NASA/TM—2000–209891, Vol. 159

Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall and Shelaine Curd, Editors

Volume 159

BOREAS TE-9 In Situ Understory Spectral Reflectance within the NSA

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October 2000

Available from:

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7121 Standard Drive
Hanover, MD 21076-1320
Price Code: A17

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Price Code: A10

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Jan Supronowicz, Geoffrey Edwards, Alain Viau, Keith Thomson

Summary

The BOREAS TE-9 team collected several data sets related to chemical and photosynthetic properties of leaves in boreal forest tree species. Spectral reflection coefficients of the forest understory at the ground level, in three boreal forest sites of Northern Manitoba (56 degrees N latitude and 98 degrees W longitude), were obtained and analyzed in 1994. In particular, angular variation of the reflection coefficients in the old jack pine and young jack pine forests, as well as nadir reflection coefficient in the young aspen forest, were investigated. The complexity of understory composition and the light patterns limited quantitative conclusions; however, a number of interesting trends in the behavior of the measured values can be inferred. In particular, the unique spectral profiles of lichens show very strongly in the old jack pine understory, yet are definitely less conspicuous for young jack pine, and virtually absent in the aspen forest. The angular variation of the reflection coefficient by the young pine understory seems to be significantly toned down by fine-structured branches and their shadows. Our study also indicates how difficult the ground reflection coefficient problem in a forest is, compared to certain previously investigated areas that have a more uniform appearance, such as prairie grassland, bare soil, or agricultural crops. This is due to several factors, generally typical of a forest environment, that may influence the overall understory reflection coefficient, including: (i) a strong diversity of the forest floor due to the presence of dead tree trunks, holes in the ground, patches of different types of vegetation or litter, etc.; (ii) pronounced 3-D structures at the ground level, such as shrubs, bushes, and young trees; and (iii) an irregular shadow mosaic, which not only varies with the time of the day, causing intensity variations, but likely also effectively modifies the spectrum of the illuminating light and hence the reflection coefficient signal as well. The data are stored in tabular ASCII files.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS TE-09 In Situ Understory Spectral Reflectance within the NSA

1.2 Data Set Introduction

The data set attempts to evaluate the characteristics of forest understory reflectance at the ground level. Whenever possible, this goal was pursued in a reasonably selective manner by avoiding or at least minimizing the direct contribution of mature trees to the recorded spectra. The field work was designed to concentrate on randomly selected fragments of the ground landscape rather than its individual components, which gives a distinctly statistical character to the data.

First of all, the variable measured at the ground level is, strictly speaking, the local relative luminance, rather than reflectance, of the patch of ground corresponding to the instrument's footprint. To obtain the actual reflectance one would have to, by definition, normalize the understory signal to the reference signal acquired under identical illumination conditions, i.e., sun or shade, depending on the site. Such an approach has been chosen by J. Miller's team (RSS-19, York University) but is not the case with our data, based on the reference panel routinely fully sunlit. In a broader sense, however, one might argue that these results constitute a very reasonable statistical representation (sample) of a mean reflectance averaged over a larger area and thus taking into account all of its features, including shadows, which vary with the illumination conditions. In the same way, for instance, the perceived reflectance of a fully grass-covered lawn may be different from the reflectance of a single grass blade, because of the structural complexity of the lawn surface. Furthermore, all the submitted data are valid in the sense that they were acquired in the manner described in Section 5 while all the elements of the equipment were functioning properly to the best of our knowledge. However, because of the field of view (FOV) being factually subject to variations with the viewing angle, as well as of the presence of pronounced 3-D structures in several of the investigated sites, it is not possible to know exactly which objects and/or area had in each case contributed to the recorded spectrum, especially for the off-nadir measurements. This circumstance also underscores the particular suitability of the data to be viewed in a statistical context.

1.3 Objective/Purpose

The long-term objective of the study within which these data were acquired was the following: To estimate light levels inside the forest canopy and to link these estimates with airborne images taken above the canopy, in order to tie the photosynthetic experiments and models with the remotely sensed measurements. The BOReal Ecosystem-Atmospheric Study (BOREAS) Terrestrial Ecosystem (TE)-09 project contained several subprojects designed to work together to meet this goal: a high-resolution canopy modeling component, extensive measurements of canopy architecture and structure, photometric measurements inside the canopy, and spectral measurements of both the canopy and the understory.

During the planning discussions, it was determined that the weakest link in this effort was the characterization of the subcanopy at a level sufficiently systematic to support the analysis of high-resolution airborne imagery. This seemed even more important at the Northern Study Area (NSA) than at the Southern Study Area (SSA). Appropriate understory measurements would provide good support for the canopy modeling effort by providing much needed additional data for this work. Furthermore, the understory, especially in the northern sites, contributes a serious "noise" component to the canopy spectral properties, as measured above the canopy. Because of this, appropriate measurements of the understory are essential to understanding both the angular light response of the canopy and scaling issues.

Furthermore, the understory contains information about the boreal environment that should not be ignored. We therefore participated in canopy structure measurements and in some basic photometric measurements, but focused most of our attention on laboratory and in situ spectral measurements of the understory in the NSA.

Within this framework, the following specific objectives were set:

- To study the spatial variability of in situ spectral reflection coefficient measurements of the understory at accessible sites in the NSA.
- To study the seasonal change of the in situ spectral measurements during leaf-up.
- To study the angular dependence of spectral measurements of the understory.
- To obtain laboratory spectral measurements of canopy and understory components.

1.4 Summary of Parameters

The parameters measured include the following:

- visible & near infrared spectra at selected gridded plot sample locations in three NSA sites Old Jack Pine (OJP), Young Jack Pine (YJP) and Young Aspen (YA), taken at seven different angles;
- simultaneous Photosynthetically-Active Radiation (PAR) measurements;
- simultaneous reflectance panel measurements;
- spectral measurements of selected vegetative and non-vegetative components;
- 35-mm photographs taken at the time of the measurements;
- notes on sun and view angles, time of day and date;
- and a detailed physiological characterization of plant species present at each plot sample location.

1.5 Discussion

Two types of spectral reflection coefficient measurements were obtained. One consisted of sequences of angular measurements, while the second consisted of a larger sample of nadir measurements. For each type of measurement, a different instrument mounting was designed and built. For the angular measurements, a tripod mounting was built that permitted the spectrometer to be oriented in seven directions (-45 degrees, -30 degrees, -15 degrees, 0 degrees, 15 degrees, 30 degrees, and 45 degrees). The average height of the spectrometer head was 1.5 meters, but it could be adjusted between 1.3 and 1.6 meters. A spectrometer head with a field of view (FOV) of 18 degrees was used, giving a ground footprint of 50 centimeters at nadir.

A swivel bracket for the reflectance panel was added, and a camera mount was also installed. For each sample plot location, the mount was set up, leveled, and adjusted for height. Reflection coefficient panel measurements were taken only at nadir and only with the panel fully sunlit (non-sunlit panel measurements are marked as suspect in the data set).

Photographs were also taken only at nadir. To the extent possible, repeat measurements of sample plots were taken at the same time of day and a similar azimuth orientation, so that shadowing on the sample plot would be similar. The nadir mount was simpler, but also contained a means to level it and adjust the height. The same spectrometer head was used at a height of 1.4 meters, giving a similar, although slightly smaller, footprint. Data were acquired only on clear days, or through large holes in the clouds on partially cloudy days. The simultaneous PAR measurements and frequent reflection coefficient panel measurements allowed for control over poor light measurements. Measurements were not taken at either the Old Black Spruce (OBS) or the Old Aspen (OA) site. Access to the first was too difficult since the instrument mounts were somewhat fragile, and a 45-minute ride on an Argo in each direction would have ruined the instruments. The OA site was characterized by an understory well above 2 meters in height, and hence could not be properly characterized by the instrumentation setup we had.

