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

Forrest G. Hall and Jaime Nickeson, Editors

Volume 58

BOREAS RSS-11 Ground Network of Sunphotometer Measurements

B.L. Markham and J. Schafer

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

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BOREAS RSS-11 Ground Network of Sunphotometer Measurements

Brian L. Markham, Joel Schafer

Summary

The BOREAS RSS-11 team operated a network of five automated (Cimel) and two hand-held (Miami) solar radiometers from 1994 to 1996 during the BOREAS field campaigns. The data provide aerosol optical depth measurements, size distribution, phase function, and column water vapor amounts over points in northern Saskatchewan and Manitoba, Canada. The data are useful for the correction of remotely sensed aircraft and satellite images. The data are provided in tabular ASCII files.

Table of Contents

1. Data Set Overview

1.1 Data Set Identification

BOREAS RSS-11 Ground Network of Sunphotometer Measurements

1.2 Data Set Introduction

A ground-based sunphotometer network was installed within the BOReal Ecosystem-Atmosphere Study (BOREAS) study areas to characterize the size and distribution of atmospheric aerosols and column water vapor amount and to aid in the correction of aircraft and satellite imagery. Automated sunphotometer data are available fairly continuously from early 1994 through 1996 for two sites in the Northern Study Area (NSA) and two in the Southern Study Area (SSA). Data were collected from a fifth automated instrument located at the Flin Flon airport at the Manitoba/Saskatchewan border; this instrument was moved in 1996 to Paddockwood, SK, in the SSA. Measurements made by two additional hand-held instruments, operated during the 1994-96 time period at each of the study areas, are also a part of this data set. A local observer made the hand-held measurements near noon when the Sun was not obscured by any clouds.

1.3 Objective/Purpose

The purpose was to establish a data set of aerosol, water vapor, and ozone atmospheric properties in the BOREAS region for a 3-year period for use by BOREAS in atmospheric correction of remotely sensed data. Another goal was to establish an aerosol climatology of the region by specifying, for example, the annual cycle of aerosol loading across the region.

1.4 Summary of Parameters

Parameters:

Direct solar irradiance (340, 380, 440, 500, 670, 870, 1020 nm)
Sky radiance (440, 670, 870, 1020 nm)
Aerosol optical thickness
Column water vapor amount

1.5 Discussion

A network of five automated (Cimel) and two hand-held (Miami) solar radiometers were operated during the 1994-96 time period for BOREAS to provide aerosol optical depth measurements, size distribution, phase function, and column water vapor amounts. The purpose was to establish a data set of aerosol, water vapor, and ozone atmospheric properties in the BOREAS region for a 3-year period for use by BOREAS in atmospheric correction of remotely sensed data.

1.6 Related Data Sets

BOREAS RSS-03 Reflectance Measured from a Helicopter-Mounted Barnes MMR
BOREAS RSS-12 Airborne Tracking Sunphotometer Measurements
BOREAS RSS-12 Automated Ground Sun Photometer Measurements in the SSA
BOREAS RSS-18 Ground Sunphotometer Measurements in the SSA

An additional data set collected and used in comparison was sunphotometer measurements made by Norman O'Neill (RSS-19) at the Canada Centre for Remote Sensing (CCRS). These data were not submitted to the BOREAS Information System (BORIS).

2. Investigator(s)

2.1 Investigator(s) Name and Title

Brian L. Markham
Physical Scientist

2.2 Title of Investigation

Characterization of Atmospheric Optical Properties for BOREAS

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3. Theory of Measurements

Sunphotometers measure direct surface irradiance. Because direct solar irradiance depends on the atmospheric transmission, the components affecting this transmission such as aerosol optical thickness (AOT), water vapor column abundance, ozone absorption, and molecular scattering can either be estimated or bemeasured.

Optical thickness is calculated from spectral extinction of direct beam radiation at each wavelength based on Beer's Law:

$$V_\lambda = V_o \cdot R^2 \cdot e^{-(m \cdot \tau)}$$

where: V_λ = digital voltage measured at wavelength λ
V_o= extraterrestrial voltage
m = optical airmass
τ= total optical thickness
R = relative Earth-Sun distance

Attenuation due to Rayleigh scatter, and absorption by ozone and gaseous pollutants is estimated and removed to isolate the AOT (τ).

The dependence of transmission, T_w, on water column abundance can be written as the following [Halthore et al., 1992, Bruegge et al, 1992]:

$$T_w = e^{-a \cdot m^b \cdot w^b}$$

where: W = vertical column abundance (cm)
a, b = constants that depend on the wavelength position, width and shape of the filter function, and atmospheric conditions.

Sky radiance measurements are inverted with radiative transfer equations [Nakajima et al., 1983] to provide aerosol properties of size distribution and phase function over the particle size range of 0.1 to 5 μm.

4. Equipment

4.1 Sensor/Instrument Description

4.1.1 Collection Environment

The automated sunphotometers operated during nonwinter months according to their diurnal schedule (Section 4.1) when there was no precipitation and the atmosphere is clear enough to allow the instrument to focus on the Sun with a four-quadrant detector (AOT roughly <6.0). Precipitation activates an externally mounted wet sensor that causes the instrument to remain in the parked (nadir) position.

4.1.2 Source/Platform

All instruments were mounted on the roof of a building or hut, with a clear view of the sky above 5 degrees elevation angle. The hand-held instruments were held by the human observer.

4.1.3 Source/Platform Mission Objectives

The building roof provided a convenient place to mount the sunphotometers. The objective of the human observer during the measurement times was to obtain good measurements.

4.1.4 Key Variables

Direct solar irradiance Sky radiance

4.1.5 Principles of Operation

Eight interference filters are located in a filter wheel that is rotated by a direct drive stepping motor. A thermistor measures the temperature of the detector, allowing compensation for any temperature dependence in the silicon detector.

The sensor head is pointed by stepping azimuth and zenith motors with a precision of 0.05 degrees. A microprocessor computes the position of the Sun based on time, latitude, and longitude and directs the sensor head to within approximately 1 degree of the Sun. Then, a four-quadrant detector tracks the Sun precisely prior to a programmed measurement sequence.

