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Retrieving forest background reflectance in a boreal region from Multi-angle Imaging SpectroRadiometer (MISR) data

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Abstract

Studies of the bidirectional behavior of forest canopy have shown that the total reflectance of a forest canopy is the combination of illuminated and shaded components of the tree crown as well as the background. In this study, we estimate the background portion from the bidirectional reflection observed by Multi-angle Imaging SpectroRadiometer (MISR) instrument which scans the earth in nine different view angles in an oblique plane relative to the sun. The nadir and 60° forward directions of the MISR images were used to derive the reflectivity of the forest background based on the probabilities of viewing the illuminated tree crown and background on those view angles. The probabilities were estimated using the Four-Scale model. In the study, background reflectivity mosaic images in red and NIR wavelengths covering the BOREAS region during winter and spring seasons were obtained. The mosaic images of winter show high background reflectivity in both wavelengths, and in most of the areas the reflectivity was more than 0.3. In mosaic images of spring the spatial variations in the background reflectivity were considerable. The seasonal changes in the background reflectivity were also studied with multi temporal MISR data, and a similarity in the temporal pattern was found between the retrieved forest background reflectivity and grass land reflectance. These spatial and temporal patterns of the background component retrieved from MISR would be critically important in retrieving the biophysical parameters of vegetation and in ecosystem modeling.

Keywords: Multi-angle remote sensing; Forest background reflectance; MISR; BOREAS

1. Introduction

Understanding the global climate changes and developing strategies for sustainable use of our environmental resources are major scientific and political challenges (Hese et al., 2005). Vegetation response to the level of CO_2 and other greenhouse gases in the atmosphere is significant in climate change modeling (Field et al., 2003; Peddle et al., 1999; Potter et al., 2003). Carbon fluxes between atmosphere and biosphere have been estimated using biosphere models (Chen et al., 2003a; Hese et al., 2005) which require biophysical information of vegetation such as biomass, LAI and NPP (Chen et al., 2003b). Remote sensing has been demonstrated to have wide applicability in analyzing biophysical parameters of vegetation (Treitz & Howarth, 1999). However, traditional methods such as NDVI for deriving these variables from remotely sensed data have been inconsistent and unsatisfactory due to factors such as the confounding influence of background reflectance and canopy structure on the overall pixel reflectance (Peddle et al., 1999).

Multi-angle remote sensing delivers additional information about vegetation in terms of directional characteristics related to its vertical structure (Diner et al., 1999; Hese et al., 2005; Leblanc et al., 1999; Verstraete et al., 1996), and there have been a number of studies carried out to extract information on optical properties and structure of vegetation from the multi-angle data (Chen et al., 2003b; Cierniewski et al., 2004; Deering et al., 1999; Gao et al., 2003; Rautiainen et al., 2004; Sandmeier & Deering, 1999; White et al., 2001; Zhang et al., 2002b,a). Sandmeier and Deering (1999) and Zhang et al. (2002b,a) introduced angular indices of forest canopy structure to characterize biome signatures and used these indices to classify land cover types. Hu et al. (2003), Knyazikhin et al. (1998) and Chen et al. (2003b) proposed methods for deriving the leaf area

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index (LAI) and the fraction of photosynthetically active radiation (FPAR) absorbed by the canopy using multi-angle data. Leblanc et al. (2005) and Chen et al. (2005) developed an angular index based on hotspot and darkspot reflectances for mapping the foliage clumping index from multi-angle measurements. Gobron et al. (2002) demonstrated the potential to map surface cover heterogeneity from multi-angle data at the subpixel scale resolution. Nolin (2004) retrieved the forest cover density over snow and Chopping et al. (2003) studied the canopy attributes of desert grassland using multi-angle imagery. All these studies demonstrate the large information content of multi-angle remote sensing. However, the ability of multi-angle remote sensing for retrieving vegetation background optical properties has not been systematically investigated.

Based on the field measurements (Peltoniemi et al., 2005; Pradhan, 2001) the reflectance values of the backgrounds such as soil, grass, moss, shrub, litter, lichen and their mixture vary as per their physical and chemical properties. Gemmell (2000) illustrated that the variations in the background reflectance would prevent the retrieval of forest structural characteristics at low to intermediate covers unless these variations can be taken into account. Field measurements of the background reflectance involve significant technical and logistical challenges, including complex spatial distributions of forest understory features and variable illumination conditions, as well as the demands of field measurements in relatively remote field sites (Gemmell, 2000). In this study, we examine the feasibility of using multi-angle remote sensing to determine the optical properties of the vegetation background (soil/moss/grass/shrub in forests). The Four-Scale model (Chen & Leblanc, 1997; Leblanc et al., 1999), which uses geometric-optical and radiative transfer theories (Chen & Leblanc, 2001) to calculate the angular reflectance of vegetation, was used to examine the feasibility of determining the background information given two viewing geometries with an inversion approach.

