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

Forrest G. Hall and Jaime Nickeson, Editors

Volume 45

BOREAS RSS-3 Atmospheric Measurements from a Helicopter-Mounted Sunphotometer

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July 2000

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BOREAS RSS-3 Atmospheric Measurements from a Helicopter-Mounted Sunphotometer

Charles L. Walthall, Sara Loechel, Rangasayi Halthore

Summary

The BOREAS RSS-3 team collected and processed helicopter-based measurements of atmospheric conditions to estimates of aerosol optical thickness and atmospheric water vapor. The automatic sun-tracking photometer for helicopters was deployed during all three 1994 IFCs at numerous tower and auxiliary sites in both the NSA and the SSA. Six spectral channels (440, 540, 613, 670, 870, and 1030 nm) were chosen to span the visible and NIR wavelengths and to avoid gaseous absorption. One additional channel, 940 nm, was selected to measure the water column abundance above the helicopter platform. The data are stored in tabular ASCII files.

Note: An extensive helicopter log (in Acrobat format) is available for the 1994 IFC's. Environmental, technical, instrumental, and operational conditions are noted for each observation where applicable. It is strongly recommended that any researcher doing extended work with this data set review this helicopter log.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS RSS-03 Atmospheric Measurements from a Helicopter-Mounted Sunphotometer

1.2 Data Set Introduction

The Remote Sensing Science (RSS)-03 helicopter-based optical depth measurements are used to perform atmospheric corrections to radiance to obtain at-ground reflectance estimates from the helicopter-mounted radiometers. Sunphotometer measurements were taken from a helicopter platform at BOReal Ecosystem-Atmosphere Study (BOREAS) forested tower and auxiliary sites simultaneously with radiometric ground measurements from the same platform. The instrumentation used was designed and developed at National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center (GSFC). The data were collected during the green-up, peak, and senescent stages of the growing season at numerous tower and auxiliary sites in both the Northern Study Area (NSA) and the Southern Study Area (SSA). The data derived from the sunphotometer cover the three Intensive Field Campaigns (IFCs) in 1994:

- 31-May - 10-Jun (IFC-1)
- 21-Jul - 08-Aug (IFC-2)
- 06-Sep - 16-Sep (IFC-3)

1.3 Objective/Purpose

The objective was to acquire atmospheric optical depth data of the study sites for assessments of spectral, spatial, and temporal variability of atmospheric aerosols and water vapor, and assessments of the impacts of these variability's on atmospheric correction of surface reflectance and vegetation indices. A helicopter with a pointable, stabilized mount was used to carry a spectrometer (visible and near-infrared (NIR)), a spectroradiometer, an infrared thermometer, and a video camera. The automatic sun-tracking photometer for helicopters (ASTPH) was deployed to provide data for calculations of irradiance for atmospheric correction of the other sensors.

1.4 Summary of Parameters

Helicopter-based, optical depth measurements during all three IFCs in 1994 at tower and auxiliary sites. Aerosol optical depths (ranging from 440 to 1030 nm) and atmospheric water vapor are reported.

1.5 Discussion

These measurements were collected as part of the effort to evaluate models that estimate surface biophysical characteristics from remotely measured optical signatures.

Successful use of a helicopter-mounted sunphotometer is demonstrated. Due to the rapid response time of the silicon detector and the associated electronics, the passage of the rotor blade is a nuisance that can be removed during data analysis. Sufficiently accurate values of the aerosol optical thickness are obtained in all channels. Variability in the measured voltages translates directly to variability in derived aerosol optical thickness.

The addition of an onboard automatic sun-tracking sunphotometer system has made the helicopter optical remote sensing system a self-contained mobile unit that can be used to acquire calibrated remote measurements of surface parameters. Initial experience with this system shows that accurate and reliable measurements of surface irradiance, surface reflectance, and temperature can be made in remote areas where surface access is difficult or impractical.

1.6 Related Data Sets

BOREAS RSS-01 PARABOLA Surface Reflectance and Transmittance Data
BOREAS RSS-02 Level-1b ASAS Imagery: At-sensor Radiance in BSQ Format
BOREAS RSS-03 Reflectance Measured from a Helicopter-Mounted SE-590
BOREAS RSS-03 Reflectance Measured from a Helicopter-Mounted Barnes MMR
BOREAS RSS-11 Ground Network of Sun Photometer Measurements
BOREAS RSS-12 Airborne Tracking Sunphotometer Measurements
BOREAS RSS-12 Automated Ground Sun Photometer Measurements in the SSA
BOREAS RSS-19 Background Spectral Reflectance Data
BOREAS RSS-20 POLDER Measurements of Surface BRDF

2. Investigator(s)

2.1 Investigator(s) Name and Title

Dr. Charles L. Walthall, Physical Scientist

2.2 Title of Investigation

Biophysical Significance of Spectral Vegetation Indices in the Boreal Forest

2.3 Contact Information

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3. Theory of Measurements

Radiation striking a vegetative canopy interacts with individual phytoelements (leaves, stems, branches) and the underlying substrate. The interaction depends on light quality, radiative form (direct or diffuse), illumination incidence angle, vegetative component optical properties, and canopy architecture. Radiation is reflected, transmitted, or absorbed.

