NASA/TM—2000–209891, Vol. 49

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

Forrest G. Hall and Jaime Nickeson, Editors

Volume 49

BOREAS RSS-4 1994 Southern Study Area Jack Pine LAI and FPAR Data

S. Plummer

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

July 2000

The NASA STI Program Office … in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.
- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and mission, often concerned with subjects having substantial public interest.
- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at http://www.sti.nasa.gov/STI-homepage.html
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at (301) 621-0134
- Telephone the NASA Access Help Desk at (301) 621-0390
- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076-1320

NASA/TM—2000–209891, Vol. 49

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

Forrest G. Hall and Jaime Nickeson, Editors

Volume 49

BOREAS RSS-4 1994 Southern Study Area Jack Pine LAI and FPAR Data

Stephen Plummer, Institute of Terrestrial Ecology, UK

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

July 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 RSS-4 1994 Southern Study Area Jack Pine LAI and FPAR Data

Stephen Plummer

Summary

The RSS-4 team collected several data sets related to leaf, plant, and stand physical, optical, and chemical properties. This data set contains leaf area indices and FPAR measurements that were taken at the three conifer sites in the BOREAS SSA during August 1993 and at the jack pine tower flux and a subset of auxiliary sites during July and August 1994. The measurements were made with LAI-2000 and Ceptometer instruments. The measurements were taken for the purpose of model parameterization and to test empirical relationships that were hypothesized between biophysical parameters and remotely sensed data. The data are stored in tabular ASCII files.

Table of Contents

1. Data Set Overview

1.1 Data Set Identification

BOREAS RSS-04 1994 Southern Study Area Jack Pine LAI and FPAR Data

1.2 Data Set Introduction

Estimates of Leaf Area Index (LAI) and fraction of Photosynthetically Active Radiation (FPAR) were made during the Focused Field Campaign in summer 1993 (FFC-93) and the second Intensive Field Campaign (IFC-2) in 1994. In FFC-93, preliminary measurements were made using a LI-COR LAI-2000 and a Decagon Devices Ceptometer at the three conifer tower flux sites Young Jack Pine (YJP), Old Jack Pine (OJP), and Old Black Spruce (OBS) in the BOReal Ecosystem-Atmosphere Study (BOREAS) Southern Study Area (SSA), while in 1994 attention was focused on jack pine tower flux and auxiliary sites in the SSA. LAI was estimated using both instruments; FPAR was obtained using the Ceptometer. Both the Ceptometer and the LAI-2000 rely on the relationships between radiation transmission, canopy gap fraction, and LAI. The assumptions of these approaches are summarized below (see Section 9) and have been assessed for the BOREAS sites in Chen et al. (1997).

1.3 Objective/Purpose

The Remote Sensing Science (RSS)-04 investigations were designed to obtain LAI, FPAR, and foliar chemistry data for a complex spatially variable forest canopy in order to:

- Parameterize an ecosystem simulation model.
- Test empirical relationships hypothesized between biophysical parameters and remotely sensed data.
- Parameterize a forest reflectance model and compare it with Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) data to deduce whether observed 'relationships' between canopy chemistry and reflectance are a product of canopy structure rather than foliar chemical variations themselves (see references list and biochemistry data set).
- Drive the ecosystem simulation model with estimates of LAI and chemistry derived from remotely sensed data.

1.4 Summary of Parameters

LAI, FPAR.

1.5 Discussion

The measurements that comprise this data set were collected as a contribution to the determination of the biophysical characteristics of the BOREAS SSA.

1.6 Related Data Sets

BOREAS RSS-01 SSA PARABOLA Surface Reflectance and Transmittance Data
BOREAS RSS-04 1994 Jack Pine Leaf Biochemistry and Modeled Spectra in the SSA
BOREAS RSS-07 LAI, Gap Fraction, and FPAR Data

2. Investigator(s)

2.1 Investigator(s) Name and Title

Dr. Stephen Plummer
Professor Paul Curran

2.2 Title of Investigation

RSS-04: Coupling Remotely Sensed Data to Ecosystem Simulation Models

2.3 Contact Information

Contact 1:
Dr. Stephen Plummer
Role: Data collection, transport, and project supervision
Section for Earth Observation
Institute of Terrestrial Ecology
Monks Wood
Abbots Ripton
Cambs, PE17 2LS UK
+44 1487 773381 (tel)
+44 1487 773277/467 (fax)
S.Plummer@ite.ac.uk

*formerly Remote Sensing Applications Development Unit British National Space Centre

Contact 2:
Jaime Nickeson
Raytheon ITSS
NASA GSFC
Code 923
Greenbelt, MD 20771
(301) 286-3373
(301) 286-0239 (fax)
Jaime.Nickeson@gsfc.nasa.gov

3. Theory of Measurements

For a discussion of the theory behind measurements presented here, users are directed to the review by Welles (1990), Welles and Norman (1991), and Chen et al. (1997).

