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COMPARISONS BETWEEN *IN SITU* ANISOTROPIC REFLECTANCE MEASUREMENTS AND SIMULATIONS FOR VEGETATION CANOPIES: VALIDATION AND SENSITIVITY ANALYSIS

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ABSTRACT

In situ directional reflectance observations were taken on trees of three species and were used to validate the Four-Scale Linear Model for AnIsotropic Reflectance (FLAIR). FLAIR-simulated spectra were satisfactory in general, especially for the shaded and shaded/sunlit mixed portions of the canopy but were species dependent. Good agreements with field observations were found when utilizing these simulations to derive band ratio indexes, Normalized Difference Vegetation Index (NDVI) and Photochemical Reflectance Index (PRI). Sensitivity analysis were performed to investigate the importance of three canopy biophysical parameters, and the leaf to shoot ratio showed the most impact on simulation results. The results in this study showed the potential to simulate directional reflectances with FLAIR on canopies with complicated structure.

Index Terms—NDVI, four-scale, FLAIR, Photochemical Reflectance Index (PRI)

1. INTRODUCTION

Modeling directional reflectance in conjunction with *in situ* measurements provides an opportunity to quantitatively examine vegetation responses expressed under a variety of viewing geometries and illumination conditions and to improve our understanding of carbon exchange between plants and the atmosphere [1, 2]. Recent studies have demonstrated that remotely acquired estimates of light use efficiency (LUE) can be obtained by utilizing directional reflectances of specific spectral indices to account for

physiological responses of foliage exposed to a range of illumination conditions [3-5]. In particular, the Photochemical Reflectance Index (PRI), $[(R531 - R570)/(R531 + R570)]$, has been demonstrated in many studies to express responses to environmental stresses, especially high light stress, via the photoprotective xanthophyll cycle [3-6]. In this study, directional reflectance was simulated with the Four-Scale Linear Model for AnIsotropic Reflectance (FLAIR)[1, 2] and compared with *in situ* canopy level measurements for validations. The FLAIR model is a linear kernel-like model and utilizes four levels of architecture and distribution from leaves to crowns to describe canopy reflectance.

2. METHODS

During the summer of 2007, field campaigns were conducted on young trees in experimental plots at the USDA's Beltsville Agricultural Research Center (BARC) and at a stand dominated by mature tulip poplar at the Smithsonian Experimental Research Center (SERC) in Maryland. At BARC, we examined individual trees of three species, tulip poplar (*Liriodendron tulipifera* L.), red maple (*Acer rubrum*) and sweet gum (*Liquidambar styraciflua*). Hyperspectral (~1 nm) reflectance was acquired using USB4000 Miniature Fiber Optic Spectrometer (Ocean Optics Inc., Dunedin, Florida, USA). At SERC, measurements (~3 nm) were taken with FieldSpec Spectroradiometer (ASD Inc., Boulder, CO, USA). Parts of these observations were utilized as essential input for FLAIR model. The rest of them were used to validate the output from FLAIR. These validation spectra were taken with a viewing zenith angle of 30° on canopy sectors for

which illumination conditions represented foliage that was either sunlit, shaded, or mixed sunlit/shaded, based on the relative azimuth angle between the observer and the sun. The shaded foliage was associated with the darkspot of the Bidirectional Reflectance Distribution Function (BRDF) while the sunlit canopy is similar to the hotspot. Validations were done using the original spectra and vegetation indices (PRI and NDVI) derived from them.