Reflected radiation measurements were converted to radiances and reflectance factor values. The reflectance factor is the ratio of the target reflected radiant flux to an ideal radiant flux reflected by a Lambertian standard surface irradiated in exactly the same way as the target. Reflected radiation from a field reference panel corrected for nonperfect reflectance and sun angle was used as an estimate of the ideal Lambertian standard surface (Walter-Shea and Biehl, 1990).

The BOREAS RSS-03 helicopter missions were designed to provide a rapid means of intensive spectral characterization of sites and to provide an intermediate scale of sampling between the surface measurements and the higher altitude aircraft and spacecraft multispectral imaging devices. The instruments onboard the helicopter were chosen to provide compatibility with surface-based radiometers and Thematic Mapper (TM) spaceborne sensors.

The RSS-03 helicopter-based optical depth measurements are used to perform atmospheric corrections to radiance to obtain at-ground reflectance estimates from the helicopter-mounted radiometers. The addition of an onboard automatic sun-tracking sunphotometer system has made the helicopter optical remote sensing system a self-contained mobile unit that can be used to acquire calibrated remote measurements of surface parameters. Initial experience with this system shows that accurate and reliable measurements of surface irradiance, surface reflectance, and temperature can be made in remote areas where surface access is difficult or impractical.

4. Equipment

4.1 Sensor/Instrument Description

The primary instruments for the BOREAS RSS-03 deployment were the SE-590, a Barnes Modular Multiband Radiometer (MMR), a color charge-coupled device (CCD)-based video camera, and a sun-tracking photometer.

Design, development, and fabrication of the automatic sun-tracking photometer for use with the helicopter took place during the year prior to the 1994 BOREAS field season. This activity was overseen by the Principal Investigator (PI). The principal design, software development, and management were performed by Mr. Greg Elman (Science Systems and Applications, Inc. (SSAI)). The engineering expertise of Mr. Max Strange, who had a major role in the development of the airborne tracking sunphotometer used on the NASA C-130 fixed-wing aircraft, was an important part of the system development. Dr. Steven Chan (SSAI), Ms. Needa Walsh (SSAI), and Mr. David Rosten (Ressler Assoc.) contributed software expertise, optics design, and bench-testing. Mr. John Schafer (SSAI) contributed to the system fabrication and provided hardware support in the field. Mr. Moon Kim (Univ. of Maryland) provided software support in the field.

The automatic sun-tracking photometer consists of an optical head containing the sensors for the eight spectral channels and a quad-detector, which is used for tracking the sun. The field of view (FOV) on the data channels is 2 degrees, while the FOV on the quad-detector is 30 degrees. The optical head is mounted on a motorized mount with azimuth and zenith axes. An off-the-shelf mount from Aerotech Corporation was used for time and cost savings. The entire optical sensor unit is mounted on the roof of the helicopter cabin on the starboard side, directly above the primary instrument operator. Data and control cables are fed down through a port in the helicopter cabin roof to the rear of the center instrument rack. The length of the cables and the location of the sunphotometer with respect to the helicopter main rotor mast create a zone of azimuthal occlusion. The usable azimuth range is roughly 0 to 150 degrees on the starboard side of the aircraft, with 0 degrees being the direction of the aircraft nose.

The two-axis mount controls are handled by a controller with electronics that are isolated from the data collection system. Operator inputs for moving the mount in both the azimuthal and vertical directions are via a joystick. Both the detector system and the mount controller system are located in the center equipment rack. The laptop computer used for data logging is mounted on a small shelf in the center rack.

Analog voltages from the detectors are sent to a circuit that performs the analog-to-digital (A/D) conversion and performs the quad-detector operations for solar tracking. The digital data streams from this device are then sent to the port of a 486-based PC laptop computer. Data logging and real-time readout of sensor voltages are accomplished with a DOS Windows version of Labtech software. An

LED readout is positioned on the front panel of the sensor system box with a rotary switch for selection of the detector channel to be displayed there. The temperature of the detector assembly is also recorded with the detector data.

Sampling rate considerations were key issues in the design of the instrument. A major problem of mounting a sunphotometer on a helicopter is that the system must acquire data and stay locked on the solar disk while viewing between the moving rotor blades. Reduction of irradiance beneath moving rotor blades can be considerable. A sampling rate programmable up to 333 ks/sec can be obtained, but was not necessary with the rotor blade frequency of 9 Hz for a complete rotation (18 Hz for blade-to-blade rotation). The sampling of the solar irradiance through the main rotor blades was fast enough to plot the chopping motion of the blades. A filtering procedure was used to separate the higher, unobstructed data from the sun from chopper-interfered signal.

The band centers chosen for 7 of the possible 10 channels of the system were 0.440, 0.540, 0.613, 0.670, 0.870, 0.940, and 1.030 µm. Each spectral band was approximately 0.10 µm wide. These bands were chosen because of their compatibility with the spectral channels of the Cimel surface-based sunphotometers being used by other BOREAS teams at various sites within the BOREAS study areas.

Computer control of the instruments provides precise, automatic control and ensures proper timing of data collection. The radiometric instruments are configured such that all sensors except the photographic camera can be triggered near-simultaneously with a single computer keyboard keystroke. The command sent from the keyboard is first sent to the SE-590, then to the A/D systems. Raw data from each of the instruments are displayed via graphics and tabular listings on the main computer screen immediately after scanning.