4. Equipment

4.1 Sensor/Instrument Description

i) LAI

Two instruments were used to estimate LAI: a LI-COR LAI-2000 leaf area meter and a Decagon Devices Ceptometer. The LAI-2000 uses either one or two sensors to make measurements of the incoming diffuse incident flux above (A) and below (B) the canopy in blue wavelengths (<490 nm). Each reading comprises measurements of the amount of radiation at five zenith angles simultaneously over either the full azimuth or some portion of it, dictated by a viewing mask attached to the optical head. One measurement comprise a minimum of 10 numbers corresponding to 5 values of A (above) and 5 of B (below), at zenith angles of 0, 22.5, 37.5, 52.5, and 67.5 degrees. The Ceptometer is a line quantum sensor consisting of 80 separate photodiodes spaced at 1-cm intervals that are sensitive to radiation in the PAR region (400-700 nm). Measurements above and below the canopy are made to determine canopy transmittance at a number of solar zenith angles.

ii) FPAR

The Ceptometer was also used to determine the fraction of PAR absorbed by the canopy at a number of solar zenith angles.

4.1.1 Collection Environment

Measurements were collected during ambient surface atmospheric conditions at the SSA during August 1993 (FFC-93) and July to August 1994 (IFC-2). The LAI-2000 measurements were made at dusk and dawn, Ceptometer data were collected on sunny days.

4.1.2 Source/Platform

The instruments were held by the human investigators.

4.1.3 Source/Platform Mission Objectives

The objective was to collect LAI and FPAR measurements at various locations.

4.1.4 Key Variables

LAI, FPAR, Mean Tip Angle

4.1.5 Principles of Operation

The LAI-2000 and Ceptometer are instruments that make measurements of the incoming radiation below a plant canopy. In the case of the LAI-2000, measurements are made in the blue (<490 nm) region, while the Ceptometer records incoming radiation in the PAR (400-700 nm) region. These data can be used to estimate LAI indirectly by making assumptions about the canopy architecture (leaf distribution). LAI is derived by inverting the radiation transmission (or gap fraction) information. The gap fraction is the fraction of view in any direction from below a plant canopy that is not blocked (by leaves). If it is assumed that leaves are the only elements that block radiation, that they are nontransmitting, and that they are randomly distributed in space, then the transmission of a beam of radiation can be related to the mean foliage density (see Section 9 for equations). If the canopy is horizontally homogenous, then the mean foliage density can be related to LAI.

The LAI-2000 can be considered to be analogous to hemispherical photography in that it uses a fish eye light sensor that measures diffuse radiation in five distinct angular bands about zenith. The incoming radiation is projected onto photodiodes arranged as concentric rings. To derive gap fraction information, light conditions are assumed diffuse and uniform (dusk, dawn, or overcast conditions), and measurements are made of the sky above the canopy followed by readings below the canopy. The ratio of above-to-below canopy readings is used to obtain gap fraction. Because foliage is not normally randomly distributed and there is a proportion of nonfoliage matter that blocks radiation (dead leaves, branches, stems, or trunks), the derived measurement is normally referred to as "effective" LAI. Correction of these measurements can be made by derivation of factors that represent the woody-to-total area ratio and the clumping factors (needle-to-shoot area ratio and foliage clumping at greater than shoot level).

The Ceptometer measures PAR radiation using 80 photodiodes spaced at each centimeter along an 80-cm rod. These are used to provide an average value of PAR over the 80-cm length and for the specific solar zenith angle and relative azimuth. To account for azimuthal variation in foliage distribution, it is advisable to use the average over several azimuth directions (in this case, eight). Because the instrument is primarily used to measure the fraction of absorbed PAR (FPAR), measurements are taken in direct sun conditions, with the proviso that the solar illumination is consistent over the period of measurement. In the same way as with the LAI-2000, measurements are obtained first outside the canopy and subsequently below the canopy. In line with gap fraction measurements, these can be converted into an estimate of LAI using the approach of Norman (1988) (see Section 9). This also requires measurement of the ratio of diffuse-direct incident radiation. The diffuse component can be obtained by shading the Ceptometer from direct sun using an appropriately sized object such that the entire length of instrument is covered for the width of the solar disk (this is an acquired skill). More recent instruments (Delta-T SunScanô) come with a separate quantum sensor and shading ring for use with a line PAR sensor. Chen et al. (1997) indicate that the Ceptometer provides a measurement of plant area index, although the finite averaging does account for error caused by clumping at scales larger than the averaging length.

