Studies on the advanced remote sensing techniques for monitoring CO_2 absorption in the terrestrial ecosystems

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Development of Remote Sensing Techniques for Evaluating Forest Ecosystem
- Aboveground Biomass Assessment Method by Laser Measurements –

1. Introduction

Remote sensing techniques are expected to play an important role in establishing the carbon sink assessment system for the Kyoto Protocol and the study of the carbon cycle on both the regional and global scale. With view to evaluating the technique for monitoring photosynthetic activity of larch trees by passive remote sensing and the aboveground biomass measurement techniques by laser remote sensing are being developed and verified at the Tomakomai Flux Research Site (Tomakomai FRS).

2. Research Objective

(1) Evaluation of forest ecosystems using remote sensing -Photochemical Reflectance Index-

The spectral reflectance obtained by remote sensing provides valuable information for evaluating CO_2 uptake by vegetation through the leaf amount, vegetation density, and physiological activities such as photosynthesis. Many spectral reflectance indices calculated by using several wavelengths have been proposed. For example, the normalized difference vegetation index (NDVI), which is generally calculated by the reflectance at the wavelengths of the absorption band of chlorophyll *a* (near 680 nm) and near infrared (760 to 1000 nm), is particularly useful for estimating leaf area index, photosynthetically-active radiation absorbed by plants, and/or foliar chlorophyll concentration[1-3]. However, although NDVI can be used for plant activities on the scale of annual or seasonal variations, it cannot detect the short-term change of CO_2 uptake of plants linked to down regulation of daily photosynthesis.

Recently, the photochemical reflectance index (PRI), which reflects the xanthophyll cycle activity and photosynthetic light use efficiency (LUE) in plant leaves, has been proposed for evaluating the short-term change in daily photosynthesis[4)]. This index is calculated by using the leaf reflectance at the wavelengths of 531 nm and 570 nm. In this study, the seasonal variation in relationship between daily PRI and photosynthetic activity of larch trees was investigated to establish a remote sensing monitoring technique for estimating CO_2 uptake in northern forest ecosystems.

The PRI and LUE of Japanese larch (*Larix kaempferi*), which is widely planted in forests in northern Japan, were periodically measured at a NIES experimental field in Tsukuba from July to November 2002. The canopy spectral reflectance, foliar net photosynthetic rate, and photosynthetic photon flux density (PPFD) were measured at a 4-year-old larch plantation on July 26, September 25, Octobe29, and November 19, which were clear days. LUE was calculated as the net photosynthetic rate divided by incident PPFD. PRI was calculated using the canopy reflectance at 531nm (R_{531}) and 570 nm (R_{570}) by the following equation,

$$\mathrm{PRI} = (R_{531}-R_{570})/(R_{531}+R_{570}).$$

(2) Assessment of aboveground biomass

The airborne laser-profiler is a remote sensing technology that promises to increase the accuracy of wide-area biomass measurements. It can measure to an accuracy of about 15 cm in the vertical direction and 3cm in the horizontal direction.

Although the three-dimensional shape of the crown surface could be measured by the laser-profiler, the three-dimensional structure of a forest, e.g., the spatial distribution of the leaves within a crown, and the distribution of the leaves of medium-height trees and vegetation on the forest floor, which is covered by the crown, could not be detected. Therefore, the new techniques to measure the three-dimensional distribution of leaf area within the forest and aboveground biomass assessment by laser measurements were developed

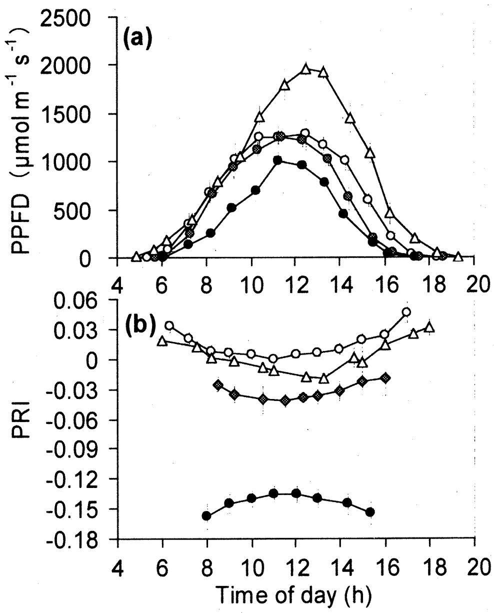

Fig. 1. Diurnal variations of (a) photosynthetic photon flux density (PPFD) above the larch canopy and (b) photochemical reflectance index (PRI). Each value is the mean (± S.D.) of six determinations. Observation date: 26 Jul. (△), 25 Sep. (○), 29 Oct. (●), 19 Nov. (●).

