NASA/TM—2000–209891, Vol. 167

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

Forrest G. Hall and Shelaine Curd, Editors

Volume 167

BOREAS TE-12 Leaf Optical Data for SSA Species

Elizabeth A. Walter-Shea, Mark A. Mesarch, and L. Chen
University of Nebraska-Lincoln

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

October 2000

Available from:

NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076-1320
Price Code: A17

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

BOREAS TE-12 Leaf Optical Data for SSA Species

Elizabeth A. Walter-Shea , Mark A. Mesarch, L. Chen

Summary

The BOREAS TE-12 team collected several data sets in support of its efforts to characterize and interpret information on the reflectance, transmittance, and gas exchange of boreal vegetation. This data set contains measurements of hemispherical spectral reflectance and transmittance factors of individual leaves, needles (ages: current and past 2 years' growth, i.e., for 1993, the growing seasons of 1993, 1992, and 1991 were measured; in 1994, the growing seasons of 1994, 1993, and 1992 were measured), twigs (reflectance only), and substrate at near-normal incidence measured using a LI-COR LI-1800-12 integrating sphere attached to a Spectron Engineering SE590 spectroradiometer. Procedures of Daughtry et al. (1989) were followed. These procedures permitted measurement of samples that: 1) filled the entire integrating sphere sample port, and 2) were narrow with a length greater than the sample port diameter. Optical properties were measured in 1993 and 1994 at the SSA Fen, YJP, YA, and OBS sites. The data are stored in tabular ASCII files.

Table of Contents

1. Data Set Overview

1.1 Data Set Identification

BOREAS TE-12 Leaf Optical Data for SSA Species

1.2 Data Set Introduction

Hemispherical spectral reflectance and transmittance factors of individual leaves, needles (ages: current and past 2 years' growth, i.e., for 1993, the growing seasons of 1993, 1992, and 1991 were measured; in 1994, the growing seasons of 1994, 1993, and 1992 were measured), twigs (reflectance only), and substrate at near-normal incidence were measured using a LI-COR LI-1800-12 integrating sphere attached to a Spectron Engineering SE590 spectroradiometer. Each SE590 has a unique wavelength associated with each of its 252 bands. A cubic spline interpolation was applied to the 252-bands to standardize the wavelengths to every 5 nm from 400 to 1,000 nm, so that wavelength-to-wavelength comparisons can be made between SE590s.

1.3 Objective/Purpose

The purpose of this work was to characterize optical properties of boreal forest canopy and substrate elements.

1.4 Summary of Parameters

Hemispherical reflectance and transmittance factors of needles and twigs (from current and past years' growth) and individual leaves and substrate elements. Measurements were made for both tops and bottoms of leaves and needles.

1.5 Discussion

Intensive Field Campaign (IFC)-1993:

Optical properties were measured at two sites in the BOReal Ecosystem-Atmosphere Study (BOREAS) Southern Study Area (SSA): at or near the Nipawin Fen (FEN) and Nipawin Jack Pine [Young-Dry] (YJP). Canopy access was limited to only ground level collection of samples. Samples from trees were from various heights within the tree, but generally were from the lower third of the entire canopy height. Black spruce [Picea mariana], jack pine [Pinus banksiana], Labrador tea [Ledum groenlandicum], and aspen [Populus tremuloides] were sampled near the SSA-FEN site. Bog birch [Betula pumila], buck bean [Menyanthes trifloiate], marsh marigold [Caltha palustris], and cinquefoil [Potentilla palustris] were sampled in the SSA-FEN site. Jack pine needles and substrate (dead needles, bark, blueberry [Vaccinium sp.], and bearberry [Arctostaphylos uva-ursi]) were sampled at the SSA-YJP site.

Procedures of Daughtry et al. (1989) were followed. These procedures permitted measurement of two sample types: type 1, which filled the entire integrating sphere sample port, and type 2, which were narrow with a length greater than the sample port diameter. One of the two external light sources was used with the integrating sphere: a standard illuminator with a beam (11.4-mm-diameter spot size) and a modified illuminator with a restricted beam spot (slitted illuminator -- 3.5-mm x 11-mm spot size). Sample type 1 used the standard light source, while sample type 2 used either the standard or the modified light source depending on sample length.

Optical properties measured for sample type 1 were reflectance and transmittance of the adaxial (top) and abaxial (bottom) surfaces. Measurement procedures limited to sample type 2 reflectance and transmittance measurements to only one surface of a sample; generally, the adaxial surface was measured.

Focused Field Campaign (FCC)-Winter (W):

Optical properties were measured at two sites in the SSA: Old Jack Pine (OJP) and Old Black Spruce (OBS). The measurement methods described above were used. Jack pine trees were sampled at SSA-OJP, and black spruce trees were sampled at SSA-OBS. Adaxial and abaxial surfaces of the needles were measured.

FFC-Thaw (T):

Optical properties were measured at two sites in the SSA: OJP and OBS. Jack pine trees were sampled at SSA-OJP, and black spruce trees were sampled at SSA-OBS. Measurements were made following the modified procedures of Daughtry et al. (1989) in which an image analysis system was used to measure the nonintercepted illumination beam. Reflectance and transmittance of the adaxial and abaxial surfaces of the samples were measured.

IFC-1, -2, and -3:

Optical properties were measured at five sites in the SSA: YJP, FEN, OBS, Old Aspen (OA), and Young Aspen (YA). Jack pine, bearberry, fuzzy-spiked wild rye [Elymus Innovatus], and some substrate components (dead needles and bark) were sampled at SSA-YJP. Bog birch (of various senescing stages), buck bean, and a sedge [Carex sp.] were measured at SSA-FEN. Black spruce, wildrose [Rosa woodsii], Labrador tea [Ledum groenlandicum], and blueberry were sampled at SSA-OBS. Mature aspen was measured at SSA-OA during IFC-1 only. Young aspen, hazelnut [Corylus cornuta], alder [Alnus crispa], and balsam poplar [Populus balsamifera] were measured at the SSA-YA (IFC-2 and -3); aspen, hazelnut, and balsam poplar were measured at various senescent stages during IFC-3 only.

Optical properties were measured following the modified procedures of Daughtry et al. (1989). An image analysis system was used to measure the nonintercepted illumination beam area. Reflectance and transmittance of the adaxial (top) and abaxial (bottom) surfaces were measured for sample types 1 and 2. Generally, the adaxial surface was measured.

1.6 Related Data Sets

BOREAS TE-12 SSA Shoot Geometry Data
BOREAS TE-12 SSA Water Potential Data
BOREAS TE-10 Leaf Optical Properties

2. Investigator(s)

2.1 Investigator(s) Name and Title

Elizabeth A. Walter-Shea Associate Professor

2.2 Title of Investigation

Radiation and Gas Exchange of Canopy Elements in a Boreal Forest

2.3 Contact Information

Contact 1:
Mark A. Mesarch
University of Nebraska- Lincoln
107 LW Chase Hall
Lincoln, NE 68583-0728
(402) 472-5904
(402) 472-0284
(402) 472-6614 (fax)
mmesarch@unlinfo.unl.edu

Contact 2:
Elizabeth A. Walter-Shea
University of Nebraska- Lincoln
246 LW Chase Hall
Lincoln, NE 68583-0728
(402) 472-1553
(402) 472-6614 (fax)
agme012@unlvm.unl.edu

Contact 3:
Cynthia J. Hays
University of Nebraska- Lincoln
105 LW Chase Hall
Lincoln, NE 68583-0728
(402) 472-6701
(402) 472-6614 (fax)
agme025@unlvm.unl.edu

Contact 4:
Shelaine Curd
Raytheon ITSS
Code 923
NASA GSFC
Greenbelt, MD 20771
(301) 286-2447
(301) 286-2039 (fax)
shelaine.curd@gsfc.nasa.gov

Contact 5:
Andrea Papagno
Raytheon ITSS
Code 923
NASA GSFC
Greenbelt, MD 20771
(301) 286-3134
(301) 286-2039 (fax)
apapagno@pop900.gsfc.nasa.gov

3. Theory Of Measurements

Leaves, needles, and bark are canopy elements that are important in scattering radiation in boreal forest vegetation (Norman and Jarvis, 1974). Needle and bark properties can vary considerably depending on age and height in the canopy; elements deep in the canopy may be covered with algae and fungi, and shade-induced effects on shoot development may exist (Norman and Jarvis, 1974; Smith and Carter, 1988). In the near-infrared portion of the electromagnetic spectrum, little radiation is absorbed; thus, scattering by canopy elements will be significant. In contrast, leaves and needles absorb a large portion of photosynthetically active radiation (PAR) (Daughtry et al., 1989; Williams, 1991). Conifer needles absorb more PAR than deciduous leaves do; twigs, especially the current year's growth, also absorb PAR (Williams, 1991). Thus, the scattering component of PAR may be small except in sparse canopies with high underlying surface albedo.

In the LI-COR 1800-12 integrating sphere (LI-COR, Inc., Lincoln, NE), the sample is held to the outside of the sphere, with a small section of the sample acting as part of the sphere wall. The interior of the sphere is coated with barium sulfate to make a uniform diffuse reflector. In this type of sphere, the sensor, in this case the SE590, does not directly observe the sample. The field of view of the sensor is a section of the sphere wall.

To calculate reflectance, a comparison of the wall illumination caused by a beam of radiation reflected by the sample material to that reflected from the reference material is calculated. The LI-COR 1800-12 uses the same illumination source for both cases. The source is moved between ports to illuminate the sample and reference material. Under ideal conditions, the sample reflectance is given by the ratio of the illuminated sample output and the reference output. In reality, other factors must be considered. First, the reference material is not a perfect reflector. Also, not all of the incoming radiation beam hits the sample or reference; some radiation is scattered off of the sphere walls without hitting the target. Finally, adjustments must be made if the sample does not cover the entire port of the integration sphere.

Transmittance is calculated by comparing the wall illumination from radiation passed through the sample to the illumination when no sample was present. As with reflectance measurements, corrections must be made to the ideal case. Daughtry et al. (1989) describes the measurement methods for the three cases of leaf sizes. Case 1 is for leaves that can completely cover the sample port of the integration sphere; case 2 is for leaves that are too narrow to cover the sample port but are long enough to be attached to a sample holder outside of the view through the sample port.

The difficulty in determining the reflectance and transmittance of leaves that are too small to cover the sample port (case 2) is that what is observed in the sample port now consists of a combination of the leaves and the material between the leaves; air for case 2. The problem in this case is to determine the area of leaves covering the sample port and adjust the measured reflected and transmitted fluxes by that fractional area. The fractional area of the needles was determined using a solid-state camera. The image of the sample was transferred to a PC, where the areas were calculated.

