Examination of Relations Between NDVI and Vegetation Properties Using Simulated MISR Data

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Abstract-Relations between NDVI and FAI (foliage area index) and fAPAR (fraction of absorbed photosynthetically active radiation) are examined using simulated MISR data. More linear, statistically significant relationships between FAI (fAPAR) and shaded (sunlit) foliage fraction are identified. The dominant role of the sunlit scene component in determining scene NDVI is physically interpreted, and a more effective (accurate) way to use NDVI (to estimate FAI and fAPAR) is also suggested.

INTRODUCTION

The normalized difference vegetation index (NDVI) is an extensively used index to assess the state of vegetation in terms of characteristics such as LAI and fAPAR. Clearly, however, its performance is significantly affected by other factors including background brightness, sun and view geometries and vegetation structure [1,2]. Recent studies have found NDVI to be much more sensitive to changes in sunlit vegetation fraction than to LAI [3,4], implying an indirect but possibly better way to use NDVI for vegetation property estimation (e.g., using mixture decomposition method [4]). The goals of this paper are 1) to thoroughly examine the relations between NDVI and FAI and fAPAR using simulated MISR multiangular observations for computer-generated 3-D forest scenes, and 2) to explore how NDVI, FAI and fAPAR are related to areal fractions of spectrally distinct scene components like sunlit and shaded foliage or background. This simulation study seeks a more reliable estimation of FAI and fAPAR through sunlit and shaded scene fractions, and explores MISR's potential for vegetation property estimation.

SCENE GENERATION AND RADIOSITY CALCULATION

A series of 3-D broadleaf forest scenes (with FAI increasing from 0.2 to 7.5 and the mean height rising from 7m to 15m) were generated using a modified extended L-systems method (MELS) [5], with which one can randomly or non-randomly place many architecturally realistic trees on the background. The individual tree has its own height and crown geometry varying within the statistic limits of the whole scene.

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Fig.1 is a 90mx90m sample of the generated forest stands with FAI of 1.0 The same optical properties for foliage elements and background as in [1] are used.

With the inherent detailed information about physical and geometric properties of every scene element, we can directly calculate all the geometric quantities such as FAI, foliage angle distribution, ground cover percentage as well as projection areas of foliage elements in either one (sun or view) or both directions on any given plane [6]. We can thus produce the areal fraction of sunlit and shaded foliage elements or background.

Due to its capability to exactly handle the complex, discrete, 3-D assemblies of finite-sized scatterers and multiple scattering, the radiosity method is most suitable to describe the radiation regime for such simulated forest stands [7]. The radiosity model used is a radiosity-graphics combined model (RGM, [5]), which has a unique capability to fast compute projections (and scene component fractions) and view factors between facets, leading to substantially reduced computation time. For sun-view geometry, we use the scenario of MISR's BRF (directional reflectance factor) sampling capabilities for a hypothetical site at 50°N at the March equinox. The corresponding solar zenith angle is within 50° to 55°, and view zenith angles (VZAs) are 0°, ±26.1°, ±45.6°, ±60°, and ±70.5° ("-" stands for backscatter direction) in the relative view azimuth (RVA) within the 30°-120° transect relative to the solar principal plane.

RESULTS AND ANALYSIS

Relations between NDVI and FAI and fAPAR

Fig.2 shows the relationship between NDVI and FAI to be more nonlinear than that between NDVI and fAPAR, although the latter becomes nonlinear too for a very dense canopy. Both relationships are strongly influenced by background brightness and VZA. NDVI is insensitive to changes in FAI larger than 3.0 at high VZA. But this saturation point can be as high as 6.0 at nadir. From these results, it is no doubt that without considering the influences of background, sun and view angles, and vegetation heterogeneity, one cannot expect a reliable estimation of FAI or fAPAR from NDVI.

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Correlation of NDVI with Scene Component Fractions

Fig.3 plots different scene component fractions against scene NDVI for all of MISR's nine angles at a solar zenith of 52.5°. Basically, NDVI increases (non-) linearly as (shaded) sunlit foliage fractions increase. But the correlation with sunlit foliage fraction deteriorates when NDVI exceeds 0.7. However, there is a very good linear, negative relationship between NDVI and sunlit background fraction, regardless of view angle and background brightness. This implies that NDVI can be applied to accurately estimate sunlit background fraction. Mixture decomposition methods can be used to infer other scene component fractions which may be more closely related to FAI and fAPAR than NDVI does.