4.1.6 Instrument Measurement Geometry

LAI-2000

The LAI-2000 is simple to operate and acquires data relatively fast. Operation can be through single-head, dual-head, or remote-head modes. In single-head mode, as used in this experiment, both A (above) and B (below) measurements are made with the same optical head. Because the calculation is made by comparison of A and B measurements, the instrument does not require either absolute or relative calibration. However, there is a need for ready access to a clear sky view near to the measurement site. In BOREAS operation, this caused difficulties, especially at mature pine sites with tree heights of approximately 15 m. Measurements had to be tailored to site conditions, and given the need to cover as many sites as possible, operation often occurred in nonoptimal conditions. Sites were measured at dawn or dusk, although the distance between sites limited coverage on any given day. For short tree sites, e.g., SSA-YJP, it was possible to get above the canopy (using the back of a standard Jeep or by climbing the flux tower in periods of nonoperation (1993) to a height of approx. 3-4 m). The LAI-2000 head requires leveling, but it contains a bubble level to make leveling easier. The best practice is to maintain instrument orientation for all measurements (A and B). This is particularly important where the availability of a clear area is restricted to a logging road. In such cases, the A reading was made from the back of a Jeep with the optical head masked downward such that only a proportion of the view was used (see Section 5). In all cases, the optical head was masked for the observer using a 45-degree mask unless more was required. A measurements were made as regularly as possible (before and after single B runs) to minimize the effect of variation in sky conditions and linear interpolation used to provide A values for each B value. Repetitions of each measurement were made to increase the representativeness, and in cases where the B value exceeded a corresponding A the data point was ignored. This usually applied to measurements from the fifth ring. Removal of the fifth ring measurement in software meant that the data could be reintroduced. In all cases, the measurements were made at the same height, 1 m above the ground, except for reference measurements. The latter were made 1 m above the canopy (F8L6T), from the top of a large flux tower (G2L3T), or from a Jeep + 1 m height.

Ceptometer

As with the LAI-2000, there are a number of issues that affect the representativeness of measurements made with the Ceptometer. In all cases, reference measurements were made at the same locations as for the LAI-2000, and all measurement runs started and finished with a reference measurement. Since the same set of measurements was used for FPAR and LAI, these measurements were all made under direct sun conditions and included diffuse incident, canopy, and understory measurements. Each measurement comprised eight azimuth directions with the instrument level and out of any shadow cast by the operator. The eight measurements were made at the cardinal and subcardinal directions. Measurements were made at approximately 1 m where significant understory existed or 30 cm above ground where the understory was moss/lichen. Experience dictated whether a particular set of measurements was acceptable, especially for diffuse measurements, which required shading of the 80 photodiodes. It should be noted that because each individual measurement (1 through 8) was averaged "on the fly," one unshaded diffuse measurement could bias the data. When this occurred, measurements were repeated. A measurement sequence took considerably longer than the equivalent LAI-2000, and the processing was more laborious because no software was written for this purpose. This is now available with the Delta-T Sunscanô and may be available with the Decagon Accuparô.

4.1.7 Manufacturer of Instrument

LI-COR LAI-2000:
LI-COR, Inc.
4421 Superior Street
P.O. Box 4425
Lincoln, NE 68504
(402) 467-3576
http://env.licor.com/products/LAI2000/2000.htm

Ceptometer:
Decagon Devices, Inc.
950 NE Nelson Ct.
P.O. Box 835
Pullman, WA 99163
(509) 332-2756
http://www.decagon.com/

4.2 Calibration

i) LAI-2000

Sensor calibration consists of five multipliers for the outputs of the five rings of the detector. These values are supplied on a calibration sheet and relate one ring to another. The values do not convert outputs to absolute values of energy. In one-sensor mode, this is unimportant because the same sensor makes both A and B measurements. In two-sensor mode, the two sensors are compared under the same diffuse light conditions to adjust the sensitivity of the two sensors. The instrument is calibrated using an integrating sphere supplied by the UK representatives of LI-COR, Inc., Glen Spectra Ltd.

ii) Ceptometer

For LAI and FPAR determination, as long as the relative calibration of the 80 sensors is consistent, the same method applies as above. However, for determination of PAR, absorbed PAR (APAR), or incident PAR (PAR0), calibration must be applied to convert from output to SI units (µmol/m^2/s). Calibration is checked regularly by the owners of the instrument, University of Wales, Swansea, by comparison against an accurate PAR sensor under a standard daylight lamp. The accurate PAR quantum sensor is traceable to UK national standards.

4.2.1 Specifications

Ceptometer - The ideal spectral response for a quantum sensor is a "top hat" function with 100% dropoff at 400 nm and 700 nm. All quantum sensors approximate this; however, errors caused by imperfect spectral response are small for daylight conditions. The system cosine response matches the ideal accurately (>90% below 70 degrees). Individual Ceptometer measurement time is nominally 120 ms over a range of 2500 µmol/m^2/s with a resolution of 0.3 µmol/m^2/s. Accuracy of the instrument is ±10%. Maximum recorded values were approximately 1,500 µmol/m^2/s.