1.6 Related Data Sets

BOREAS RSS-19 1994 Seasonal Understory Reflectance Data

2. Investigator(s)

2.1 Investigator(s) Name and Title

Dr. Geoffrey Edwards, Associate Professor
Dr. Keith P. B. Thomson, Full Professor
Dr. Alain P. Viau, Assistant Professor

2.2 Title of Investigation

Relationship Between Measures of Absorbed and Reflected Radiation and the Photosynthetic Capacity of Boreal Forest Canopies and Understories

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3. Theory of Measurements

The value of the reflectance function for a reasonably flat surface, in a direction characterized by angles phi and theta (see Figure 1), can be expressed as a ratio of the luminance of a fragment of that area (perceived from the defined direction), to the luminance of a fragment of a fully diffuse reflecting (Lambertian) plane, identical in size and shape, seen from the same direction and distance, and under the same illumination conditions:

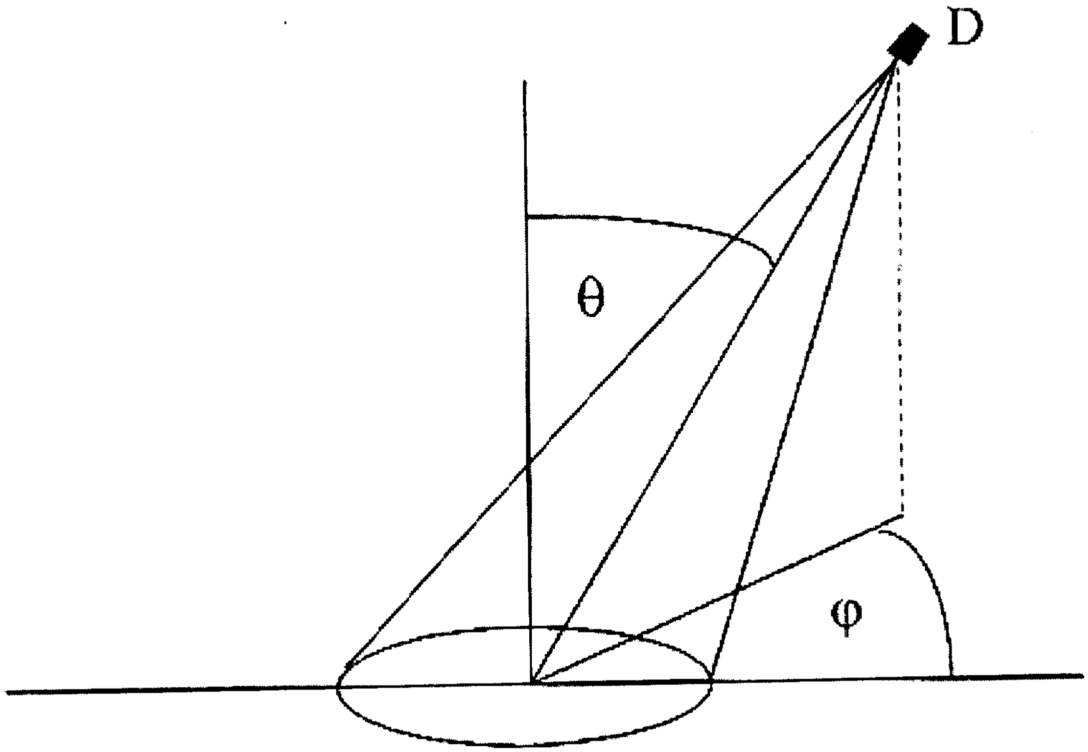

Fig. 1. A schematic diagram, illustrating the principle of angular reflectance measurements. The angle θ can be varied during the experiment; φ remains constant. D - detector.

Figure 1. A schematic diagram illustrating the principle of angular reflectance measurements. The angle theta can be varied during the experiment; Phi remains constant, D = detector.

Rlambda(phi, theta) = llambda,s(phi, theta)/llambda,l(phi, theta)   (1)

where llambda,s and llambda,l are luminances of the investigated surface and the Lambertian (reference) plane, respectively. The angle phi is introduced to account for the possible anisotropy in the azimuth distribution of the reflectance factors, which a priori may be due either to anisotropic illumination or to specific asymmetrical structure of the examined area itself. The above formula is, of course, an idealization of a real physical situation, a fact that has important implications in our case. To begin with, it is rigorously valid only in the limit of an infinitesimally small solid angle of view, subtended by the dimensions of the observed patch as compared with the viewing range. Secondly, in the case of anisotropic illumination, e.g., direct sunlight, the variables in Eqn. (1) may also comprise the sun angular coordinates: the solar azimuth phisol and the solar zenith angle thetasol. Finally, Eqn. (1) is strictly wavelength selective, which is indicated by the subscript "lambda." In practice, both the solid angle of view and the spectral range of luminance intensity measurements are finite. The assumption of the reference surface as having Lambertian properties means that the intensity of light reflected into the direction (phi, theta) is directly proportional to the cosine of the polar angle, cos(theta). However, for small solid angles of view, the area seen by a detector aimed at the surface at angle theta is proportional with a very good approximation to 1/(cos(theta)). Moreover, in the case of the conical FOV, that area has the shape of an ideal ellipse. In consequence, since the detector always sees the same solid angle, determined by its own geometry, those two effects will cancel one another. Hence, the amount of radiative energy per unit solid angle or, in other words, the perceived luminance intensity of the observed surface, will vary only very weakly with the polar angle theta. It is, therefore, perfectly reasonable to make use of the reference nadir (theta = 0 degrees) measurements in place of angular (theta different from 0 degrees) measurements also, as both are expected to yield virtually the same result. The idea of the angular reflectance measurements was to acquire values of forest understory reflection coefficient at nadir, i.e., vertical direction with respect to the ground, as well as at directions 15, 30, and 45 degrees with respect to the vertical on both sides of the vertical in the same plane, perpendicular to the ground. Each set of data constitutes a spectral series, in which the reflectance in each narrow spectral increment is represented by a number, denoting the fraction of radiative energy reflected by the observed spot on the ground, as compared with the amount of energy in the same spectral region, reflected by a "white" reference standard (barium sulfate panel) ($BaSO_4$). The basic concept of carrying out the angular measurements was to have a detector attached to a rigid arm that was allowed to swing in a plane perpendicular to the ground, around a pivot placed at the ground level. In this way, the arm was able to assume and be locked in any required position within the desired interval, while the detector could "look" along the direction of the arm -- from the same distance at the same point of the ground irrespective of the angle between the arm and the vertical.

4. Equipment

4.1 Sensor/Instrument Description

- portable spectrometer PS II, from the company Analytical Spectral Devices (ASD):
  - spectral range: 342 nm - 1068 nm
  - number of spectral channels - 512
  - resolution: 10 nm (in the recent communication with an ASD representative, a resolution of 3.5 nm was quoted) - accuracy: 1 nm at 24 degrees C and a maximum of 4 nm between 0 degrees C and 50 degrees C
  - integration time: 44 ms - 5.6 s
  - spectrometer heads with FOV of 18 degrees, 10 degrees, 5 degrees, and 1 degree
  - a mounting for the ASD PS II spectrometer was provided by ASD
- portable personal computer POQET, which served as a controller for the PS II
- 35-mm camera:
  - during measurements attached to the tilting arm, next to the spectrometer head

4.1.1 Collection Environment

All the field measurements were carried out at various points within the BOREAS NSA, an 80- by 100-km rectangle whose geometrical center is located approximately at 98 degrees10 W longitude and 55 degrees 52 N latitude, about 25 km bearing W-NW from the town of Thompson, Manitoba. The terrain is rather flat, with local relief generally not exceeding 15 m, while its elevation above sea level varies between 220 and 350 m. The climate of the region is moderately dry continental. The jack pine (Pinus banksiana) sites can be divided into two distinct types: old (mature) jack pine and young (regeneration) jack pine, subsequently referred to as OJP and YJP. In the mature forest, the mean tree height is close to 10 m, while the mean age is approximately 60 years. Apart from the trees themselves, the understory is mostly free of natural three dimensional structures such as plants taller than 10-15 cm or branches at the ground level. It is dominated by various species of the lichen family (e.g., Cladina stellaris, Cladina mitis, Cladina rangiferina), usually pastel bluish, pinkish, or whitish in color, with the addition of rusty brownish litter and/or miscellaneous types of ordinary green-colored forest herbs in places, as well as moss (Pleurozium schreberi) at random locations.

The appearance of the YJP landscape is notably different. First of all, it is characterized by a far greater density of live tree stems per unit area, which leads to a significant overlap of the branches of adjacent young pines, as the average distance between trees is considerably less than 1 meter. Secondly, the height of the young pines (aged ~25 years in our case) reaches only up to about 5 m, but many of them are much shorter and may be considered bushes for all practical purposes. Finally, the forest floor alone also differs from that of the OJP. Other than the live tree branches, the understory does not exhibit much vivid green color. It seems predominantly brownish with numerous dead tree trunks of diameter in the 5-10 cm range, devoid of bark and sometimes partially decomposed. The trunks have a silvery-grayish tint, while the pale reddish-brown hue of the floor itself is due to an abundance of dried pine needles spread over bare soil. Lichens and mosses of varying light hues also occur in places, but in a considerably smaller amount than in the OJP forest. The aspen (Populus tremuloides) stand understory was characterized at the time of the field campaigns (June-July 1994) by the abundance of litter, i.e., dried leaves on the ground. Those leaves, which vary in color from pale gold to dark grayish-brown, determine the appearance of the floor cover in certain places. In other locations, however, the dead leaves can be overlapped to a considerable degree by live, broadleaf vegetation (herbs and grasses), in which case a bright green color dominates the understory. There are also some isolated dead tree trunks and branches of an ashen grayish tint, but the occurrence of lichens or mosses is less than sporadic in the aspen forest. Table I gives an account of the basic parameters of the three types of forest.