4.1.6 Sensor/Instrument Measurement Geometry

The Cimel automatic sunphotometers take direct solar irradiance and sky radiance measurements with a 1.2-degree Field of View (FOV).

4.1.7 Manufacturer of Sensor/Instrument

The automatic sunphotometers were made by:
Cimel Electronique
5 Cite de Phalsbourg
75011 Paris, France

The hand-held sunphotometers were made by:
University of Miami
Dept. of Meteorology
Coral Gables, FL 33124

4.2 Calibration

A number of automatic sunphotometers from the Goddard Space Flight Center (GSFC) were regularly taken to the Mauna Loa Observatory in Hawaii, where the Langley method of calibration [Shaw, 1983] was used for absolute calibration. Instruments used for BOREAS were calibrated by intercomparison with reference instruments using measurements conducted on the top of a building at GSFC on clear days with low aerosol loading. On occasion, in-field Langley calibrations were performed.

For the 940-nm channel that includes water absorption, calibration was performed using the following procedure.

At 940 nm, the measured digital voltage is:

$$V = V_o \cdot R^2 \cdot e^{-(m \cdot \tau)} \cdot T_w$$

where τ is the extinction due to Rayleigh and aerosol scatter and water vapor absorption, and T_w, again, is water vapor transmission.

Combining this relation with that of Section 3 describing

$$T_w = e^{-(a m^b w^b)}$$

yields:

$$\ln V + m \cdot \tau = \ln(V_o) - a \cdot m^b \cdot W^b$$

Plotting the left-hand side of the above equation against m^b gives a straight line with the desired y-intercept $\ln(V_o)$ and slope W^b [Halthore et al 1997]. This modified Langley method was used only for calibrating the water vapor band.

Hand-held instruments are intercalibrated at the beginning and end of the season with collocated automatic instruments on clear days of low aerosol.

4.2.1 Specifications

The automatic instruments used were Cimel CE-318s, which, during 1994, had 10-nm bandpass filters in the visible and near-infrared with center wavelengths at 340, 380, 440, 670, 870, 940, and 1020 nm, with an additional 50-nm bandpass filter centered at 940 nm. The two 940-nm channels were to be used for column water vapor abundance determination. The wider bandpass filter proved unnecessary for determining water vapor column abundance, so it was replaced with a 10-nm bandpass filter centered at 500 nm in spring of 1995. In addition to measuring solar irradiance with an FOV of 1.2 degrees, these instruments measure the sky radiance in four spectral bands (440, 670, 870, and 1020 nm) along the solar principal plane (i.e., at constant azimuth angle, with varied solar zenith angles) up to nine times a day and along the solar almucantar (i.e., at constant solar zenith angle, with varied azimuth angles) up to six times a day.

The two hand-held sunphotometers have four channels (500, 670, 870, and 940 nm). They are capable of only the direct solar measurements and require manual data entry. They have a peak hold feature that allows them to record the highest voltage response when pointed in the general direction of the Sun.

4.2.1.1 Tolerance

If the aerosol conditions were considered to be constant during the Langley procedures at Mauna Loa, then deviation of measurements from the linear regression line gives an indication of the sunphotometer precision. Triplet variability from three reference instruments deployed at Mauna Loa was calculated based on 168, 264, and 288 observations, respectively. For all wavelengths, the variability of a triplet was always less than 1%, and generally about 0.3%, suggesting that uncertainty due to instrument precision is minimal [Holben et al., 1996].

4.2.2 Frequency of Calibration

The instruments were intercompared at GSFC on clear days with reference Cimels calibrated by Langley or modified Langley techniques at Mauna Loa. This process was done before and after each field campaign, and the reference instrument (#13) was taken to Mauna Loa every 6 months. Occasionally, filter changes during deployment or short-term contamination by spider webs in the collimator warranted the use of in-field Langley calibrations.

4.2.3 Other Calibration Information

The instrument referred to below as #13 is the reference instrument used for BOREAS.

1994 Cimel Sun Photometr Data Calibration

The ratios of the post season to preseason calibrations follow for each instrument in the order. The bracketed numbers are for instrument #31 and #32.

1020	870	670	440	340[380]	380[340]

#11 NSA-YJP -- interpolated between the May cross comparison with #13 and the November cross comparison with #13 (with the exception of the June 26 through July 4 -- a spider web incident that was calibrated with onsite Langley techniques for 26-Jun-1994).

0.99233306	1.00224738	0.99804205	1.0118189	0.97430213	1.01370528

#12 Flin Flon -- interpolated between the May cross comparison with #13 and the November cross comparison with #13.

0.96776048	0.97619891	0.98253527	0.95644371	0.89236603	0.90532343

#31 SSA-YJP -- interpolated between the May cross comparison with #13 and November cross comparison with #13.

0.99090514	0.99927597	0.98348781	0.99160097	0.99534901	0.94812591

#32 Waskesiu -- used May cross comparison with #13 for full BOREAS season (with exception of 21-25 July-1994 spider web incident calibrated with onsite Langley techniques) -- the November cross comparison with #13 was not valid for BOREAS because of an apparent change in the instrument during its return.

#6 Thompson Zoo/Prince Albert -- used May cross comparison with #13 until 09-Jun-1994; used cross comparison with #13 in July until 11-Jul-1994; interpolated between 11-July-1994 cross comparison with #13 and 12-Oct-1994 cross comparison with #13.

1.00103256	0.98735627	0.96687931	0.74577641	1.02234866	mid season
1.01655301	1.016745	0.99002756	0.74729656	1.05768801	post season

1995 Cimel Sun Photometer Data Calibration

The time and date are given for each zero airmass voltage (V_0) and for each wavelength and the seasonal change in filter response is given as well.

