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# Temporal Attributes of the Bidirectional Reflectance for Three Boreal Forest Canopies

D.W. Deering, S.P. Ahmad\*, T.F. Eck\* and B.P. Banerjee\*  
Biospheric Sciences Branch, Code 923 (\*Hughes/STX Corp.)  
NASA/Goddard Space Flight Center, Greenbelt, MD 20771 U.S.A.  
Tel.: 301-286-9186/Fax: 301-286-0239/Email: ddeering@ltpmail.gsfc.nasa.gov

**Abstract** -- Multidirectional ground-based optical measurements were acquired along tramways above and beneath three important boreal forest canopies to characterize the complete radiative transfer of visible through shortwave infrared wavelengths. The three forest canopy types exhibited bidirectional reflectance features that were distinctively different from each other not only in their magnitudes of reflectance in a given spectral wavelength band and at forward and backscatter angles but also in their diurnal and seasonal changes. The above-canopy data analyses indicate that each of these forest types must be considered as having unique bidirectional reflectance distribution functions and should be modeled individually for both direct (e.g. albedo) and indirect (e.g., biophysical parameter assessments) applications in the quantitative remote sensing of the boreal forest biome.

## INTRODUCTION

The boreal forest biome has been shown to be potentially one of the most sensitive biological systems to possible future global climate change [1]. Global warming will likely have its earliest impacts in the regions of boreal forests with the consequence of additional modifications to the release and uptake of CO<sub>2</sub>, CH<sub>4</sub> and other trace gases and alterations to other biogeochemical processes as the ecological functioning of the biome changes. Thus, the ability to accurately monitor the state and changes of state of the boreal forest may prove pivotal to early detection of responses to global climate change.

Remote sensing tools will be required to effectively monitor the vast extent of the typically sparsely populated boreal forests; but the high latitudes with the attendant large solar zenith angles that result in low illumination conditions which may make remote sensing interpretations difficult. Understanding the complete bidirectional reflectance distribution functions for the major forest types of the boreal forest biome is a critical first step, therefore, to quantitative remote sensing assessment and monitoring of the boreal forests.

This paper reports on the first analysis results from a ground based Boreal Ecosystem-Atmosphere Study (BOREAS) remote sensing experiment whose general objectives are to characterize the multidirectional interactions of solar energy in various types

of boreal forest canopies through intensive measurements and through modeling and to relate these characteristics to ecologically important biophysical parameters.

## METHODS

PARABOLA (Portable Apparatus for Rapid Acquisitions of Bidirectional Observations of Land and Atmosphere) bidirectional reflectivity/directional transmittance data were collected at 5° solar zenith angle intervals, clouds permitting, from approximately 75° solar zenith angle to solar noon for the three primary boreal forest canopy types in the Southern Study Area of the BOREAS project in north central Canada -- aspen, jack pine and black spruce. Measurements were acquired during four periods from the early spring thawing period (FFC-Thaw) through the summer (IFC-1, early summer and IFC-2, mid-summer) and concluding in the early senescence period of the fall (IFC-3) in 1994.

The measurements reported in this paper were acquired from a movable platform supported by 70 meters long dual steel cable tramways at more than 10 m above each of the three forest canopies. The PARABOLA measures a 4 $\pi$  hemisphere area with 15° IFOV sectors in 11 seconds in three wavelength bands covering the red, near-infrared and shortwave infrared spectral regions (662, 826 and 1656 nm, respectively)[2]. Measurements of the reflected radiances from a characterized barium sulfate reference panel with a Barnes Modular Multiband Radiometer (MMR) were taken concurrently with PARABOLA measurements during the experiment in order to characterize spectral solar irradiance.

## RESULTS AND DISCUSSION

Coniferous forest ecosystems, which dominate the boreal forest landscapes, are structurally and spectrally complex surfaces that have been shown to exhibit considerable reflectance anisotropy [3]. The bidirectional reflectance distribution function or BRDF from which reflectance anisotropy characteristics derive, can be considered to have two "temporal" components; a diurnal or daily variation and a seasonal variation. Many factors contribute to these variations, but the solar zenith angle changes can be understood to cause the principal effects in forest canopies during the course of a clear sky day. However, phenological events (which often result in significant canopy structural changes) coupled with the

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seasonal changes in solar position cause reflectance anisotropy variations observed in forest canopies.

#### BRDF Changes with Diurnal Solar Zenith Angle

In mid-summer when the mature deciduous aspen canopies (leaf area index or LAI  $\approx 2$ ) with a dense understory of hazelnut (LAI  $\approx 3$ ) were at the peak of their development, the reflectance anisotropy was highly structured (Fig.1). The backscatter hot spot was prominent in the solar principal plane in all three spectral bands for all solar zenith angles, but there was also a relatively strong forwardscatter (negative values on x-axis of figures) increase in reflectance. Nadir values of reflectance for the aspen canopy for the 40° solar zenith angle were 1.5%, 30%, and 7% for the red, near infrared and shortwave infrared spectral bands, respectively.