4. Equipment

4.1 Instrument Description

The Spectron Engineering SE590 is a portable battery- or A/C-operated spectroradiometer consisting of a CE500 data analyzer/logger controller, CE390 spectral detector head, and an external battery charger/power supply. The CE500 is a self-contained microprocessor-based controller that processes the signal from the detector head, amplifying and digitizing it with 12-bit resolution. For each spectral scan, the controller actuates the CE390 shutter, measures and stores the dark current, calculates optimum integration time, acquires the spectrum, and automatically subtracts the noise for all 256 spectral elements. A series of scans can be taken and automatically averaged; for these measurements, four scans were averaged for full leaf samples and eight scans were averaged for all other samples. The entire 12-bit binary spectrum is stored in a double-precision register until it is transmitted through the RS-232C port. The spectral detector head uses a diffraction grating as the dispersive element; the spectrum is imaged onto a 256-element photodiode array. Each element integrates simultaneously, acquiring the spectrum in a fraction of a second. The interconnect cable from the spectral head to the controller couples the spectral signals to the controller, and the timing and control signals to the detector head. A shutter in the detector head, operated by the controller, closes the light path for dark current measurements. For further information, consult the SE590 operating manual. Serial Number 1571 was used.

The LI-COR LI-1800-12 Integrating Sphere is an instrument for collecting radiation that has been reflected from or transmitted through a sample material. An external light source illuminates a spot on the sample. Either a standard light source (11.4 mm diameter) or a modified light source that restricts the illumination spot size (3.5 mm x 11 mm) was used. The lamp used in the external light source is a 6-Volt 10-Watt glass-halogen. For a further description, see the LI-COR Integrating Sphere Instruction Manual. Serial Number IS115-8304 was used in 1993, and IS319 was used in 1994.

An image analysis system was used to measure the gaps between sample elements (e.g., needles, twigs) when a sample did not fill the entire integrating sphere sample port or a single sample element was too narrow to be completely encompassed by the modified light source.

A Coho solid-state camera (model 4812-2000/ES16) with a 60-mm focal length: 2.8 Nikon lens was used to view a sample. A near-infrared filter was added to the lens after 20-August-1994. The camera was mounted approximately 24.1 cm above the sample. The lens was set at an aperture of 11 mm.

The sample was placed on a Wolff two-bulb fluorescent light table. Red transparencies were placed under the sample to restrict the total amount of light in the system to an area of peak response (608 nm) to avoid saturating the signal from the camera. After 30-August-1994, a black cloth was draped around the camera lens down to the light table to reduce the amount of extraneous light shining on the sample or into the lens.

A Data Translation frame grabber board (UM-08128-B) was used to input the signal from the camera to an IBM 80286. SPSS' software JAVA version 1.4 was used to measure the areas of the gaps between needles. The display monitor was an IBM VGA with 640 by 480 pixels.

4.1.1 Collection Environment

Measurements of black spruce and jack pine needles were made in the control environment of the laboratory. Aspen leaves were measured onsite at the SSA-YA and SSA-OA site. Other samples were measured at the site where they were collected or back at the lab.

4.1.2 Source/Platform

The Spectron Engineering SE590 was connected to the LI-COR integrating sphere. This assembly was mounted on a camera tripod and adjusted to ensure that the light source was level.

4.1.3 Source/Platform Mission Objectives

None given.

4.1.4 Key Variables

Specular reflectance, transmittance and absorbance of needle and leaf elements.

4.1.5 Principles of Operation

The SE590 spectral detector head uses a diffraction grating as the dispersive element; the spectrum is imaged onto a 256-element photodiode array. Each element integrates simultaneously, acquiring the spectrum in a fraction of a second.

The LI-COR LI-1800-12 integrating sphere is an external integrating sphere, which means that the sample is external to the sphere; when it is in place, a small part of the sample actually makes up part of the sphere wall. For further information, see the LI-COR 1800-12 Integrating Sphere Instruction Manual.

The Cohu solid state camera transmits a signal to the frame grabber board, which translates the intensity of each pixel to a gray scale from 0 (black) to 255 (white) levels. The JAVA software program was set up to count the number of pixels in a defined area of interest for a range of gray scales that represent the "white" gaps between the sample needle elements.

4.1.6 Instrument Measurement Geometry

The SE590 was mounted on the LI-COR LI-1800-12 integrating sphere. A tripod is attached to the support connecting the SE590 and integrating sphere. A modified external light source with a slitted beam (3.5 mm x 11 mm) was used to illuminate narrow samples and associated reference. A standard external light source with a circular beam (11.4-mm-diameter spot size) was used to illuminate all other samples and associated reference. The light source was kept in a horizontal position according to integrating sphere manual requirements.

4.1.7 Manufacturer of Instrument

Spectron Engineering, Inc.
25 Yuma Court
Denver, CO 80223
(303) 733-1060

LI-COR LI-1800-12 Integrating Sphere:
LI-COR, Inc.
Box 4425
Lincoln, NE 68504
(402) 467-3576

Cohu Solid State Camera:
Cohu, Inc., Electronics Division
5755 Kearny Villa Road
P.O. Box 85623
San Diego, CA 92138-0221
(619) 277-6700
(619) 277-0221 (fax)

Frame Grabber Board:
Data Translation, Inc.
100 Locke Drive
Marlboro, MA 01752-1192
(508) 481-3700

SPSS, Inc.
233 S. Wacker Drive
11th Floor
Chicago, IL 60606-6307
(800) 543-2185
(800) 841-0064 (fax)

4.2 Calibration

4.2.1 Specifications

Each SE590 has a unique wavelength associated with each of its 252 bands. A cubic spline interpolation was applied to the 252 bands to standardize the wavelengths to every 5 nm from 400 to 1,000 nm, so that wavelength-to-wavelength comparisons can be made between SE590s.

4.2.1.1 Tolerance

The SE590 response was checked periodically using neutral density filters of known transmittances (Mesarch et al., 1991). For all measurement periods, no corrections were made to the SE590 response, because mean relative errors were less than 0.2 percent across wavelengths. The collimation of the LI-COR LI-1800-12 integrating sphere illuminator was checked daily by making a stray light measurement (LI-COR, 1983). Results from a temperature dependency study indicate that measurements at 1,000 nm may result in discrepancies of approximately 50-W/m^2/sr/µm if the instrument temperature varies for 16 to 43.5 °C (Blad et al., 1990). The temperature effect should be negligible because the suite of measurements required to calculate reflectance and transmittance ratios is acquired in a short period of time, during which temperature change is minor to nonexistent.

4.2.2 Frequency of Calibration

Transmittance filter tests were conducted before, during, and after field measurements. A preseason wavelength characterization was performed at Goddard Space Flight Center (GSFC) in April 1993 and March 1994.

4.2.3 Other Calibration Information

Wavelengths, in nanometers, used for data reduction for IFC-1993 and FFC-W were:

channel	wavelength	ch.	wavelength	ch.	wavelength
1	369.0514	2	371.7167	3	374.3852
4	377.0569	5	379.7318	6	382.4099
7	385.0912	8	387.7756	9	390.4633
10	393.1541	11	395.8481	12	398.5453
13	401.2457	14	403.9493	15	406.6561
16	409.3661	17	412.0792	18	414.7955
19	417.5151	20	420.2378	21	422.9637
22	425.6928	23	428.4250	24	431.1605
25	433.8992	26	436.6410	27	439.3860
28	442.1342	29	444.8856	30	447.6402
31	450.3980	32	453.1590	33	455.9231
34	458.6905	35	461.4610	36	464.2347
37	467.0116	38	469.7917	39	472.5750
40	475.3615	41	478.1512	42	480.9440
43	483.7400	44	486.5393	45	489.3417
46	492.1473	47	494.9561	48	497.7680
49	500.5832	50	503.4016	51	506.2231
52	509.0478	53	511.8757	54	514.7068
55	517.5411	56	520.3786	57	523.2193
58	526.0631	59	528.9102	60	531.7604
61	534.6138	62	537.4704	63	540.3302
64	543.1932	65	546.0594	66	548.9288
67	551.8013	68	554.6770	69	557.5560
70	560.4381	71	563.3234	72	566.2119
73	569.1035	74	571.9984	75	574.8965
76	577.7977	77	580.7021	78	583.6097
79	586.5205	80	589.4345	81	592.3517
82	595.2721	83	598.1956	84	601.1224
85	604.0523	86	606.9854	87	609.9217
88	612.8612	89	615.8039	90	618.7498
91	621.6989	92	624.6511	93	627.6065
94	630.5652	95	633.5270	96	636.4920
97	639.4602	98	642.4315	99	645.4061
100	648.3839	101	651.3648	102	654.3489
103	657.3362	104	660.3267	105	663.3204
106	666.3173	107	669.3174	108	672.3206
109	675.3271	110	678.3367	111	681.3495
112	684.3655	113	687.3847	114	690.4071
115	693.4327	116	696.4615	117	699.4934
118	702.5285	119	705.5669	120	708.6084
121	711.6531	122	714.7010	123	717.7520
124	720.8063	125	723.8638	126	726.9244
127	729.9882	128	733.0552	129	736.1254
130	739.1988	131	742.2754	132	745.3552
133	748.4381	134	751.5243	135	754.6136
136	757.7061	137	760.8018	138	763.9007
139	767.0028	140	770.1081	141	773.2166
142	776.3282	143	779.4430	144	782.5611
145	785.6823	146	788.8067	147	791.9343

148	795.0650	149	798.1990	150	801.3362
151	804.4765	152	807.6200	153	810.7667
154	813.9166	155	817.0697	156	820.2260
157	823.3855	158	826.5481	159	829.7140
160	832.8830	161	836.0552	162	839.2306
163	842.4092	164	845.5910	165	848.7760
166	851.9642	167	855.1555	168	858.3500
169	861.5478	170	864.7487	171	867.9528
172	871.1601	173	874.3705	174	877.5842
175	880.8011	176	884.0211	177	887.2443
178	890.4707	179	893.7003	180	896.9331
181	900.1691	182	903.4083	183	906.6506
184	909.8962	185	913.1449	186	916.3968
187	919.6519	188	922.9102	189	926.1717
190	929.4364	191	932.7043	192	935.9753
193	939.2495	194	942.5270	195	945.8076
196	949.0914	197	952.3784	198	955.6685
199	958.9619	200	962.2585	201	965.5582
202	968.8611	203	972.1672	204	975.4765
205	978.7890	206	982.1047	207	985.4236
208	988.7456	209	992.0709	210	995.3993
211	998.7309	212	1002.0650	213	1005.4030
214	1008.7440	215	1012.0890	216	1015.4360
217	1018.7870	218	1022.1410	219	1025.4980
220	1028.8590	221	1032.2220	222	1035.5890
223	1038.9590	224	1042.3320	225	1045.7080
226	1049.0870	227	1052.4700	228	1055.8560
229	1059.2450	230	1062.6370	231	1066.0320
232	1069.4310	233	1072.8330	234	1076.2380
235	1079.6460	236	1083.0570	237	1086.4720
238	1089.8890	239	1093.3100	240	1096.7340
241	1100.1620	242	1103.5920	243	1107.0260
244	1110.4620	245	1113.9020	246	1117.3460
247	1120.7920	248	1124.2420	249	1127.6940
250	1131.1500	251	1134.6090	252	1138.0720