#6 Flin Flon				
Wavelength	1020	870	670	500
DATE: 08-May-95	12517.458	12897.622	13899.506	13655.055
TIME: 22:32:37				
DATE: 05-Nov-95	12582.104	12927.327	13833.724	13723.94
TIME: 15:58:58				
Post/preseason	1.005	1.002	0.995	1.005

#11 Waskesiu				
Wavelength	1020	870	670	500
DATE: 07-May-95	12885.336	9326.284	14941.283	18483.47
TIME: 14:41:54				
DATE: 29-Dec-95	13404.445	9648.732	15809.717	18588.241
TIME: 17:31:53				
Post/preseason	1.04	1.035	1.058	1.006
#12 Thompson				
Wavelength	1020	870	670	500
DATE: 08-May-95	13327	13223	12849	17887
TIME: 15:49:24				
DATE: 07-Dec-95	13291	13418	13149	17854
TIME: 16:37:45				
Post/preseason	0.997	1.015	1.023	0.998
#31 SSA-YJP				
Wavelength	1020	870	670	500
DATE: 07-May-95	13329.603	13645.573	14900.62	18606.043
TIME: 15:49:23				
DATE: 29-Dec-95	13620.063	14025.419	15261.078	18132.432
TIME: 17:31:58				
Post/preseason	1.022	1.028	1.024	0.975
#35 NSA-YJP				
Wavelength	1020	870	670	500
DATE: 08-May-95	19516.054	14028.61	22462.976	9513.898
TIME: 22:21:34				
DATE: 07-Jun-95	19819.766	14270.977	22896.422	9808.112
TIME: 11:12:32				
DATE: 02-Dec-95	19953.95	14316.853	22858.584	9665.12
TIME: 16:34:38				
Post/preseason	1.022	1.021	1.018	1.016
#6 Flin Flon				
Wavelength	440	380	340	940
DATE: 08-May-95	18147.869	19241.212	19757.94	22399.36
TIME: 22:32:37				
DATE: 05-Nov-95	18344.145	20505.336	18284.42	20831.22
TIME: 15:58:58				
Post/preseason	1.108	1.066	0.925	0.93
#11 Waskesiu				
Wavelength	440	380	340	940
DATE: 07-May-95	18296.37	21366.285	33970.048	21292.029
TIME: 14:41:54				
DATE: 29-Dec-95	19135.821	22185.209	30718.195	21590.383
TIME: 17:31:53				
Post/preseason	1.046	1.038	0.904	1.014

#12 Thompson				
Wavelength	440	380	340	940
DATE: 08-May-95	16964	24463	32590	29583.1
TIME: 15:49:24				
DATE: 07-Dec-95	17465	25282	31927	28451.3
TIME: 16:37:45				
Post/preseason	1.03	1.033	0.98	0.962
#31 SSA-YJP				
Wavelength	440	380	340	940
DATE: 07-May-95	16585.035	17619.795	32936.416	23163.098
TIME: 15:49:23				
DATE: 29-Dec-95	15980.247	18374.366	28336.05	22616.378
TIME: 17:31:58				
Post/preseason	0.964	1.043	0.86	0.976
#35 NSA-YJP				
Wavelength	440	380	340	940
DATE: 08-May-95	18035.776	6789.077	33650.941	32735.451
TIME: 22:21:34				
DATE: 07-Jun-95	17950.115	7319.054	34008.235	32404.751
TIME: 11:12:32				
DATE: 02-Dec-95	18170.429	7149.50	32357.469	31599.466
TIME: 16:33:38				
Post/preseason	1.007	1.053	0.962	0.965

1996 Cimel Sun Photometer Data Calibration

The time and date are given for each zero airmass voltage (V_0) and for each wavelength, and the seasonal change in filter response is given as well, where appropriate.

#12 Thompson				
Wavelength	1020	870	670	500
DATE: 27-Apr-96	13420.234	13491.316	13087.821	18244.657
TIME: 20:05:38				
DATE: 04-Nov-96	13557.683	13635.545	12996.507	18142.348
TIME: 17:32:28				
Post/preseason	1.01	1.011	0.993	0.994
#12 Thompson				
Wavelength	440	380	340	940
DATE: 27-Apr-96	17474.941	25292.378	30613.31	29172.311
TIME: 20:05:38				
DATE: 04-Nov-96	17271.154	24877.615	30012.10	28021.078
TIME: 17:32:28				
Post/preseason	0.988	0.984	0.98	0.961
#10 Paddockwood				
Wavelength	1020	870	670	500
DATE: 31-Mar-96	12449.513	8361.421	11602.164	15602.52
TIME: 15:59:22				

#10 Paddockwood				
Wavelength	440	380	340	940
DATE: 31-Mar-96	15192.358	20776.75	26675.68	20253.18
TIME: 15:59:22				

#31 SSA-YJP				
Wavelength	1020	870	670	500
DATE: 29-Dec-95	13620.063	14025.419	15261.078	18132.432
TIME: 17:31:58				

#31 SSA-YJP				
Wavelength	440	380	340	940
DATE: 29-Dec-95	15980.247	18374.366	28336.050	22616.378
TIME: 17:31:58				

#35 NSA-YJP				
Wavelength	1020	870	670	500
DATE: 24-Apr-96	19600.860	14273.589	22715.018	9523.237
TIME: 15:20:45				
DATE: 20-Dec-96	19295.777	13997.458	22520.035	9453.443
TIME: 18:32:59				
Post/preseason	0.984	0.981	0.991	0.993

#35 NSA-YJP				
Wavelength	440	380	340	940
DATE: 24-Apr-96	18016.307	6759.045	30243.207	31001.937
TIME: 15:20:45				
DATE: 20-Dec-96	18160.719	6866.885	29525.022	29548.983
TIME: 18:32:59				
Post/preseason	1.008	0.976	1.016	0.953

#11 Waskesiu				
Wavelength	1020	870	670	500
DATE: 24-Apr-96	13622.427	9649.122	15575.813	18969.570
TIME: 16:13:30				
DATE: 02-Dec-96	13602.240	9565.654	15565.203	18980.755
TIME: 19:10:59				
Post/preseason	0.999	0.991	0.999	1.001

