# VALIDITY OF NDVI-BASED BIOPHYSICAL PARAMETERS FOR ECOSYSTEM MODELS


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**ABSTRACT :** NDVI has been very frequently used to estimate several biophysical parameters that are required for ecosystem models. Leaf area index (LAI), canopy closure, and biomass are among those biophysical parameters that are estimated by empirical relationship with NDVI. However, the type of remote sensing signals (raw DN value, at-sensor radiance, atmospherically corrected reflectance) used can vary the calculation of NDVI. In this study, we tried to attempt to compare the influence of NDVI linked with forest LAI for the watershed-scale ecosystem models to estimate evapotranspiration. Landsat ETM+ data were used to obtain various NDVI values over the study area in central Korea. The NDVI-based LAI and the resultant evapotranspiration estimation were greatly varied by the remote sensing signal applied.



**KEY WORDS:** remote sensing signal, NDVI, LAI, biophysical parameters, ecosystem model


## 1. INTRODUCTION

Modelling has been a very effective tool to understand overall structure and process of ecosystems over wide range of time and spatial scales. Several ecological process models have been developed to predict, investigate, and simulate effects of diverse circumstances (Franklin, 2001). These models often require several input parameters that are not readily available with conventional field survey. For instance, leaf area index (LAI) is one of critical input parameters for several forest ecosystem models to calculate photosynthesis, evapotranspiration, and net productivity. Ground measurement of LAI is very difficult and requires a great amount of time and efforts (Gower et al., 1999). Since plant canopy is composed of leaves, which is a direct source of the energy-matter interactions that are observed by earth-observing remote sensor systems, LAI has been an attractive variable of interest in vegetative remote sensing.

Remote sensing is probably only practical method to collect such biophysical parameters that are required to run ecological models over large geographical area. The primary approach for estimating such parameters from remote sensing has relied on the empirical relationship between the field-measured values and corresponding spectral responses from remote sensor data. (Curran et al., 1992; Peddle et al., 1999). As a single value to represent the spectral responses from remote sensor data, normalized difference vegetation index (NDVI) have been frequently used to indirectly estimate biophysical variables of vegetation.

Although NDVI can be directly linked to the biophysical parameter of interest, the calculation of NDVI is greatly varied by the type of remote sensing signals used. There are several kinds of remote sensing signals that represent the spectral response and can be used to calculate NDVI. Depend on the type of remote sensing signal used, the NDVI value varies significantly. In this study, we attempt to address and to analyze the problem of using various NDVI values that are linked with forest LAI for the ecosystem process model.

## 2. NDVI-BASED BIOPHYSICAL PARAMETERS

Normalized difference vegetation index (NDVI) has been a popular spectral index with which to estimate several vegetation-related biophysical variables over diverse ecosystems. There are numerous attempts to estimate biophysical parameters using NDVI that can be derived from red and near-infrared spectral bands of several multispectral remote sensor data. Table 1 shows a few examples of equation to estimate biophysical parameters as a function of NDVI. These equations were mostly developed by empirical relationship between ground-measured value and corresponding NDVI. In addition, these relationships are mostly limited to a specific ecosystem over a specific geographic region. These biophysical variables are often key input parameters for several ecological, hydrological, and metrological process models. Sometimes, NDVI-estimated variables are used to estimate secondary biophysical variable. For example, a research working on the validation of MODIS products has developed one of such functions to estimate fraction of photosynthetically active radiation (fPAR) from the NDVI-derived LAI (Cohen et al., 2003).

Since NDVI is highly correlated with the amount of green vegetation, the estimation of such biophysical variables using NDVI seems to be a reasonable approach. However, there is not enough consideration in which the NDVI can be greatly varies by several factors. First of all, one should know whether NDVI is truly quantitative. Although NDVI has a value ranging from −1 to 1 and it represents more green vegetation when its value is close to 1, there is no exact information about distance between NDVI values. There is no information to precisely define the distance between NDVI 0.5 and 0.6. Therefore, we may say that NDVI is ordinal scales of measurement rather than interval or ratio scales.

