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Retrieving leaf area index for coniferous forest in Xingguo County, China with Landsat ETM+ images

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Abstract

Spatial distributions of the leaf area index (LAI) needed for carbon cycle modeling in Xingguo County, China were estimated based on correlations between the field-measurements and vegetation indices (VIs). After making geometric and atmospheric corrections to two Landsat ETM+ images, one in January 2000 and the other in May 2003, three VIs (SR, NDVI, and RSR) were derived, and their separate correlations with ground LAI measurements were established. The correlation with RSR was the highest among the three VIs. The retrieved LAI values for January 2000 were lower than those for May 2003 because of a small seasonal variation in the coniferous forests (predominantly masson pine) and the decrease in the understorey vegetation during winter.

Keywords: Landsat ETM+; Coniferous forest; Leaf area index; Vegetation index

1. Introduction

Leaf area index (LAI), defined as one-half the total green leaf area (all-sided) per unit ground surface area (Chen and Black, 1992), is an important structural variable for quantifying the energy and mass exchange characteristics of terrestrial ecosystems. It is probably the most useful parameter to be extracted from remote sensing data for crop yield prediction and crop stress assessment as well as estimation of the exchanges of carbon dioxide, water, and nutrients in forests. Vegetation indices (VIs), in which spectral bands sensitive to leaf pigments and the canopy density are combined through simple mathematical forms (usually ratios of individual bands or differences between bands) are an effective way to retrieve LAI using optical remote sensing data (Qi et al., 1993; Pu and Gong, 2000). The purpose of this paper is to describe LAI algorithms developed using several vegetation indices and ground measurements in Xingguo County, Jiangxi Province, China. We also produced LAI maps for this area which can be used as input to carbon cycle models and for validation of other LAI maps.

2. Study sites

The study sites are located in coniferous forest stands in Xingguo County (E115°01′–115°52′, N26°03′–26°44′) located in the south of Jiangxi Province under semitropical monsoon climate. The major coniferous tree species in the area are masson pine and Chinese fir.

The ground-based optical LAI measurements were obtained in July 2003 using the instrument tracing radiation and architecture of canopies (TRAC) (Chen and Cihlar, 1996). The sites were chosen to represent the forest and landform characteristics in the area. At each site, 100–120 m long transects were marked and the measurements were made using protocols of Chen et al. (2002).

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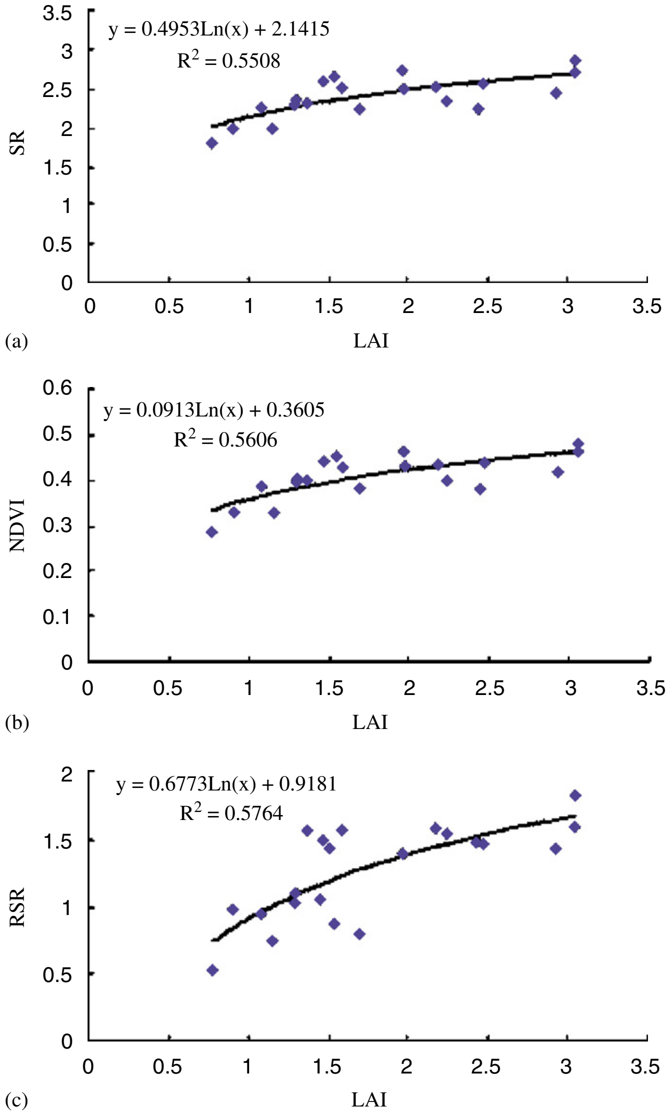

Fig. 1. Correlation between LAI and VIs (SR (a), NDVI (b), or RSR (c)) in January.