Table I: Basic characterization of the investigated forest types

OLD JACK PINE	
Stem density :	~1900/ha
Age :	55-60 years
Height :	~10 m
Ground cover :	lichen-dominated + mosses + vascular herbs
YOUNG JACK PINE	
Stem density :	~23000/ha (even denser including young regenerating trees)
Age :	25 years
Height:	3-5 m (even shorter including regenerating trees)
Ground cover :	young pines, needle litter, bare soil, dead wood, lichens, herbs
YOUNG ASPEN	
Stem density :	~2400/ha
Age :	14-24 years (Data for BOREAS Southern Study Area)
Height :	6-12 m
Ground cover :	mostly leaf litter, green herbs, dead wood

4.1.2 Source/Platform

Source: plant species, forest litter and bare soil present at each plot sample location. Platform: portable tripod mounting. Angular mounting - a pivot mounting allows the spectrometer head to be tilted, while ensuring that the target remains constant. Nadir mounting - fixed. Device is operated by a person on the ground.

4.1.3 Source/Platform Mission Objectives

The objective was to perform in situ measurements of the forest understory reflection coefficient.

4.1.4 Key Variables

Spectral distribution of reflected radiation intensity, angular distribution of reflected radiation intensity.

4.1.5 Principles of Operation

The main device used for measurements is a holographic grating spectrometer, designed to disperse the captured light and project the respective components onto an array of silicon photodiodes. Each illuminated photodiode generates an electric current, which is proportional to the number of photons of light striking it from the corresponding spectral interval. The photodiode output signal is registered by a microcomputer and stored in its memory. The photo camera plays only an auxiliary role to obtain the pictures (from the nadir angle of view) of the investigated sites.

4.1.6 Sensor/Instrument Measurement Geometry

Angular mounting:

sensor height = 1.5 - 0.2 m at nadir; conical FOV with cone angle of 18 degrees
angular settings = -45 degrees, -30 degrees, -15 degrees, 0 degrees, 15 degrees, 30 degrees, 45 degrees

Nadir mounting:

height = 0.75 - 1.5 m, depending on plot
conical FOV = 18 degrees

4.1.7 Manufacturer of Instrument

Analytical Spectral Devices
4760 Walnut Street, Suite 105
Boulder, CO 80301
USA
(303) 444-6522
(303) 444-6825 (fax)

4.2 Calibration

Dark count subtraction occurs at the time of measurement. Integration time was varied to maintain similar signal-to-noise ratio. Each recorded spectrum is an average of five "snapshot" spectra. Three spectra were recorded at each location. A 4-inch barium sulfate reflectance panel was used.

4.2.1 Specifications

The calibration of the spectral measurements with the reflectance panel was carried out by plotting the reflectance panels throughout the day. Panel reflectances were acquired before and after each sequence of spectral measurements. For each data set, the appropriate panel reflectance was then interpreted along these curves. Linearity of spectral response was also evaluated during the calibration procedure by ratioing reflectance panel spectra, to ensure that the spectra could be reliably scaled in intensity. The instrument was calibrated at the ASD headquarters before the field campaign. This included calibration of the wavelengths and intensity response of the individual diode elements.

4.2.1.1 Tolerance

Each of the 512 photodiode channels is capable of registering 4095 counts (photons), after which it becomes saturated. Hence, care has to be taken that for each measurement the signal amplitude in the largest count channel does not exceed that number while, on the other hand, it is reasonably large to make the best use of the dynamic range of the instrument. This is done by varying the accumulation (integration) time, depending on the luminosity of the scene.

4.2.2 Frequency of Calibration

The calibration with respect to the standard panel was carried out before and after the series of measurements at each site. We relied upon the company wavelength calibration.

4.2.3 Other Calibration Information

The factory calibration: First channel corresponds to 342 nm Step 1.4209 nm over the next 511 channels Last channel 1068.08 nm Reproducibility 1 nm at constant temperature 24 degrees C; resolution 3.5 nm

5. Data Acquisition Methods

The mounting constructed for angular measurements was placed in a designated spot. Three "raw" spectra were recorded for each of the seven positions of the movable arm, corresponding to angles -45, -30, -15, 0, 15, 30, and 45 degrees between the arm and the vertical. Both before and after taking these data, the spectra of the reference panel were recorded (3 before and 3 after). At the nadir arm position, a photo picture of the site was taken by the camera, mounted on the arm. In the case of nadir measurements, the reference spectra also preceded and followed three recordings of the understory signal. The spectra in digitized form were subsequently transferred to floppy disks.

6. Observations

6.1 Data Notes

The orientation of the plane of measurements, i.e., the plane in which the arm of the mount was able to swing, relative to the solar plane, is a piece of information usually important for the overall interpretation of the results. That orientation (angle between the planes) is known in all but one case of the angular data. The angular solar elevation above the horizon is also known for all cases, although it does not vary much from site to site: all the angles are included within the 43.7 - 55.2 degrees interval. See Section 11.4 for more precise information. In certain cases, a tree branch would be very close to the instrument's sensor, blocking its FOV. Generally, such a situation should be regarded as nothing else but an event of recording the spectrum of a randomly chosen fragment of the landscape. If, however, the measuring device itself projected a shadow upon the investigated element, then the outcome of the experiment ought to be considered as somewhat distorted by the very act of measurement, and hence treated with caution.

6.2 Field Notes

Some of the YA data originating from 31-JUL-1994 were recorded in the presence of a certain amount of smoke in the air. The smoke most likely originated from a forest fire burning nearby.

7. Data Description

7.1 Spatial Characteristics

The data are submitted as a collection of spectral series, each one of which was recorded at a predefined location in one of the three types of boreal forests: YJP, OJP, and YA, and at a specific time.

7.1.1 Spatial Coverage

The sites where data were collected and the North American datum of 1983 (NAD83) coordinates are as follows. The data pertaining to the old jack pine forest were collected at seven preselected sites within a radius of about 40 m, in the area adjacent to the NSA OJP Flux Tower (site ID: T7Q8T, BORIS Grid coordinates: X=768.5, Y=617.1; longitude 98.624 degrees W, latitude 55.927 degrees N). For the young jack pine forest, eight sites were chosen in a similar-size area around the NSA YJP Flux Tower (site ID: T8S9X, BORIS Grid coordinates: X=789.6, Y=618.2; longitude 98.288 degrees W, latitude 55.903 degrees N). In the young aspen forest, the data were recorded twice at the same 14 spots in mid-June and at the end of July. The data collection area was approximately 50 m x 50 m. It was located at one of the auxiliary sites, W0Y5A (BORIS Grid coordinates: X=845.9, Y=640.5; longitude 97.336 degrees W, latitude 56.004 degrees N).

7.1.2 Spatial Coverage Map

Not available.

7.1.3 Spatial Resolution

The "footprint" of the instrument collecting signal in the nadir position was a circle of a diameter of approximately 44 cm. At non-nadir positions, the footprint would become an ellipse having its major axis increasing in the direction of displacement from the nadir. At 45 degrees, that axis was about 64 cm. The minor axis stays practically unchanged vs. displacement. This implies that also the area of the observed ellipse increases for non-nadir viewing angles.

7.1.4 Projection

Not applicable.

7.1.5 Grid Description

In all cases, the actual investigated spots were selected near the corners of a local rectangular coordinate system (grid). In the OJP forest it was a 10- x 10-m grid, and the examined sites had the following coordinates (all numbers are given in meters), where the first of the coordinates denotes bearing southeast of the T7Q8T flux tower (130 degrees relative to the north), and the second one northeast (40 degrees relative to the north).

(90: 12)
(100.8: 9.8)
(110.8: 8.5)
(120.8: -0.8)
(81: -11)
(90.6: -20)
(110.7: -19.8)

The YJP site was covered by a 5- x 5-m grid, anchored at the T8S9X tower. The spot coordinates were:

(160: 28.2)
(130: 6.3)
(121.6: 5)
(120.8: 15)
(126.4: 20)
(130.9: 25)
(136.3: 30.2)
(146.9: 35)

with the angular orientation of the axes identical as in the OJP case.