#11 Waskesiu				
Wavelength	440	380	340	940
DATE: 24-Apr-96	19495.370	29884.542	22098.695	21705.495
TIME: 16:13:30				
DATE: 02-Dec-96	19322.585	28941.093	21926.102	21078.678
TIME: 19:10:59				
Post/preseason	0.991	0.992	0.968	0.971

5. Data Acquisition Methods

A preprogrammed sequence of measurements is taken by these instruments starting at an airmass of 7 in the morning and ending at an airmass of 7 in the evening. During the large airmass periods, direct Sun measurements are made at 0.25 airmass intervals; at smaller airmasses, the interval between measurements is typically 15 minutes. The almucantar measurements are taken at 0.5-degree intervals near the Sun (within 6 degrees) and increase from 2 to 10 degree intervals away from the solar position. The data are collected and transmitted via the Geostationary Operational Environmental Satellite (GOES) at 1-hour intervals to a computer at Wallops Island Flight Facility [Holben et al., 1996].

The hourly transmitted radiometer data stream includes date, time, temperature, battery voltage, wet sensor status, and time of transmission as well as several levels of identification numbers. The Vitel transmitter adds a time stamp at the time of transmission, as does the Wallops receiving station. The transmitter also checks for parity errors and signal strength of the transmission. After data are downloaded from the central receiving station, a status report and a troubleshooting report are automatically generated and e-mailed to appropriate system and instrument managers. The status report provides a comprehensive assessment of the operation of the radiometer and the Vitel transmitter for the data transmitted with the current download. Network managers then have sufficient information to assess the operation of individual stations.

Within Demonstrat, a package of user-friendly UNIX software, the raw data (voltages) are converted to AOT or precipitable water using the relevant instrument-specific calibration coefficients.

6. Observations

6.1 Data Notes

The data sets are generally complete from May to October or September with some exceptions noted below.

1994	
#11 NSA-YJP	26-Jun - 04-Jul collimator obstruction
#32 Waskesiu, SK	21-Jul - 25-Jul collimator obstruction
1995	
#11 Waskesiu, SK	01-Aug - 22-Aug collimator obstruction
#31 SSA-YJP	04-Sep - 07 Sep
	12-Sep - 22-Sep
	01-Jun - 01-Jul removed because of local forest fire
1996	
#10 Paddockwood	18-Apr - 27-Apr * Installed in February *
	02-Sep - 14-Sep
#11 Waskesiu, SK	01-May - 12-May
	04-Sep - 30-Sep
#31 SSA-YJP	23-Sep - 02-Oct
	15-May - 29-May
	04-Sep - 08-Sep (440-nm unusable)
	12-Sep - 23-Sep (440-nm unusable)
#35 NSA-YJP	24-Sep - 03-Oct

The hand-held records are generally complete for the whole year depending on availability of the observer.

6.2 Field Notes

None given.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The North American Datum of 1983 (NAD83) coordinates of the sites are:

Deployment Sites	Latitude	Longitude	UTM Easting	UTM Northing
1994:				
Flin Flon, MB	54.67777N	101.67843W	327315.2	6062229
NSA-YJP	55.89575N	98.28706W	544583.9	6194706.9
NSA-Thompson Airport	55.78344N	97.83359W	573151.1	6182593.1
SSA-YJP	53.87581N	104.64529W	523320.2	5969762.5
Prince Albert Airport	53.20004N	105.68383W	454320.6	5894742.2
SSA-Lake Waskesiu	53.91672N	106.06717W	429909.5	5974783.3
1995:				
SSA-YJP	53.87581N	104.64529W	523320.2	5969762.5
NSA-YJP	55.89575N	98.28706W	544583.9	6194706.9
SSA-Lake Waskesiu	53.91672N	106.06717W	429909.5	5974783.3
Flin Flon, MB	54.67777N	101.67843W	327315.2	6062229
NSA-Thompson Zoo	55.75N	97.8867W	571137	6178837
1996:				
SSA-YJP	53.87581N	104.64529W	523320.2	5969762.5
NSA-YJP	55.89575N	98.28706W	544583.9	6194706.9
SSA-Lake Waskesiu	53.91672N	106.06717W	429909.5	5974783.3
SSA-Paddockwood School	53.50951N	105.56697W	462400	5929100
NSA-Thompson Zoo	55.75N	97.8867W	571137	6178837

In addition, a hand-held sunphotometer was operated at Lake Waskesiu and Thompson during each year.

7.1.2 Spatial Coverage Map

Not available.

7.1.3 Spatial Resolution

Each sunphotometer takes measurements that are generally representative of the local area under quiescent conditions. During forest fire episodes, however, the spatial resolution depends on the nature of smoke dispersion.

7.1.4 Projection

Not applicable.

7.1.5 Grid Description

Not applicable.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

Automatic sunphotometer data are acquired at 0.25 or 0.5 airmass intervals from an airmass of 7 up to 2. Air mass is approximately equal to 1/cos(zenith angle). Then, measurements are made every 15 minutes until an afternoon airmass of 2, where time intervals are again dictated by airmass fractions.

7.2.2 Temporal Coverage Map

The following are the operation periods for the Cimel automatic sunphotometers during the 1994, 1995, and 1996 BOREAS campaigns:

1994	**OPERATION PERIODS**
Flin Flon, MB	19-May - 13-Sep
NSA-YJP	18-May - 26-Jun, 4-Jul - 01-Nov
SSA-YJP	23-May - 13-Oct
Waskesiu, SK	25-May - 21-Jul, 25-Jul - 13-Oct
Thompson, MB	08-Jun - 13-Jun, 27-Jul - 10-Sep
Prince Albert, SK	17-May - 06-Jun, 20-Jul - 26-Jul, 12-Sep -18-Sep

1995	**OPERATION PERIODS**
Flin Flon, MB	18-May - 07-Sep
NSA-YJP	16-May - 03-Nov
SSA-YJP	25-May - 01-Jun, 01-Jul - 12-Sep, 22-Sep - 21-Nov
Waskesiu, SK	24-May - 01-Aug, 22-Aug - 04-Nov
Thompson, MB	15-May - 29-Oct

1996	**OPERATION PERIODS**
Paddockwood, SK	27-Feb - 07-Nov
NSA-YJP	14-May - 24-Sep, 30-Sep - 09-Oct
SSA-YJP	10-May - 14-May, 28-May - 20-Sep, 01-Oct - 23-Oct
Waskesiu, SK	08-May - 14-May, 23-May - 04-Sep, 29-Sep - 27-Oct
Thompson, MB	14-May - 09-Sep

The following are the operation periods for the hand-held sunphotometers during 1994, 1995, and 1996 BOREAS campaigns. Gaps may indicate extended cloudy conditions, instrument problems, or operator unavailability.