Roles of Sunlit and Shaded Scene Components in Determining NDVI

In order to quantify the role of sunlit and shaded scene components in determining scene NDVI, we divide scene BRF into two components: one from the sunlit parts of all the scene elements or facets (BRF_s) and the other from their shaded parts (BRF_u). Either component can be evaluated as the product between the bulk reflectance R_s (or R_u) and the areal fraction F_s (or F_u):

$$\mathrm{BRF} = \mathrm{BRF}_s + \mathrm{BRF}_u = R_s \cdot F_s + R_u \cdot F_u$$

where R_s, R_u and F_s, F_u can be calculated as

$$R_s = \sum_{\text{all sunlits}} R_{s,i} \cdot F_{s,i} \big/ F_s, \qquad F_s = \sum_{\text{all sunlits}} F_{s,i},$$

$$R_u = \sum_{\text{all shadows}} R_{u,i} \cdot F_{u,i} \big/ F_u, \qquad F_u = \sum_{\text{all shadows}} F_{u,i}$$

All of these quantities are wavelength, sun and view angle dependent. The reflectance value $R_{s,i}$ ($R_{u,i}$) and areal fraction $F_{s,i}$ ($F_{u,i}$) for the sunlit (shaded) part of facet i are obtained through RGM [5]. Therefore, scene NDVI can be expressed by its sunlit and shaded components:

$$\mathrm{NDVI} = (\mathrm{NDVI}_s + C \cdot \mathrm{NDVI}_u)/(1 + C)$$

where

$$C = \frac{\mathrm{BRF}_u(\mathrm{NIR}) + \mathrm{BRF}_u(\mathrm{red})}{\mathrm{BRF}_s(\mathrm{NIR}) + \mathrm{BRF}_s(\mathrm{red})} = \frac{F_u}{F_s} \cdot \frac{R_u(\mathrm{NIR}) + R_u(\mathrm{red})}{R_s(\mathrm{NIR}) + R_s(\mathrm{red})}$$

Thus, C is the ratio between the sum of radiation in red and in NIR from shaded elements to that from sunlit elements that the instrument sensor receives at given sun and view directions. This coefficient determines the relative importance between the sunlit scene component and shaded scene component in determining the scene NDVI. Fig.4 shows the scene NDVI and its two components $NDVI_s$ (sunlit) and $NDVI_u$ (shadow) and C for different FAIs. Scene NDVI follows its sunlit component very closely in shape, implying the dominant influence of sunlit scene component. The ratio C is extremely anisotropic -- far below 0.4 in backscatter directions and rising up to 1.0 at high zenith angles in forward scatter directions -- because of a much higher sunlit fraction in the backscatter direction than in the forward scatter direction, plus a much larger total exiting radiation (red+NIR) from sunlit elements than from shaded elements. Finally, since the sunlit scene component includes both sunlit foliage and sunlit background, the above result reveals that sunlit background is also very important, particularly at low FAIs.

The above result can physically explain the non-linear relationship between NDVI and FAI and the fairly linear one between NDVI and fAPAR. First, NDVI is dominated by its sunlit component ($NDVI_s$) -- both sunlit foliage and background. Since the way sunlit foliage and sunlit background change with FAI is almost opposite, the net effect is reduced sensitivity of NDVI to FAI. However, we do find a nearly linear relation between FAI and shaded foliage fraction at small VZAs and in the forward scatter direction (Fig.5). Because of the minor role of shaded foliage fraction and its weak correlation with scene NDVI, it becomes obvious why NDVI is insensitive to FAI, especially at high FAIs or high VZAs, as shown in Fig.2.

In the backscatter direction for wide range of VZAs, fAPAR holds a linear relation with sunlit foliage fraction, although this relationship is still subject to VZA and slight background influence (Fig.6). This can be attributed to the fact that sunlit leaves absorb much more PAR than shaded ones. The linear relation between fAPAR and sunlit foliage fraction implies the linear relation between NDVI and fAPAR because of the linear dependence of NDVI on sunlit foliage fraction. But the influence of the background on the relationship between sunlit foliage fraction and fAPAR is much less than that between NDVI and fAPAR, implying the potential to estimate fAPAR via the sunlit foliage fraction.

