Validation Of Canopy Bidirectional Reflectance Models With Asas Imagery Of A Spruce Forest In Maine

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ABSTRACT

Advanced Solid-state Array Spectroradiometer (ASAS) directional imagery of a spruce forest are used in an initial validation of the Li-Strahler geometric-optical model and the Li-Strahler hybrid geometric-optical radiative-transfer model. Although the magnitudes of the modeled principal plane bidirectional reflectances generally correspond to the ASAS measurements, the geometric-optical model results reproduce the trends of the ASAS reflectances more closely. Both models tend to overestimate the impact of mutual shadowing at large view zenith angles.

INTRODUCTION

All efforts to realistically model the intrinsic anisotropy of vegetated surfaces and to simulate satellite measurements are hampered by a lack of high quality directional reflectance measurements to serve as validation data (Pinty and Verstraete, 1992). The 1990 Forest Ecosystem Dynamics Multisensor Aircraft Campaign (FEDMAC) addressed this problem by collecting the biophysical parameters necessary to exhaustively describe a spruce forest in Howland, Maine and obtaining directional radiances of the site from the airborne Advanced Solid-state Array Spectroradiometer (ASAS) to serve as an excellent source of validation (Irons *et al.*, 1991). In this study, data from the field project were used to parameterize and validate two models, the Li-Strahler geometric-optical model (Li and Strahler, 1985; 1986; 1992) and the Li-Strahler hybrid geometric-optical radiative-transfer model (Li and Strahler, 1988; Li *et al.*, 1994).

THE MODELS

Both models treat a forest as a group of spheroidal tree crowns and use geometric-optics and boolean set theory to simulate the pattern of sunlit crowns, sunlit background and shadows in the domain. The geometric-optical model determines the areal proportions of these sunlit and shadowed components and weights the proportions with characteristic component signatures to produce a Bidirectional Reflectance Distribution Function (BRDF) of the scene. The component signatures are usually based on timely ground measurements which, in the case of the sunlit canopy component signature, capture the effects of the foliage and of the multiple scattering occurring within the canopy. The hybrid model, on the other hand, does not require site specific component signatures, but combines within-canopy multiple scattering effects from radiative transfer theory with the geometric-optical effects of the individual trees. By relying on the gap probabilities and path length distributions possible through the simulated forest of spheroidal tree crowns, the amount of irradiance reaching any point in the canopy is predicted and the amount of single and multiple scattering radiation exiting from the surface is computed. The scene brightening effects characteristic of vegetation (the hotspot effect, which occurs when the solar and view zenith angles are the same, and the mutual shadowing effect, which occurs at high solar or view zenith angles when only the tree tips are illuminated and viewed) are accommodated by both of these models.

FOREST DESCRIPTIVE PARAMETERS

Although the FEDMAC spruce site is quite dense, sufficient crown height variations exist to generate complex canopy shadowing patterns. The site is on level ground in the vicinity of an instrumented meteorological tower maintained by the University of Maine at Orono (45.35° N, 68.75° W). Using variable radius plot sampling (Dilworth, 1977), a 1989 Boston University survey (supplemented with University of Virginia tree height data) characterized the spruce forest as containing trees with a 9.9m (±2.4m) basal-area-weighted mean height-to-center-of-crown, a 2.2m crown radius, a 3.6m crown vertical radius, and a 1161 trees/hectare density (with a crown closure of 84%). A foliage area volume density of 6.6 was not explicitly measured but was estimated from leaf area index measurements collected during the field project with a Licor LAI-2000 instrument.

During the field campaign of 8 Sept, 1990, handheld radiometer (Spectron Engineering SE590) measurements (band 141, 774.1 nm) were collected for use as the near-infrared sunlit and shadowed component signatures required by the geometric-optical model. The radiometer measurements were collected at the site once in the morning and once in the afternoon and the sunlit canopy component signatures were geometrically adjusted for solar zenith angle. The sunlit background radiometric measurements were also used by the hybrid model to represent ground reflectance, while the necessary foliage reflectance and transmission values for spruce needles were explicitly measured with a Licor integrating sphere.

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ASAS VALIDATION DATA

The ASAS instrument was flown on a NASA C-130 aircraft at ~4600 meters altitude in the principal plane of the sun at 9:12, 11:10, and 13:52 EDT, 8 Sept 1990. ASAS images of the site were obtained at seven look angles from +45 ° to -45°. The near-infrared band 24 (band center 773.5 nm) was selected for this validation study (the ASAS red radiances could not be used due to the low responsivity over thickly vegetated surfaces of the ASAS red band sensors in use during the field project). A region of vegetation around the tower was selected and its mean brightness and variance were obtained from each directional ASAS image. These brightnesses were transformed to radiances with the NASA-provided radiometric resolution factors and atmospherically corrected using aerosol optical depths (measured with tracking sunphotometers at the time of the ASAS overpasses) and the Liang and Strahler (1994) radiative transfer model (which uses a two-stream approximation modified to incorporate a non-lambertian surface boundary).