3. RESULTS

Simulations from the FLAIR model showed satisfactory agreements with *in situ* measurements, especially for the shaded and the sunlit/shaded mixed portions of the canopy. The agreement varied in different spectral regions and across species. Examples of *in situ* compared to FLAIR-simulated reflectance for a young maple tree at BARC and a mature tulip poplar stand at SERC are shown in Fig. 1a,b, respectively. In general, the simulations showed better results in the visible spectrum. Among all the observations we examined, FLAIR-simulated spectra showed less than a 2% difference from *in situ* measurements in the visible region for the shaded and the mixed foliage. For the sunlit segment, larger differences between modeled and measured reflectance were observed but still under 5% in most of the cases. For the young trees of the three species we analyzed, the output from the model was the closest to field measurements for maple and sweet gum trees while the least satisfactory results were found for young poplar trees at BARC. Nevertheless, for the mature poplar stand at SERC, simulations from FLAIR were much closer to field measurements and were similar to the results from the young maple and sweet gum trees at BARC. These FLAIR-generated spectra were further utilized to derive the PRI and the Normalized Difference Vegetation Index (NDVI). In the best cases, both simulated NDVI and PRI were within a 1% difference of *in situ* measurements, but better agreement overall was found using NDVI. Comparisons between *in situ* and simulated PRI and NDVI for all the cases are shown in Figure 2. For NDVI, the best agreement was found for the sunlit/shaded mixed foliage of the maple trees while the best simulated PRI was for the shaded foliage of the sweet gum trees. Furthermore, a sensitivity analysis was conducted for better understanding of the response to three important canopy structure parameters, leaf area index (LAI), the clumping index, and the leaf to shoot ratio.

The clumping index showed the most impact on simulated reflectance. Figure 3a showed changes of the reflectance values at 531 nm, red and NIR region responded to increase of clumping index. Changes of LAI showed more significant impacts in the red and NIR spectral region while the leaf to shoot ratio exhibited similar results. While values of the clumping index or LAI had positive correlation with reflectance, increase of leaf to shoot ratio resulted in decrease of reflectance, as shown in Figure 3b.

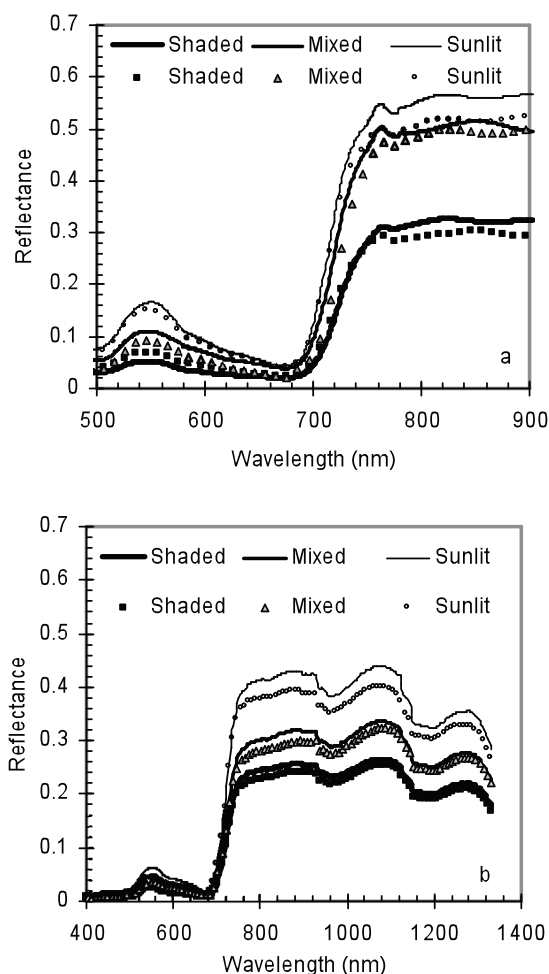


Figure. 1. Comparisons between *in situ* (lines) and simulated (symbols) reflectance from FLAIR for three foliage groups (sunlit, shaded, and sunlit/shaded mixed) for : (a) a young red maple tree at BARC ; and (b) a mature tulip poplar stand at SERC. The difference in wavelength range was due to different instruments.