CONCLUSIONS

From this simulation study, we find that (1) due to strong influences by background brightness and view angle, estimation of FAI and fAPAR from NDVI is usually not reliable without accounting for these influences; (2) sunlit scene components play a dominant role in determining scene NDVI; (3) scene NDVI has stable, negative and linear relationship with sunlit background fraction; and (4) FAI (fAPAR) is almost linearly increased as shaded (sunlit) foliage fraction increases. Such relationships are less affected by soil brightness than those with NDVI. This study proves that inferring FAI (fAPAR) from shaded (sunlit) foliage fraction should be more reliable than directly from NDVI.

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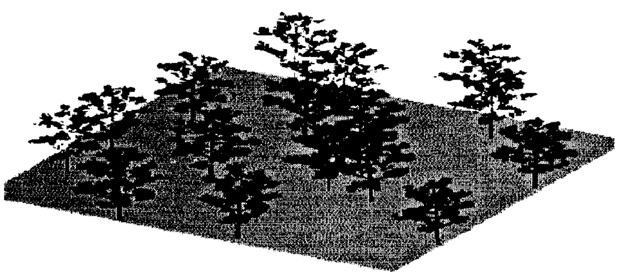

Fig.1 A 90mx90m sample of MELS generated infinite scene.

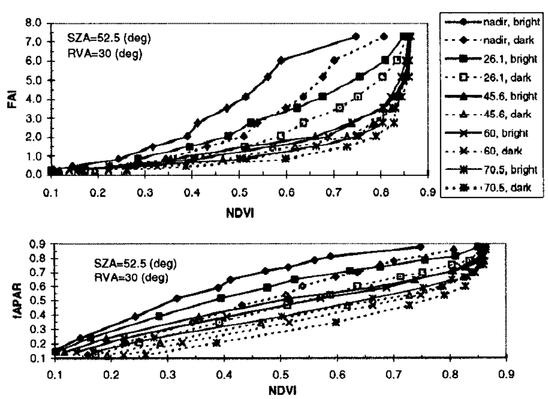

Fig.2 FAI and fAPAR vs. NDVI for different VZAs.

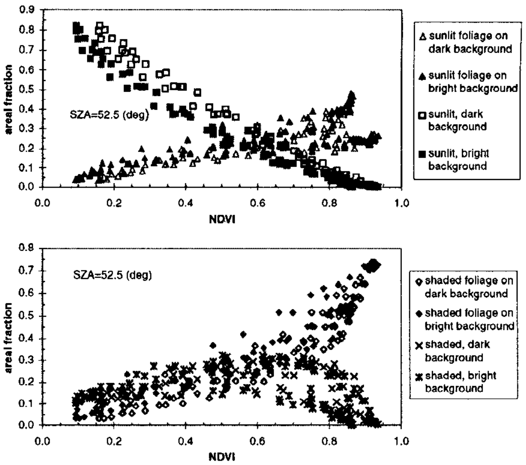

Fig.3 NDVI vs. different sunlit and shaded scene fractions.

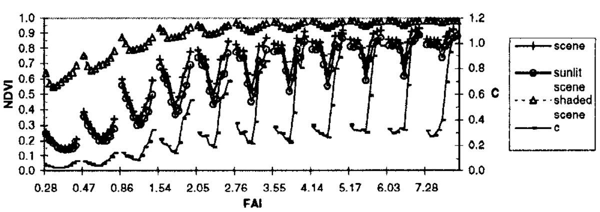

Fig.4 NDVI components and C vs. FAI.

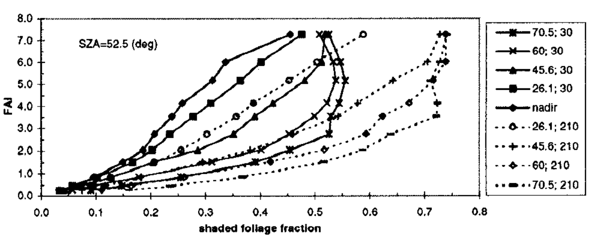

Fig.5 FAI vs. shaded foliage fraction.

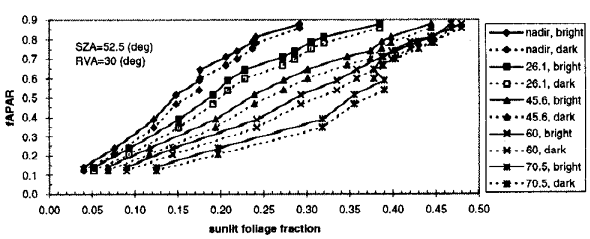

Fig.6 fAPAR vs. sunlit foliage fraction.