RESULTS

The models were initialized with the spruce foliage and tree characteristics, the component signatures, and the appropriate solar zenith angles to produce principal plane bidirectional reflectances which could be compared to the ASAS values (Figure 1). Both models produced directional values with magnitudes similar to those measured by ASAS. However, the geometric-optical model results, which were tuned specifically to the site with the component signatures, more closely resembled the trends of the ASAS values then did the hybrid model. A consideration of the directionality of multiple scattering might improve the hybrid model results in the hotspot to nadir region of the principal plane. Multiple scattering is treated isotropically by the hybrid model, while in actuality may be somewhat directional since the majority of the lower order scattering will occur off of sunlit foliage. While the directionality of the multiple scattering occurring in a canopy may be captured by the field measured component signatures, and thus incorporated into the geometric-optical model, there is (in contrast to the hybrid model) no accommodation for the leaf-scale hotspot effect. This accounts somewhat for the underestimation of the overall hotspot by the geometric-optical model. Both models predicted brighter values in the forward scattering directions than were detected by the ASAS imagery, indicating an overestimation of the impact of mutual shadowing. ASAS images from larger view zenith angles (as available now on the current ASAS instrument) are needed to clarify whether the scene eventually brightened due to mutual shadowing (as the models would suggest) or not.

These model validation provide some promising results and identify some possible deficiencies. However, the Maine site represents only one very dense spruce canopy situated on level terrain. ASAS data of forest canopies with a variety of tree types, shapes, and densities are required for a significant validation. In the future, ASAS data from forests on sloping terrain will also be required to test the abilities of these models in complex topography.

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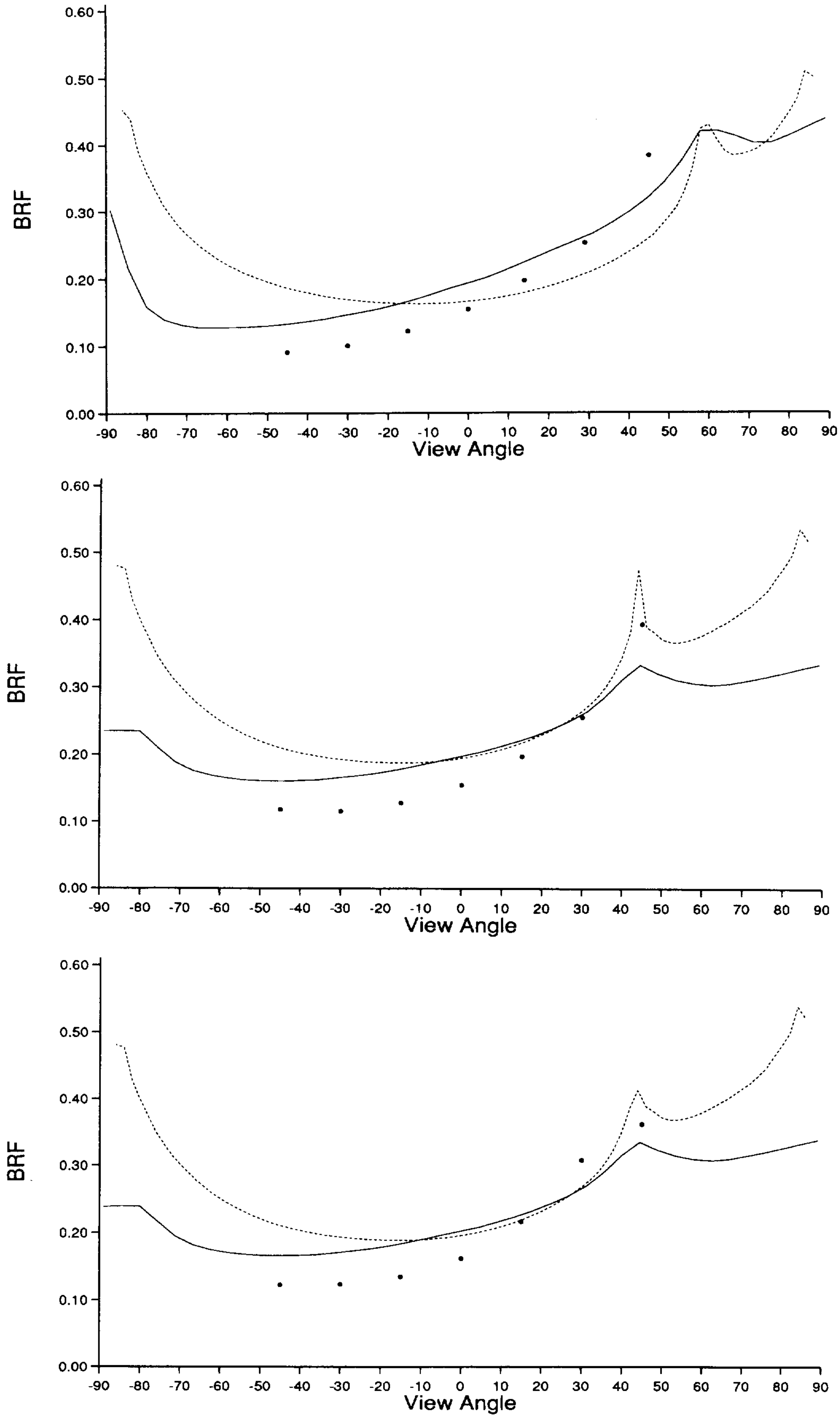

Figure 1. Mean NIR ASAS reflectances (●) compared with the geometric-optical model BRFs (—) and the hybrid model BRFs (--) along the principal plane (a) 9:12 EDT, (b) 11:10 EDT, (c) 13:52 EDT.