The YA grid was also 10 x 10 m, yet its (0: 0) origin was chosen arbitrarily in the forest, as there were no discriminated points or objects at the W0Y5A site to which such a grid could be anchored. The first and second coordinates were measured along the axes directed toward east and north, respectively. On 13-JUN-1994 they were:

(-20: -19)
(-20: -8.8)
(-20: 1)
(-20: 10.9)
(-20: 21)
(-20: 31.5)
(-20: 42.4)
(18.9: -20) (no photo available from 13-JUN-1994)
(19.2: -10)
(18.5: 0)
(19: 10)
(18.9: 20)
(8.9: 10) and
(-1.1: 0)

On 31-JUL-1994 all the above sites underwent investigation one more time. The actual positions of the instrument footprint were in most cases reproduced with the accuracy better than 0.1 m. In two instances, however, namely for sites (-20: 21) and (-20: 42.4), it can be inferred from the appropriate photos that the difference between the coordinates on those two dates may have been considerably larger, and that in fact signals from different patches of the ground may have been recorded. In addition, data from a site having coordinates (-11.1: -10) were also acquired on that day.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

The data pertaining to the OJP forest were recorded on two different days: the (81: -11), (90.6: -20) and (110.7: -19.8) sites were investigated on 16-JUL-1994, whereas the remaining OJP sites were investigated on 21-JUL-1994. All the data pertaining to the YJP forest were recorded on 17-JUL-1994. The YA data were recorded twice at the same sites: on 13-JUN-1994 and on 31-JUL-1994.

7.2.2 Temporal Coverage Map

The times of measurements (all in Greenwich Mean Time (GMT)) are given below.

TABLE IIa: Times of data acquisition at the Old Jack Pine site (GMT):

SITE (OJP)	16-JUN-1994
(81: -11)	15:48
(90.6: -20)	16:10
(110.7: -19.8)	16:38

SITE (OJP)	21-JUL-1994
(90: 12)	16:22
(100.8: 9.8)	16:40
(120.8: -0.8)	19:12
(110.8: 8.5)	19:34

TABLE IIb: Times of data acquisition at the Young Jack Pine site (GMT):

SITE (YJP)	17-JUL-1994
(130: 6.3)	15:45
(121.6: 5)	16:09
(120.8: 15)	16:25
(126.4: 20)	16:42
(130.9: 25)	17:00
(136.3: 30.2)	18:15
(146.9: 35)	18:58
(160: 28.2)	19:15

TABLE IIc: Times of data acquisition in the Young Aspen forest (GMT):

SITE (YA)	13-JUN-1994	31-JUL-1994
(-20: -19)	15:25	18:02
(-20: -8.8)	16:09	18:15
(-20: 1)	16:20	18:24
(-20: 10.9)	16:28	18:35
(-20: 21)	16:40	18:44
(-20: 31.5)	16:58	19:01
(-20: 42.4)	17:26	19:10
(18.9: -20)	19:23	20:02
(19.2: -10)	19:35	19:50
(18.5: 0)	19:50	19:42
(19: 10)	20:00	19:31
(18.9: 20)	20:04	19:22
(8.9: 10)	20:14	20:33
(-1.1: 0)	20:23	20:23
(-11.1: -10)	-	20:15

7.2.3 Temporal Resolution

At each site, carrying out the measurements, including the successive placing of the mount in all seven positions, took a few minutes. However, the actual data recording time was much shorter: the spectral series of the reference panel were acquired in the time span of 88 or 175 ms each, while those of the forest understory - over 700 ms or 1.4 s, depending on the luminance intensity.

7.3 Data Characteristics

7.3.1 Parameter/Variable

The parameters contained in the data files on the CD-ROM are:

```
          Column Name
------------------------------
SITE_NAME
SUB_SITE
DATE_OBS
TIME_OBS
WAVELENGTH
REFL_45_DEG_FORWARD_VIEW
REFL_30_DEG_FORWARD_VIEW
REFL_15_DEG_FORWARD_VIEW
REFL_NADIR_VIEW
REFL_15_DEG_BACKWARD_VIEW
REFL_30_DEG_BACKWARD_VIEW
REFL_45_DEG_BACKWARD_VIEW
RELATIVE_VIEW_AZ_ANG
SOLAR_ZEN_ANG
SOLAR_AZ_ANG
LOCAL_COORD
CRTFCN_CODE
REVISION_DATE
```

7.3.2 Variable Description/Definition

The descriptions of the parameters contained in the data files on the CD-ROM are:

```
          Column Name                              Description
------------------------------ --------------------------------------------------
SITE_NAME                      The identifier assigned to the site by BOREAS,
                               in the format SSS-TTT-CCCCC, where SSS identifies
                               the portion of the study area: NSA, SSA, REG,
                               TRN, and TTT identifies the cover type for the
                               site, 999 if unknown, and CCCCC is the identifier
                               for site, exactly what it means will vary with
                               site type.
SUB_SITE                       The identifier assigned to the sub-site by
                               BOREAS, in the format GGGGG-IIIII, where GGGGG is
                               the group associated with the sub-site
                               instrument, e.g. HYD06 or STAFF, and IIIII is the
                               identifier for sub-site, often this will refer to
                               an instrument.
DATE_OBS                       The date on which the data were collected.
TIME_OBS                       The Greenwich Mean Time (GMT) when the data were
                               collected.
WAVELENGTH                     Spectral wavelength at which measurement was
```

	acquired.
REFL_45_DEG_FORWARD_VIEW	Spectral reflectance measured at a 45 degree forward scatter angle.
REFL_30_DEG_FORWARD_VIEW	Spectral reflectance measured at a 30 degree forward scatter angle.
REFL_15_DEG_FORWARD_VIEW	Spectral reflectance measured at a 15 degree forward scatter angle.
REFL_NADIR_VIEW	Spectral reflectance measured at nadir.
REFL_15_DEG_BACKWARD_VIEW	Spectral reflectance measured at a 15 degree backward scatter angle.
REFL_30_DEG_BACKWARD_VIEW	Spectral reflectance measured at a 30 degree backward scatter angle.
REFL_45_DEG_BACKWARD_VIEW	Spectral reflectance measured at a 45 degree backward scatter angle.
RELATIVE_VIEW_AZ_ANG	The relative view azimuth angle.
SOLAR_ZEN_ANG	The angle from the surface normal (straight up) to the sun during the data collection.
SOLAR_AZ_ANG	Direction referred to as a circular scale of degrees read clockwise describing the position of the sun where 0=north, 90=east, 180=south and 270=west.
LOCAL_COORD	Local coordinate system set up by the TE09 team taking spectral reflectance measurements. Please see the documentation for further explanation.
CRTFCN_CODE	The BOREAS certification level of the data. Examples are CPI (Checked by PI), CGR (Certified by Group), PRE (Preliminary), and CPI-??? (CPI but questionable).
REVISION_DATE	The most recent date when the information in the referenced data base table record was revised.

7.3.3 Unit of Measurement

The measurement units for the parameters contained in the data files on the CD-ROM are:

Column Name	Units
SITE_NAME	[none]
SUB_SITE	[none]
DATE_OBS	[DD-MON-YY]
TIME_OBS	[HHMM GMT]
WAVELENGTH	[micrometers]
REFL_45_DEG_FORWARD_VIEW	[percent]
REFL_30_DEG_FORWARD_VIEW	[percent]
REFL_15_DEG_FORWARD_VIEW	[percent]
REFL_NADIR_VIEW	[percent]
REFL_15_DEG_BACKWARD_VIEW	[percent]
REFL_30_DEG_BACKWARD_VIEW	[percent]
REFL_45_DEG_BACKWARD_VIEW	[percent]
RELATIVE_VIEW_AZ_ANG	[degrees]
SOLAR_ZEN_ANG	[degrees]
SOLAR_AZ_ANG	[degrees]
LOCAL_COORD	[none]
CRTFCN_CODE	[none]
REVISION_DATE	[DD-MON-YY]

7.3.4 Data Source

The sources of the parameter values contained in the data files on the CD-ROM are:

Column Name	Data Source
SITE_NAME	[BORIS Designation]
SUB_SITE	[BORIS Designation]
DATE_OBS	[Human Observer]
TIME_OBS	[Human Observer]
WAVELENGTH	[Field Equipment]
REFL_45_DEG_FORWARD_VIEW	[Spectrometer]
REFL_30_DEG_FORWARD_VIEW	[Spectrometer]
REFL_15_DEG_FORWARD_VIEW	[Spectrometer]
REFL_NADIR_VIEW	[Field Equipment]
REFL_15_DEG_BACKWARD_VIEW	[Spectrometer]
REFL_30_DEG_BACKWARD_VIEW	[Spectrometer]
REFL_45_DEG_BACKWARD_VIEW	[Spectrometer]
RELATIVE_VIEW_AZ_ANG	[Spectrometer]
SOLAR_ZEN_ANG	[Calculated]
SOLAR_AZ_ANG	[Calculated]
LOCAL_COORD	[Human Observer]
CRTFCN_CODE	[BORIS Designation]
REVISION_DATE	[BORIS Designation]

7.3.5 Data Range

The following table gives information about the parameter values found in the data files on the CD-ROM.