1994	**OPERATION PERIODS**
Waskesiu, SK	04-Jan - 03-Mar, 22-Mar - 26-Sep, 10-Oct - 22-Dec
Thompson, MB	01-Jan - 29-Jun, 01-Aug - 21-Oct

1995	**OPERATION PERIODS**
Waskesiu, SK	01-Jan - 11-Apr, 04-May - 02-Sep, 21-Sep - 08-Oct
Thompson, MB	04-Feb - 20-Dec

1996	**OPERATION PERIODS**
Waskesiu, SK	03-Jan - 31-Dec
Thompson, MB	03-Jan - 31-Dec

7.2.3 Temporal Resolution

Cimels operated approximately every 15 minutes from morning to evening. Hand-held sunphotometers were operated near noon only.

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
AEROSOL_OPT_THICK_340
AEROSOL_OPT_THICK_380
AEROSOL_OPT_THICK_440
AEROSOL_OPT_THICK_500
AEROSOL_OPT_THICK_670
AEROSOL_OPT_THICK_870
AEROSOL_OPT_THICK_1020
COLUMN_WATER_VAPOR
AIR_TEMP
AIRMASS
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.
AEROSOL_OPT_THICK_340	The aerosol optical thickness measured between 0.339 and 0.341 micrometers.
AEROSOL_OPT_THICK_380	The aerosol optical thickness measured at 0.380 micrometers.
AEROSOL_OPT_THICK_440	The aerosol optical thickness measured between 0.438 and 0.441 micrometers.
AEROSOL_OPT_THICK_500	The aerosol optical thickness measured at 0.499 or 0.500 micrometers.
AEROSOL_OPT_THICK_670	The aerosol optical thickness measured between

	0.669 and 0.672 micrometers.
AEROSOL_OPT_THICK_870	The aerosol optical thickness measured between 0.871 and 0.873 micrometers.
AEROSOL_OPT_THICK_1020	The aerosol optical thickness measured at 1.022 micrometers.
COLUMN_WATER_VAPOR	The 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).
AIR_TEMP	The measured air temperature.
AIRMASS	The relative distance measurement of the atmosphere through which the radiance measurement is taken.
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]
AEROSOL_OPT_THICK_340	[unitless]
AEROSOL_OPT_THICK_380	[unitless]
AEROSOL_OPT_THICK_440	[unitless]
AEROSOL_OPT_THICK_500	[unitless]
AEROSOL_OPT_THICK_670	[unitless]
AEROSOL_OPT_THICK_870	[unitless]
AEROSOL_OPT_THICK_1020	[unitless]
COLUMN_WATER_VAPOR	[grams][millimeter^-2]
AIR_TEMP	[degrees Celsius]
AIRMASS	[unitless]
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 Staff]
SUB_SITE	[Assigned by BORIS Staff]
DATE_OBS	[Cimel sunphotometers, Miami hand-held sunphotometers]
TIME_OBS	[Cimel sunphotometers, Miami hand-held sunphotometers]
AEROSOL_OPT_THICK_340	[Cimel sunphotometers, Miami hand-held sunphotometers]
AEROSOL_OPT_THICK_380	[Cimel sunphotometers, Miami hand-held sunphotometers]
AEROSOL_OPT_THICK_440	[Cimel sunphotometers, Miami hand-held sunphotometers]

AEROSOL_OPT_THICK_500	[Cimel sunphotometers, Miami hand-held sunphotometers]
AEROSOL_OPT_THICK_670	[Cimel sunphotometers, Miami hand-held sunphotometers]
AEROSOL_OPT_THICK_870	[Cimel sunphotometers, Miami hand-held sunphotometers]
AEROSOL_OPT_THICK_1020	[Cimel sunphotometers, Miami hand-held sunphotometers]
COLUMN_WATER_VAPOR	[Cimel sunphotometers, Miami hand-held sunphotometers]
AIR_TEMP	[Cimel sunphotometers, Miami hand-held sunphotometers]
AIRMASS	[Demonstrat software]
CRTFCN_CODE	[Assigned by BORIS Staff]
REVISION_DATE	[Assigned by BORIS Staff]

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-999-WTH01	TRN-999-FFN02	None	None	None	None
SUB_SITE	RSS11-SPH01	RSS11-SPH01	None	None	None	None
DATE_OBS	01-JAN-94	30-DEC-96	None	None	None	None
TIME_OBS	0	2359	None	None	None	None
AEROSOL_OPT_THICK_340	0.015899	6.079923	-999	None	None	Blank
AEROSOL_OPT_THICK_380	0.017223	6.168681	-999	None	None	Blank
AEROSOL_OPT_THICK_440	0.008924	5.590672	-999	None	None	Blank
AEROSOL_OPT_THICK_500	0.000247	5.315648	-999	None	None	Blank
AEROSOL_OPT_THICK_670	0.000386	3.080577	-999	None	None	None
AEROSOL_OPT_THICK_870	0.000049	3.084524	-999	None	None	None
AEROSOL_OPT_THICK_1020	0.000005	3.109977	-999	None	None	Blank
COLUMN_WATER_VAPOR	0.61	53.06	-999	-888	None	None
AIR_TEMP	-34.8	41.3	None	None	None	Blank
AIRMASS	1.16	7.08	None	None	None	Blank
CRTFCN_CODE	CPI	CPI	None	None	None	None
REVISION_DATE	30-DEC-96	17-JUN-97	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 a sample data table on the CD-ROM:

Automatic Sunphotometer Data

```
SITE_NAME,SUB_SITE,DATE_OBS,TIME_OBS,AEROSOL_OPT_THICK_340,AEROSOL_OPT_THICK_380,
AEROSOL_OPT_THICK_440,AEROSOL_OPT_THICK_500,AEROSOL_OPT_THICK_670,
AEROSOL_OPT_THICK_870,AEROSOL_OPT_THICK_1020,COLUMN_WATER_VAPOR,AIR_TEMP,AIRMASS,
CRTFCN_CODE,REVISION_DATE
'SSA-YJP-FLXTR','RSS11-SPH01',23-MAY-94,2010,.277377,.249425,.204145,,.107646,
.079551,.06547,.01823,21.2,,'CPI',30-DEC-96
'SSA-YJP-FLXTR','RSS11-SPH01',23-MAY-94,2125,.29485,.24701,.236938,,.156992,
.131025,.120655,.01612,20.5,,'CPI',30-DEC-96
```

Handheld Sunphtometer Data

```
SITE_NAME,SUB_SITE,DATE_OBS,TIME_OBS,AEROSOL_OPT_THICK_340,AEROSOL_OPT_THICK_380,
AEROSOL_OPT_THICK_440,AEROSOL_OPT_THICK_500,AEROSOL_OPT_THICK_670,
AEROSOL_OPT_THICK_870,AEROSOL_OPT_THICK_1020,COLUMN_WATER_VAPOR,AIR_TEMP,AIRMASS,
CRTFCN_CODE,REVISION_DATE
'SSA-999-WSK01','RSS11-SPH01',04-MAY-94,1712,,,,.08099,.071275,.033016,,.386,,
1.66,'CPI',17-JUN-97
'SSA-999-WSK01','RSS11-SPH01',04-MAY-94,1714,,,,.081449,.070921,.032415,,.391,,
1.65,'CPI',17-JUN-97
```

8. Data Organization

8.1 Data Granularity

The smallest unit of data that is tracked by BORIS is all of the data for a given day at a given 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 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

Equation	Used For:
$V_\lambda = V_o \cdot R^2 \cdot e^{-(m \cdot \tau)}$	Calculation of optical depth
$T_w = e^{-a \cdot m^b \cdot w^b}$	Calculation of precipitable water
$\ln V + m \cdot \tau = \ln(V_o) - a \cdot m^b \cdot W^b$	Calibration of water vapor channel
$\alpha = -\left(\frac{\Delta \ln \tau}{\Delta \ln \lambda}\right)$	Cloud-screening procedure

9.1.1 Derivation Techniques and Algorithms

Optical thickness is calculated from spectral extinction of direct beam radiation at each wavelength based on Beer's Law:

$$V_\lambda = R^2 \cdot e^{-(m \cdot \tau)}$$

where: V_λ = digital voltage measured at wavelength λ
m = optical airmass
τ = total optical thickness
R = relative Earth-Sun distance

Attenuation due to Rayleigh scatter and absorption by ozone and gaseous pollutants is estimated and removed to isolate the AOT (τ).

The dependence of transmission, T_w, on water column abundance can be written as the following [Halthore et al., 1992, Bruegge et al., 1992]:

$$T_w = e^{-a \cdot m^b \cdot w^b}$$

where: W = vertical column abundance (cm)
a, b = constants that depend on the wavelength position, width and shape of the filter function, and atmospheric conditions.

Sky radiance measurements are inverted with radiative transfer equations [Nakajima et al., 1983] to provide aerosol properties of size distribution and phase function over the particle size range of 0.1 to 5 µm.

9.2 Data Processing Sequence

9.2.1 Processing Steps

The automatic radiometers acquire data regardless of sky conditions, except for rain, and thus require cloud-screening procedures. Three quality control schemes are considered to reject data obtained under marginal conditions. The Cimels perform three scan sequences spaced 30 seconds apart, and thus acquire three AOT measurements at each wavelength. If any of these triplets exhibit a coefficient of variation of more than 12%, the data derived from all channels are rejected. Secondly, data exhibiting an increasing or nearly flat AOT with wavelength between 440 nm and 870 nm are considered cloud-contaminated. Therefore, data with an Angstrom coefficient, a, of less than or equal to zero are removed. The Angstrom coefficient is calculated by:

$$\alpha = -\left(\frac{\Delta \ln \tau}{\Delta \ln \lambda}\right)$$ for τ at 440 nm and 870 nm, where λ is wavelength

Finally, the remaining data are plotted along with the direct Sun observations acquired during almucantar measurements exhibiting high azimuthal symmetry about the solar plane, which are expected to represent cloudless conditions. A regression line through these almucantar observations is plotted as well. The abscissa shows the AOT at 440 nm, while the ordinate depicts the ratio of this AOT to the Angstrom coefficient described above. The core of the remaining data set is found to follow the trend of the almucantar regression, and outliers are removed by subjectively drawn polygons.

Data from the hand-held sunphotometers are cloud-screened in a similar, but less rigorous, manner because the manual instruments do not take triplet measurements. The same plotting technique is used with axes of x: [500-nm AOT] and y: [500-nm / a (500/870)], although no almucantar measurements are available to plot simultaneously.

9.2.2 Processing Changes

None.

9.3 Calculations

None.

9.3.1 Special Corrections/Adjustments

None.

9.3.2 Calculated Variables

Water vapor, AOT.

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

Error	Result
Tracking misalignment	Overestimation of AOT and/or reduced reproducibility
Filter degradation	Generally underestimation of AOT
Detector response	Over- or underestimation of AOT
Temperature stability	Over- or underestimation of AOT at 1020 nm
Collimator obstruction	Overestimation of AOT
Failure to find peak response (hand-held)	Overestimation of AOT

10.2 Quality Assessment

All data have been cloud-screened and checked for almucantar symmetry.

