Topographic Effect on the Canopy Reflectance

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Abstract— Many research works indicate that the topographic factors have strong influence on forest canopy reflectance. However, the quantative effects of canopy reflectance by topographic is difficult to be evaluated. For this purpose, the topographic effects on sloping forest reflectance are quantitatively evaluated based on GOST model and the observed remotely-sensed images. The major findings are summarized as follows: First, the topographic factors (slope and aspect) have great impacts on sloping canopy reflectance. A case study shows that the modeled topographic index for reflectance ([bidirectional reflectance distribution of a sloping forest-bidirectional reflectance distribution of a flat forest]/bidirectional reflectance distribution of a flat forest), which is the relative error in modeled canopy reflectance by ignoring the topographic effects, can reach up to 58%, while the maximum observed topographic index for reflectance varies from 0.012 to 0.038. Second, model simulations show that topography has different effects on the sloping canopy reflectance in different view directions. These effects should be considered in analyzing multi-angle images. Third, topographic factors have different impacts on sloping canopy reflectance of different canopy structures. Canopy structure should also be considered in topographic correction on reflectance images because topographic factors alone is insufficient for correcting all variations of reflectance with slope and view angle.

1. INTRODUCTION

Topography modifies canopy structures and causes terrain effects on satellite observations [1]. As yet, there are rarely specific studies to quantify the topographic effects on the forest reflectance. Richter, et al. [2] indicate that in mountainous areas there is a strong influence of topography on the signals recorded by space-borne optical sensors, i.e., for the same surface cover slopes oriented away from or towards the sun will appear darker or brighter, respectively, if compared to a horizontal geometry. This behavior causes problems for a subsequent scene classification and thematic evaluation. Teillet [3] noted that not enough work has been done in this area to establish guidelines on the relative importance of topographic effects in remotely-sensed imagery.

The accurate hybrid canopy reflectance model named GOST for modeling canopy reflectance on slopes is developed and validated by Fan et al. [4, 5]. GOST has common advantages in both of GO models and RT models and the ability to simulate the reflectance of shaded forest components as well as the total BRF (Bidirectional reflectance factor) on slopes. The validation shows that GOST has the ability to simulate the canopy structure (gap fraction and the area ratios of the 4 scene components) and canopy reflectance on sloping terrains. It also indicates that GOST has the ability to quantatively analyze the topographic effects on sloping canopy reflectance. The topographic effects on canopy reflectance will be evaluated using the simulated results by GOST and observed results by Landsat TM5 images in this paper.

2. STUDY SITES AND METHODS

2.1. The Study Sites and Its Corresponding TM Images

A rectangular forest region (94,581 m × 123,375 m) in the northeast of China (near to 53N, 124E) is selected as the study site 1 (SS1). The vegetation cover is predominantly conifer forest in this region. The corresponding Landsat TM5 image at a solar azimuth angle of 154° and zenith angle of 46° is acquired on August 30, 2009 and a total of 3,153 × 4,113 nadir view pixels are selected for this study. The study site 2 (SS2) is also a conifer forest region (25,320 m × 61,830 m) in the southwest of China (near to 30N, 107E). The corresponding Landsat TM5 image is acquired on September 2, 2009 at a solar azimuth angle of 129° and zenith angle of 32° . A total of 844 × 2,061 nadir view pixels are selected for the forest region. The DEM (digital elevation model) datasets for SS1 and SS2 are used to produce images of the slope and aspect.

2.2. A Typical Boreal Canopies for Model Simulation

The parameters of the old Jack Pine (OJP) canopies (Latitude N 53°54′58″, Longitude W −104°41′24″) on flat terrains are selected from Leblanc et al. [6]. Based on this parameter set, the 0°, 30° and 60° slopes are considered for evaluating the topographic effects on canopy reflectance. This forest has 1850 stems per hectare and an LAI of 2.2. The trees are 12 m–15 m in height. It exhibits large crowns with a mean radius 1.3 m. The needle-to-shoot ratio is $\gamma_E = 1.3$. In the red band, the reflectance of foliage is 0.07, the tranmittance of foliage is 0.05 and the reflectance of background is 0.09.