Wavelengths, in nanometers, used for data reduction for FFC-T and IFC-1, -2, and -3 were:

channel	wavelength	ch.	wavelength	ch.	wavelength
1	369.1879	2	371.884	3	374.5831
4	377.285	5	379.9898	6	382.6975
7	385.4081	8	388.1217	9	390.8381
10	393.5574	11	396.2796	12	399.0047
13	401.7327	14	404.4635	15	407.1973
16	409.934	17	412.6736	18	415.4161
19	418.1614	20	420.9097	21	423.6609
22	426.4149	23	429.1719	24	431.9317
25	434.6945	26	437.4601	27	440.2286
28	443.0001	29	445.7744	30	448.5516
31	451.3317	32	454.1147	33	456.9007
34	459.6895	35	462.4812	36	465.2758
37	468.0733	38	470.8737	39	473.6769
40	476.4831	41	479.2922	42	482.1042
43	484.9191	44	487.7368	45	490.5575
46	493.3811	47	496.2075	48	499.0369
49	501.8691	50	504.7043	51	507.5423
52	510.3832	53	513.2271	54	516.0738
55	518.9234	56	521.7759	57	524.6313
58	527.4897	59	530.3509	60	533.215
61	536.082	62	538.9519	63	541.8247
64	544.7003	65	547.5789	66	550.4604
67	553.3448	68	556.2321	69	559.1222
70	562.0153	71	564.9113	72	567.8101
73	570.7119	74	573.6165	75	576.5241
76	579.4345	77	582.3478	78	585.2641
79	588.1832	80	591.1052	81	594.0301
82	596.9579	83	599.8887	84	602.8223
85	605.7588	86	608.6982	87	611.6405
88	614.5857	89	617.5337	90	620.4847
91	623.4386	92	626.3954	93	629.3551
94	632.3176	95	635.2831	96	638.2515
97	641.2227	98	644.1969	99	647.1739
100	650.1539	101	653.1367	102	656.1224
103	659.1111	104	662.1026	105	665.097
106	668.0943	107	671.0945	108	674.0977
109	677.1037	110	680.1126	111	683.1244
112	686.1391	113	689.1567	114	692.1771
115	695.2005	116	698.2268	117	701.256
118	704.2881	119	707.323	120	710.3609
121	713.4017	122	716.4453	123	719.4919
124	722.5413	125	725.5937	126	728.6489
127	731.707	128	734.7681	129	737.832
130	740.8988	131	743.9685	132	747.0411
133	750.1167	134	753.1951	135	756.2764
136	759.3606	137	762.4477	138	765.5377
139	768.6305	140	771.7263	141	774.825
142	777.9266	143	781.0311	144	784.1384
145	787.2487	146	790.3619	147	793.4779
148	796.5969	149	799.7187	150	802.8435

151	805.9711	152	809.1016	153	812.2351
154	815.3714	155	818.5106	156	821.6527
157	824.7977	158	827.9457	159	831.0965
160	834.2502	161	837.4068	162	840.5663
163	843.7287	164	846.8939	165	850.0621
166	853.2332	167	856.4072	168	859.5841
169	862.7638	170	865.9465	171	869.1321
172	872.3205	173	875.5119	174	878.7061
175	881.9033	176	885.1033	177	888.3062
178	891.5121	179	894.7208	180	897.9324
181	901.1469	182	904.3643	183	907.5847
184	910.8079	185	914.034	186	917.263
187	920.4949	188	923.7297	189	926.9673
190	930.2079	191	933.4514	192	936.6978
193	939.9471	194	943.1992	195	946.4543
196	949.7123	197	952.9731	198	956.2369
199	959.5035	200	962.7731	201	966.0455
202	969.3208	203	972.5991	204	975.8802
205	979.1642	206	982.4511	207	985.7409
208	989.0337	209	992.3293	210	995.6278
211	998.9292	212	1002.233	213	1005.54
214	1008.85	215	1012.163	216	1015.479
217	1018.798	218	1022.12	219	1025.444
220	1028.772	221	1032.102	222	1035.435
223	1038.771	224	1042.11	225	1045.452
226	1048.797	227	1052.145	228	1055.496
229	1058.849	230	1062.206	231	1065.565
232	1068.927	233	1072.292	234	1075.66
235	1079.031	236	1082.405	237	1085.782
238	1089.161	239	1092.544	240	1095.929
241	1099.317	242	1102.709	243	1106.103
244	1109.5	245	1112.899	246	1116.302
247	1119.708	248	1123.116	249	1126.528
250	1129.942	251	1133.359	252	1136.78

5. Data Acquisition Methods

The CANOPY_LOCATION parameter of the data set is a relative measure based upon the height of the sample location relative to the height of the canopy. Therefore, a sample collected from the top of a short tree in a tall canopy and a sample collected from the bottom of a short tree in a short canopy can both be designated as "low" for the HEIGHT parameter. CANOPY_LOCATION parameters used are HIGH, LOW, MIDDLE, GROUND, and UNDER. UNDER refers to an understory component being measured. GROUND refers to the lower third of the total canopy height.

For IFC-1993 and IFC-1, -2, and -3:

Samples were cut from plants, covered with damp cheesecloth, sealed in a Ziploc-type storage bag, and stored and transported in a cool ice chest to the lab for processing. Generally, processing of conifer needles and twigs required 2 to 3 days to complete. If the samples were not measured on the same day they were cut from the plant, they were stored in a refrigerator for processing in the next 1 or 2 days. The cut end of the samples from YA and FEN (i.e., aspen, bog birch, buck bean, marsh marigold, cinquefoil, and sedge) were placed in water-filled vials upon cutting and remained so until completion of optical measurements, generally within 10 minutes of cutting.

For FFC-W and FFC-T:

Samples were collected from trees and placed in Ziploc-type storage bags containing damp paper towels. The samples were packed in ice and shipped to Lincoln, NE, for measurement.

Adaxial leaf surfaces of aspen, buck bean, bog birch, and substrate element samples typically were brighter in color and had a glossier sheen than the abaxial surfaces. The abaxial surface of Labrador tea leaves was heavily pubescent; the current year's growth was white pubescent, and the prior years' growth having rust-colored pubescent. The black spruce surface without the whitish lines was defined as the adaxial surface. Jack pine needles were attached to twigs in paired fascicles and generally had a semicircular cross-sectional shape. The outer semicircular convex, curved side of the needle was considered the adaxial surface. (For a more detailed description of the shape of the needles, see the BOREAS TE-12 shoot geometry document.)

Approximately 40 needles for a particular age class (e.g., 1994 growth, 1993 growth) were selected from three shoots on a cut sample and placed in a bag. Needles were randomly sampled from this mixture to produce three samples per age class.

A sample mount was designed to maintain the sample elements in the same orientation relative to one another for all measurements. Two types of sample mounts were constructed, one for each light source. One sample mount had an aperture the same size as the integrating sphere sample port and slightly larger than the illumination spot of the full lamp (e.g., 11.4 mm diameter); the second sample mount had an aperture (5.5 mm x 15 mm) designed to hold the short black spruce needles and slightly larger than the beam dimensions of the slitted illuminator (3.5 mm x 11 mm) for the integrating sphere. Approximately 6-11 sample elements (e.g., needles or twigs) were placed on the sample mount using transparent tape to affix the needle ends to the sample mount in such a way that the tape would not be visible in the integrating sphere sample port. The elements were placed so that gaps between elements were approximately equal. Prior to 20-Jul-1994, elements were spaced a sample element apart. Samples made after 20-Jul-1994 were constructed so that the sample elements were evenly spaced, but the fraction of nonintercepted illumination beam was approximately 5-15-% of the total beam area.

Stray light was measured at the beginning of each day and/or at the beginning of a set of measurements with each light source used. The color of the needles and twigs was coded using the Munsell color chips (Munsell, 1977) prior to optical measurements. The method of sample measurement varied based on physical size of the sample element:

For sample type 1, the sample element filled the integrating sphere sample port (samples included were aspen, hazelnut, balsam poplar, alder, blueberry, wildrose, bearberry, sedge, bog birch, and buck bean). Procedures for optical property measurements are described by Daughtry et al.(1989). During the measurement, individual leaves remained attached to the branch that was cut from the plant. Each leaf measured was inserted into the integrating sphere sample port with the adaxial (top) surface facing the inside of the sphere. Three measurements followed: 1) light reflected from the reference for the adaxial surface, 2) light reflected from the adaxial surface, and 3) light transmitted through the abaxial (bottom) surface. The sample was removed from the sample port and reinserted so that the abaxial surface faced the inside of the sphere; the sample was arranged so that the same portion of the sample as for the adaxial surface was measured. Three additional measurements followed: 1) light transmitted through the adaxial surface, 2) light reflected from the abaxial surface, and 3) light reflected from the reference for the abaxial surface. The modified external light source was used for narrow leaf samples (e.g., wildrose, blueberry, and bearberry). All other samples were illuminated with the standard external light source.

For sample type 2, the sample elements were narrow and the tape holding the needles was not visible in the sample holder (samples included were jack pine and black spruce needles and twigs).

Prior to 20-Apr-1994:

The fraction of nonintercepted illumination beam was determined using the painting technique described in Daughtry et al. (1989). This method allowed only one surface to be measured per sample. Either the standard or the modified light source was used depending on the sample mount used.

The sample mount was inserted into the integrating sphere sample holder with the adaxial needle surfaces facing inside the sphere. Light reflected from the adaxial needle surface and from the reference with the sample in place (adaxial reference) was measured. The sample mount was removed from the sphere. Light reflected from the reference without a sample and integrating sphere wall (transmitted mode without sample) was measured. The sample mount was placed back into the integrating sphere sample holder with the adaxial needle surfaces facing toward the inside of the sphere. Light transmitted through the abaxial surfaces was measured. The sample was turned so that the abaxial needle surfaces of the sample were facing the inside of the sphere. Three additional measurements followed: 1) light transmitted through the adaxial needle surfaces, 2) light reflected from the reference with the sample in place (abaxial reference), and 3) light reflected from the abaxial needle surfaces.