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SITE_NAME	NSA-ASP-AUX09	NSA-YJP-FLXTR	None	None	None	None
SUB_SITE	9TE09-SPC01	9TE09-SPC01	None	None	None	None
DATE_OBS	13-JUN-94	31-JUL-94	None	None	None	None
TIME_OBS	1525	2033	None	None	None	None
WAVELENGTH	.34342	1.06808	None	None	None	None
REFL_45_DEG_FORWARD_VIEW	.73	53.11	None	None	None	Blank
REFL_30_DEG_FORWARD_VIEW	.67	49.34	None	None	None	Blank
REFL_15_DEG_FORWARD_VIEW	.62	43.75	None	None	None	Blank
REFL_NADIR_VIEW	.61	54.87	None	None	None	None
REFL_15_DEG_BACKWARD_VIEW	.73	40.68	None	None	None	Blank
REFL_30_DEG_BACKWARD_VIEW	.75	38.11	None	None	None	Blank
REFL_45_DEG_BACKWARD_VIEW	.9	39.4	None	None	None	Blank
RELATIVE_VIEW_AZ_ANG	12	175	None	None	None	Blank
SOLAR_ZEN_ANG	35	47	None	None	None	Blank
SOLAR_AZ_ANG	120	203	None	None	None	Blank
LOCAL_COORD	N/A	N/A	None	None	None	None

```
CRTFCN_CODE          CPI          CPI          None    None    None    None
REVISION_DATE        25-JUN-98    29-JUN-98    None    None    None    None
-----------------------------------------------------------------------------

Minimum Data Value -- The minimum value found in the column.
Maximum Data Value -- The maximum value found in the column.
Missng Data Value  -- The value that indicates missing data. This is used to
                      indicate that an attempt was made to determine the
                      parameter value, but the attempt was unsuccessful.
Unrel Data Value   -- The value that indicates unreliable data.  This is used
                      to indicate an attempt was made to determine the
                      parameter value, but the value was deemed to be
                      unreliable by the analysis personnel.
Below Detect Limit -- The value that indicates parameter values below the
                      instruments detection limits.  This is used to
                      indicate that an attempt was made to determine the
                      parameter value, but the analysis personnel determined
                      that the parameter value was below the detection
                      limit of the instrumentation.
Data Not Cllctd    -- This value indicates that no attempt was made to
                      determine the parameter value.  This usually
                      indicates that BORIS combined several similar but
                      not identical data sets into the same data base table
                      but this particular science team did not
                      measure that parameter.

Blank -- Indicates that blank spaces are used to denote that type of value.
N/A   -- Indicates that the value is not applicable to the respective column.
None  -- Indicates that no values of that sort were found in the column.
-----------------------------------------------------------------------------
```

7.4 Sample Data Record

The following is a sample of the first few records from the data table on the CD-ROM:

```
SITE_NAME,SUB_SITE,DATE_OBS,TIME_OBS,WAVELENGTH,REFL_45_DEG_FORWARD_VIEW,
REFL_30_DEG_FORWARD_VIEW,REFL_15_DEG_FORWARD_VIEW,REFL_NADIR_VIEW,
REFL_15_DEG_BACKWARD_VIEW,REFL_30_DEG_BACKWARD_VIEW,REFL_45_DEG_BACKWARD_VIEW,
RELATIVE_VIEW_AZ_ANG,SOLAR_ZEN_ANG,SOLAR_AZ_ANG,LOCAL_COORD,CRTFCN_CODE,
REVISION_DATE
'NSA-OJP-FLXTR','9TE09-SPC01',16-Jul-94,1548,1.06808,7.5,7.08,6.67,8.75,9.17,10,
11.25,50,46,121,'(81:-11)','CPI',25-Jun-98
'NSA-OJP-FLXTR','9TE09-SPC01
',16-Jul-94,1548,1.06666,7.08,7.08,7.92,8.33,8.75,10.42,
12.08,50,46,121,'(81:-11)','CPI',25-Jun-98
```

8. Data Organization

8.1 Data Granularity

The smallest unit of orderable data is data collected on one day at one site.

8.2 Data Format(s)

The Compact Disk-Read Only Memory (CD-ROM) files contain American Standard Code for Information Interchange (ASCII) numerical and character fields of varying length separated by commas. The character fields are enclosed with single apostrophe marks. There are no spaces between the fields.

Each data file on the CD-ROM has four header lines of HyperText Markup Language (HTML) code at the top. When viewed with a Web browser, this code displays header information (data set title, location, date, acknowledgments, etc.) and a series of HTML links to associated data files and related data sets. Line 5 of each data file is a list of the column names, and line 6 and following lines contain the actual data.

9. Data Manipulations

9.1 Formulae

The formulae used in processing the reflection coefficient data are rather simple and straightforward in that they do not require any particular justification and/or derivation explanation. First of all, all the data are corrected for dark current signal:

Icor(lambda) = Iraw(lambda) - IDC(lambda) (2)

where IDC(lambda) is a value averaged over N successive measurements (in case of the dark current N = 5), taken over the same period of time (integration time) as the raw data:

IDC(lambda) = (Sum(I1DC(lambda) + ... + INDC(lambda)))/N (3)

Subsequently, the corrected white-reference and forest understory series are used to calculate the reflection coefficient of the understory:

R(lambda, theta) = Iund(lambda, theta)/Iwr(lambda, theta=0)* tauwr/tauund (4)

where the understory signals are averaged over 3 (for each angle setting) measurements, while the white reference data over 6 measurements (3 taken before and 3 after the recording of all the understory signals for a given site), according to a formula analogous to (2).The appropriate tau-values are the integration times of the white reference and understory signals, and theta is the angle between the swing arm and the vertical.

9.1.1 Derivation Techniques and Algorithms

The conversion of the originally acquired binary spectra to ASCII format was carried out with the aid of a program "portspec.exe", provided with the Personal Spectrometer II software utility package designed to run on the IBM family of PCs.

9.2 Data Processing Sequence

9.2.1 Processing Steps

The dark current-corrected data pertaining to both white reference and raw understory measurements were converted to the ASCII format on an IBM PC. The ASCII files were subsequently imported into an Excel worksheet. Both sets of data were in turn averaged over the appropriate number of records, according to the formula similar to (3). The following step was to apply formula (4) to calculate the reflection coefficient. In this way, the final result of the data processing sequence was, in the case of each site, a table representing the functional dependence of the understory reflection coefficient on the wavelength and additionally - in the cases of OJP and YJP - also on the viewing angle.

9.2.2 Processing Changes

None.

9.3 Calculations

All the necessary calculations, essentially making use of formulae (3) and (4), were performed using the Microsoft Excel 5.0 spreadsheet software.

9.3.1 Special Corrections/Adjustments

The first channel of the PS II spectrometer corresponding to lambda = 342 nm yielded erroneous readings, and thus has not been included in tables and graphs.

9.3.2 Calculated Variables

The calculated variables are reflection coefficient spectra whose functional form R(lambda, theta) is defined by Eqn. (4). It is a function of two arguments (or just one in the case of YA forest) and has dimensionless values that can be expressed as ordinary or percentage fractions.

9.4 Graphs and Plots

All the graphs were created with the aid of the Excel 5.0 spreadsheet software. The graphs include plots - in the rectangular coordinate system - of the reflection coefficient dependence on the wavelength for various viewing angles, as well as plots in the polar coordinate system of the angular dependence of the signal intensity at selected wavelengths. Graphs of the averaged (separately over all the OJP, YJP, and YA sites) reflection coefficient at nadir were also produced.