The LAI-2000 measurements were made in one-sensor mode because calculation is based on the ratio of A to B measurements. Issues of calibration, resolution, and accuracy are not a problem provided that the relative calibration between individual view rings is accurate and consistent.

4.2.1.1 Tolerance

Ceptometer - Accuracy of the instrument is ±10%. Maximum recorded values were approximately 1,500 µmol/m^2/s, well within the stated instrument range. Comparison of Ceptometer measurements against the Tracing Radiation and Architecture of Canopies (TRAC) instrument indicated a discrepancy of approximately 200 counts, but this was consistent over a range of light conditions. Absolute values of PAR were therefore not reported. Error analysis for the FPAR measurements could not be conducted against those from other Principal Investigators (PIs) (Chen, RSS-07) because measurements were not coincident. Within canopy variability (n=10) indicates that for FPAR values greater than 0.7, an error of ±10% should be expected, but because of clumping this can rise to 20-30% for FPAR values of 0.5.

The LAI estimates from the Ceptometer, LAI-2000, TRAC, and allometry were assessed by Chen et al. (1997). All the methods have limitations, and an absolute accuracy could not be attributed to any one method. The error range for LAI measurement method is on the order of 15-30%.

4.2.2 Frequency of Calibration

See Section 4 comments above - all measurements are ratio values, and the only issue is sensitivity of the instrument across the measurement range. This has not been checked but is assumed to be acceptable. Intercalibration between instruments was not performed for the LAI-2000 because it was used in one-sensor mode. Comparison of Ceptometer measurements against the TRAC instrument indicated a discrepancy of approximately 200 counts, but this was consistent over a range of light conditions. Absolute values of PAR are not provided in this data set.

4.2.3 Other Calibration Information

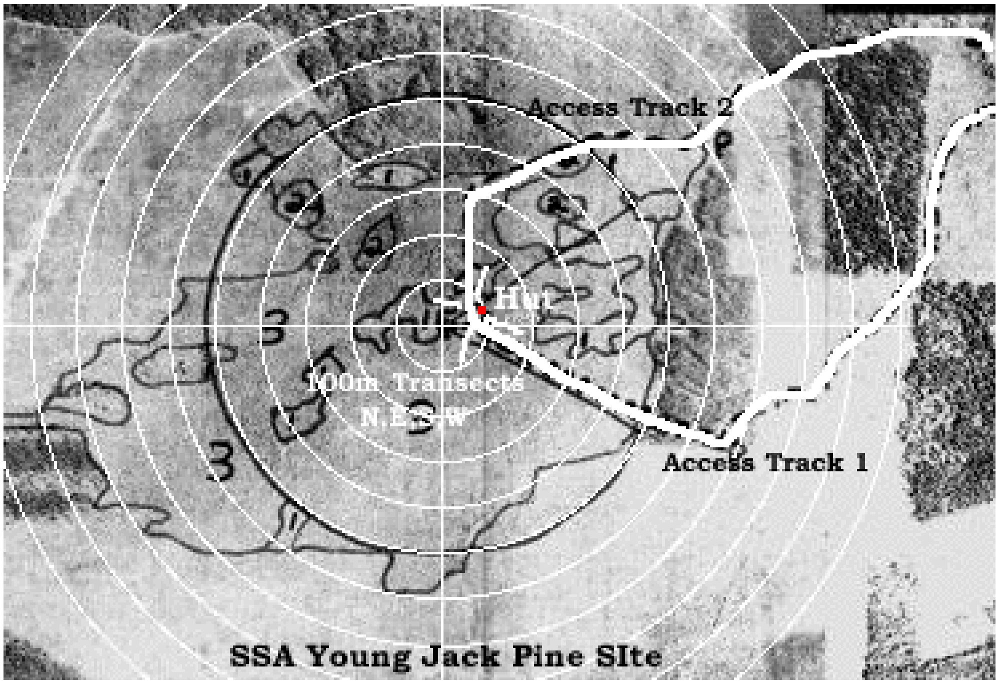
None given.