2. Methodology

2.1. Retrieval of background reflectivity

The total spectral reflectance (R) of a pixel results from the reflection of the scene components. In the case of a forest canopy, the reflectance is calculated by associating reflectivities of the sunlit and shaded tree crowns (R_T and R_{ZT}) and background (R_G and R_{ZG}) to the corresponding four probabilities of these scene components viewed by the sensor (Chen & Leblanc, 1997; Li & Strahler, 1985):

$$R = P_T \times R_T + P_G \times R_G + Z_T \times R_{ZT} + Z_G \times R_{ZG} \tag{1}$$

where P_T and P_G are the probabilities of viewing illuminated tree crown and background, respectively, and Z_T and Z_G are the probabilities of seeing shaded crown and background, respectively. Here the term background indicates all the materials below the forest canopy including rock, soil, leaf litter, lichen, moss, grass, shrub and snow or their mixture which are visible from above (Gemmell, 2000).

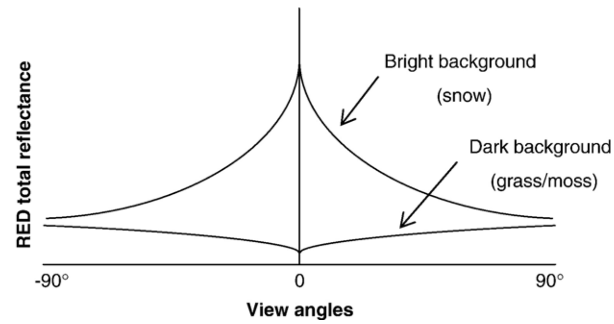

Fig. 1. The variation of the total reflectance of a forest canopy in a Red band with view zenith angle on the perpendicular plane for two contrasting background types.

The contribution of the background to the total reflectance changes with view angle as the probability of viewing the background decreases with increasing view zenith angle. Fig. 1 shows the influence of the background on the total bidirectional reflectance of a coniferous forest canopy at different view angles on a perpendicular plane (defined by the sensor and the ground target in a vertical plane) relative to the sun's azimuth. In this conceptual sketch, it is assumed that the sun is at a fixed angle and the total reflectance from a vegetated surface consisting of vegetation and the background varies with view angle. This variation occurs due to the contributions of the vegetation and the background varies with view angle. At nadir, the background contribution is the largest, while at the largest view zenith angle, the contribution of the vegetation is the largest. If the background is snow with a higher reflectivity than that of the overlying forest canopy in a red band, as an example, its contribution to the total reflectance would be high in the nadir direction, and the contribution would reduce rapidly with view zenith angle as the probability of viewing the background decreases. Assuming that the reflected radiance from the canopy changes little on the perpendicular plane, the total reflectance would then decrease with increasing view zenith angle. On the other hand, grass or moss with a reflectivity that is similar to or lower than the forest canopy would have the opposite effect on the total reflectance as the view zenith angle increases. However, in reality the reflected radiance from the canopy alone would change significantly across the zenith angle range even on the perpendicular plane on which the canopy shadow fraction viewed by the sensor changes significantly, and this issue can be effectively tackled by a geometrical optical model (Section 2.2).

Though the satellite orbit falls on an oblique plane, the difference in bidirectional reflectance due to the influence of the background could be observed by cameras viewing the surface on a plane that is not too close to the principal plane. By using the observed reflectance at nadir and at an angle in the forward direction (dark spot side) one can derive the background reflectivity (R_G). Assuming the background reflection is Lambertian, i.e., the reflectivity does not change with angle of observation, the reflectance at nadir (n) and another zenith angle (a) can be expressed using Eqs. (2) and (3).

$$R_n = P_{Tn} \times R_T + P_{Gn} \times R_G + Z_{Tn} \times R_{ZT} + Z_{Gn} \times R_{ZG} \tag{2}$$

$$R_a = P_{Ta} \times R_T + P_{Ga} \times R_G + Z_{Ta} \times R_{ZT} + Z_{Ga} \times R_{ZG} \tag{3}$$