10. Errors

10.1 Sources of Error

The main source of error appears to be the following fact, which found confirmation in an auxiliary experiment, carried out in the laboratory. In the off-nadir positions, the wooden rod that serves as a swinging arm tends to bend toward the ground under its own weight and the weight of the attached equipment. Because of the considerable length of the arm, even a slight amount of bending results in an appreciable shift of the FOV ellipse away from nadir. The ellipse also becomes slightly larger, as bending of the rod effectively increases both the angle theta and the actual distance from the sensor to the viewing spot, which ideally is supposed to remain constant. It turned out that for the left and right 45-degree position of the arm, the common FOV is not quite 50%. A similar condition, albeit less severe, also exists for smaller deflection angles. Hence the aim of measuring the angular reflection coefficient of the same spot on the ground has been to a certain degree compromised. This effect becomes particularly aggravating in a highly diverse environment such as a forest. Irregularly and asymmetrically shaded areas, tree branches, dead tree trunks, and other inhomogeneities cause the signal amplitude to depend on the "swing" angle in a very complex manner, which includes not only the a priori expected direct dependence of the reflection coefficient on the reflection angle, but also indirectly via the change in the position of an actual spot on the ground giving rise to the recorded spectrum. Hence, the directional variability of the reflection coefficient signal, which might be perceived with a coarser resolution from a much larger distance, is often effectively masked. This problem is further complicated in forests featuring rich undercanopy vegetation, which tends to change perspective with the viewing angle and sometimes even completely obscures the view of the ground. Another, perhaps only moderately important, source of error is the variation in the signal amplitude due to fluctuations of the illumination intensity and possibly also due to the movement of vegetation caused by wind. We try to alleviate these effects by recording a few, rather than one, spectral series for each case, and using the average as the result.

10.2 Quality Assessment

10.2.1 Data Validation by Source

The data to be submitted constitute only a part of all the data recorded in the course of the field campaign, and are in our opinion the most reliable and error-free. Data containing crude inaccuracies and uncertainties due to malfunctioning or missing parts of equipment, weak batteries, smoke or fog suddenly appearing in the middle of measurements, etc., were eliminated. Certain submitted data, however, may also initially seem to make little sense, mostly in the cases of sites with pronounced 3-D structures present, for instance low tree branches or undercanopy vegetation. These complexities notwithstanding, we have decided to include such data as well, considering that their contribution would render more realistic the overall representation of the understory reflectance.

10.2.2 Confidence Level/Accuracy Judgment

In spite of the above shortcomings, the collected data do carry and can yield a considerable amount of information, especially when carefully reviewed in the context of the accompanying photo pictures pertaining to each site. The angular variation of the signal amplitudes is usually intuitively correct for cases where it is governed mainly by the forward and backward scatter, that is to say when the forest floor is well sunlit and has an approximately homogeneous appearance over the region of data collection; i.e., at least 1 m x 0.5 m at each investigated spot. For other cases, it is a priori less predictable and its character alters a great deal from site to site, depending on which side of the scene with respect to the nadir point seems to be greener, brighter, more brown, more beige, etc., but even there the results generally tend to be in agreement with intuition and common sense. The already-mentioned lack of ordering from the point of view of the solar plane versus measurement plane orientation, as well as a virtually random, so to speak, a priori choice of the spots to investigate, introduces also a positive aspect to the qualitative analysis of the results, particularly from the remote sensing point of view. A set of data characteristic of the "clean" situations both in the sense of appearance and angular orientation would arguably constitute a better basis for testing various simple theories and models. However, while it certainly would be useful to have such a data set, it could not really be considered as representative of the forest floor as a whole, since the certain amount of bias necessary to make the selections might discriminate either for or against all the features correlated with the criterion of choice, for instance different vegetation in more intensely sunlit places. The data also look promising from the spectral point of view. A relatively large number of spectral series, taken at different sites and at different angles, can provide material for various types of analyses, including correlation of the spectra with the type of ground cover and undercanopy vegetation, relative luminance of shadowed vs. sunlit areas, averaging spectra from several sites in a given forest type to produce a representative of the understory signature, etc..

10.2.3 Measurement Error for Parameters

The uncertainties associated with the diversity in appearance of the forest floor and/or the presence of 3-D structures at some of the sites, do not lend themselves easily to a quantitative treatment, as the signal amplitudes can vary rather wildly not only from site to site, but sometimes even from angle to angle at the same site. The statistical error associated with signal intensity fluctuations during the angular and reference panel measurements was estimated using the standard formula for the uncertainty in the arithmetic mean of N samples xi:

$$S\langle x\rangle = ((\langle X^2\rangle - \langle X\rangle^2)/(N-1))^{1/2} \quad (5)$$

where N was 3 for each arm position at each site, and 6 for the reference panel calibration runs. The above formula was evaluated independently for the signals in each of the 512 wavelength increments. The relative error of the calibrated reflection coefficient values at each wavelength was subsequently obtained as:

$$\text{Delta } R/R = ((S\langle wr\rangle/\langle wr\rangle)^2 + (S\langle und\rangle/\langle und\rangle)^2)^{1/2} \quad (6)$$

where "wr" stands for the white reference and "und" for the understory signals, respectively. In the majority of cases, this error turned out to be not particularly significant, at least in the 400 - 900-nm wavelength interval, where it often did not exceed 2%, and very rarely reached 4%. For other wavelengths, however, it tended to be generally larger, peaking for the lower and upper limits of our scanning region (342 and 1068 nm, respectively) at values approximately 2 - 2.5 times larger than the middle plateau. Such a behavior is not unexpected in view of the very weak white reference signal for the limiting wavelengths, which increases the relative uncertainty. It is reflected in a noticeable increase in the signal-to-noise ratio for wavelengths longer than 900 nm, shared by virtually all the spectral curves.

10.2.4 Additional Quality Assessments

Even though derived from in situ measurements, the information contained in the collected data has a distinctly statistical character. First of all, the variable measured at the ground level is, strictly speaking, the local relative luminance, rather than reflectance, of the patch of ground corresponding to the instrument's footprint. To obtain the actual reflectance one would have to, by definition, normalize the understory signal to the reference signal acquired under identical illumination conditions, i.e., sun or shade, depending on the site. Such an approach has been chosen by J. Miller's team (RSS-19, York University) but is not the case with our data, based on the reference panel routinely fully sunlit. In a broader sense, however, one might argue that these results constitute a very reasonable statistical representation (sample) of a mean reflectance averaged over a larger area and thus taking into account all its features, including shadows that vary with the illumination conditions. In the same way, for instance, the perceived reflectance of a fully grass-covered lawn may be different from the reflectance of a single grass blade, because of the structural complexity of the lawn surface. Furthermore, all the submitted data are valid in the sense that they were acquired in the manner described in Section 5 while all the elements of the equipment were functioning properly to the best of our knowledge. However, because of the FOV being factually subject to variations with the viewing angle, as well as of the presence of pronounced 3-D structures in several of the investigated sites, it is not possible to know exactly which objects and/or area had in each case contributed to the recorded spectrum, especially for the off-nadir measurements. This circumstance also underscores the particular suitability of the data to be viewed in a statistical context.

10.2.5 Data Verification by Data Center

Data were examined for general consistency and clarity.

11. Notes

11.1 Limitations of the Data

While preponderance of the submitted data have been normalized to the fully sunlit reference panel (see also Sections 1.5 and 10.2.4), the calibration of the June YA data was carried out with the panel in (partial) shadow, and therefore they are not entirely compatible with the series recorded in July. However, we still wish to present some of these data, while being particularly candid and clear about their limited compatibility with the main data set.

11.2 Known Problems with the Data

Data from the OJP site (120.8, -0.8) seem to be not fully reliable, especially for -30 degrees and -45 degrees. Both a field note and the photo of this site indicate, that at those arm positions the detector might have been very close to a leafy tree branch, and hence its FOV blocked (at least partially). This assumption is consistent with the apparent amplitudes of the appropriate spectral curves. The OJP site (110.7, -19.8) data are distorted by the fact, that the right-hand side of the scene was dominated by a deep hole in the ground, caused by a falling tree. As that side was predominantly viewed by the detector at positive swing angles, the observed angular variation of the signal is largely artificial, and does not reflect the actual differences in the forward- and backward-scattered signal, but rather the highly asymmetrical disposition of the scene. The results pertaining to the OJP (90, 12) site rank on the whole among the best of all the series of OJP data, as the forest floor there appeared fairly homogeneous from the optical point of view. However, according to a field note, at arm positions of

30 degrees and 45 degrees, the shadow of the camera found itself in the FOV. It can be estimated from the picture that at most 8% of the FOV is occupied by the camera shadow, so it should not introduce too big an error. As already mentioned in Section 7.1.5, at sites (-20, 21) and (-20, 42.4) in the YA, not the same patches of ground may have undergone observation on 13-JUN-1994 and 31-JUL-1994, contrary to what was intended. The reflection coefficient spectrum of the YA site (18.9, -20) from 13-JUN-1994 has an unusual shape, although no obvious inconsistency in the raw data used to produce that profile is apparent. Because of that, and also in view of the unavailability of the corresponding photograph, that spectrum has not been taken into account when calculating the average.