After the entire suite of measurements was made, the sample mount was removed from the integrating sphere. The intended measured surface was painted with Testors (1149) black paint, with care taken not to paint the other side of the sample element. The sample mount was placed in the integrating sphere sample holder with the blackened surface facing away from the sphere. Light transmitted through the blackened sample was measured.

After 20-Apr-1994:

A modified set of procedures for optical property measurements described by Daughtry et al. (1989) was used. The sample mount was attached to a mask with an aperture the size of the illumination light source beam. This assembly was placed on the light table underneath an image analysis system's camera. The image was captured and the gap area measured by counting the number of "whitish" pixels. The area was ratioed to the total area of the incident beam (i.e., the area of the mask) to give the gap fraction (area of nonintercepted illumination beam). The sample was then placed in the integrating sphere sample holder and the suite of measurements, described above, was made. The measurement of the blackened sample was not made.

Prior to 20-Apr-1994:

To calculate the fraction of nonintercepted illumination beam, the painting technique described in Daughtry et al. (1989) was used. The standard light source was used for all samples.

Multiple measurements of the transparent tape alone were made of reflectance and transmittance properties; little variation was found between pieces of tape. Thus, a sample, constructed of tape only, was used to characterize the light reflected and transmitted through the tape for each sample in the suite of measurements described below. The tape sample was placed in the integrating sphere with the adhesive side of the tape facing the inside of the sphere. The light reflected from the tape and the light reflected from the reference with the sample in place (adhesive side) were measured. The tape sample was turned so that the adhesive side was facing away from the inside of the sphere. The light reflected from the reference with the sample in place (nonadhesive side) and the light transmitted through the tape were measured. The needle sample mount was placed in the sample holder with the sample elements facing away from the inside of the sphere. Light transmitted through the sample was measured. The sample mount was removed from the sphere. The light transmitted through the sample port without the sample (i.e., a sphere wall reference) and the light reflected from the reference (without the sample) were measured. Then, the sample mount was placed in the sample holder with the sample elements facing away from the inside of the sphere. Light reflected from the reference with the sample in place (for transmittance calculation) was measured. Then the sample mount was placed in the sample holder with the sample elements facing toward the inside of the sphere. Light reflected from the reference with the sample in place (for reflectance calculation) and the light reflected from the sample were measured.

After the entire suite of measurements was made, the sample mount was removed from the integrating sphere. The intended measured surface was painted with Testors (1149) black paint, with care taken not to paint the tape. The sample mount was placed in the integrating sphere sample holder with the blackened surface facing away from the sphere. Transmitted radiation through the blackened sample was measured.

After 20-April-1994:

This method allows measurement of only one side of the sample. The image analysis system was used, in the same manner as type 2, to measure the fraction of nonintercepted illumination beam. The sample was then placed in the integrating sphere, and the suite of measurements, as described above, was made except for the measurement of the blackened sample.

For more details on the LI-COR LI-1800-12 integrating sphere configuration for each measurement, see Mesarch et al. (1991).

6. Observations

6.1 Data Notes

None given.

6.2 Field Notes

Needle ages measured in 1993 were 1993 growth, 1992 growth and 1991 growth. Needle and twig ages measured in 1994, unless otherwise noted, are 1994 growth, 1993 growth, and 1992 growth.

Sampled: 04-Aug-1993 (Measured: 04-Aug-1993)

Leaf optical properties from aspen near SSA-FEN; 3 trees x 3 branches x 3 replications; both adaxial and abaxial surfaces. First replication was for a leaf at the top of the branchlet, second replication was for a leaf in the middle of the branchlet, and third replication was for a leaf on the lowest part of the branchlet. Branches were selected from the north side of the trees.

Sampled: 04-Aug-1993 (Measured: 05-Aug-1993)

Needle optical properties from jack pine near SSA-FEN; 3 trees x 1 branch x 3 ages x 3 replications of adaxial needle surfaces; several measurements of abaxial needle surface and adaxial twig surface. Branches from trees 1 and 2 were sunlit, and the branch from tree 3 was shaded.

Sampled: 06-Aug-1993 (Measured: 07-10-Aug-1993)

Coordinate measurements of leaf gas exchange and needle optical properties from black spruce near SSA-FEN. 3 trees x 4 branches x 3 ages x 3 replications of adaxial needle surface. Tree 1 was sunlit, tree 2 was lightly shaded, and tree 3 was deeply shaded. All trees were about 3 to 3.5 m tall in a grove of trees about 10 m tall. Needles from the shoots that were measured for photosynthesis rates were not used for optical property measurements. Instead, needles from a shoot near those sampled for gas exchange were used.

Sampled: 16-Aug-1993 (Measured: 17-18-Aug-1993)

Optical properties from jack pine needle and substrate elements at SSA-YJP. 9 trees x 1 branch x 3 ages x 1 replication of adaxial needle surface; several measurements of abaxial needle surface and adaxial twig surface. 9 samples were measured of dead needles, bark, blueberry, bearberry, and leafy lichen; both adaxial and abaxial surfaces were measured of all substrate elements except the dead needles.

Sampled: 19-Aug-1993 (Measured: 19-Aug-1993)

Coordinated measurements of leaf gas exchange and leaf optical properties on aspen near SSA-FEN (11 trees x 1 branch x 1 replication on both adaxial and abaxial leaf surfaces). Trees were approximately 2 m tall. Also leaf optical properties of bog birch (5 plants x 3 color classes x 1 replication of adaxial and abaxial leaf surface) and buck bean (9 plants x 1 replication of adaxial and abaxial leaf surface).

Sampled: 20-Aug-1993 (Measured: 21-Aug-1993)

Coordinated measurements of leaf gas exchange and needle optical properties on black spruce near SSA-FEN. 5 trees x 1 branch x 3 ages x 1 replication of adaxial needle surface; several measurements of abaxial needle surface and adaxial twig surface. Needles measured for photosynthesis rates were not used for optical property measurements; instead, needles from shoots close to the shoot used for gas exchange were used. Leaf optical properties of other vegetation in or near the SSA-FEN (e.g., marsh marigold, cinquefoil and Labrador tea) were measured (5 plants x 1 replication of adaxial and abaxial leaf surface).

Sampled: 03-Feb-1994 (Measured: 13-Feb-1994)

Needle optical properties on jack pine collected at SSA-OJP. 7 trees x 1 branch x 3 ages x 3 replications; measurement of both adaxial and abaxial surfaces. Needles were from the 1993, 1992, and 1991 growth.

Sampled: 07-Feb-1994 (Measured: 14-Feb-1994)

Needle optical properties from black spruce collected at SSA-OBS. 8 trees x 1 branch x 3 ages x 3 replications; measurement of both adaxial and abaxial surfaces. Needles were from the 1993, 1992, and 1991 growth.

Sampled: 14-Apr-1994 (Measured: 20-21-Apr-1994)

Needle optical properties from jack pine collected at SSA-OJP. 1 tree x 3 branches x 3 ages x 3 replications; measurement of both adaxial and abaxial surfaces. Needles were from the 1993, 1992, and 1991 growth.

Sampled: 15-Apr-1994 (Measured: 20-21-Apr-1994)

Needle optical properties from black spruce collected at SSA-OBS. 6 trees x 2 branches x 3 ages x 3 replications; measurement of both adaxial and abaxial surfaces. Needles were from the 1993, 1992, and 1991 growth.

Sampled: 26-May-1994 (Measured: 27-29-May-1994)

Needle leaf optical properties on jack pine collected at SSA-YJP. 9 trees x 1 branch x 3 ages x 3 replications; measurements of both adaxial and abaxial surfaces. Trees were located about 150 m east of the hut and 20-50 m north of access road. Branches were from the south side of the trees and generally in full sunlight at 1230-1600 local time. Branches were collected 2-4 m from the soil surface. Needles were from the 1993, 1992, and 1991 growth.

Sampled: 29-May-1994 (Measured: 29-May-1994)

Leaf optical properties from aspen collected at SSA-YA. 3 trees x 3 branches x 3 replications; measurements of both adaxial and abaxial surfaces. Leaves were from branches sampled from the south side of the trees and 1.5-2 m from the soil surface.

Sampled: 01-Jun-1994 (Measured: 2-4-Jun-1994)

Needle optical properties from black spruce collected at SSA-OBS. 3 trees x 3 branches x 3 ages x 3 replications; measurements of mostly adaxial surfaces. Needles were from the 1993, 1992, and 1991 growth. Samples were collected from the top of the trees via the canopy access tower and on the south-facing side of the trees. Branches were sunlit.

Sampled: 04-Jun-1994 (Measured: 04-Jun-1994)

Needle optical properties from jack pine samples that were coordinated with shoot gas exchange measurements. Samples were collected at SSA-YJP. 4 trees x 1 branch x 2 ages x 3 replications; measurements of both adaxial and abaxial surfaces. Needles were from the 1993 and 1992 growth. In addition, reflectance was measured from 1994's unexpended growth (the entire unexpended shoot); 1 replication for each tree.

Sampled: 06-Jun-1994 (Measured: 06-Jun-1994)

Measurements of leaf optical properties on aspen collected at SSA-OA. 3 trees x 3 branches x 3 replications for the top of the canopy and 1 tree x 3 branches x 3 replications from the lowest leaf level in the canopy. Measured adaxial and abaxial surfaces. Sample collection was made from the canopy access tower.

Sampled: 07-Jun-1994 (Measured: 8-9-Jun-1994)

Needle optical properties from black spruce collected at SSA-OBS. 3 trees x 3 branches x 3 ages x 3 replications; measurements of mostly adaxial surfaces. Needles were from the 1993, 1992, and 1991 growth. Samples were collected from lower in the canopy (approximately 9 m from the soil surface) via the canopy access tower. Branches from trees 1 and 2 were mostly shaded. Branches from tree 3 were sunlit most of the time. Measured reflectance properties of black spruce twigs.

Sampled: 07-Jun-1994 (Measured: 07-Jun-1994)

Leaf optical properties from aspen collected at SSA-YA. 3 trees x 3 branches x 3 replications from sunlit branches at the top of the canopy; measured adaxial and abaxial surfaces.

Sampled: 10-Jun-1994 (Measured: 10-12-Jun-1994)

Needle optical properties from jack pine collected at SSA-YJP. 9 trees x 1 branch x 3 ages x 3 replications; measurements of both adaxial and abaxial surfaces. Trees were located about 150 m east of the hut and 20-50 m south of the access road. Branches were collected near the top of the south side of trees. Needles were from the 1993 and 1992 growth. In addition, reflectance was measured from 1994's growth (the shoot was just expanding) for the entire shoot. Measured reflectance for 3 replications of male cones from each tree.