10.2.1 Data Validation by Source

Pre/postdeployment intercomparison was made with reference instruments, pre/postdeployment filter calculations were made, and agreement of proximal instruments was verified.

10.2.2 Confidence Level/Accuracy Judgment

Data are generally good, with an absolute AOT accuracy of typically ±0.02 for the automatic sunphotometers and ±0.04 for the hand-held sunphotometers. Precipitable water measurements have agreed within 10% of radiosonde measurements [Halthore et al., 1997].

10.2.3 Measurement Error for Parameters and Variables

The Cimels make three direct Sun measurements at each wavelength in a 30-second scan sequence. This group of three measurements is referred to as a triplet. The coefficient of variability of the triplets for three reference instruments deployed at Mauna Loa was calculated based on 168, 264, and 288 observations, respectively. For all wavelengths, the variability of a triplet was always less than 1%, and generally about 0.3%, giving an estimate of the instrument's reproducibility [Holben et al., 1996]. The calibration coefficients, Vo, are usually determined by averaging the y-intercepts from three to seven Langley plots at Mauna Loa Observatory. The averaged Vo values from all calibration sessions at Mauna Loa have a coefficient of variability of ~0.25% to 0.5% for the visible and near-infrared wavelengths, ~0.5% to 2% for the ultraviolet, and ~1.0% to 3.0% for the water vapor channel [Holben et al., 1996]. The overall accuracy of AOT measurements is expected to be in the range of 0.02 at an airmass of 1.0. The hand-held sunphotometers were calibrated by intercomparison with colocated Cimels. The estimated level of uncertainty for these instruments is greater (0.04) because of less frequent recalibration. For the sky radiance measurements, calibration was performed at the NASA GSFC Calibration Facility using a calibrated integrating sphere to an accuracy of +/- 5%. For the 940-nm channel that includes water absorption, calibration was performed using a variant of the modified Langley method as described in Halthore et al. [1997]. The method used is similar to that described elsewhere; for instance, Bruegge et al., 1992b, and Halthore et al., 1992b. Column amounts of precipitable water derived from sunphotometer measurements at BOREAS have compared favorably with radiosonde observations [Halthore et al., 1997] to within +/- 10%.

10.2.4 Additional Quality Assessments

None given.

10.2.5 Data Verification by Data Center

BORIS personnel have reviewed portions of the actual parameter values and generated plots for use in visually spotting any anomalous values.

11. Notes

11.1 Limitations of the Data

None given.

11.2 Known Problems with the Data

Most data are good, though occasionally the AOT at 1020 nm will exceed that at 870 nm, or the AOT at 500 nm will exceed that at 440 nm for very low aerosol conditions (AOT 500 < 0.04), when sensitivity to aerosol is minimal and calibration errors are greatly accentuated. Most of the apparent errors are on the order of 0.01 in AOT, so it is typically a minor concern. On most instruments, the 340- and 380-nm channels are less reliable than the longer wavelengths, likely because of the nature of the filter design, and at times, they yield AOT values that are lower for 340 nm than 380 nm.

Triplet variation is larger for instrument #31, which is currently suspected to result from a 4-quadrant detector that is misaligned or otherwise functioning inadequately. Similar problems in other instruments at GSFC not involved with BOREAS are being investigated.

11.3 Usage Guidance

None given.

11.4 Other Relevant Information

None given.

12. Application of the Data Set

The AOT data can be used as input for standard radiative transfer programs such as LOW-resolution Radiative Transfer Code (LOWTRAN-7), MODerate Resolution Radiative Transfer Code (MODTRAN), or the Second Simulation of the Satellite Signal in the Solar Spectrum (6S) to perform atmospheric correction of remotely sensed data.

13. Future Modifications and Plans

Possible fully objective cloud-screening routine.

14. Software

14.1 Software Description

"Demonstrat" is a package of user-friendly UNIX software developed at GSFC used for data analysis and can be found at spamer.gsfc.nasa.gov.

Within Demonstrat, the raw data (voltages) are converted to AOT or precipitable water using the relevant instrument-specific calibration coefficients.

14.2 Software Access

Guest accounts are available and accessible via X-term window. Contact persons: Brent Holben (Brent.N.Holben.1@gsfc.nasa.gov) or Ilya Slutsker (Ilya.Slutsker.1@gsfc.nasa.gov).

15. Data Access

The RSS-11 sunphotometer 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

Ahern, F.J., R.P. Gauthier, P.M. Teillet, J. Sirois, G. Fedosejevs, and D. Lorente. 1991. Investigation of continental aerosols with high-spectral-resolution solar-extinction measurements. Appl. Optics, 30, 5276-5287.

Bruegge, C.T., J.E. Conel, R.O. Green, J.S. Margolis, R.G. Holm, and G. Toon. 1992. Water vapor column abundance retrievals during FIFE. JGR, 97(D19), 18759-18768.

Bruegge, C.T., R.N. Halthore, B. L. Markham, M. Spanner, and R. Wrigley, 1992, Aerosol optical depth retrievals over the Konza Prairie, Journal of Geophysical Research, 97(d19), 18,743-18,758.

d'Almeida, G.A. and P. Koepke. 1998. An approach to a global optical aerosol climatology. In Aerosols and Climate, edited by P.V. Hobbs and M.P. McCormick, Deepak Publishing, Hampton, VA.

Halthore, R.N., B.L. Markham, R.A. Ferrare, and T.O. Aro. 1992. Aerosol optical properties over the midcontinental United States. Journal of Geophysical Research, 97(D17), 18,769-18,778.

Halthore, R.N., T.F. Eck, B.N. Holben, and B. Markham. 1997. Sunphotometric measurements of atmospheric water vapor column abundance in the 940-nm band. Journal of Geophysical Research, 102, 4343-4352.

Hansen, J.E. and A.A. Lacis. 1990. Sun and dust versus greenhouse gases: An assessment of their relative roles in global climate change. Nature, 345, 713-719.