11.3 Usage Guidance

An important caution to bear in mind when working with these data is that no set of results pertaining to an individual site should be regarded as "typical" for a particular kind of forest since, in principle, there is no such thing as a typical spectral signal (meaning both amplitude and signature) due to a small fragment of the understory of the size of our instrument's footprint. On the contrary, the only typical feature of the ground appearance is its great diversity, at least on the scale of our measurements. This notice is particularly relevant to the case of the OJP data, which tend to differ more from site to site than the YJP or YA spectra. The whole data set is "randomized" even further due to the absence of constant orientation of the plane of measurements with respect to the solar azimuth (see the following Section), and partial shifting of the FOV with the angle at which the spectra were acquired.

11.4 Other Relevant Information

Table III gives the solar angles phisol and thetasol, as well as the relative (solar plane - swing plane) azimuth (see also Figure 2) relevant in the OJP and YJP measurements. This table is also included as a data file on the BOREAS CD.

TABLE III

			Degrees	
Date	Site	Solar Zenith Angle	Solar Azimuth Angle*	Relative Azimuth
	OJP			
16-JUL	(81: -11)	46	121	~50
16-JUL	(90.6: -20)	44	127	86
16-JUL	(110.7: -19.8)	41	136	~120
21-JUL	(90: 12)	43	131	~175
21-JUL	(100.8: 9.8)	41	137	92
21-JUL	(120.8: -0.8)	36	194	~90
21-JUL	(110.8: 8.5)	37	203	~100
	YJP			
17-JUL	(130: 6.3)	47	120	~170
17-JUL	(121.6: 5)	44	126	~100
17-JUL	(120.8: 15)	42	131	~100
17-JUL	(126.4: 20)	41	137	~88
17-JUL	(130.9: 25)	39	143	102
17-JUL	(136.3: 30.2)	35	171	~127
17-JUL	(146.9: 35)	35	189	120
17-JUL	(160: 28.2)	35	195	12

* clockwise from the true North direction
ã estimated from the direction of shadows in the photo

The solar angles have been estimated with the aid of the Multiyear Interactive Computer Almanac software system (MICA, see Section 14.1) taking into account the Julian day number, hour of the day and geographical longitudes and latitudes of the OJP and YJP sites, and rounded off to the nearest degree.

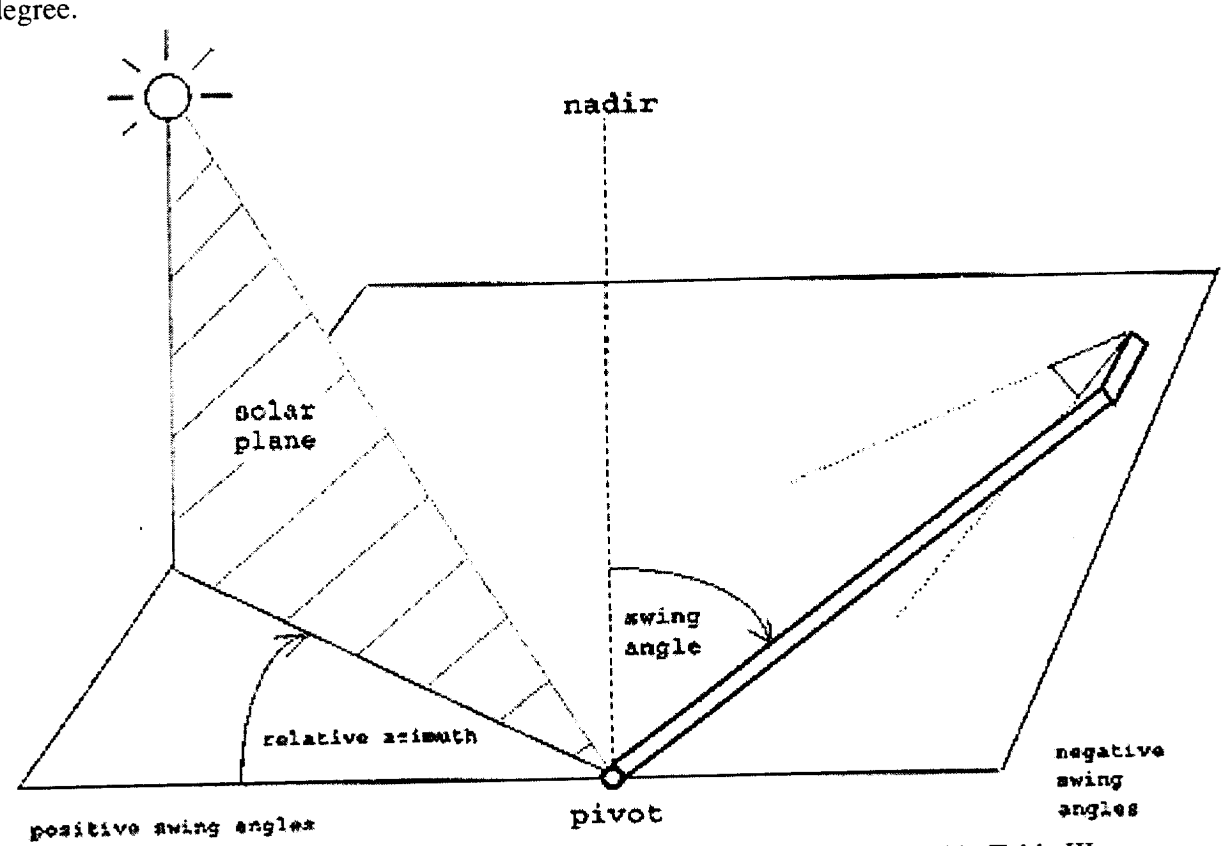

Figure 2: a scematic diagram explaining some of the angle listed in Table III.

12. Application of the Data Set

This data set was designed to: (1) study the spatial variability of in situ spectral reflection coefficient measurements of the understory at accessible sites in the NSA; (2) study the seasonal change of the in situ spectral measurements during leaf-up; (3) study the angular dependence of spectral measurements of the understory; and (4) obtain laboratory spectral measurements of canopy and understory components.

13. Future Modifications and Plans

In addition to the results that have been interpreted and are presented in this report, we have a substantial amount of other data. Those data originate predominantly from measurements aimed at obtaining separate spectral characteristics of "pure" elements of the forest landscape, in particular specific plant species, litter, soil, etc.. They were procured either by means of in situ estimation at narrow (1 degrees or 5 degrees) FOV, or in the laboratory with the aid of an integrating sphere (LI-COR Model 1800-12 Integrating Sphere). However, an initial quality screening as well as analysis of that additional material would require considerable extra time and effort, and we are at present unable to plan any action along these lines in the foreseeable future. Prospective investigation of the various questions related to the problems of forest understory reflectance could be pursued along several lines. In addition to the issue of shadows, it would be interesting, especially in forests with little or no undercanopy growth, to examine more systematically the angular reflectance function in relation to the solar coordinates. Tracing changes in reflectivity due to a recent rainfall (i.e., dry vs. wet understory) also looks as a challenging task. Following the approach of Goward et al. (1994) (see Section 17.2), it would be quite useful as well to obtain some specific information on the spectral reflectivity of old wood, particularly in view of its abundant presence in certain types of the boreal forests, and likely appreciable contribution to the understory signal.

14. Software

14.1 Software Description

- Program "portspec.exe", developed by Microsoft Corporation, and provided with the Personal Spectrometer II software utility package. The program was used to convert the originally acquired binary spectra to the ASCII format.
- Excel 5.0 for Windows software, used to further process the ASCII data.
- MICA for DOS 1990-1999, Version 1.0. Developed by the staff of Astronomical Applications Department, U.S. Naval Observatory,3450 Massachusetts Avenue, N.W., Washington, DC 20392-5420, USA. Used to calculate sun's angular coordinates.

14.2 Software Access

The software is commercially available.

15. Data Access

The NSA understory spectral reflectance data are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services
Oak Ridge National Laboratory
P.O. Box 2008 MS-6407
Oak Ridge, TN 37831-6407
Phone: (423) 241-3952
Fax: (423) 574-4665
E-mail: ornldaac@ornl.gov or ornl@eos.nasa.gov

15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics http://www-eosdis.ornl.gov/.

15.3 Procedures for Obtaining Data

Users may obtain data directly through the ORNL DAAC online search and order system [http://www-eosdis.ornl.gov/] and the anonymous FTP site [ftp://www-eosdis.ornl.gov/data/] or by contacting User Services by electronic mail, telephone, fax, letter, or personal visit using the contact information in Section 15.1.