Sampled: 15-Jun-1994 (Measured: 15-Jun-1994)

Leaf optical properties from aspen collected at SSA-YA. 3 trees x 3 branches x 3 replications for the top of the canopy; measured adaxial and abaxial surfaces. The optical property system was set up inside the van because rain prevented "outdoor" measurements.

Sampled: 21-Jul-1994 (Measured: 23-24-Jul-1994)

Needle optical properties from jack pine collected at SSA-YJP. 9 trees x 1 branch x 3 ages x 3 replications; measurements of both adaxial and abaxial surfaces. Trees were located about 250 m east of the hut and 80 m south of the access road. Branches were collected from the south side of sunlit trees, 1.5-2 m from the soil surface. Needles from 1994, 1993, and 1992 growth were measured.

Sampled: 25-Jul-1994 (Measured: 26-27-Jul-1994)

Needle optical properties from jack pine collected at SSA-YJP. 9 trees x 1 branch x 3 ages x 3 replications; measurements of both adaxial and abaxial surfaces. Trees were located about 150 m east of the hut and 20-40 m north of the access road. Branches were collected from the south side of sunlit trees at the top of the canopy. Twig reflectance was measured. Needles from 1994, 1993, and 1992 growth were measured.

Sampled: 29-Jul-1994 (Measured: 29-Jul-1994)

Leaf optical properties from aspen collected at SSA-YA. 3 trees x 3 branches x 3 replications from the top of the canopy; measured adaxial and abaxial surfaces. Branches were sunlit. Leaf optical properties on understory components (hazelnut, balsam poplar, and alder) collected at SSA-YA. 9 trees x 1 replication. Samples were shaded within the aspen canopy.

Sampled: 01-Jun-1994 (Measured: 31-Jul-02-Aug-1994)

Needle optical properties from black spruce collected at SSA-OBS. 3 trees x 3 branches x 3 ages x 3 replications; mostly adaxial surfaces. Samples were collected from sunlit branches at the top of the canopy via the canopy access tower. Needles were from the 1994, 1993, and 1992 growth.

Sampled: 02-Aug-1994 (Measured: 02-04-Aug-1994)
Needle optical properties from black spruce collected at SSA-OBS. 3 trees x 3 branches x 3 ages x 3 replications; mostly adaxial surfaces. Samples were collected from shaded branches lower in the canopy (approximately 9 m from the soil surface) via the canopy access tower. Needles were from the 1994, 1993, and 1992 growth. Reflectance properties of black spruce twigs were measured. Optical properties of understory components were also measured (e.g., wildrose, Labrador tea, and blueberry); 5 samples of each component.

Sample: 05-Aug-1994 (Measured: 05-Aug-1994)
Leaf optical properties on species (e.g., bog birch, buck bean, buck bean with dried, rusty residue {rimpis}, and sedge) at SSA-FEN. 5 samples of each species; adaxial and abaxial surfaces were measured.

Sampled: 04-Sep-1994 (Measured: 05-06-Sep-1994)
Needle optical properties from black spruce collected at SSA-OBS. 3 trees x 3 branches x 3 ages x 3 replications; mostly adaxial surfaces. Samples were collected from lower in the canopy (approximately 9 m from the soil surface) via the canopy access tower. Trees 1 and 3 are sunlit samples, and tree 2 is shaded. Measurements were not made on tree 3 branch 2. Needles from 1994, 1993, and 1992 growth were measured.

Sampled: 04-Sep-1994 (Measured: 04-Sep-1994)
Leaf optical properties from aspen collected at SSA-YA. 3 trees x 3 branches x 3 replications from sunlit branches at the top of the canopy; adaxial and abaxial surfaces were measured.

Sampled: 07-Sep-1994 (Measured: 08-11-Sep-1994)
Needle optical properties from black spruce collected at SSA-OBS. 3 trees x 3 branches x 3 ages x 3 replications. Samples were collected from the top of the canopy via the canopy access tower. Reflectance properties of black spruce twigs were measured. Optical properties of understory components (e.g., wildrose, Labrador tea, and blueberry); 5 samples of each component.

Sampled: 07-Sep-1994 (Measured: 07-Sep-1994)
Coordinated measurements of leaf optical properties and gas exchange on aspen, hazelnut, and balsam poplar collected at SSA-YA. 3 leaf color classes x 3 replications from the middle of the canopy. The color classes were leaves that were identified as Strong Yellow Green (5GY 4/4 to 5GY 6/8), Moderate Yellow Green (2.5GY 5/6 to 2.5GY 7/4), and Strong Yellow (5Y 8/6 to 5Y 8/12).

Sampled: 11-Sep-1994 (Measured: 11-13-Sep-1994)
Needle optical properties from jack pine collected at SSA-YJP. 9 trees x 1 branch x 3 ages x 3 replications; both adaxial and abaxial surfaces were measured. Needles were from 1994, 1993, and 1992 growth. Trees were located about 150 m east of the hut and 20-40 m north of the access road; branches were collected from the top of the canopy. Twig reflectance was measured. Understory components (e.g., brown and yellow jack pine needles, bark, bearberry, and fuzzy-spiked wild rye) were measured.

Sampled: 14-Sep-1994 (Measured: 14-15-Sep-1994)
Needle optical properties from jack pine collected at SSA-YJP. 9 trees x 1 branches x 3 ages x 3 replications; both adaxial and abaxial surfaces were measured. Trees were located about 100 m east of the hut and 20-40 m north of the access road (near the canopy access scaffolding). Sunlit branches were collected from the south side of the trees approximately 2-3 m from soil surface. Twig reflectance was measured.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The measurement sites and associated North American Datum of 1983 (NAD83) coordinates are:

- SSA-OBS canopy access tower located at the flux tower site, site id G8I4T, Lat/Long: 53.98717°N, 105.11779°W, Universal Transverse Mercator (UTM) Zone 13, N:5,982,100.5 E:492,276.5
- SSA-FEN site id F0L9T, Lat/Long: 53.80206°N, 104.61798°W, UTM Zone 13, N:5,961,566.6 E: 525,159.8
- SSA-OA canopy access tower located 100 m up the path to the flux tower site, site id C3B7T, Lat/Long: 53.62889°N, 106.19779°W, UTM Zone 13, N:5,942,899.9 E:420,790.5
- SSA-YA canopy access tower, site id D0H4T, Lat/Long: 53.65601°N, 105.32314°W, UTM Zone 13, N:5,945,298.9, E:478,644.1
- SSA-YJP near the flux tower site, site id F8L6T, Lat/Long: 53.87581°N, 104.64529°W, UTM Zone 13, N:5,969,762.5 E:523,320.2

7.1.2 Spatial Coverage Map

Not available.

7.1.3 Spatial Resolution

The standard external light source has a spot size 11.4 mm in diameter. The modified external light source has a spot size restricted to 3.5 mm x 11 mm. Jack pine needles were longer than the spot size of 11.4 mm, while the black spruce needles were slightly longer than the 3.5-mm narrow part of the modified external light source. Broad leaves easily fit into the 11.4-mm diameter of the standard light source.

7.1.4 Projection

None given.

7.1.5 Grid Description

None given.

7.2 Temporal Characteristics

Aspen, hazelnut, balsam poplar, alder, marsh marigold, cinquefoil, sedge, buck bean, and bog birch leaves were measured on the same day that the samples were cut from the plant. Samples of aspen, hazelnut, and poplar were measured at least once every IFC; the other species were measured at least once during BOREAS. Substrate elements were measured up to 2 days after they were collected. Black spruce and jack pine samples were measured between 1 and 4 days after they were collected. Jack pine and black spruce samples were collected two times each IFC.

7.2.1 Temporal Coverage

Branches were collected from 1530-0023 Greenwich Mean Time (GMT). Leaf, needle, and twig optical properties measurement times ranged from 1130-0500 GMT. Measurements were not made continuously (IFC-1993: 04-Aug-1993 through 21-Aug-1993; IFC-1 1994: 26-May-1994 through 15-Jun-1994; IFC-2: 21-Jul-1994 through 05-Aug-1994; IFC-3: 04-Sep-1994 through 11-Sep-1994).

The following list gives the date, site, and type of samples collected:

Date	Site	Species
04-AUG-1993	SSA-FEN	Jack Pine
04-AUG-1993	SSA-FEN	Aspen
06-AUG-1993	SSA-FEN	Black Spruce
16-AUG-1993	SSA-YJP	Jack Pine
19-AUG-1993	SSA-FEN	Aspen
19-AUG-1993	SSA-FEN	Buck Bean
19-AUG-1993	SSA-FEN	Bog Birch
20-AUG-1993	SSA-FEN	Black Spruce
21-AUG-1993	SSA-FEN	Ledum
26-May-1994	SSA-YJP	Jack Pine
29-May-1994	SSA-YA	Aspen
01-JUN-1994	SSA-OBS	Black Spruce
04-JUN-1994	SSA-YJP	Jack Pine
06-JUN-1994	SSA-OA	Aspen
07-JUN-1994	SSA-OBS	Black Spruce
07-JUN-1994	SSA-YA	Aspen
10-JUN-1994	SSA-YJP	Jack Pine
15-JUN-1994	SSA-YA	Aspen
21-JUL-1994	SSA-YJP	Jack Pine
25-JUL-1994	SSA-YJP	Jack Pine
29-JUL-1994	SSA-YA	Aspen
29-JUL-1994	SSA-YA	Hazelnut
29-JUL-1994	SSA-YA	Alder
29-JUL-1994	SSA-YA	Balsam Poplar
30-JUL-1994	SSA-OBS	Black Spruce
02-AUG-1994	SSA-OBS	Black Spruce
02-AUG-1994	SSA-OBS	Ledum
02-AUG-1994	SSA-OBS	Wild Rose
02-AUG-1994	SSA-OBS	Blueberry
05-AUG-1994	SSA-FEN	Bog Birch
05-AUG-1994	SSA-FEN	Buck Bean
05-AUG-1994	SSA-FEN	Sedge
04-SEP-1994	SSA-OBS	Black Spruce
04-SEP-1994	SSA-YA	Aspen
07-SEP-1994	SSA-OBS	Black Spruce
07-SEP-1994	SSA-OBS	Ledum
07-SEP-1994	SSA-OBS	Wild Rose
07-SEP-1994	SSA-OBS	Blueberry
07-SEP-1994	SSA-YA	Aspen
07-SEP-1994	SSA-YA	Hazelnut
07-SEP-1994	SSA-OBS	Balsam Poplar
08-SEP-1994	SSA-YJP	Jack Pine
11-SEP-1994	SSA-YJP	Jack Pine

7.2.2 Temporal Coverage Map

None given.