Hegg, D.A., P.V. Hobbs, R.J. Ferek, and A.P. Waggoner. 1995. Measurements of some aerosol properties relevant to radiative forcing on the east coast of the United States. J. Appl. Meteor., 34, 2306-2315.

Holben, B.N., T.F. Eck, and R.S. Fraser. 1991b. Temporal and spatial variability of aerosol optical depth in the Sahel region in relation to vegetation remote sensing. Int. J. Remote Sens., 12, 1147-1163.

Holben, B.N., T.F. Eck, I. Slutsker, D. Tanrè, J.P. Buis, A. Setzer, E. Vermote, J.A. Reagan, Y.J. Kaufman, T. Nakajima, F. Lavenu, I. Jankowiak, and A. Smirnov. 1998. AERONET - A federated instrument network and data archive for aerosol characterization. Rem. Sens. Environ. 66, 1-16.

Holben, B.N., Y.J. Kaufman, A. Setzer, D. Tanrè, and D.E. Ward. 1991a. Optical properties of aerosol from biomass burning in the tropics, BASE-A. In Global Biomass Burning, the MIT Press, Cambridge, MA, 403-411.

Kaufman, Y.J., A. Setzer, D. Ward, D. Tanrè, B.N. Holben, P. Menzel, M.C. Pereira, and R. Rasmussen. 1992. Biomass burning airborne and spaceborne experiment in the Amazonas (BASE-A). Journal of Geophysical Research, 97(D13), 14,581-14,599.

Kaufman, Y.J., B.N. Holben, D. Tanrè, and D.E. Ward. 1994. Remote sensing of biomass burning in the Amazon. Remote Sensing Reviews, 10, 51-90.

Lenoble, J. 1993. Atmospheric Radiative Transfer. Deepak Publishing: Hampton, VA, pp. 532.

Markham, B.L., J.S. Schafer, B.N. Holben, and R.N. Halthore. 1997. Atmospheric aerosol and water vapor characteristics over north central Canada during BOREAS. Journal of Geophysical Research 102(D24): 29,737-29,745.

Nakajima, Y., M. Tanaka, and T. Yamauchi. 1983. Retrieval of the optical properties of aerosols from aureole and extinction data. Appl. Opt., 22, 2951-2959.

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. 2000. Collected Data of The Boreal Ecosystem-Atmosphere Study. NASA. CD-ROM.

Reagan J.A., K.J. Thome, and B.M. Herman. 1992. A simple instrument and technique for measuring columnar water vapor via Near-IR differential solar transmission measurements. IEEE Trans. Geosci. Remote Sensing, 30, 825-831.

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).

Sellers, P., F. Hall, and K.F. Huemmrich. 1997. Boreal Ecosystem-Atmosphere Study: 1996 Operations. NASA BOREAS Report (OPS DOC 96).

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.

Shaw, G.E. 1983. Sun photometry. Bull. Am. Meteorol. Soc., 64, 4-10.

Thome, K.J., B.M. Herman and J.A. Reagan. 1992. Determination of precipitable water from solar transmission. J. Appl. Met., 31, 157-165.

Twomey, S. 1991. Aerosols, clouds and radiation. Atmos. Environ., 25(A), 2435-2442.

Ward, D.E., R.A. Susott, J.B. Kauffman, R.E. Babbit, D.L. Cummings, B. Dias, B.N. Holben, Y.J. Kaufman, R.A. Rasmussen, and A.W. Setzer. 1992. Smoke and fire characteristics for cerrado and deforestation burns in Brazil: BASE-B experiment. Journal of Geophysical Research, 97(D13), 14,601-14,619.

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

Aerosol optical depth	a dimensionless measure of the extinction of the direct solar beam due to scattering and absorption by atmospheric particulates.
Air mass	approximately equal to 1/cos(solar zenith angle)
Almucantar	sunphotometer procedure that measures the sky radiance in four spectral bands (440, 670, 870, and 1020 nm) at constant solar zenith angle, with varied azimuth angles ranging from 0.25-degree intervals near the solar azimuth position to 10-degree intervals far from the solar azimuth position.
Asymmetry parameter	average cosine of the scattering angle weighted by the phase function.
Phase function	a dimensionless measure of the relative scattering intensity of a particle as a function of angle relative to the original propagation direction.
Rayleigh scatter	scatter of solar energy by gaseous molecules that is highly predictable for a given atmospheric pressure.

19. List of Acronyms

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6S      - Second Simulation of the Satellite Signal in the Solar Spectrum
AOT     - Aerosol Optical Thickness
ASCII   - American Standard Code for Information Interchange
BOREAS  - BOReal Ecosystem-Atmosphere Study
BORIS   - BOREAS Information System
CCRS    - Canada Centre for Remote Sensing
CD-ROM  - Compact Disk-Read-Only Memory
DAAC    - Distributed Active Archive Center
EOS     - Earth Observing Satellite
EOSDIS  - EOS Data and Information System
FOV     - Field of View
GIS     - Geographic Information System
GMT     - Greenwich Mean Time
GOES    - Geostationary Operational Environmental Satellite
GSFC    - Goddard Space Flight Center
HTML    - HyperText Markup Language
LOWTRAN - LOW resolution radiative TRANsfer code
MODTRAN - MODerate resolution radiative TRANsfer code
NASA    - National Aeronautics and Space Administration
NSA     - Northern Study Area
ORNL    - Oak Ridge National Laboratory
PANP    - Prince Albert National Park
RSS     - Remote Sensing Science
SSA     - Southern Study Area
URL     - Uniform Resource Locator
UTM     - Universal Transverse Mercator
YJP     - Young Jack Pine
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The BOREAS RSS-11 team operated a network of five automated (Cimel) and two hand-held (Miami) solar radiometers from 1994 to 1996 during the BOREAS field campaigns. The data provide aerosol optical depth measurements, size distribution, phase function, and column water vapor amounts over points in northern Saskatchewan and Manitoba, Canada. The data are useful for the correction of remotely sensed aircraft and satellite images. The data are provided in tabular ASCII files.

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