5. Data Acquisition Methods

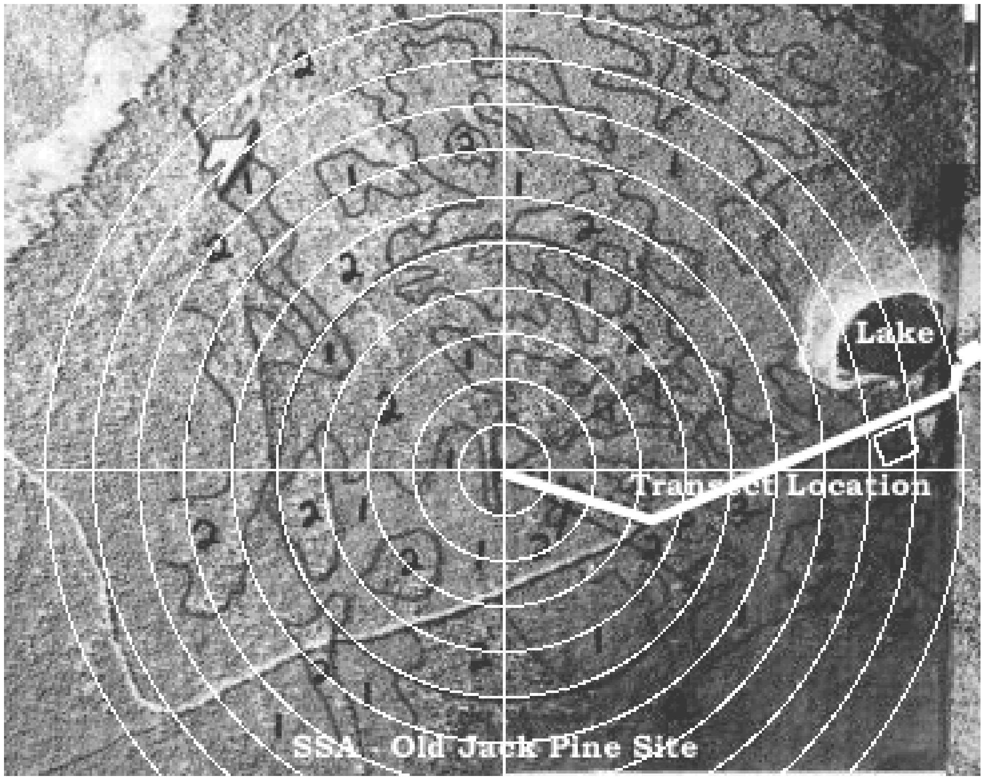
1993 Procedure:

i) LAI using the LAI-2000

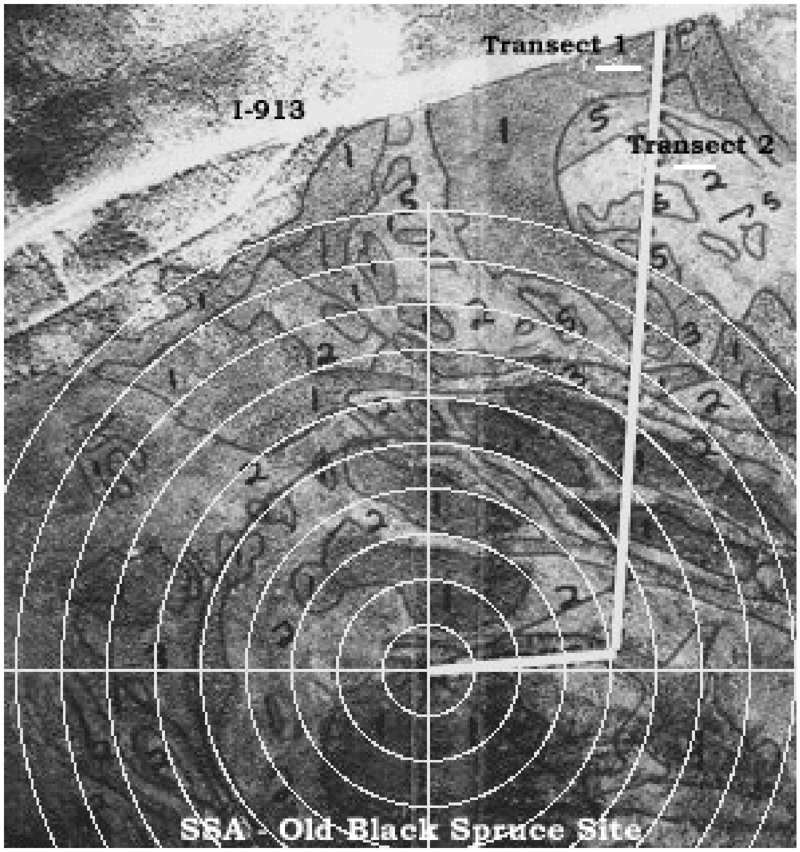
At each of the three conifer tower flux sites, 100-m transects were established with access to a nonforest area for determination of radiation flux.