3. Results

(1) Evaluation of forest ecosystems using remote sensing -PRI-

The diurnal variation of PPFD and PRI for larch canopy is shown in Fig. 1. PRI decreased in the daytime in July, September, and October as PPFD increased. In November, when the needle leaves started to turn yellow, PRI gradually increased in the daytime as PPF increased. The daily mean PRI decreased seasonally from summer to autumn. As shown in Fig. 2, daily changing PRI significantly (p <0.01) correlated with LUE in each month, but the slope and the intercept of regression line differed among the observation periods. The X-axis intercept in the regression line tended to decrease from October prior to needle leaves turning yellow. Meanwhile, the slope of regression lines sharply changed in November, and it reversed from plus to minus.

These results suggest that the diurnal variation of LUE, which is an important index for estimating the net photosynthetic rate of Japanese larch, can be estimated based on PRI obtained by remote sensing. In addition, as the LUE-PRI correlation has been shown to vary depending on the season, it is expected that annual photosynthetic activity will be evaluated by the PRI model formulated in consideration of the seasonal variation.

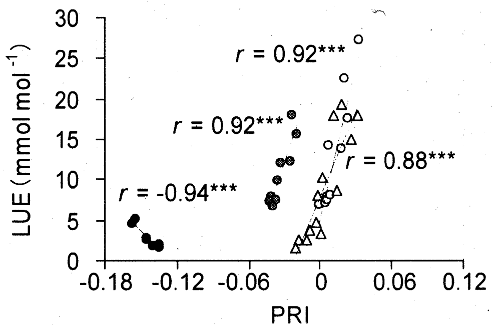

Fig. 2. Correlation between PRI and photosynthetic light use efficiency (LUE). Each plot is the mean of six trees. *** p < 0.001 (Pearson's correlation test).

(2) Assessment of aboveground biomass

Ground-based measurements were conducted once per month from April to December 2003 in the Tomakomai FRS for a Japanese larch forest. In order to measure the three-dimensional distribution of leaf area, the forest space over a measurement area of 50 m × 5m was divided into volumes of 10 m × 10 horizontally by 1 m vertically, and for each volume the plant area density (PAD: plant area per unit volume) was measured. Fig. 3 shows the three-dimensional distribution of PAD in August. As shown, the laser-profiler measurements successfully reproduced the actual PAD distribution which revealed horizontal inhomogeneity, i.e., leaves and branches were concentrated at the canopy height of about 12 m, with sporadic variations in leaf densities. The distribution of medium-height trees of 4 m or lower and of forest floor vegetation could also be reproduced.

The method of forest stand measurement using ground-based 3D imaging sensor was examined. The tree number, DBH and coordinate of trees were measured by the method of cylinder reconstruction, and the accuracy and precision was verified. The precision of coordinate was less than 8cm. In a short distance from the scanner, the precision of DBH was less than 1cm, and the accuracy was less than 4.3cm. The measurement result of coordinate and DBH had enough accuracy and precision for forest stand measurement in a small area. So, this method is effective as a truth of remote sensing to investigate stands in small area and many sites.

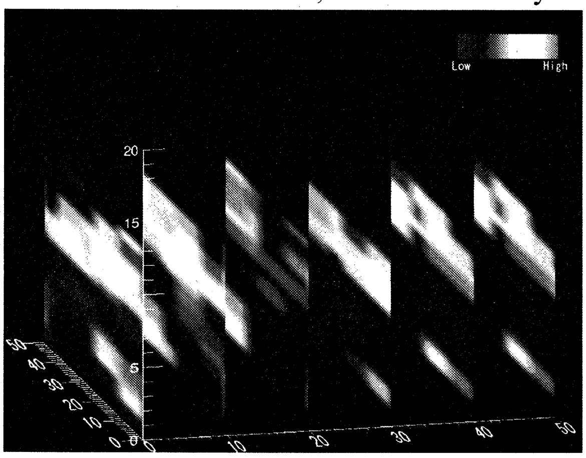

Fig. 3 PAD cross sections of the Japanese larch forest measured using a ground-based laser-profile

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