15.4 Data Center Status/Plans

The ORNL DAAC is the primary source for BOREAS field measurement, image, GIS, and hardcopy data products. The BOREAS CD-ROM and data referenced or listed in inventories on the CD-ROM are available from the ORNL DAAC.

16. Output Products and Availability

16.1 Tape Products

None.

16.2 Film Products

None.

16.3 Other Products

These data are available on the BOREAS CD-ROM series.

17. References

17.1 Platform/Sensor/Instrument/Data Processing Documentation

ASP Personal Spectrometer II Technical Reference. Analytical Spectral Devices, Inc., Boulder, CO.

ASP Personal Spectrometer II User's Reference. Analytical Spectral Devices, Inc., Boulder, CO.

ASP Personal Spectrometer II Utility Reference. Analytical Spectral Devices, Inc., Boulder, CO.

MICA for DOS 1990-1999, Version 1.0, User's Guide. Astronomical Applications Department, U.S. Naval Observatory,3450 Massachusetts Avenue, N.W., Washington, DC 20392-5420, USA.

17.2 Journal Articles and Study Reports

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17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

- Bidirectional reflectance - In the case of strongly anisotropic source of illumination (e.g., the sun), the functional dependence of the surface-reflected radiation intensity on both the two angular coordinates of the light source (solar coordinates) and the direction of reflection (also defined by two angles).
- Dark count (dark current), IDC - A residual electrical signal outputted by a photoelectric sensor (e.g., photodiode) under its normal operating voltage but in the absence of any incoming optical signal.
- Forest litter - Naturally occurring, dead but once part of a living plant, components of the forest floor cover; this category comprises, in the first instance, fallen tree leaves and needles.
- Forest understory - All the components present and observable at the ground level in the forest environment; may comprise lichens, mosses, mushrooms, low vascular vegetation, forest litter, soil, dead tree trunks, etc.
- Holographic grating - A type of diffraction grating whose groove structure in the form of interference fringe pattern has been holographically recorded and permanently fixed in photographic emulsion.
- Instrument footprint - A surface fragment actually undergoing observation or giving rise to the detected signal, its shape and size determined by the geometry of the instrument sensor and by the surface sensor distance.

- Julian day number - The interval of time in days since January 1, 4713 BC, Julian Calendar. For instance, 16-JUL-1994 is Julian day 2449551.
- Lambertian reflector - A conceptual surface reflecting 100% of the impinging radiation in such a way, that its radiance intensity is isotropic irrespective of the irradiance conditions. Hence, the perceived radiance (brightness) of such a reflector does not depend on the direction of view.
- Lichens - Primitive, autotrophic plants of the order Lichenace , composed of parasitic fungi interwoven with algal cells. Many species of lichens with variously colored crusts occur, often abundantly, in certain types of forests on rocks, soil, tree bark, etc.
- Solar azimuth, phisol - The angle formed by the solar plane and the plane of the local meridian.
- Solar plane - The plane defined by the vertical upward (zenith) direction and the direction toward the instantaneous position of the sun in the sky as perceived by an observer on the ground. At the moment of the sun position exactly coinciding with the zenith point, the notion of solar plane loses its meaning.
- Solar zenith angle, thetasol - The angle between the zenith direction and the direction toward the instantaneous position of the sun in the sky. Solar zenith angle and solar elevation above the horizon complement each other to 90 degrees.

19. List of Acronyms

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ASCII   - American Standard Code for Information Interchange
ASD     - Analytical Spectral Devices Inc.
BOREAS  - BOReal Ecosystem-Atmosphere Study
BORIS   - BOREAS Information System
CD-ROM  - Compact Disk-Read-Only Memory
DAAC    - Distributed Active Archive Center
FOV     - Field of View
GIS     - Geographic Information System
GMT     - Greenwich Mean Time
GSFC    - Goddard Space Flight Center
HTML    - HyperText Markup Language
IBM     - International Business Machines Inc.
MICA    - Multiyear Interactive Computer Almanac
NAD83   - North American Datum of 1983
NASA    - National Aeronautics and Space Administration
NSA     - Northern Study Area
OA      - Old Aspen
OBS     - Old Black Spruce
OJP     - Old Jack Pine
ORNL    - Oak Ridge National Laboratory
PANP    - Prince Albert National Park
PAR     - Photosynthetically Active Radiation
PC      - Personal Computer
RSS     - Remote Sensing Science
SSA     - Southern Study Area
TE      - Terrestrial Ecology
URL     - Uniform Resource Locator
YA      - Young Aspen
YJP     - Young Jack Pine
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20. Document Information

20.1 Document Revision Date
Written: 30-May-1997
Last Updated: 06-Jul-1999

20.2 Document Review Date(s)
BORIS Review: 09-Feb-1999
Science Review: 14-Oct-1998

20.3 Document ID

20.4 Citation
When using these data, please include the following acknowledgment as well as citations of relevant papers in Section 17.2:

Jan Supronowicz of the Centre de Recherche en Geomatique and Geoffrey Edwards of the Centre de Recherche en Geomatique.

If using data from the BOREAS CD-ROM series, also reference the data as:

Edwards, G., K.P.B. Thomson, and A.P. Viau, "Relationship Between Measures of Absorbed and Reflected Radiation and the Photosynthetic Capacity of Boreal Forest Canopies and Understories." In Collected Data of The Boreal Ecosystem-Atmosphere Study. Eds. J. Newcomer, D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers. CD-ROM. NASA, 2000.

Also, cite the BOREAS CD-ROM set as:

Newcomer, J., D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers, eds. Collected Data of The Boreal Ecosystem-Atmosphere Study. NASA. CD-ROM. NASA, 2000.

20.5 Document Curator

20.6 Document URL

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 2000

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)
BOREAS TE-9 In Situ Understory Spectral Reflectance within the NSA

5. FUNDING NUMBERS
923
RTOP: 923-462-33-01

6. AUTHOR(S)
Jan Supronowicz, Geoffrey Edwards, Alain Viau, and Keith Thomson
Forrest G. Hall and Shelaine Curd, Editors

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS (ES)
Goddard Space Flight Center
Greenbelt, Maryland 20771

8. PEFORMING ORGANIZATION REPORT NUMBER
2000-03136-0

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS (ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
TM—2000–209891
Vol. 159

11. SUPPLEMENTARY NOTES
J. Supronowicz, G. Edwards, A. Viau, and K. Thomson: Université Laval, Sainte-Foy, Quebec, Canada; S. Curd: Raytheon ITSS, NASA Goddard Space Flight Center, Greenbelt, Maryland

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified–Unlimited
Subject Category: 43
Report available from the NASA Center for AeroSpace Information,
7121 Standard Drive, Hanover, MD 21076-1320. (301) 621-0390.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The BOREAS TE-9 team collected several data sets related to chemical and photosynthetic properties of leaves in boreal forest tree species. Spectral reflection coefficients of the forest understory at the ground level, in three boreal forest sites of Northern Manitoba (56 degrees N latitude and 98 degrees W longitude), were obtained and analyzed in 1994. In particular, angular variation of the reflection coefficients in the old jack pine and young jack pine forests, as well as nadir reflection coefficient in the young aspen forest, were investigated. The complexity of understory composition and the light patterns limited quantitative conclusions; however, a number of interesting trends in the behavior of the measured values can be inferred. In particular, the unique spectral profiles of lichens show very strongly in the old jack pine understory, yet are definitely less conspicuous for young jack pine, and virtually absent in the aspen forest. The angular variation of the reflection coefficient by the young pine understory seems to be significantly toned down by fine-structured branches and their shadows. Our study also indicates how difficult the ground reflection coefficient problem in a forest is, compared to certain previously investigated areas that have a more uniform appearance, such as prairie grassland, bare soil, or agricultural crops. This is due to several factors, generally typical of a forest environment, that may influence the overall understory reflection coefficient, including: (i) a strong diversity of the forest floor due to the presence of dead tree trunks, holes in the ground, patches of different types of vegetation or litter, etc.; (ii) pronounced 3-D structures at the ground level, such as shrubs, bushes, and young trees; and (iii) an irregular shadow mosaic, which not only varies with the time of the day, causing intensity variations, but likely also effectively modifies the spectrum of the illuminating light and hence the reflection coefficient signal as well. The data are stored in tabular ASCII files.

14. SUBJECT TERMS
BOREAS, terrestrial ecology, leaf properties.

15. NUMBER OF PAGES
26

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39.18
298-102