At the SSA-YJP site, four transects were laid out on the cardinal points centered on the road next to the site hut (see accompanying .gif file). Data acquisition comprised an A measurement followed by 10 B measurements for each transect and finished with additional A measurement. A samples were taken at the flux tower and B samples at 10-m intervals along each transect. Data were collected on 14-Aug-1993 at 08:00 local time (15:00 Greenwich Mean Time (GMT). All the A measurements were acquired above the canopy at 3-4 m using the steps on the flux tower. In all cases, a 45-degree view cap was used to eliminate the observer.



At the SSA-OJP site, suitable access to a clear area at the flux tower site to make irradiance measurements was not available. Therefore, a similar stand adjacent to the site access road near a small lake (see accompanying .gif file) was selected. Irradiance measurements were taken at the lake edge using a 180-degree view cap. Four transects were established; however, the restricted size of the stand required a reorientation of these transects at some point along the 100-m length. Data were acquired on 16-Aug-1993 at 05:20 (12:20 GMT) and 06:30 (13:30 GMT).



Similarly, in the SSA-OBS, reasonable access to the flux tower site in 1993 was unavailable and there was no access above the canopy. Transects were therefore established nearer the road, and the road served as the irradiance site with a 315-degree view cap. A transect was established in each of the two main strata types, tall, high LAI black spruce, and short, low LAI black spruce. Data were acquired every 5 meters to give a sample size of 20 for each transect. Data were recorded on 25-Aug-1993 at 13:30 (20:30 GMT).

LAI was calculated using options available in the LAI-2000 processing software. Four different methods were used: standard, slope/intercept (Lang, 1987), ellipsoidal leaf distribution (Campbell, 1986), and constrained least squares (Norman and Campbell, 1989).

ii) LAI using the Ceptometer

At the same sites as in i), measurements were made several times per day. Each measurement on a transect was the average of eight azimuthal measurements of PAR flux. Total and diffuse incident flux were measured before and after each transect using a shade to block the sun. Similarly, at the first and last transect point, diffuse within-canopy flux and PAR reflected by the understory were measured. LAI was determined empirically using the method described by Norman (1988) with the beam fraction determined by interpolation for each transect point (see Section 9).

iii) FPAR

The measurements described above for the Ceptometer were also used to calculate the variation in FPAR for each transect using measurements of canopy transmission and interpolated values of incident flux and soil reflected flux. The canopy reflected flux was calculated using an average of eight measurements of a short roadside tree. FPAR was calculated for three solar zenith angles and for two transects at each site.

1994 Procedure:

i) LAI with the LAI-2000

The data acquisition in 1994 concentrated on the jack pine tower and auxiliary sites in the SSA and covered the same transects/plots as those laid out by RSS-07 and Terrestrial Ecology (TE)-23 for allometric measurements. For each auxiliary site, this comprised two perpendicular 50-m transects oriented in due S-N and E-W directions. Deviation from such an arrangement is explained in Section 6.

A total of nine jack pine sites were sampled with the LAI-2000. In all cases, the data were acquired either before sunrise or after sunset and with a large view cap (315 or 330 degrees) because the only irradiance site in most cases was the access road. Tree edge effects were reduced by measuring irradiance from the top of a Jeep.

ii) LAI with the Ceptometer

Ceptometer data were acquired at the same sites as the LAI-2000 using the method described above for 1994 site locations. Ten sites were covered, with runs recorded at three solar zenith angles for seven of the sites and two solar zenith angles for the other three sites. In addition, a series of comparative analyses was conducted with Jing Chen (RSS-07) at the following sites: SSA-Young Aspen (YA) (D6H4T), Black Spruce (D0H6S) and Mixed (D9I1M) and with Don Deering (RSS-01) at the SSA-OJP.

iii) Fraction of Absorbed Photosynthetically Active Radiation (FPAR)

Measurements of FPAR for each of the sites above were also made using the method described in 1993. At sites with significant understory vegetation, additional measurements were made above and below the understory (D6H4T, D0H6S).

iv) Canopy Chemistry

Samples for determination of nitrogen, chlorophyll, water, etc., were acquired for the nine sites covered by the LAI-2000 using clippers for the short sites and with a shotgun for the sites with tall canopies. Branchlets were subdivided into current year and 1 year or greater, and the needles were then stripped off and frozen with CO_2 (see related data sets Section 1.6).

6. Observations

6.1 Data Notes

None given.