7.2.3 Temporal Resolution

Measurements of sample type 1 required approximately 3 minutes. Measurements of sample type 2 required a minimum of 7 minutes. The most time-consuming part of the procedure was creating the sample. The optimum time interval between sample measurements was a few minutes during a measurement period.

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
START_DATE
START_TIME
END_DATE
END_TIME
DATE_COLLECTED
TIME_COLLECTED
SPECIES
CANOPY_LOCATION
SAMPLE_ID
TREE_ID
BRANCH_ID
SAMPLE_GROWTH_YEAR
SAMPLE_DESCR
ADAXIAL_MUNSELL_COLOR
ABAXIAL_MUNSELL_COLOR
NUM_OBS
WAVELENGTH
MEAN_ADAXIAL_REFL
SDEV_ADAXIAL_REFL
MEAN_ADAXIAL_TRANS
SDEV_ADAXIAL_TRANS
MEAN_ABAXIAL_REFL
SDEV_ABAXIAL_REFL
MEAN_ABAXIAL_TRANS
SDEV_ABAXIAL_TRANS
LEAF_TWIG
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.
START_DATE	The date on which the collection of data commenced.
START_TIME	The starting Greenwich Mean Time (GMT) for the data collected.
END_DATE	The date on which the collection of the data was terminated.
END_TIME	The ending Greenwich Mean Time (GMT) for the data collected.
DATE_COLLECTED	The date on which the samples were collected.
TIME_COLLECTED	The Greenwich Mean Time (GMT) when the samples were collected.
SPECIES	Botanical (Latin) name of the species (Genus species).
CANOPY_LOCATION	Location in the canopy from which the sample was taken.

The CANOPY_LOCATION parameter of the data set is a relative measure based upon the height of the sample location relative to the height of the canopy. Therefore, a sample collected from the top of a short tree in a tall canopy and a sample collected from the bottom of a short tree in a short canopy can both be designated as "low" for the HEIGHT parameter. CANOPY_LOCATION parameters used are HIGH, LOW, MIDDLE, GROUND, AND UNDER. UNDER refers to an understory component being measured. GROUND refers to the lower third of the total canopy height.

SAMPLE_ID	The sample identifier used by data collectors (see documentation for a detailed description).
TREE_ID	Identifier of the mapped tree or plant stem.
BRANCH_ID	Identifier of the mapped branch (number).
SAMPLE_GROWTH_YEAR	The year in which the collected sample first grew.
SAMPLE_DESCR	Description of the leaf/needle/twig sample.
ADAXIAL_MUNSELL_COLOR	Munsell color code of the adaxial surface.
ABAXIAL_MUNSELL_COLOR	Munsell color code of the abaxial surface.
NUM_OBS	Number of observations of the given sample used to calculate given values.
WAVELENGTH	Spectral wavelength at which measurement was acquired.
MEAN_ADAXIAL_REFL	The mean reflectance of the adaxial surface of sample.
SDEV_ADAXIAL_REFL	Standard deviation of reflectance of the adaxial surface of sample.
MEAN_ADAXIAL_TRANS	The mean transmittance of the adaxial surface of the sample. The adaxial surface was illuminated during measurements.
SDEV_ADAXIAL_TRANS	Standard deviation of transmittance through the adaxial surface of sample.
MEAN_ABAXIAL_REFL	Mean reflectance of the abaxial surface of sample.
SDEV_ABAXIAL_REFL	Standard deviation of reflectance of the abaxial surface of sample.
MEAN_ABAXIAL_TRANS	The mean transmittance of the abaxial surface of the sample. The abaxial surface was illuminated during measurements.

SDEV_ABAXIAL_TRANS	Standard deviation of reflectance through the abaxial surface of sample.
LEAF_TWIG	Indicates the portion of the tree from which the optical measurements were 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]
START_DATE	[DD-MON-YY]
START_TIME	[HHMM GMT]
END_DATE	[DD-MON-YY]
END_TIME	[HHMM GMT]
DATE_COLLECTED	[DD-MON-YY]
TIME_COLLECTED	[HHMM GMT]
SPECIES	[none]
CANOPY_LOCATION	[none]
SAMPLE_ID	[none]
TREE_ID	[none]
BRANCH_ID	[unitless]
SAMPLE_GROWTH_YEAR	[unitless]
SAMPLE_DESCR	[unitless]
ADAXIAL_MUNSELL_COLOR	[none]
ABAXIAL_MUNSELL_COLOR	[none]
NUM_OBS	[counts]
WAVELENGTH	[micrometers]
MEAN_ADAXIAL_REFL	[percent]
SDEV_ADAXIAL_REFL	[percent]
MEAN_ADAXIAL_TRANS	[percent]
SDEV_ADAXIAL_TRANS	[percent]
MEAN_ABAXIAL_REFL	[percent]
SDEV_ABAXIAL_REFL	[percent]
MEAN_ABAXIAL_TRANS	[percent]
SDEV_ABAXIAL_TRANS	[percent]
LEAF_TWIG	[none]
CRTFCN_CODE	[none]
REVISION_DATE	[DD-MON-YY]

7.3.4 Data Source

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

Column Name	Data Source
SITE_NAME	[BORIS Designation]
SUB_SITE	[BORIS Designation]
START_DATE	[Human Observer]
START_TIME	[Human Observer]
END_DATE	[Human Observer]
END_TIME	[Human Observer]
DATE_COLLECTED	[Human Observer]
TIME_COLLECTED	[Human Observer]
SPECIES	[Human Observer]
CANOPY_LOCATION	[Human Observer]
SAMPLE_ID	[Human Observer]
TREE_ID	[Human Observer]
BRANCH_ID	[Human Observer]
SAMPLE_GROWTH_YEAR	[Human Observer]
SAMPLE_DESCR	[Human Observer]
ADAXIAL_MUNSELL_COLOR	[Human Observer]
ABAXIAL_MUNSELL_COLOR	[Human Observer]
NUM_OBS	[Human Observer]
WAVELENGTH	[Human Observer]
MEAN_ADAXIAL_REFL	[Laboratory Equipment]
SDEV_ADAXIAL_REFL	[Laboratory Equipment]
MEAN_ADAXIAL_TRANS	[Laboratory Equipment]
SDEV_ADAXIAL_TRANS	[Laboratory Equipment]
MEAN_ABAXIAL_REFL	[Laboratory Equipment]
SDEV_ABAXIAL_REFL	[Laboratory Equipment]
MEAN_ABAXIAL_TRANS	[Laboratory Equipment]
SDEV_ABAXIAL_TRANS	[Laboratory Equipment]
LEAF_TWIG	[Human Observer]
CRTFCN_CODE	[BORIS Designation]
REVISION_DATE	[BORIS Designation]

7.3.5 Data Range

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

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SITE_NAME	SSA-9OA-FLXTR	SSA-YJP-FLXTR	None	None	None	None
SUB_SITE	9TE12-LOP01	9TE12-LOP01	None	None	None	None
START_DATE	04-AUG-93	14-SEP-94	None	None	None	None
START_TIME	12	2343	None	None	None	None
END_DATE	04-AUG-93	15-SEP-94	None	None	None	None
END_TIME	12	2359	None	None	None	None
DATE_COLLECTED	04-AUG-93	14-SEP-94	None	None	None	None
TIME_COLLECTED	1	2302	None	None	None	None
SPECIES	N/A	N/A	None	None	None	None
CANOPY_LOCATION	Bottom	Under	None	None	None	None
SAMPLE_ID	N/A	N/A	-999	None	None	None

TREE_ID	1	28	-999	None	None	None
BRANCH_ID	1	4	-999	None	None	None
SAMPLE_GROWTH_YEAR	1991	1994	None	None	None	None
SAMPLE_DESCR	N/A	N/A	None	None	None	Blank
ADAXIAL_MUNSELL_COLOR	10R 4/10	7.5YR 7/8	None	None	None	None
ABAXIAL_MUNSELL_COLOR	10R 4/8	7.5YR 7/8	-999	None	None	None
NUM_OBS	1	28	None	None	None	None
WAVELENGTH	.4	1	None	None	None	None
MEAN_ADAXIAL_REFL	3.68	58.73	None	None	None	None
SDEV_ADAXIAL_REFL	0	20.73	-999	None	None	None
MEAN_ADAXIAL_TRANS	-1.4	54.27	-999	None	None	None
SDEV_ADAXIAL_TRANS	0	17.86	-999	None	None	None
MEAN_ABAXIAL_REFL	5.67	57.63	-999	None	None	None
SDEV_ABAXIAL_REFL	0	14.75	-999	None	None	None
MEAN_ABAXIAL_TRANS	-3.69	57.75	-999	None	None	None
SDEV_ABAXIAL_TRANS	0	18.57	-999	None	None	None
LEAF_TWIG	LEAF	TWIG	None	None	None	None
CRTFCN_CODE	CPI	CPI	None	None	None	None
REVISION_DATE	21-NOV-96	12-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 are wrapped versions of data record from a sample data file on the CD-ROM.

```
SITE_NAME,SUB_SITE,START_DATE,START_TIME,END_DATE,END_TIME,DATE_COLLECTED,
TIME_COLLECTED,SPECIES,CANOPY_LOCATION,SAMPLE_ID,TREE_ID,BRANCH_ID,
SAMPLE_GROWTH_YEAR,SAMPLE_DESCR,ADAXIAL_MUNSELL_COLOR,ABAXIAL_MUNSELL_COLOR,
NUM_OBS,WAVELENGTH,MEAN_ADAXIAL_REFL,SDEV_ADAXIAL_REFL,MEAN_ADAXIAL_TRANS,
SDEV_ADAXIAL_TRANS,MEAN_ABAXIAL_REFL,SDEV_ABAXIAL_REFL,MEAN_ABAXIAL_TRANS,
SDEV_ABAXIAL_TRANS,LEAF_TWIG,CRTFCN_CODE,REVISION_DATE
'SSA-9OA-FLXTR','9TE12-LOP01',04-JUN-94,1837,04-JUN-94,1837,04-JUN-94,1820,
'Populus tremuloides','Top','940115',4,1,'1994','Fully expanded aspen leaves',
'5GY 4/4','5GY 5/4',3,.4,6.05,.1,3.51,.14,8.18,.34,3.71,.14,'LEAF','CPI',
21-NOV-96
'SSA-9OA-FLXTR','9TE12-LOP01',04-JUN-94,1837,04-JUN-94,1837,04-JUN-94,1820,
'Populus tremuloides','Top','940115',4,1,'1994','Fully expanded aspen leaves',
'5GY 4/4','5GY 5/4',3,.405,5.59,.02,3.37,.05,8.06,.12,3.53,.23,'LEAF','CPI',
21-NOV-96
```

8. Data Organization

8.1 Data Granularity

The smallest unit of orderable data is the reflectance transmittance of a single sample of needles coordinated with gas exchange measurements or an average of 27 samples of needles.