3. Landsat ETM+ image analysis

Two Landsat ETM+ scenes were used in the study dated 27 January 2000 and 27 May 2003, respectively. The scenes were co-registered using 15 ground control points distributed across the scene. Atmospheric corrections were performed using the 6S model (Vermote et al., 1997) representing a continental air mass, mid-latitude summer, uniform target, and 30 km atmospheric visibility.

Three vegetation indices—simple ratio (SR), normalized difference vegetation index (NDVI), reduced simple ratio (RSR)—were computed from the geometrically and atmospherically corrected images, as follows (see also Chen, 1996):

$$\mathrm{SR} = \frac{\rho_{\mathrm{n}}}{\rho_{\mathrm{r}}}, \tag{1}$$

$$\mathrm{NDVI} = \frac{\rho_{\mathrm{n}} - \rho_{\mathrm{r}}}{\rho_{\mathrm{n}} + \rho_{\mathrm{r}}}, \tag{2}$$

$$\mathrm{RSR} = \frac{\rho_{\mathrm{n}}}{\rho_{\mathrm{r}}}\left(\frac{(\rho_{\mathrm{s}} - \rho_{\mathrm{s\ min}})}{(\rho_{\mathrm{s\ max}} - \rho_{\mathrm{s\ min}})}\right), \tag{3}$$

where ρ_{r}, ρ_{n}, and ρ_{s} are spectral reflectance values in red, near-infrared (NIR) and shortwave infrared (SWIR) bands, respectively; $\rho_{\mathrm{s\ min}}$ is the SWIR reflectance of a fully closed canopy; and ρ_{max} is the SWIR reflectance of an open canopy.

4. Results

The individual VI combinations are illustrated in Fig. 1 (for January 2000) and Figs. 2, 3 (May 2003). Table 1 shows the correlations between the three VIs and field-measured LAI values. It is evident that: (i) the correlation

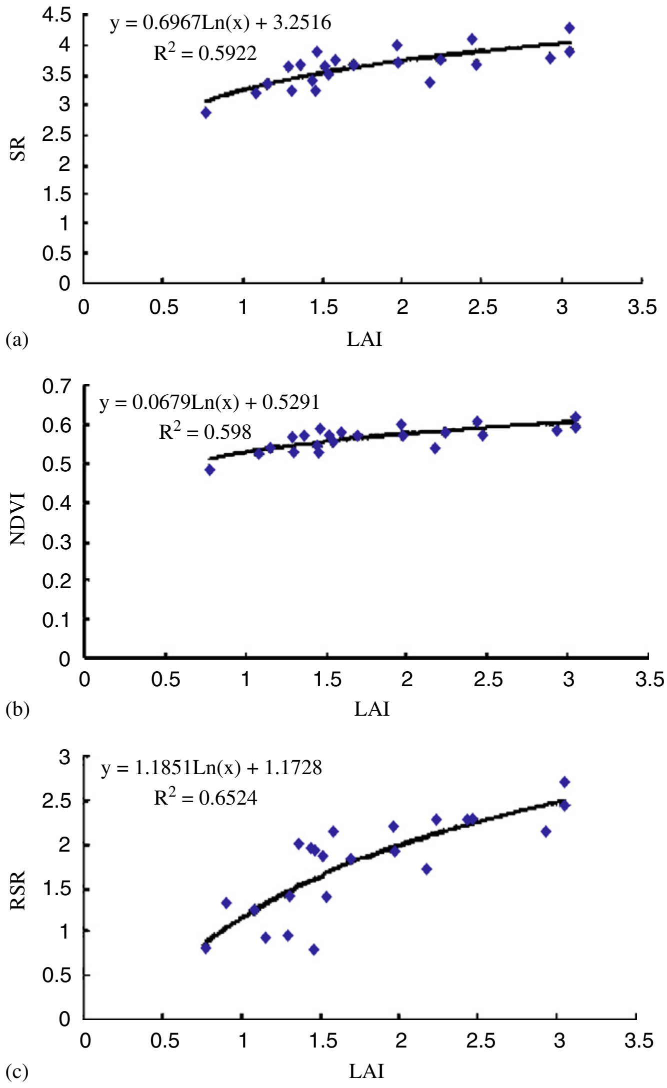

Fig. 2. Correlation between LAI and VIs (SR (a), NDVI (b), or RSR (c)) in May.