Date	Notes
27-Jul-1994	Site D9I1M Run 1: Transect of Pink Flags E/W from Tower - TE-06? Run 2: Transect of Red Stakes N/S from Tower - RSS-07.
27-Jul-1994	Site D4H6T Aspen: Understory data acquired with Ceptometer.
27-Jul-1994	Site D0H6S Black Spruce: Cirrus Cloud. Problem finding site. Used RSS-07 Transect.
28-Jul-1994	Site G9L0P: Cirrus Cloud.
28-Jul-1994	Site F7J1P: Cumulus Cloud.
28-Jul-1994	Comparison of Ceptometer with TRAC.
30-Jul-1994	Site G8L6P: No Markers present - Markers inserted N/E/S/W.
2-Aug-1994	Site F5I6P: Site not found so established at 150 m in from Route 913 on a bearing of 59 degrees.
2-Aug-1994	Site F7J1P: 60% Jack Pine, 20% Spruce, 20% Aspen.
2-Aug-1994	Site F7J0P: 34% Jack Pine, 33% Spruce, 33% Aspen.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

Data were collected at treed SSA tower sites and SSA jack pine auxiliary sites. The following table lists the North American Datum of 1983 (NAD83) coordinates of the site locations that were sampled :

Name	Notes	West Longitude	North Latitude	UTM Easting	UTM Northing	UTM Zone
F8L6T	SSA YJP	104.64527	53.87581	523350.7	5969540.0	13
G2L3T	SSA OJP	104.69203	53.91634	520257.0	5974035.0	13
G8I4T	SSA OBS	105.11779	53.98718	492306.1	5981879.0	13
F5I6P	JIH-4 Pine	105.11174	53.86608	492681.9	5968405.0	13
F7J0P	JMH-5 Pine	105.05116	53.88334	496666.7	5970320.0	13
F7J1P	JMH-A2 Pine	105.03226	53.88211	497909.2	5970183.0	13
G1K9P	JMM-6 Pine	104.74810	53.90881	516576.8	5973183.0	13
G4K8P	JMM-5 Pine	104.76399	53.91884	515529.6	5974295.0	13
G7K8P	JMM-8A Pine	104.77147	53.95882	515023.9	5978742.0	13
G8L6P	JDM-8 Pine	104.63755	53.96558	523807.6	5979530.0	13
G9L0P	JMH-10 Pine	104.73778	53.97576	517227.6	5980634.0	13
D0H6S	BMM-1 Spruce	105.29534	53.64878	480506.0	5944267.0	13
D0H4T	SSA YA	105.32313	53.65602	478675.2	5945077.0	13
D9I1M	AIH-3 Mixed	105.20643	53.72540	486410.2	5952768.0	13

7.1.2 Spatial Coverage Map

Not available.

7.1.3 Spatial Resolution

The measurements provided by the LAI-2000 should be regarded as representative of the sample site, while those by the Ceptometer (LAI and FPAR) are provided as individual samples for each sample point. It is recommended that these also be used at the sample site level rather than individually since the variation from point to point can be large because of clumping; this is particularly important in the case of FPAR. Where there was significant understory, the Ceptometer data are provided at two levels, above and below the understory layer.

7.1.4 Projection

Not applicable.

7.1.5 Grid Description

Not applicable.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

FFC-93: 07-Aug to 30-Aug-1993
IFC-94: 25-Jul to 05-Aug-1994

7.2.2 Temporal Coverage Map

```
1993  LAI using the LAI-2000
SSA-YJP - Data were collected on 14-Aug at 08:00 local time (15:00 GMT).
SSA-OJP - Data were acquired on 16-Aug at 05:20 (12:20 GMT) and 06:30
          (13:30 GMT)
SSA-OBS - Data were recorded on 25-Aug at 13:30 (20:30 GMT).
```

```
1993  LAI using the Ceptometer
SSA-YJP - Data were collected several times a day on 14-Aug.
SSA-OJP - Data were acquired several times a day on 16-Aug.
SSA-OBS - Data were recorded several times a day on 25-Aug.

1994  LAI using the LAI-2000
F5I6P  -  04-Aug-1994
F7J0P  -  03-Aug-1994
F7J0P  -  31-Jul-1994
F7J1P  -  03-Aug-1994
F7J1P  -  31-Jul-1994
G1K9P  -  31-Jul-1994
G2L3T  -  05-Aug-1994
G4K8P  -  31-Jul-1994
G7K8P  -  31-Jul-1994
G8L6P  -  05-Aug-1994
G9L0P  -  03-Aug-1994
G9L0P  -  31-Jul-1994

1994  LAI using the Ceptometer
D0H6S  -  28-Jul-1994
D6H4A  -  27-Jul-1994
D9I1M  -  27-Jul-1994
F5I6P  -  03-Aug-1994
F5I6P  -  04-Aug-1994
F7J0P  -  04-Aug-1994
F7J0P  -  28-Jul-1994
F7J1P  -  03-Aug-1994
F7J1P  -  28-Jul-1994
F8L6T  -  02-Aug-1994
F8L6T  -  30-Jul-1994
G1K9P  -  26-Jul-1994
G2L3T  -  30-Jul-1994
G4K8P  -  26-Jul-1994
G4K8P  -  27-Jul-1994
G7K8P  -  03-Aug-1994
G7K8P  -  28-Jul-1994
G8L6P  -  30-Jul-1994
G9L0P  -  26-Jul-1994
G9L0P  -  27-Jul-1994
G9L0P  -  28-Jul-1994
```