8.2 Data Format

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

None given.

9.1.1 Derivation Techniques/Algorithms

For sample type 1: sample fills the integrating sphere sample port:

$$REFL(I) = [(R(I) - STR(I)) / (REF(I) - STR(I))] * 100 \qquad [1]$$

where: REFL = hemispherical reflectance of adaxial or abaxial leaf surface (percent)
I = channel
R = adaxial or abaxial reflected measurement (counts)
STR = stray light measurement (counts)
REF = adaxial or abaxial reference measurement (counts)

$$TRAN(I) = [T(I) / (REF(I)-STR(I))] * 100 \quad [2]$$

where: TRAN = hemispherical transmittance adaxial or abaxial leaf surface (percent)
T = adaxial or abaxial transmitted measurement (counts)
REF = abaxial or adaxial reference measurement (counts)

Measurements of nonintercepted beam fraction for sample types 2 and 3 after 20-Apr-1994: The image analysis system was used to measure the gaps between the sample elements. The ratio of the total gap area to the incident beam area was used as a measure of the fractional area of nonintercepted beam, FRACT.

For sample type 2:

$$REFL(I) = \{[R(I) - STR(I)] * [1 - FRACT] / [REFR(I) - STR(I)]\} * 100 \quad [3]$$

where: I = channel
R = adaxial or abaxial reflected measurement (counts)
STR = stray light measurement (counts)
REFL = hemispherical reflectance of surface (percent)
REFR = reference measurement with surface (intended to be calculated) facing toward the sphere (counts)
FRACT = fractional area of nonintercepted beam

$$TRAN(I) = \{[T(I) / (REFT(I) - STR(I))] - [(W(I) * FRACT) / (REF(I) - STR(I))]\} * [1.0 / (1.0 - FRACT)] * 100 \quad [4]$$

where: TRAN = hemispherical transmittance of surface (percent)
REFT = reference measurement with surface (intended to be calculated) facing away from sphere (counts)
REF = adaxial or abaxial reference measurement (counts)
W = integrating sphere wall reference measurement (transmitted without a sample) (counts)
T = transmitted measurement of sample (counts)

For sample type 2 and measurements made before 20-Apr-1994: the fractional area of nonintercepted beam is calculated from a measurement of the painted sample.

$$FRAC1 = TBLACK(ii) / \{[REFT(ii) - STR(ii)] * W(ii) / REFN(ii) - STR(ii)]\} \quad [5]$$

where: FRAC1 = first iteration of fraction of beam not intercepted by sample
ii = channel centered at approximately 680 nanometers
TBLACK = transmitted measurement of painted sample (counts)
REFT = reference measurement with surface facing away from sphere (counts)
W = integrating sphere wall reference measurement (transmitted without a sample) (counts)
REFN = reference measurement without sample (count)
STR = stray light measurement (counts)

$$TRAN680 = \{[T(ii) / (REFT(ii) - STR(ii))] - [(W(ii) * FRAC1) / (REFN(ii) - STR(ii)]\} / (1.0 - FRAC1) \quad [6]$$

where: TRAN680 = transmittance of sample at 680 nanometers
T = transmitted measurement of unpainted sample (counts)

$$\text{FRACT} = \{[T(ii) / (\text{REFT}(ii) - \text{STR}(ii))] - \text{TRAN680}\} / \{[W(ii) / [\text{REFN}(ii) - \text{STR}(ii)] - \text{TRAN680}\} \quad [7]$$

where FRACT = fractional area of nonintercepted beam

For instrument check using the neutral density filters:

$$\text{TRAND}(I) = \{[T(I) / (\text{REF}(I) - \text{STR}(I))] * [(X(I) - \text{STR}(I)) / W(I)]\} * 100.0 \quad [8]$$

where: TRAND = transmittance of the neutral density filter (percent)
T = transmitted measurement of unpainted sample (counts)
I = channel
W = integrating sphere wall reference measurement (transmitted without a sample) (counts)
REF = reference measurement with filter in sample port (counts)
X = reference measurement with nothing in sample port (counts)
STR = stray light measurement (counts)

9.2 Data Processing Sequence

9.2.1 Processing Steps

For sample type 1, where the sample filled the integrating sphere sample port (e.g., aspen, buck bean, bog birch, bearberry, and lichen), equation 1 was used to calculate the hemispherical reflectance for the adaxial and abaxial surfaces. Equation 2 was used to calculate the hemispherical transmittance for adaxial and abaxial surfaces. Note that the transmittance calculations use the reference from the opposite surface (e.g., adaxial transmittance uses reference with abaxial surface facing into the sphere).

For sample type 2, where the narrow sample was not completely covering the sample port, but was long enough to extend across the sample mount (e.g., jack pine and black spruce), equations 3 and 4 were used to calculate hemispherical reflectance and transmittance, respectively, based on the fraction of nonintercepted beam.

For sample type 2, where the narrow sample was not completely covering the sample port and the date was before 20-Apr-1994, the fraction of the nonintercepted beam was calculated using the measurement from the painting technique (e.g., jack pine and black spruce). Equation 5 was used to make a first estimate of the fraction of the illumination beam not intercepted by the sample. Measurements from the instrument channel that was centered around 680 nm (i.e., channel 109 was centered at 678.97 nm and 677.10 nm in 1993 and 1994, respectively) were used, because minimal transmitted radiation through the sample at this wavelength was assumed (Daughtry et al., 1989). Equation 5 was used to calculated the actual transmittance for the channel close to 680 nm, based on the estimate of the fraction of beam not striking the sample calculated in Equation 5. The actual fraction of nonintercepted beam was calculated with Equation 7.

For the neutral density filter test of the integrating sphere and spectroradiometer, equation 8 was used to calculate the hemispherical transmittance of the neutral density filter. Each filter was measured three times. The results were compared to the known transmittances of the filters.

For all sample measurements:

- Each SE590 has a unique centered wavelength associated with each of its 252 channels that varies over time. A cubic spline interpolation was applied to the 252 channels to standardize the centered wavelength to every 5 nm from 400 to 1,000 nm, so that from wavelength to wavelength and year to year, comparisons could be made among measurements from various SE590s used in BOREAS.
- The measurements submitted are individual sample measurements or averaged by replication and/or branch. Individual sample measurements are listed when a corresponding gas exchange measurement was made. Average values were submitted for other measurements. Averages

are composed of all replications for a tree/age. For example, black spruce samples collected on 01-Jun-1994 included three trees by three branches/tree by three ages by three replications/age for one height in the canopy. Nine files would be submitted for this collection, one file for each tree and age class for this height. All understory and substrate elements were averaged together per sampling date, unless age or color classification is stated. Files that include averages also include standard deviations.

9.2.2 Processing Changes

For sample type 2, where the narrow sample was not completely covering the sample port and the date was before 20-Apr-1994, the fraction of the nonintercepted beam was calculated using the measurement from the painting technique (e.g., jack pine and black spruce).

9.3 Calculations

None given.

9.3.1 Special Corrections/Adjustments

None given.

9.3.2 Calculated Variables

None given.

9.4 Graphs and Plots

None given.

10. Errors

10.1 Sources of Error

Errors can result if the sample thickness does not permit proper sealing around the sample holder of the integrating sphere (this can be a problem especially in the midvein area of leaves or with twigs and bark). Light entering or exiting from the loose seal can result in erroneous values. If the light source is not maintained in a horizontal position, the light output can vary, leading to errors as the light source is placed in different configurations in the suite of measurements to calculate reflectance and transmittance. Samples of bark and lichen tended to crack when placed in the integrating sphere sample holder thus allowing light to pass through the sample; reflectances could be biased lower and transmittances could be biased higher than if no cracks were present.

Sample type 2 measurements had a greater chance of error than sample type 1 measurements, especially in the calculation and measurement of the fraction of nonintercepted beam. The measurement method requires that the sample always be placed in the integrating sphere sample holder in the same orientation relative to the integrating sphere for each measurement; otherwise, the fraction of nonintercepted illumination beam will not be representative of the true gap fraction between elements throughout the suite of measurements. The sample mount was designed to minimize this error. The lower light intensity of the modified external light source (compared to the standard light source) and the low reflectance and transmittance of the samples (particularly in the blue region of the spectrum; 400 to 500 nm) result in low illumination levels in the sphere that approach the sensitivity level of the SE590.

Samples created with large gap fractions complicated the transmittance measurements. Large fractions allowed more nonintercepted light into the sphere than small gap fractions, dominating the transmitted light signal.

Variations in the sample transmitted component may be masked by the nonintercepted light and/or be below the sensitivity of the SE590.

Errors in the calculation of the fraction of the nonintercepted beam using the image analysis system were due to the variability of the light intensity of the fluorescent light source, resolution of the solid-state camera with respect to the individual gap areas to be measured, and the pixel-counting selection process. These errors resulted in approximately 10 to 30 percent relative error when estimating the fraction. Larger relative errors tended to occur when samples were created with small fractions (i.e., 5 to 20 percent). However, the sensitivity of the optical property calculations to the error in the fraction is minimal at the small fractions. Reflectance calculations are negligibly affected across the wavelength range of 400 to 1,000 nm. Transmittance calculations vary 1 to 1.5 percent absolute for small fractions with relative errors of 10 percent in fraction estimation. Samples made before 20-Jul-1994 were constructed with a wide range of fractions, 30 to 80 percent, and the relative error in fraction measurement was also large (i.e., 10 to 30 percent). Optical properties, especially transmittance, are more sensitive to errors in the gap fraction estimation when the gap fraction is large than when it is small. A 10-percent relative error in large gap fraction measurement gives a 1- to 5-percent and 5-percent absolute error in reflectance and transmittance calculations, respectively, across the wavelength range.

The following table lists the range of gap fractions that were measured/calculated, the extreme relative error of the gap fraction, and the resulting error in the calculation of optical properties using these gap fractions.