4.1.1 Collection Environment

In general, the helicopter was flown during relatively clear days when possible. Data collection was attempted during conditions of highest possible solar elevation. All observations were attempted from a nadir observation point and usually at 300 m above ground level (AGL). Exceptions are noted in the helicopter log.

4.1.2 Source/Platform

A Bell UH-1H "Iroquois" helicopter, operated by NASA's Wallops Flight Facility (WFF), was used as the airborne platform during BOREAS. This particular aircraft, call number N415, was built in 1965 and was acquired by WFF in 1993. Upon acquisition, the aircraft was slightly modified for use as a scientific platform.

Helicopter N415 operates with standard or low-mount, rear-leaning skids. The engine is a Lycoming T53/L13, which provides 1,400 shaft HP with 1,290 transmission HP. The fuel capacity provides 2.0 hours of flying time with a 20-minute fuel reserve under normal modes of operation. The addition of an auxiliary fuel tank in the port-side door crewman's position provided an additional 15 minutes of flight time during BOREAS given optimum flight conditions. The weight of the entire helicopter system with full instrumentation, full fuel, and crew members was 9,500 lbs.

4.1.3 Source/Platform Mission Objectives

One solution for atmospheric correction and calibration of remotely sensed data from airborne platforms is the use of radiometrically calibrated instruments, sunphotometers, and an atmospheric radiative transfer model. Sunphotometers are used to measure the direct solar irradiance at the level at which they are operating and the data are used in the computation of atmospheric optical depth. Atmospheric optical depth is an input to atmospheric correction algorithms that convert at-sensor radiance to required surface properties such as reflectance and temperature. Airborne sunphotometry has thus far seen limited use and has not been used before with a helicopter platform. The addition of the sunphotometer to the helicopter system adds another tool for monitoring the environment and makes the helicopter remote sensing system capable of collecting calibrated, atmospherically corrected data independent of the need for measurements from other systems.

Although the primary motivation for development of the helicopter automatic sun-tracking photometer was to provide data for calibration and correction of remotely sensed measurements, the system is also useful for the acquisition of measurements in support of atmospheric research. Optical thickness as a function of height in the boundary layer, which an airborne sunphotometer easily provides, is necessary to better understand vertical aerosol distributions.

4.1.4 Key Variables

Aerosol optical thickness and atmospheric water vapor.

4.1.5 Principles of Operation

Computer control of the instruments provides precise, automatic control and ensures proper timing of data collection. The radiometric instruments are configured such that all sensors except the photographic camera can be triggered near-simultaneously with a single computer keyboard keystroke. The command sent from the keyboard is first sent to the SE-590, then to the A/D systems. Raw data from each of the instruments are displayed via graphics and tabular listings on the main computer screen immediately after scanning.

The system is configured for multiple sensor data collection. The MMR, SE-590, infrared thermometer, auto-tracking sunphotometer, and video sensor were the primary payload during BOREAS.

4.1.6 Sensor/Instrument Measurement Geometry

The NASA GSFC/WFF helicopter-based optical remote sensing system was deployed to acquire canopy multispectral data simultaneously with atmospheric properties while hovering approximately 300 meters AGL (Walthall et al., 1996).

4.1.7 Manufacturer of Sensor/Instrument

The ASTPH was designed and built for the special environmental conditions of a helicopter platform. The sunphotometer is the latest of a series of modifications to a helicopter-based optical remote sensing system developed since 1984 by researchers at NASA's GSFC and WFF (Williams et al., 1984; Walthall et al., 1996). Design, development, and fabrication of the ASTPH took place in 1993 prior to the field deployment for BOREAS in 1994.

4.2 Calibration

The sunphotometers used during BOREAS were calibrated before and after the field season. The Cimel units had been extensively calibrated and were considered a source of calibration themselves. The helicopter sunphotometer was shipped to the calibration site without the thermal control boards operating prior to the field season. The thermal control boards were working in time for the field deployments and for the postseason calibration. Hence, the calibration values changed. It was decided to use data from comparisons of the voltages from the helicopter unit with nearby Cimel units as a means of calibration.

4.2.1 Specifications

Calibration of a sunphotometer involves determining the exoatmospheric voltage response in each of the channels. Langley plots and intercomparison methods that use the Bouguer law of atmospheric extinction were used for those channels that did not include discrete gaseous absorption.

The raw data were first screened for voltage dropouts caused by the passage of a rotor blade. The resulting "clear" data were then processed to obtain aerosol optical thickness. Calibration was performed by two methods. In April 1994, the sunphotometer was taken to Mount Lemmon (elevation 9167') to perform a Langley calibration (Halthore et al., 1992) for the non-water absorption channels. Because the instrument wiring was reconfigured after the calibration, it was felt that the Mount Lemon calibration may not be valid for flights in the BOREAS IFCs. Thus, a special effort was made to perform calibration by intercomparison with sunphotometers that were thought to be better calibrated.

During IFC-1 in May 1994, intercomparison was performed with the NASA Ames Research Center sunphotometer at Candle Lake (Wrigley, R., private communication). The resulting calibration coefficients differed from the Mount Lemmon calibrations by at most 3% and typically 2% in most channels, thus showing that the instrument response had not been drastically altered by the reconfiguration. However, it was decided that the Ames intercomparison coefficients for both IFC-1 and -2 would be used.