2.3. Experiment Description

The quantitative analysis of the topographical effects on the sloping canopy reflectance is based on model simulated results by GOST, and the observed Landsat TM reflectance data are used to support the simulated results of GOST model because no ground observations are available for the sloping canopy parameters corresponding to these selected pixels.

The aspects are set as 0° and the slopes are set as 30° and 60°, respectively for OJP. The sunlight azimuth angle is set as 0° . In order to evaluate the topographic effects on reflectance, the distribution of relative error in reflectance (called topographic index) is calculated as follows (Eq. (1)).

$$RE_R = \frac{R_{\theta g} - R_{\theta g=0}}{R_{\theta g=0}} \tag{1}$$

where $R_{\theta g}$ is the bidirectional reflectance distribution of a sloping forest, and $R_{\theta g=0}$ is the bidirectional reflectance distribution of a flat forest. The greater absolute value RE_R is, the stronger the topographic factors influence the reflectance.

Figure 1 is an illustration of the topographic index distribution. The slope of the canopy is 30° in this case. The solar azimuth angle is 0°. S, N, W and E are south, north, west and east directions. The legend shows the topographic index values. The black and blue boxes show the perpendicular and principle planes, respectively.

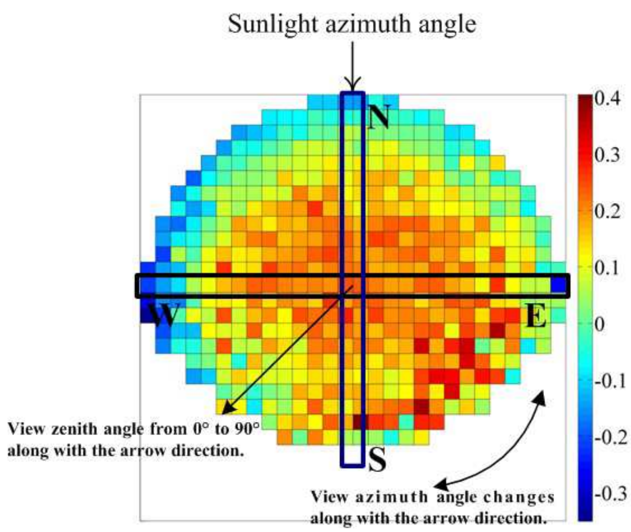


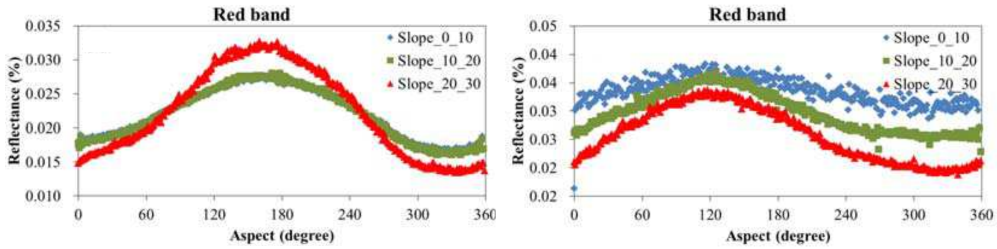
Figure 1: An illustration of the relative error distribution.

3. RESULTS AND DISCUSSIONS

Figure 2 show the variations of the red band reflectance of TM images with slope and aspect in SS1 and SS2, respectively. Fig. 3 is the topographic index distributions in reflectance of OJP forests in the red band simulated by GOST model.

