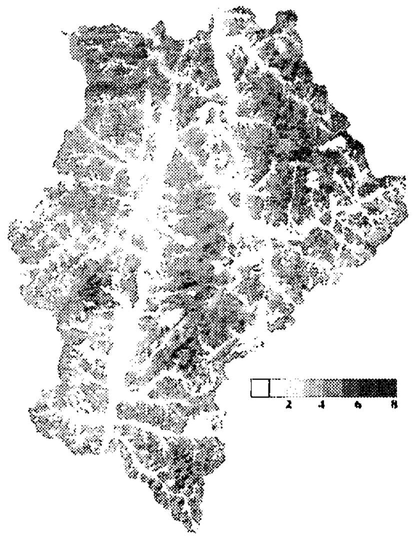

Fig 4. LAI map generated by applying the MODIS backup algorithm to the ETM+ NDVI.

The above LAI map shows relatively lower LAI values as compared to the original MODIS LAI product over the same area. The lower LAI value may be explained by the difference in NDVI value between MODIS and ETM+. Figure 5 shows the relation of MODIS NDVI and ETM+ NDVI NDVI value over the study area in early September 2003. Although the two dataset were obtained about the same date of the year and were also calculated using atmospherically corrected reflectance value, the MODIS NDVI values are higher than the ETM+ NDVI. As seen in Figure 1, the higher NDVI provides the larger LAI value. Even if the MODIS backup algorithm is appropriate for a certain biome at particular area, we need to pay more attention about the magnitude of NDVI that are obtainable from essentially most multispectral remote sensor data.

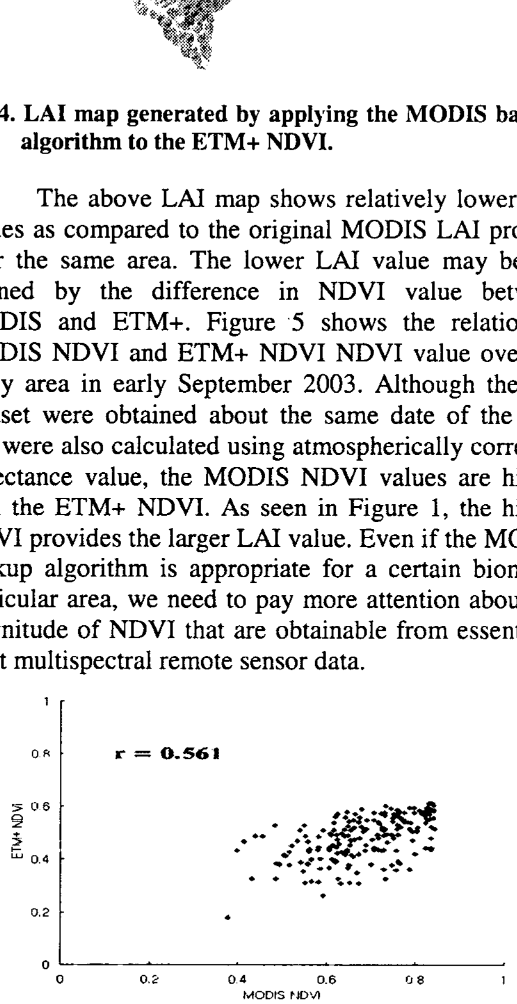

Fig 5. Relationship between MODIS NDVI and ETM+ NDVI over the study area in early September 2003.

5. Conclusions

MODIS specific NDVI-LAI relationship (backup algorithm) is essential an exponential function. When we evaluate the backup algorithm with field-measured LAI and Landsat ETM+ NDVI over the forested study area, it the MODIS specific NDVI-LAI relationship was not quite effective for the study area where the forest canopy is almost fully closed and LAI is relatively high. Although MODIS LAI product is designed to help global scale studies of ecological and environmental issues, its applicability to local and regional area has not been confirmed yet. From the result obtained from this study, it is advised to use site-specific empirical model, other than the MODIS backup algorithm, to generate LAI map for the forest area having relatively dense canopy structure.

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