4.2.1.1 Tolerance

None given.

4.2.2 Frequency of Calibration

None given.

4.2.3 Other Calibration Information

Because of problems with data logging during IFC-3 in September 1994, the signals from three channels were lost (channels 2, 5, and 6). Calibration once again became a problem of utmost concern. Intercomparison with an eight-channel sunphotometer, commonly called SXM-2, was performed at the BOREAS SSA Operations Center near Candle Lake on a clear day (16-Sep). In the absence of a high mountain calibration, the NASA-built SXM-2 sunphotometer, with detector temperature control and automatic operation and data logging, was calibrated by comparison with a "standard" Cimel sunphotometer at GSFC in October following the conclusion of IFC-3. The transferred calibration shows deviations of less than 3% in all functioning channels. It was decided that the calibration from IFC-3 (16-Sep) would be sufficient for analyzing data.

The fact that different calibration methods yield coefficients within about 3% indicates that the uncertainty of the measured aerosol optical thickness will also be on the order of about 0.03; the actual uncertainty is probably a little higher than this because of variability in the data. Considering the conditions under which the helicopter sunphotometer operated, this level of uncertainty is acceptable.

5. Data Acquisition Methods

See Walthall et al., 1996.

The UNIDEX-11 operates in two different modes: TRACK and REGULAR. The REGULAR mode is used to move the mount to the desired starting position (zenith and azimuth). The TRACK mode is used when the quad detectors are commanded to take control and track the sun.

The data collection process begins by moving the mount from the HOME (azimuth angle = solar noon, zenith angle = 0 degrees) to the desired zenith and azimuth angles as specified from operator input. This initial input must be within 30 degrees of the sun. The PC-486 then switches the UNIDEX-11 into the TRACK mode and the quad-detectors take control, "locking on" the sun. The analog output of the photodetectors is sampled for 10 cycles per ms and usually contains at least one blade passing in the data stream. The data are acquired from the hardware, and then all data are plotted on the operator screen. The digital raw solar irradiance data are saved to disk along with barometric pressure and altitude data, that are used later in the data processing sequence. Analog voltages from the seven photodetectors located in the optical head are digitized by an A/D converter.

6. Observations

6.1 Data Notes

None given.

6.2 Field Notes

An extensive helicopter log is available. Environmental, technical, instrumental, and operator conditions are noted for each observation where applicable.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The helicopter visited all of the NSA and SSA tower and category-1 auxiliary sites. Each site listed below was observed by the instrument at least once during the 1994 campaign at BOREAS. The coordinates in the table are based on the North American Datum of 1983 (NAD83).

Site Id	Operat'l Grid ID	Longitude	Latitude	UTM Easting	UTM Northing	UTM Zone
Flux Tower Sites						
SSA:						
SSA-FEN-SE501	F0L9T	104.61798° W	53.80206° N	525159.8	5961566.6	13
SSA-OBS-SE501	G8I4T	105.11779° W	53.98717° N	492276.5	5982100.5	13
SSA-OJP-SE501	G2L3T	104.69203° W	53.91634° N	520227.7	5974257.5	13
SSA-YJP-SE501	F8L6T	104.64529° W	53.87581° N	523320.2	5969762.5	13
SSA-9OA-SE501	C3B7T	106.19779° W	53.62889° N	420790.5	5942899.9	13
SSA-9YA-SE501	D0H4T	105.32314° W	53.65601° N	478644.1	5945298.9	13
NSA:						
NSA-OBS-SE501	T3R8T	98.48139° W	55.88007° N	532444.5	6192853.4	14
NSA-OJP-SE501	T7Q8T	98.62396° W	55.92842° N	523496.2	6198176.3	14
NSA-YJP-SE501	T8S9T	98.28706° W	55.89575° N	544583.9	6194706.9	14
NSA-BVP-SE501	T4U6T	98.02747° W	55.84225° N	560900.6	6188950.7	14
NSA-FEN-SE501	T7S1T	98.42072° W	55.91481° N	536207.9	6196749.6	14
Auxiliary Sites						
SSA:						
SSA-9BS-SE501	D0H6S	105.29534° W	53.64877° N	480508.7	5944263.4	13
SSA-9BS-SE501	G2I4S	105.13964° W	53.93021° N	490831.4	5975766.3	13
SSA-9BS-SE501	G2L7S	104.63785° W	53.90349° N	523793.6	5972844.3	13
SSA-9BS-SE501	G6K8S	104.75900° W	53.94446° N	515847.9	5977146.9	13
SSA-9BS-SE501	G9I4S	105.11805° W	53.99877° N	492291.2	5983169.1	13
SSA-9JP-SE501	F5I6P	105.11175° W	53.86608° N	492651.3	5968627.1	13
SSA-9JP-SE501	F7J0P	105.05115° W	53.88336° N	496667.0	5970323.3	13
SSA-9JP-SE501	F7J1P	105.03226° W	53.88211° N	497879.4	5970405.6	13
SSA-9JP-SE501	G1K9P	104.74812° W	53.90880° N	516546.7	5973404.5	13
SSA-9JP-SE501	G4K8P	104.76401° W	53.91883° N	515499.1	5974516.6	13
SSA-9JP-SE501	G7K8P	104.77148° W	53.95882° N	514994.2	5978963.8	13
SSA-9JP-SE501	G8L6P	104.63755° W	53.96558° N	523778.0	5979752.7	13
SSA-9JP-SE501	G9L0P	104.73779° W	53.97576° N	517197.7	5980856.0	13
SSA-9JP-SE501	I2I8P	105.05107° W	54.11181° N	496661.4	5995963.1	13
SSA-ASP-SE501	B9B7A	106.18693° W	53.59098° N	421469.8	5938447.2	13
SSA-ASP-SE501	D6H4A	105.31546° W	53.70828° N	479177.5	5951112.1	13
SSA-ASP-SE501	D6L9A	104.63880° W	53.66879° N	523864.0	5946733.2	13
SSA-ASP-SE501	D9G4A	105.46929° W	53.74019° N	469047.1	5954718.4	13
SSA-MIX-SE501	D9I1M	105.20643° W	53.72540° N	486379.7	5952989.7	13
SSA-MIX-SE501	F1N0M	104.53300° W	53.80594° N	530753.7	5962031.8	13
SSA-MIX-SE501	G4I3M	105.14246° W	53.93750° N	490677.3	5976354.9	13
SSA-CLR-SE501	FRSHCL	104.69194° W	53.91639° N	520205.2	5974269.4	13