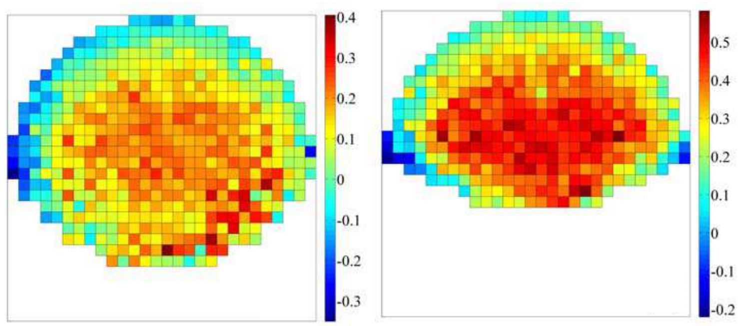
3.1. The Quantitative Effects of the Topography on the Sloping Canopy Reflectance

According to the simulation results, the topographic index (RE_R) varies from −35% to 40% at a slope of 30°, and from −22% to 58% at a slope of 60° (Fig. 3). It indicates that the topographic factors have significant influences on the reflectance of sloping canopies because the area ratios of



(a) (b)

Figure 2: The reflectance vary with slope and aspect in SS1 (a) and SS2 (b). The blue, green and red dots represent the slope between 0° to 10°, between 10° to 20° and between 20° to 30°, respectively.



(a) (b)

Figure 3: The topographic index distributions for OJP forest in the red band. In the red band, (a) and (b) are the forest slope equals to 30° and 60°, respectively.

the 4 scene components and the multiple scattering within the canopy are modified greatly by the topographic factors. The nadir-viewed reflectance acquired from Landsat TM5 is used to support the simulated results in these cases. Fig. 2 show that topographic factors have great effects on the observed canopy reflectance. With changes in the slope and aspect, the BRF varies from 0.012 to 0.033 in SS1 and from 0.017 to 0.038 in SS2. Although the observed reflectance is only acquired at nadir, such a large difference of reflectance at different slopes is consistent with simulated results. Both the model simulated results and observed values indicate that the topographic factors are important for the forward modeling of the canopy reflectance on slopes and should be considered in forest reflectance retrieval for non-flat surfaces.

3.2. The Topographic Effects on Multi-angle Remote Sensing of Canopy Reflectance

As for OJP on slopes in the red band, the topographic effect decreases with the view zenith angle increasing (Fig. 3). It indicates that the topographic index RE_R varies greatly in different view directions even though the canopy structure remains the same. It means that the topographic factors have different effects on the reflectance observed at different angles. Therefore, in order to establish the relevant relationship between the multi-angle reflectance and canopy parameters on sloping background, a sensor with suitable view angles should be selected according to the specific research topics or the view angle correction processes should be considered to avoid or reveal the topographic effects in different view directions.

3.3. The Topographic Effects on the Reflectance of Different Canopy Structures

The reflectance observed by Landsat TM5 (Fig. 2) also show that the reflectance of sloping canopies with different canopy structures may increase or decrease with the change of slope under the same aspect and in similar sunlight/view directions. For example, in the red band, the reflectance increases with increasing slope in SS1 when the sunlight is facing with the slope, but the reflectance decreases with increasing slope in SS2 under the same conditions. The model simulations and observations show that the canopy reflectance under different canopy structures vary greatly with slopes. The approaches for general topographic correction should consider the canopy structures in forest regions. If only the topographic factors such as slope and aspect are considered, the corrections may be erroneous. It also indicates GOST model is capable of simulating the reflectance under different canopy structures on slope.

4. CONCLUSIONS

According to the quantitative evaluation of the topographic effects on reflectance, the following conclusions are drawn. First, the topographic factors (slope and aspect) have great impacts on sloping canopy reflectance. The modeled topographic index RE_R, which is the relative error in simulated canopy reflectance by ignoring the topographic effects, can reach up to 58%, while the observed BRF varies from 0.012 to 0.038 in SS2. Therefore, the forest reflectance models considering the topographic factors are recommended for canopy reflectance simulations and canopy parameters retrieval over non-flat terrains. Second, model simulations show that topography has variable effects on the sloping canopy reflectance and vegetation indices in different view directions. These effects should be considered in analyzing multi-angle images. Third, topographic factors have great impacts on sloping canopy reflectance and vegetation indices of different canopies with different structures. In addition, the canopy structures should also be considered in topographic correction on reflectance images because topographic factors alone is insufficient for correcting all variations of reflectance with slope and view angle.

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