4. DISCUSSION

BRDF measurements or simulations are the most suitable candidates to describe different partitions of the canopy and retrieve essential plant physiological properties. Recent studies have given emphasis to partitioning the canopy into groups under different illumination conditions for improved LUE estimates. This will potentially provide an opportunity of better understandings and modeling carbon exchange between the ecosystem and the atmosphere. In this study, we compared *in situ* directional reflectance measurements with FLAIR-model-simulated reflectances. The satisfactory results demonstrated the opportunity to derive directional reflectances with nadir reflectance and FLAIR model. Possible applications include utilizing existing satellite

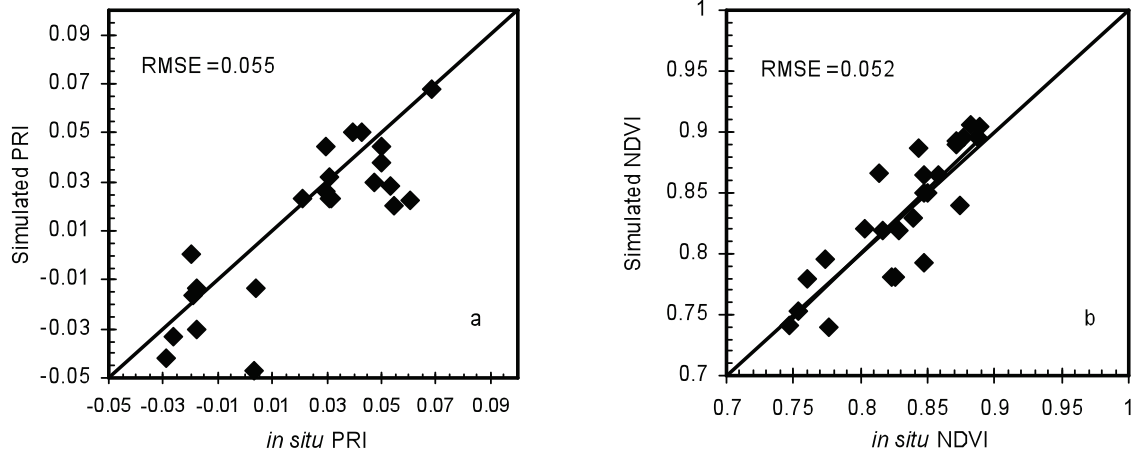


Figure 2. Comparisons between (a) PRI and (b) NDVI derived from field measurements and FLAIR-simulated spectra.

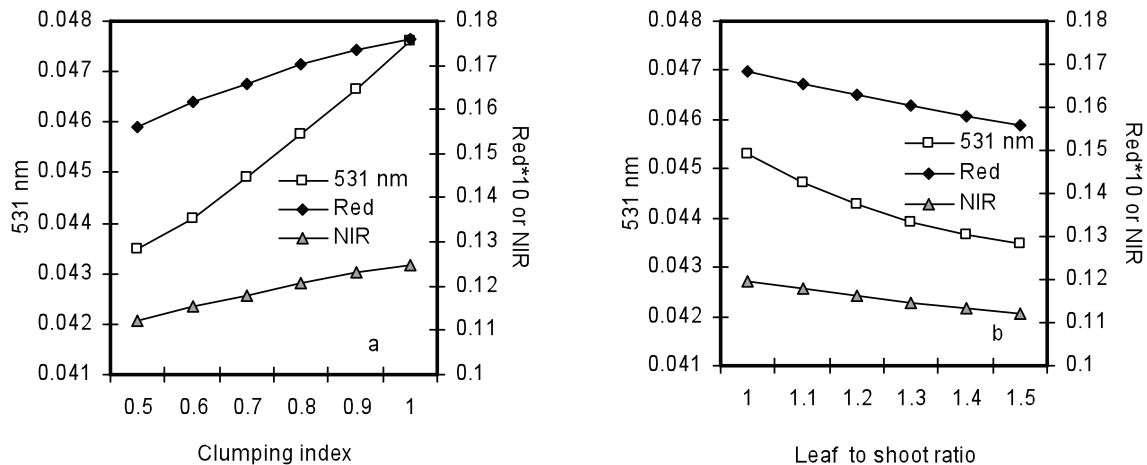


Figure 3. Changes of reflectance at green (531 nm), red (650 nm) and NIR (850 nm) corresponding to changes in clumping index or leaf to shoot ratio. Note: red reflectances were multiplied by ten to fit scale.

imagery taken at nadir point of view and deriving directional reflectances and indices that are essential inputs for ecosystem models. However, one should notice that the accuracy might be species-related, and the model seemed to deliver the least satisfactory results for the sunlit partition of the canopy.

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