Site Id	Operat'l Grid ID	Longitude	Latitude	UTM Easting	UTM Northing	UTM Zone
Auxiliary Sites						
NSA:						
NSA-9BS-SE501	S8W0S	97.84024° W	55.76824° N	572761.9	6180894.9	14
NSA-9BS-SE501	T0P7S	98.82345° W	55.88371° N	511043.9	6193151.1	14
NSA-9BS-SE501	T0P8S	98.80225° W	55.88351° N	512370.1	6193132.0	14
NSA-9BS-SE501	T0W1S	97.80937° W	55.78239° N	574671.7	6182502.0	14
NSA-9BS-SE501	T3U9S	97.98339° W	55.83083° N	563679.1	6187719.2	14
NSA-9BS-SE501	T4U8S	97.99325° W	55.83913° N	563048.2	6188633.4	14
NSA-9BS-SE501	T4U9S	97.98364° W	55.83455° N	563657.5	6188132.8	14
NSA-9BS-SE501	T5Q7S	98.64022° W	55.91610° N	522487.2	6196800.5	14
NSA-9BS-SE501	T6R5S	98.51865° W	55.90802° N	530092.0	6195947.0	14
NSA-9BS-SE501	T6T6S	98.18658° W	55.87968° N	550887.9	6192987.9	14
NSA-9BS-SE501	T7R9S	98.44877° W	55.91506° N	534454.5	6196763.6	14
NSA-9BS-SE501	T7T3S	98.22621° W	55.89358° N	548391.8	6194505.6	14
NSA-9BS-SE501	T8S4S	98.37111° W	55.91689° N	539306.4	6197008.6	14
NSA-9BS-SE501	U5W5S	97.70986° W	55.90610° N	580655.5	6196380.8	14
NSA-9BS-SE501	U6W5S	97.70281° W	55.91021° N	581087.8	6196846.5	14
NSA-9JP-SE501	99O9P	99.03952° W	55.88173° N	497527.8	6192917.5	14
NSA-9JP-SE501	Q3V3P	98.02473° W	55.55712° N	561517.9	6157222.2	14
NSA-9JP-SE501	T7S9P	98.30037° W	55.89486° N	543752.4	6194599.1	14
NSA-9JP-SE501	T8Q9P	98.61050° W	55.93219° N	524334.5	6198601.4	14
NSA-9JP-SE501	T8S9P	98.28385° W	55.90456° N	544774.3	6195688.9	14
NSA-9JP-SE501	T8T1P	98.26269° W	55.90539° N	546096.3	6195795.3	14
NSA-9JP-SE501	T9Q8P	98.59568° W	55.93737° N	525257.1	6199183.2	14
NSA-9OA-SE501	T2Q6A	98.67479° W	55.88691° N	520342.0	6193540.7	14
NSA-ASP-SE501	P7V1A	98.07478° W	55.50253° N	558442.1	6151103.7	14
NSA-ASP-SE501	Q3V2A	98.02635° W	55.56227° N	561407.9	6157793.5	14
NSA-ASP-SE501	R8V8A	97.89260° W	55.67779° N	569638.4	6170774.8	14
NSA-ASP-SE501	S9P3A	98.87621° W	55.88576° N	507743.3	6193371.6	14
NSA-ASP-SE501	T4U5A	98.04329° W	55.84757° N	559901.6	6189528.2	14
NSA-ASP-SE501	T8S4A	98.37041° W	55.91856° N	539348.3	6197194.6	14
NSA-ASP-SE501	V5X7A	97.48565° W	55.97396° N	594506.1	6204216.6	14
NSA-ASP-SE501	W0Y5A	97.33550° W	56.00339° N	603796.6	6207706.6	14
NSA-MIX-SE501	Q1V2M	98.03769° W	55.54568° N	560718.3	6155937.3	14
NSA-MIX-SE501	T0P5M	98.85662° W	55.88911° N	508967.7	6193747.3	14
NSA-BRS-SE501	BRSOL	98.28889° W	55.90528° N	544441.4	6195777.7	14
NSA-TMK-SE501	TAMRK	98.42111° W	55.91583° N	536165.1	6196874.8	14
NSA-BRN-SE501	BRNJP	99.04383° W	55.88184° N	497240.1	6192940.9	14

7.1.2 Spatial Coverage Map
Not available.

7.1.3 Spatial Resolution
The data channels of the ASTPH view the sun with a FOV of 2 degrees, while the FOV on the quad-detector is 30 degrees.