The coniferous forest canopies, particularly jack pine, exhibited a much greater variation in the magnitudes of reflectance with changes in solar zenith angle in the backscatter direction (especially in the nadir to 45° view directions than did the aspen canopy, and the hot spot effects were pronounced (Figs. 2 and 3). The black spruce site exhibited a rather "flat" (or dark) forwardscatter reflectance due to the dense shadowing

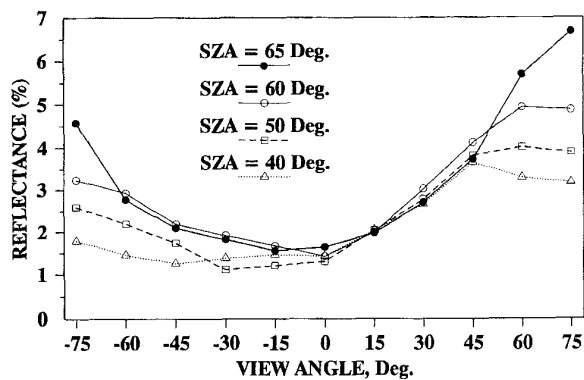


Fig.1. Old Aspen site: red (662 nm) reflectances in the solar principal plane for four solar zenith angles; July 21.

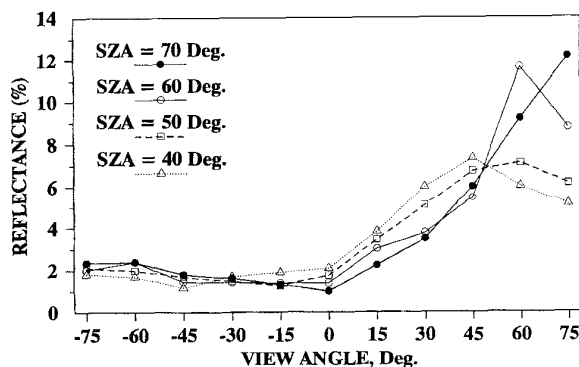


Fig.2. Old Black Spruce site: red (662 nm) reflectances in the solar principal plane for four solar zenith angles; June 7.

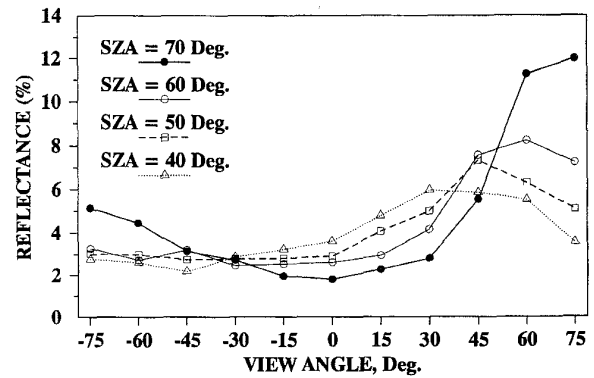


Fig.3. Old Jack Pine site: red (662 nm) reflectances in the solar principal plane for four solar zenith angles; July 25.

created by the compact needle clusters of the tree crowns. The jack pine canopy is much more open and some rise in reflectance in the forwardscatter direction was characteristic, particularly when the sun was low in the sky. Nadir values of near infrared reflectance for black spruce and jack pine (8-12% and 9-15%, respectively) were not as large as for the aspen (30-33%). The LAI for the black spruce stand was 3.5 and for jack pine was 2.3, compared with 5 for the Aspen-hazelnut canopy. Clearly, factors other than LAI are effecting the reflectance of these forest-background types.

Fig.4 illustrates the azimuthal component of the BRDF for the black spruce stand for a 45° solar zenith angle. For all azimuth planes the copious tree shadowing causes the forwardscatter direction to appear quite uniformly dark. Viewing angles ranging from nadir to 75° off-nadir displayed red spectral band reflectances of approximately 1.5%.

#### BRDF Changes with Season

An example of the changes in BRDF with season is given here for the deciduous aspen site with its deciduous hazelnut understory species. This site experienced the most dramatic changes in phenology, and consequently spectral reflectance, of

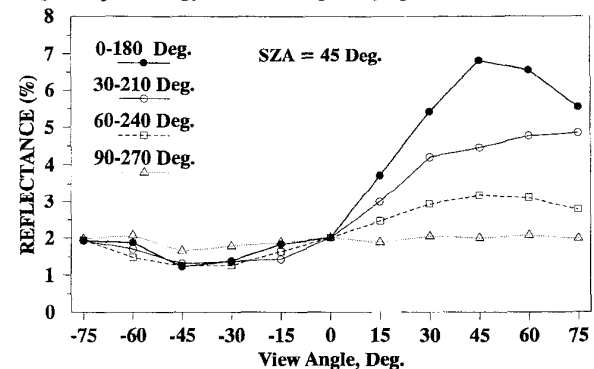


Fig.4. Old Black Spruce site: red (662 nm) reflectances in four azimuth planes for the 45° solar zenith angle; June 7.

the three forest types studied. In the early spring thaw period the aspen and hazelnut branches were barren. There was essentially no green plant material on the site, but the standing woody plant material had considerable structure (approximately 20 meters height). The aspen stand revealed a strong viewing angle dependence (Fig. 5), but only a minor dependence on solar zenith angle, except at the larger backscatter view angles.