Gap	Relative	Optical	Visible		Near Infrared	
Range	Error	Measurement	Abs .	Rel.	Abs.	Rel.
1. Round Aperture						
5 to 15	10%	Refl	<0.5	<3	1	2
		Trans	1.25	16	1.25	4.6
	20%	Refl	<0.5	<3	1.25	2.5
		Trans	2	>20	2	5
30 to 60	10%	Refl	1.5	8.5	4.5	8.5
		Trans	6.5	>20	5.5	14.5
	20%	Refl	2	11.7	7	15.5
		Trans	10	>20	8	20
40 to 80	10%	Refl	7.5	>20	12.5	20
		Trans	15	>20	14	>20
	30%	Refl	15	>20	22	>20
		Trans	>20	>20	25	>20
2. Slitted Aperture						
5 to 15	15%	Refl	<1	<6	1.25	2.5
		Trans	1.5	20	1.75	5.8
	30%	Refl	1.5	8	2	4
		Trans	4	>20	2.5	7.7

Where Abs is Absolute and Rel is Relative.

Additional information may be found in the report by Mesarch et al., 1991.

10.2 Quality Assessment

The integrating sphere/SE590 system response changed little between the measurement periods as indicated by the transmittance measurements of neutral density filters. Mean bias errors of known transmittances using the standard external light source averaged over the Thematic Mapper (TM) waveband regions were 0.13%, -0.09%, -0.09% and -0.03% (450-520, 520-600, 630-690, and 760-19,900 nanometers, respectively). Mean bias errors of known transmittances using the modified external light source averaged over the TM waveband regions were 0.13%, -0.09%, -0.13%, and -0.07%.

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
None given.

10.2.5 Data Verification by Data Center
Data were examined for general consistency and clarity.

11. Notes

11.1 Limitations of the Data
None given.

11.2 Known Problems with the Data
Transmittance measurements for sample type 2 occasionally have negative values, which resulted from errors in the measurement of the fraction of nonintercepted illumination beam and the sensitivity of the SE590, especially in the visible region of the spectrum (400 to 700 nm).

11.3 Usage Guidance
Reflectance measurements for all measurement are usable. Transmittance measurements for sample type 2 may occasionally contain negative values and should be used with discretion. Transmittance measurements made before 20-Jul-1994, especially in the visible region of the spectrum (400 to 700 nm) may not show the small changes based on canopy location or light environment (shaded or unshaded), whereas measurements after 20-Jul-1994 may show more nuances of transmittance.

11.4 Other Relevant Information
Acknowledgment of other research staff who assisted in measurements:
Liquang Chen, UNL Graduate Student
Brian P. Lang, UNL Undergraduate Student

12. Application of the Data Set

This data set can be used to examine the optical properties of boreal vegetation.

13. Future Modifications and Plans

None given.

14. Software

14.1 Software Description
SPSS' software JAVA version 1.4.

14.2 Software Access
None given.

15. Data Access

The TE-12 leaf optical 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

LI-COR LI-1800-12 Integrating Sphere Instruction Manual. 1983. Pub. No. 8305-0034. LI-COR, Inc., Lincoln, NE.

Spectron Engineering, Inc. Operating Manual: SE590 field-portable data-logging spectroradiometer, Spectron Engineering, Denver, CO 80223.

17.2 Journal Articles and Study Reports

Blad, B.L., E.A. Walter Shea, C.J. Hays, and M.A. Mesarch. 1990. Calibration of field reference panel and radiometers used in FIFE 1989. AgMet Progress Report 90-3. Department of Agricultural Meteorology. University of Nebraska-Lincoln. Lincoln, NE 68583-0728.

Daughtry, C.S.T., L.L. Biehl, and K.J. Ranson. 1989. A new technique to measure the spectral properties of conifer needles. Remote Sens. Environ. 27:81-1991.

Mesarch, M.A., E.A. Walter-Shea, B.F. Robinson, J.M. Norman, and C.J. Hays. 1991. Performance evaluation and operation of a field-portable radiometer for individual leaf optical measurements. AgMet Progress Report 91-2. Department of Agricultural Meteorology, University of Nebraska-Lincoln, Lincoln, NE 68583-0728.

Munsell Color Charts for Plant Tissue. 1977. MACBETH Div. of Kollmorgen Instrument Corp., Baltimore, MD.

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.

Norman, J.M. and P.G. Jarvis. 1974. Photosynthesis in Stika Spruce [Picea Sitchenis (Bong.) Carr.] III. Measurements of canopy structure and interception of radiation. J. Appl. Ecol. 11:375-398.

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.

Smith, W.K. and G.A. Carter. 1988. Shoot structural effects on needle temperatures and photosynthesis in conifers. Amer. J. of Bot. 75:496-500.

Williams, D.L. 1991. A comparison of spectral reflectance properties at the needle, branch and canopy level for selected conifer species. Remote Sens. Environ. 35:79-1993.

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

Abaxial: The bottom surface of a leaf or needle. For aspen, buck bean, bog birch, and substrate element samples, this side was not as bright in color and had a less glossier sheen than the adaxial surfaces. The abaxial surface of Labrador tea leaves was heavily pubescent; the current year's growth was white pubescent, and the prior years' growth having rust-colored pubescent. For black spruce, this was the surface with the whitish lines. Jack pine needles were attached to twigs in paired fascicles and generally had a semicircular cross-sectional shape. For jack pine needles, the inner semicircular concave, curved side was considered to be the abaxial surface.

Absolute (Abs) Error: Percent absolute error.

Adaxial: The top surface of a leaf or needle. For aspen, buck bean, bog birch, and substrate element samples, this side was typically brighter in color and had a glossier sheen than the abaxial surfaces. The adaxial surface of Labrador tea leaves was the least pubescent surface. For black spruce, this was the surface without the whitish lines. Jack pine needles were attached to twigs in paired fascicles and generally had a semicircular cross-sectional shape. The outer semicircular convex, curved side of the needle was considered the adaxial surface.

Adaxial Transmittance: The light shines on the adaxial surface, goes through the needle, and then passes into the integrating sphere. The spectroradiometer then measures the integrated light that is bouncing around in the sphere.

Adaxial Reflectance: The light shines on the adaxial surface, bounces off this surface, and then bounces around in the integrating sphere. The spectroradiometer then measures the integrated light that is bouncing around in the sphere.

Abaxial Transmittance: The light shines on the abaxial surface, goes through the needle, and then passes into the integrating sphere. The spectroradiometer then measures the integrated light that is bouncing around in the sphere.

Abaxial Reflectance: The light shines on the abaxial surface, bounces off this surface, and then bounces around in the integrating sphere. The spectroradiometer then measures the integrated light that is bouncing around in the sphere.

Channel (ch): One band on the SE590, each having a unique wavelength.

Reflectance (Refl): The light shines on the specified surface and bounces off this surface and then bounces around in the integrating sphere; the spectroradiometer then measures the integrated light that is bouncing around in the sphere.

Relative (Rel) Error: Percent relative error.

Transmittance (Trans): The light shines on the specified surface, goes through the needle and then passes into the integrating sphere; the spectroradiometer then measures the integrated light that is bouncing around in the sphere.

19. List of Acronyms

```
ASCII  - American Standard Code for Information Interchange
BOREAS - BOReal Ecosystem-Atmosphere Study
BORIS  - BOREAS Information System
CD-ROM - Compact Disk-Read-Only Memory
DAAC   - Distributed Active Archive Center
EOS    - Earth Observing System
EOSDIS - EOS Data and Information System
FEN    - Nipawin Fen site
FFC-T  - Focused Field Campaign/Thaw 1994
FFC-W  - Focused Field Campaign/Winter 1994
GIS    - Geographic Information System
GMT    - Greenwich Mean Time
GSFC   - Goddard Space Flight Center
HTML   - HyperText Markup Language
IFC    - Intensive Field Campaign
NAD83  - North American Datum of 1983
NASA   - National Aeronautics and Space Administration
NSA    - Northern Study Area
OA     - Old Aspen
OBS    - Old Black Spruce
OJP    - Old Jack Pine
ORNL   - Oak Ridge National Laboratory
PANP   - Prince Albert National Park
PAR    - Photosynthetically Active Radiation
SSA    - Southern Study Area
Stdev  - Standard Deviation
TE     - Terrestrial Ecology
TM     - Thematic Mapper
UNL    - University of Nebraska - Lincoln
URL    - Uniform Resource Locator
UTM    - Universal Transverse Mercator
YA     - Young Aspen
YJP    - Young Jack Pine
```

20. Document Information

20.1 Document Revision Date

Written: 30-Sept-1996
Last Updated: 23-Jul-1999

20.2 Document Review Date(s)

BORIS Review: 30-Apr-1997
Science Review: 27-Jul-1998

20.3 Document ID

20.4 Citation

When using these data, please acknowledge the efforts of E.A. Walter-Shea, M.A. Mesarch, and L. Chen at the University of Nebraska-Lincoln, and include citations of relevant papers in Section 17.2.

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

Walter-Shea, E.A., "Radiation and Gas Exchange of Canopy Elements in a 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.

Also, cite the BOREAS CD-ROM set as:

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

20.5 Document Curator

20.6 Document URL

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 2000	Technical Memorandum

4. TITLE AND SUBTITLE
Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)
BOREAS TE-12 Leaf Optical Data for SSA Species

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

6. AUTHOR(S)
Elizabeth A. Walter-Shea, Mark A. Mesarch, and L. Chen
Forrest G. Hall and Shelaine Curd, Editors

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

8. PEFORMING ORGANIZATION REPORT NUMBER
2000-03136-0

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

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
TM—2000–209891
Vol. 167

11. SUPPLEMENTARY NOTES
E.A. Walter-Shea, M.A. Mesarch, and L. Chen: University of Nebraska-Lincoln;
S. Curd: Raytheon ITSS, NASA Goddard Space Flight Center, Greenbelt, Maryland

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

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The BOREAS TE-12 team collected several data sets in support of its efforts to characterize and interpret information on the reflectance, transmittance, and gas exchange of boreal vegetation. This data set contains measurements of hemispherical spectral reflectance and transmittance factors of individual leaves, needles (ages: current and past 2 years' growth, i.e., for 1993, the growing seasons of 1993, 1992, and 1991 were measured; in 1994, the growing seasons of 1994, 1993, and 1992 were measured), twigs (reflectance only), and substrate at near-normal incidence measured using a LI-COR LI-1800-12 integrating sphere attached to a Spectron Engineering SE590 spectroradiometer. Procedures of Daughtry et al. (1989) were followed. These procedures permitted measurement of samples that: 1) filled the entire integrating sphere sample port, and 2) were narrow with a length greater than the sample port diameter. Optical properties were measured in 1993 and 1994 at the SSA Fen, YJP, YA, and OBS sites. The data are stored in tabular ASCII files.

14. SUBJECT TERMS
BOREAS, terrestrial ecology, boreal vegetation.

15. NUMBER OF PAGES
35

16. PRICE CODE

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