7.1.4 Projection
Not applicable.

7.1.5 Grid Description

Not applicable.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

Observations were made during all three BOREAS 1994 IFCs, which occurred during the following periods:

IFC-1 24-May - 16-Jun
IFC-2 19-Jul - 10-Aug
IFC-3 30-Aug - 19-Sep

Measurements were made as conditions permitted during each IFC.

7.2.2 Temporal Coverage Map

Observations were made at several sites on the following dates:

Date	Study Area
31-May-1994	SSA
01-Jun-1994	SSA
04-Jun-1994	SSA
06-Jun-1994	SSA
07-Jun-1994	SSA
08-Jun-1994	NSA
10-Jun-1994	NSA
21-Jul-1994	NSA
22-Jul-1994	SSA
23-Jul-1994	SSA
24-Jul-1994	SSA
25-Jul-1994	SSA
28-Jul-1994	SSA
04-Aug-1994	NSA
08-Aug-1994	NSA
06-Sep-1994	NSA
08-Sep-1994	NSA
09-Sep-1994	NSA
13-Sep-1994	NSA
15-Sep-1994	SSA
16-Sep-1994	SSA

7.2.3 Temporal Resolution

Measurements were collected as conditions permitted during each IFC. Each site was visited as often as possible during each IFC, with priority given to tower flux sites and category 1 auxiliary sites. Fuel constraints limited helicopter flight time to approximately 2 hours. As many sites as possible were visited during each flight.

The analog output of the photodetectors is sampled for 10C ms and usually contains at least one blade passing in the data stream. The data are acquired from the hardware every 5 milliseconds (which yields 20 data points), and then all data are plotted on the operator screen.