In mid-June (IFC-1) the young aspen and hazelnut leaves were smaller and thinner than in late July (IFC-2). These differences were not apparent in the red spectral region reflectances for the full range of viewing angles at the aspen site (Fig. 5, top). However, they were evident in the near-infrared region with the anisotropy characteristics remaining similar for the three leaf-on periods sampled; only the magnitudes were substantially different (Fig. 5, bottom).

The plants in the aspen stand were rapidly becoming senescent by mid-September (IFC-3) and had lost many leaves. Although the red band reflectances were returning to resemble the early thawing period anisotropy characteristics, the near-infrared reflectances (which had decreased in magnitude) still retained their characteristic viewing angle dependence.

#### Vegetation Indices and BRDF

It is widely understood that measuring and monitoring the characteristics and changes in biophysical and other parameters

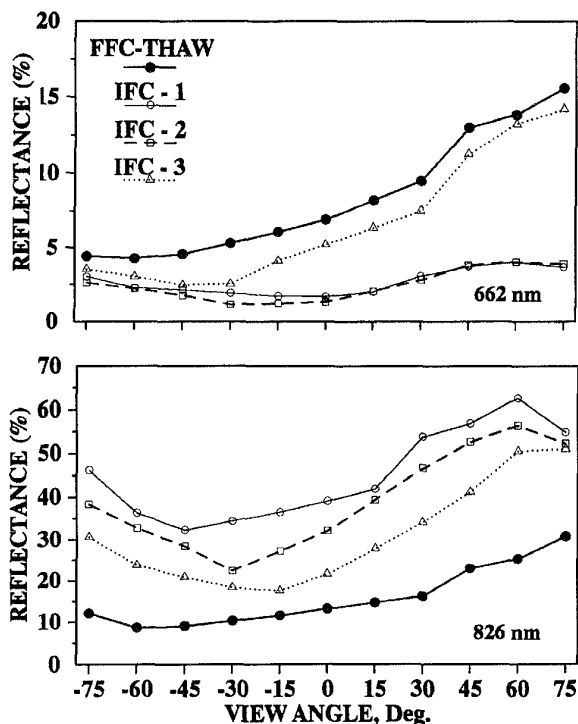


Fig. 5. Old Aspen site: red and near-infrared reflectances in the solar principal plane at four seasons; solar zenith angle = 50°.

of boreal forests with their vast global extent will require satellites. Using optical satellite sensors of the present day and the future must account for the BRDF effects of scene reflectance for accurate temporal assessments. The three forest canopy types exhibited bidirectional reflectance features that were distinctive amongst each other not only in their magnitudes of reflectance in a given spectral wavelength band and at forward and backscatter angles but also in their diurnal and seasonal changes. These forest type BRDF differences and influences are evident in the Normalized Difference Vegetation Index or NDVI (Fig. 6), which is widely used for quantifying vegetation characteristics from satellites. In Fig. 6 the three BOREAS sites are compared to a mixed spruce-hemlock forest in Maine.

These results demonstrate that each of these forest types must be considered as having unique bidirectional reflectance distribution functions and must be modeled separately for both simple and direct (e.g. albedo) and more complicated (e.g., biophysical parameter assessments) applications in the quantitative remote sensing of the boreal forest biome.

#### REFERENCES

- [1] P. Sellers, F. Hall, H. Margolis, B. Kelly, D. Baldocchi, G. den Hartog, et al., "The Boreal Ecosystem-Atmosphere Study (BOREAS): an overview and early results from the 1994 field year," *Bull. Amer. Meteorol. Soc.*, in press.
- [2] D.W. Deering and P. Leone, "A Sphere-Scanning Radiometer for Rapid Directional Measurements of Sky and Ground Radiance," *Remote Sens. of Environ.* 19:1-24, 1986.
- [3] D.W. Deering, E.M. Middleton, and T.F. Eck, "Reflectance Anisotropy for a Spruce-Hemlock Forest Canopy," *Remote Sens. of Environ.* 47:242-260, 1994.

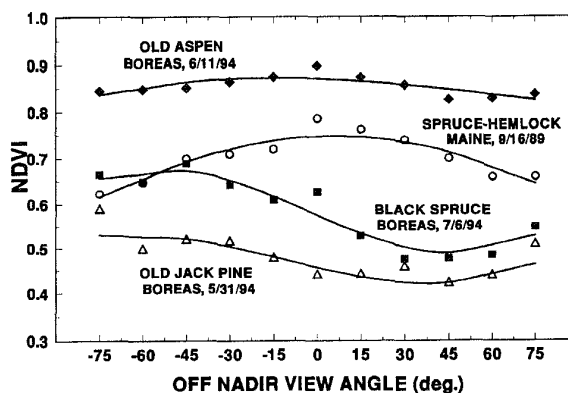


Fig. 6. The NDVI variations with view zenith angle (solar principal plane) for four northern forest canopy types.