Furthermore, NDVI value can be greatly varied by the type of remote sensing signal used. In optical remote sensor data, there are several kinds of spectral responses for calculating NDVI. As seen in Figure 1, remote sensing signals in optical image data can be raw digital number (DN) value of pixels, at-sensor radiance ($L_s$), target-leaving radiance ($L_t$), target reflectance ( $\rho$ ), and topographically corrected reflectance ( $\rho_t$). At-sensor radiance $L_s$ is obtained from DN value by simply applying the calibration coefficients (gain and offset) that are provided along with image data. To achieve target-leaving radiance ($L_t$) from $L_s$, we need somewhat complicated atmospheric correction procedure. Absolute atmospheric correction procedure uses radiative transfer model to calculate the amount of atmospheric attenuation and it requires many atmospheric parameters at the time of data acquisition. Since target-leaving radiance $L_t$ can also vary by the sun-Earth distances, the pure target signal should be reflectance ( $\rho$ ) that is obtained from $L_t$ dividing by the solar irradiance. In mountainous topography where the sun illumination is greatly affected by the undulated terrain slope, the $\rho$ can be further refined by correcting topographical radiometric distortion to get $\rho_t$. Since NDVI calculation is completely based upon spectral signals of red and near-infrared spectrum, the resultant NDVI value can also be influenced by the spectral signals adopted. Unless NDVI is very sensitive to the kind of remote sensing signals used, we need to be more careful to choose appropriate signal among the above five signals.

## EXPERIMENTS

Recently, several ecological process models were developed to use NDVI-based input parameters. In this study, several NDVI values were applied to a simple model to estimate evapotranspiration in forest ecosystem. The Penman-Monteith equation is frequently used independently to estimate evapotranspiration and interactively within other ecological models, such as biogeochemical (BGC) process model. We have applied Penman-Monteith (P-M) model to the Kyongan watershed located in southeast of the Seoul metropolitan area in central Korea. The study area covers 561km$^2$ and 67% of them is covered by forest.

Table 1. List of a few NDVI-based biophysical parameters as input to ecological process models.

| Biophysical parameters | Equation form | References |
|---|---|---|
| Tree ring growth | a+b*NDVI | D'arrigo et al. (2000) Liang et al. (2005) |
| LAI (deciduous forest) | $(NDVI/a)^b$ | Pierce et al. (1993) |
| LAI (plantation pine) | a + b * NDVI | Curran et al. (1992) |
| LAI (boreal forest) | a * e NDVI/b | Running et al (1989) |
| LAI (temperate conifers) | $(NDVI/a)^b$ | Spanner et al.(1990) |
| FPAR | a*NDVI - b | Myneni and Williams (1994) |

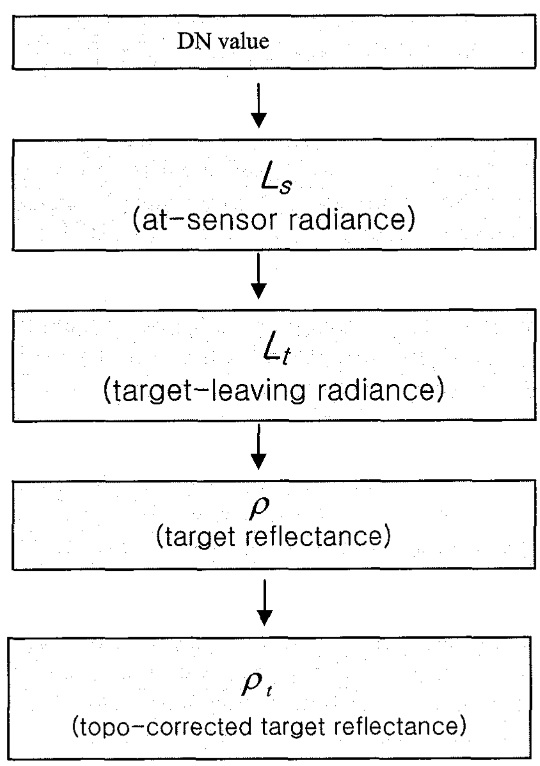


Figure 1. Type of remote sensing signals can be used to calculate NDVI.

To generate a map of evapotranspiration in rather high spatial resolution, the P-M model is applied to every pixel on Landsat-7 ETM+ data. P-M model requires several input parameters including LAI. In following equation, $r_s$ represents canopy resistance that is directly related to LAI. The other input variables are related to air and soil heat flux and meteorological conditions. Before applying this model to the study area, we have tested the sensitivity of each variable and found that potential evapotranspiration was more sensitive to LAI than other variables (Figure 2).