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
OP_GRID_ID
NUM_OBS
MEAN_PRESSURE_AT_PLATFORM
MEAN_OZONE_AMOUNT
MEAN_AEROSOL_OPT_THICK_440
MEAN_AEROSOL_OPT_THICK_540
MEAN_AEROSOL_OPT_THICK_610
MEAN_AEROSOL_OPT_THICK_670
MEAN_AEROSOL_OPT_THICK_940
MEAN_AEROSOL_OPT_THICK_1030
MEAN_COLUMN_WATER_VAPOR
ELEVATION
PLATFORM_ALTITUDE
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.
OP_GRID_ID                     The identifier given to the BOREAS auxiliary and
                               tower sites during the execution of field
                               operations.  An example of this is B9B7A.
NUM_OBS                        Number of observations of the given sample used
                               to calculate given values.
MEAN_PRESSURE_AT_PLATFORM      The mean atmospheric pressure measured at the
```

	data collection platform.
MEAN_OZONE_AMOUNT	The mean measured ozone amount.
MEAN_AEROSOL_OPT_THICK_440	The mean aerosol optical thickness measured between 0.438 and 0.441 micrometers.
MEAN_AEROSOL_OPT_THICK_540	The mean aerosol optical thickness measured at .540 micrometers.
MEAN_AEROSOL_OPT_THICK_610	The mean aerosol optical thickness measured between .610 and .613 micrometers.
MEAN_AEROSOL_OPT_THICK_670	The mean aerosol optical thickness measured at .670 micrometers.
MEAN_AEROSOL_OPT_THICK_940	The mean aerosol optical thickness measured at .940 micrometers.
MEAN_AEROSOL_OPT_THICK_1030	The mean aerosol optical thickness measured at 1.030 micrometers.
MEAN_COLUMN_WATER_VAPOR	The mean amount of precipitable water within a vertical column of air with a cross-section of 1 centimeter squared and a fixed depth (usually from the ground to the top of the atmosphere).
ELEVATION	The elevation of the site above mean sea level.
PLATFORM_ALTITUDE	The nominal altitude of the data collection platform above the target.
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]
OP_GRID_ID	[none]
NUM_OBS	[counts]
MEAN_PRESSURE_AT_PLATFORM	[kiloPascals]
MEAN_OZONE_AMOUNT	[Dobson]
MEAN_AEROSOL_OPT_THICK_440	[unitless]
MEAN_AEROSOL_OPT_THICK_540	[unitless]
MEAN_AEROSOL_OPT_THICK_610	[unitless]
MEAN_AEROSOL_OPT_THICK_670	[unitless]
MEAN_AEROSOL_OPT_THICK_940	[unitless]
MEAN_AEROSOL_OPT_THICK_1030	[unitless]
MEAN_COLUMN_WATER_VAPOR	[millimeters]
ELEVATION	[meters]
PLATFORM_ALTITUDE	[meters]
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	[Assigned by BORIS]
SUB_SITE	[Assigned by BORIS]
DATE_OBS	[Controller]
TIME_OBS	[Controller]
OP_GRID_ID	[Provided by RSS03 team]
NUM_OBS	[ASTPH]
MEAN_PRESSURE_AT_PLATFORM	[NASA Helicopter]
MEAN_OZONE_AMOUNT	[ASTPH]
MEAN_AEROSOL_OPT_THICK_440	[ASTPH]
MEAN_AEROSOL_OPT_THICK_540	[ASTPH]
MEAN_AEROSOL_OPT_THICK_610	[ASTPH]
MEAN_AEROSOL_OPT_THICK_670	[ASTPH]
MEAN_AEROSOL_OPT_THICK_940	[ASTPH]
MEAN_AEROSOL_OPT_THICK_1030	[ASTPH]
MEAN_COLUMN_WATER_VAPOR	[ASTPH]
ELEVATION	[Provided by RSS03 team]
PLATFORM_ALTITUDE	[NASA Helicopter]
CRTFCN_CODE	[Assigned by BORIS]
REVISION_DATE	[Assigned by BORIS]

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-9BS-9TETR	SSA-YJP-FLXTR	None	None	None	None
SUB_SITE	RSS03-SPH01	RSS03-SPH01	None	None	None	None
DATE_OBS	31-MAY-94	16-SEP-94	None	None	None	None
TIME_OBS	1432	2231	None	None	None	None
OP_GRID_ID	99O9P	W0Y5A	None	None	None	None
NUM_OBS	6	173	None	None	None	None
MEAN_PRESSURE_AT_ PLATFORM	9.09	9.76	None	None	None	None
MEAN_OZONE_AMOUNT	300	370	None	None	None	None
MEAN_AEROSOL_OPT_ THICK_440	.032	1.459	-999	None	None	None
MEAN_AEROSOL_OPT_ THICK_540	0	4.215	-999	None	None	None
MEAN_AEROSOL_OPT_ THICK_610	.016	4.222	-999	None	None	None
MEAN_AEROSOL_OPT_ THICK_670	.029	4.25	-999	None	None	None
MEAN_AEROSOL_OPT_ THICK_940	0	3.828	-999	None	None	None
MEAN_AEROSOL_OPT_ THICK_1030	0	4.056	-999	None	None	None
MEAN_COLUMN_WATER_	5.24	27.88	None	None	None	None

VAPOR						
ELEVATION	175.59	650.44	None	None	None	None
PLATFORM_ALTITUDE	100	300	None	None	None	None
CRTFCN_CODE	CPI	CPI	None	None	None	None
REVISION_DATE	21-NOV-98	21-NOV-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,OP_GRID_ID,NUM_OBS,
MEAN_PRESSURE_AT_PLATFORM,MEAN_OZONE_AMOUNT,MEAN_AEROSOL_OPT_THICK_440,
MEAN_AEROSOL_OPT_THICK_540,MEAN_AEROSOL_OPT_THICK_610,MEAN_AEROSOL_OPT_THICK_670,
MEAN_AEROSOL_OPT_THICK_940,MEAN_AEROSOL_OPT_THICK_1030,MEAN_COLUMN_WATER_VAPOR,
ELEVATION,PLATFORM_ALTITUDE,CRTFCN_CODE,REVISION_DATE
'SSA-ASP-AUX02','RSS03-SPH01',31-MAY-94,1523,'B9B7A',80,9.17,370.0,.068,.049,
.036,.048,.037,.041,11.73,572.0,300.0,'CPI',21-NOV-98
'SSA-OJP-FLXTR','RSS03-SPH01',31-MAY-94,1618,'G2L3T',105,9.16,370.0,.084,.056,
.04,.061,.045,.052,12.38,579.27,300.0,'CPI',21-NOV-98
'SSA-YJP-FLXTR','RSS03-SPH01',31-MAY-94,1629,'F8L6T',80,9.21,370.0,.085,.057,
.04,.059,.043,.037,13.66,533.24,300.0,'CPI',21-NOV-98
'SSA-YJP-FLXTR','RSS03-SPH01',31-MAY-94,1629,'F8L6T',62,9.21,370.0,.076,.057,
.04,.058,.044,.035,13.05,533.24,300.0,'CPI',21-NOV-98
```

8. Data Organization

8.1 Data Granularity

The smallest unit of data tracked by BOREAS Information System (BORIS) is all of the measurements for a given site on a given day.

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 Hyper-Text 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

See reference list.

9.1.1 Derivation Techniques and Algorithms

See reference list.

9.2 Data Processing Sequence

9.2.1 Processing Steps

After data collection, the data set and relevant location and condition information were used to transform the at-sensor Digital Numbers (DNs) to atmospheric optical depths and water vapor column estimates as described in Halthore et al. (1997). In order to eliminate the rotor blade swipes, an "unobstructed" value was calculated for each site/time. This was achieved in the optical thickness data set by calculating the minimum value for the data collected over a given site. For the water vapor column estimates, a median value was given. In addition, the number of observations used in calculating the minimum or median is reported; those values calculated from a larger source data set are more reliable.

9.2.2 Processing Changes

None.

9.3 Calculations

See reference list.

9.3.1 Special Corrections/Adjustments

None given.

9.3.2 Calculated Variables

See reference list.

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

None given.

10.2 Quality Assessment

Visual quality assessment was made during data collection. Also see reference list and helicopter logs.

10.2.1 Data Validation by Source

None given.

10.2.2 Confidence Level/Accuracy Judgment

None given.

10.2.3 Measurement Error for Parameters

None given.

10.2.4 Additional Quality Assessments

See helicopter logs.