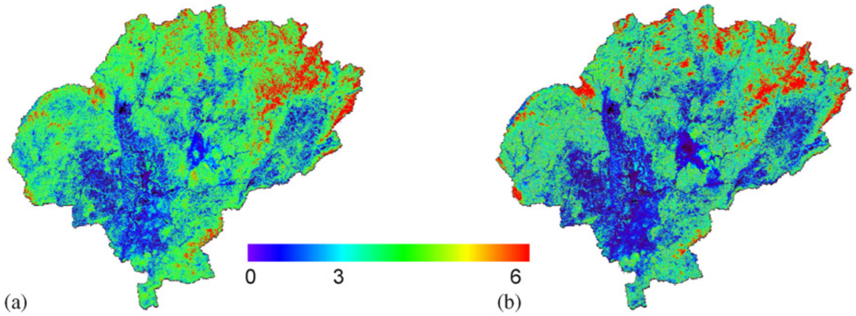

Fig. 3. LAI Mapping by RSR (a) and by NDVI (b) of Xingguo County in May.

Table 1
Correlation and t-test of LAI from landsat ETM with VIs

Time	Formula	R^2	$T_{0.05}$	T
January	SR = 0.495 ln(LAI) + 2.142	0.551		5.07
	NDVI = 0.091 ln(LAI) + 0.361	0.561		5.18
	RSR = 0.677 ln(LAI) + 0.918	0.576	2.08	5.35
	SR = 0.697 ln(LAI) + 3.252	0.592		5.52
May	NDVI = 0.068 ln(LAI) + 0.529	0.598		5.59
	RSR = 1.185 ln(LAI) + 1.173	0.652		6.28

Table 2
RMSE of retrieved LAI based on three VIs

RMSE	Raw image		Reflectance image	
	NDVI	SR	NDVI	RSR
January	0.606	0.550	0.573	0.424
May	0.663	0.510	0.493	0.371

between RSR and LAI was the highest, and (ii) the correlation coefficients were low for the January scene compared to the May scene. The differences between January and May correlations may be due to various factors. First, it is possible that a small LAI increase occurred between 2000 and 2003. Second, since the LAI was measured in summer, small seasonal variation might have occurred in this evergreen conifer species, we would expect higher correlations of the May image with ground data. Third, it is also possible that the VIs have a higher dynamic range in the summer because of the understorey growth, giving rise to the slightly better corrections in May than in January.

To estimate the accuracy of the retrieved LAI map using the three VIs, we calculated the root mean square error (RMSE) as

$$\mathrm{RMSE} = \sqrt{\sum_{i=1}^{N} (y_i - \hat{y}_i)^2 / N}, \tag{4}$$

where y_i is the field-measured LAI, $\hat{y}_i$ is the predicted LAI, and N is the number of samples.

The RMSE values of the retrieved LAI are shown in Table 2, separately for January and May. The lowest RMSE values were obtained for RSR, confirming that this index is the best choice for LAI mapping for this area. It appears that in the study area, RSR is most appropriate for coniferous forests with dense and homogenous canopies, in addition to its applicability in the Heihe River Watershed (Xu et al., 2002) and in boreal forest in Canada (Chen et al., 2002; Hu and Miller, 2004).

5. Conclusion

In this study, the LAI was estimated using SR NDVI and RSR for the coniferous forest in Xingguo County, Jiangxi province of China. The correlation between RSR and LAI was higher than those between LAI and two other VIs (Figs. 1 and 2). In general, retrieved LAI values were lower in January than in May, consistent with fact that the conifer forests dropped needles in the winter. However, the decrease in the understorey foliage could also have contributed to the overall LAI reduction in January.

This study also confirmed that vegetation indices based on the combinations of two or three spectral bands provide an effective way of retriev LAI, and it is likely that they could also be applied successfully to retrieve other biophysical parameters. It should be noted that topographic effects on reflectance and VIs were not considered, and these effects might have incurred considerable errors in areas of steep slopes. With the advances in remote sensing technology, more sophisticated methods are being developed to remove noise in optical remote sensing data caused by atmospheric attenuation, variations in sun and view angles, mixed pixels and other factors. The accuracy of LAI retrieval from optical satellite images will further benefit from these improvements.

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