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)}$$

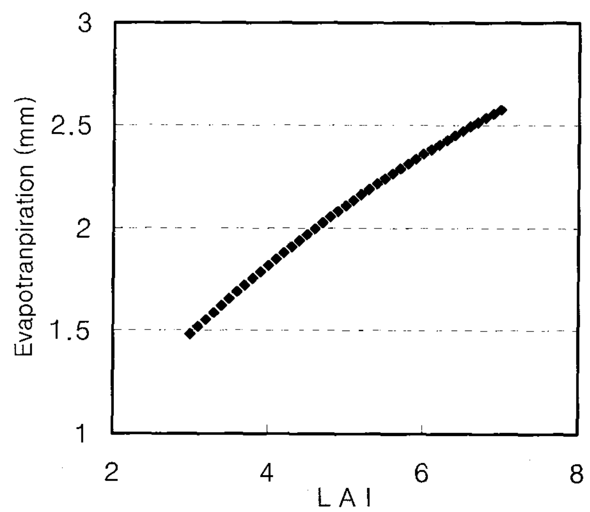


Figure 2. P-M model estimated evapotranspiration as a function of LAI.

In this simple model, LAI is usually obtained by the empirically derived equation that uses remote sensing NDVI as an independent variable. Three NDVI maps were generated obtained from ETM+ band 3 and band 4 data and they are based on 1) raw DN value, 2) at-sensor radiance value, and 3) atmospherically corrected reflectance value over the study area. Two LAI equations for deciduous and coniferous forests were used with the P-M model. In deciduous forest, LAI is estimated by the following equation developed by Pierce et al. (1990).

$$LAI = (NDVI / 0.26)^2$$

As can be seen in Figure 3, the estimated LAI values over a deciduous forest greatly vary by the type of NDVI map used. The LAI value is about 3 when the NDVI map derived from the raw DN value, while the LAI value become almost 10 when we used the NDVI map derived from atmospherically corrected reflectance value. The physical condition of leaf mass and canopy coverage between the LAI values of 3 and 10 is greatly different, Although the true LAI value is not known over the test plot, the range of LAI value of 3 and 10 seems to have large error term. Therefore, the evapotranspiration estimation from the P-M model should also be greatly influenced by the LAI value used.

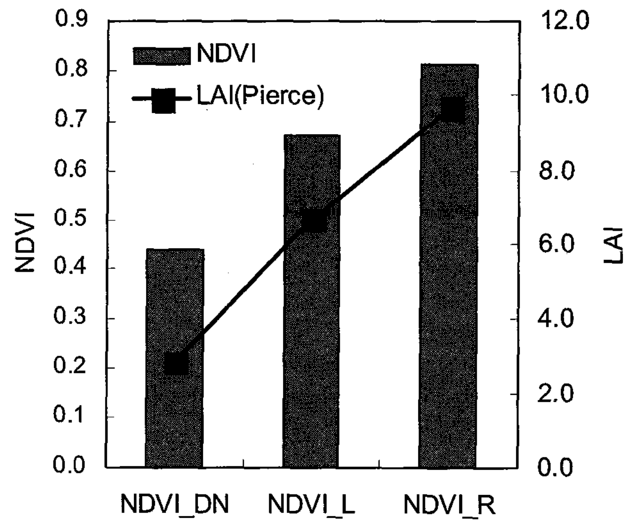


Figure 3. Variation of NDVI and LAI value by the type of remote sensing signal used (raw DN, at-sensor radiance, and atmospherically corrected reflectance).

## CONCLUSIONS

Although NDVI has been very frequently used to estimate several biophysical parameters that are required for ecological process models, the calculation of NDVI can be greatly varied by the type of remote sensing signal used. Therefore, the NDVI-based biophysical parameters, such as LAI and fPAR, could be great impact to the quality of the ecological model output. Remote sensing signal can be raw digital number (DN) value, at-sensor radiance, atmospherically corrected reflectance, and topographically corrected reflectance. In this short experiment to compare the influence of NDVI values linked with watershed-scale ecosystem models to estimate evapotranspiration, three types of NDVI maps derived from Landsat ETM+ data showed great variation in estimating LAI. Even though the forest canopy condition should be the same, the estimated LAI value varied from 3 to 10. NDVI value is an ordinal scale of measurements and therefore, it should be cautious to link them to any biophysical parameters. When we use NDVI-based empirical equation to estimate any biophysical parameters, we should carefully examine how the equation had been derived and what type of remote sensing signal actually used to calculate NDVI.

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