10.2.5 Data Verification by Data Center

BORIS staff performed some quality checks of the data in the process of loading the data into the data base.

11. Notes

11.1 Limitations of the Data

None given.

11.2 Known Problems with the Data

None given.

11.3 Usage Guidance

The RSS-03 helicopter-based optical depth measurements are relevant primarily to the helicopter-borne optical measurements, unless one is interested in the spatial distribution of atmospheric particulates over the boreal forest.

11.4 Other Relevant Information

None.

12. Application of the Data Set

The RSS-03 helicopter-based optical depth measurements are used to perform atmospheric corrections to radiance to obtain at-ground reflectance estimates from the helicopter-mounted radiometers.

Although the primary motivation for development of the helicopter automatic sun-tracking photometer was to provide data for calibration and correction of remotely sensed measurements, the system is also useful for the acquisition of measurements in support of atmospheric research. Optical thickness as a function of height in the boundary layer, which an airborne sunphotometer easily provides, is necessary to better understand vertical aerosol distributions.

13. Future Modifications and Plans

None.

14. Software

14.1 Software Description

Labtech.

14.2 Software Access

Labtech software is commercially available. Software developed specifically for the ASTPH is not available for distribution.

15. Data Access

The ASTPH 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
None.

17.2 Journal Articles and Study Reports

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Sellers, P. and F. Hall. 1994. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1994-3.0, NASA BOREAS Report (EXPLAN 94).

Sellers, P. and F. Hall. 1996. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1996-2.0, NASA BOREAS Report (EXPLAN 96).

Sellers, P., F. Hall, and K.F. Huemmrich. 1996. Boreal Ecosystem-Atmosphere Study: 1994 Operations. NASA BOREAS Report (OPS DOC 94).

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Sellers, P., F. Hall, H. Margolis, B. Kelly, D. Baldocchi, G. den Hartog, J. Cihlar, M.G. Ryan, B. Goodison, P. Crill, K.J. Ranson, D. Lettenmaier, and D.E. Wickland. 1995. The boreal ecosystem-atmosphere study (BOREAS): an overview and early results from the 1994 field year. Bulletin of the American Meteorological Society. 76(9):1549-1577.

Sellers, P.J., F.G. Hall, R.D. Kelly, A. Black, D. Baldocchi, J. Berry, M. Ryan, K.J. Ranson, P.M. Crill, D.P. Lettenmaier, H. Margolis, J. Cihlar, J. Newcomer, D. Fitzjarrald, P.G. Jarvis, S.T. Gower, D. Halliwell, D. Williams, B. Goodison, D.E. Wickland, and F.E. Guertin. 1997. BOREAS in 1997: Experiment Overview, Scientific Results and Future Directions. Journal of Geophysical Research 102(D24): 28,731-28,770.

Walter-Shea, E.A. and L.L. Biehl. 1990. Measuring vegetation spectral properties. Remote Sensing Reviews Chapter 11, Edited by Narendra Goel and John Norman, Vol. 5, pp. 179-205.

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17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

```
A/D     - Analog-to-Digital
AGL     - Above Ground Level
ASCII   - American Standard Code for Information Interchange
ASTPH   - Automatic Sun Tracking Photometer for Helicopter
BOREAS  - BOReal Ecosystem-Atmosphere Study
BORIS   - BOREAS Information System
CCD     - Charge-Coupled Device
CD-ROM  - Compact Disk-Read-Only Memory
DAAC    - Distributed Active Archive Center
DN      - Digital Number
FOV     - Field of View
GIS     - Geographic Information System
GSFC    - Goddard Space Flight Center
HTML    - HyperText Markup Language
IFC     - Intensive Field Campaign
MMR     - Modular Multiband Radiometer
NASA    - National Aeronautics and Space Administration
NIR     - Near-Infrared
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
RSS     - Remote Sensing Science
SE-590  - Spectron Engineering spectroradiometer
SSA     - Southern Study Area
SSAI    - Science Systems and Applications, Inc.
TM      - Thematic Mapper
URL     - Uniform Resource Locator
UTM     - Universal Transverse Mercator
WFF     - Wallops Flight Facility
YA      - Young Aspen
YJP     - Young Jack Pine
```

20. Document Information

20.1 Document Revision Date
Written: 30-Jul-1997
Last Updated: 18-Aug-1999

20.2 Document Review Dates
BORIS Review: 28-Nov-1998
Science Review:

20.3 Document ID

20.4 Citation
When using these data, please contact the individuals listed in Section 2.3 as well as citing relevant papers in Section 17.2.

If using data from the BOREAS CD-ROM series, also reference the data as:
Walthall, C.L., "Biophysical Significance of Spectral Vegetation Indices in the Boreal Forest." 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.

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The BOREAS RSS-3 team collected and processed helicopter-based measurements of atmospheric conditions to estimates of aerosol optical thickness and atmospheric water vapor. The automatic sun-tracking photometer for helicopters was deployed during all three 1994 IFCs at numerous tower and auxiliary sites in both the NSA and the SSA. Six spectral channels (440, 540, 613, 670, 870, and 1030 nm) were chosen to span the visible and NIR wavelengths and to avoid gaseous absorption. One additional channel, 940 nm, was selected to measure the water column abundance above the helicopter platform. The data are stored in tabular ASCII files.

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