7.2.3 Temporal Resolution

Measurements were made during FFC-93 and IFC-2 in 1994. LAI changes relatively slowly for conifer species; hence, the values can be considered to be representative of the field campaign specified. FPAR varies continuously, for a given location, as a function of solar geometry because penetration is dependent on the interception of incident PAR by individual crowns clumped in a nonrandom fashion. Three sets of measurements for each sample site are given along with time and date to provide an indication of FPAR variability. Individual runs of measurements took approximately 10 minutes from first point to last plus the time taken to gain access to the site from the nearest clear sky location (varied from 1-10 minutes with most sites less than 5 minutes).

7.3 Data Characteristics

7.3.1 Parameter/Variable

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

```
LAI from LAI-2000:
         Column Name
------------------------------
SITE_NAME
SUB_SITE
DATE_OBS
TIME_OBS
OP_GRID_ID
MASK
NUM_OBS
LAI_STD_METHOD
MTA_STD_METHOD
LAI_LANG_METHOD
MTA_LANG_METHOD
LAI_ELLIP_METHOD
MTA_ELLIP_METHOD
LAI_CLS_METHOD
MTA_CLS_METHOD
GROUP_PLOT
COMMENTS
CRTFCN_CODE
REVISION_DATE
```

```
LAI from Ceptometer:
         Column Name
------------------------------
SITE_NAME
SUB_SITE
DATE_OBS
TIME_OBS
OP_GRID_ID
LOCATION
LAI
FPAR
GROUP_PLOT
COMMENTS
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:

LAI from LAI-2000:

Column Name	Description
SITE_NAME	The identifier assigned to the site by BOREAS, in the format SSS-TTT-CCCCC, where SSS identifies the portion of the study area: NSA, SSA, REG, TRN, and TTT identifies the cover type for the site, 999 if unknown, and CCCCC is the identifier for site, exactly what it means will vary with site type.
SUB_SITE	The identifier assigned to the sub-site by BOREAS, in the format GGGGG-IIIII, where GGGGG is the group associated with the sub-site instrument e.g. HYD06 or STAFF, and IIIII is the identifier for sub-site, often this will refer to an instrument.
DATE_OBS	The date on which the data were collected.
TIME_OBS	The Greenwich Mean Time (GMT) when the data were collected.
OP_GRID_ID	The identifier given to the BOREAS auxiliary and tower sites during the execution of field operations. An example of this is B9B7A.
MASK	A number representing the presence or absence of five azimuthal viewing mask rings for each measurement.
NUM_OBS	Number of observations of the given sample used to calculate given values.
LAI_STD_METHOD	Leaf angle index calculated by the standard method with the LICOR LAI-2000.
MTA_STD_METHOD	Mean tip angle calculated by the standard method with the LICOR LAI-2000.
LAI_LANG_METHOD	Leaf angle index calculated by the slope/ intercept method of Lang (1987) with the LICOR LAI-2000.
MTA_LANG_METHOD	Mean tip angle calculated by the slope/intercept method of Lang (1987) with the LICOR LAI-2000.
LAI_ELLIP_METHOD	Leaf angle index calculated by the elliptical distribution method of Norman and Campbell (1989) with the LICOR LAI-2000.
MTA_ELLIP_METHOD	Elliptical distribution method of Norman and Campbell (1989) for determining the mean tip angle with the LICOR LAI-2000.
LAI_CLS_METHOD	Leaf angle index calculated by the constrained least squares method of Norman and Campbell (1989) with the LICOR LAI-2000.
MTA_CLS_METHOD	Mean tip angle calculated by the constrained least squares method of Norman and Campbell (1989)with the LICOR LAI-2000.
GROUP_PLOT	Group associated with or who has defined location information.
COMMENTS	Descriptive information to clarify or enhance the

	understanding of the other entered data.
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.

LAI from Ceptometer:

Column Name	Description
SITE_NAME	The identifier assigned to the site by BOREAS, in the format SSS-TTT-CCCCC, where SSS identifies the portion of the study area: NSA, SSA, REG, TRN, and TTT identifies the cover type for the site, 999 if unknown, and CCCCC is the identifier for site, exactly what it means will vary with site type.
SUB_SITE	The identifier assigned to the sub-site by BOREAS, in the format GGGGG-IIIII, where GGGGG is the group associated with the sub-site instrument e.g. HYD06 or STAFF, and IIIII is the identifier for sub-site, often this will refer to an instrument.
DATE_OBS	The date on which the data were collected.
TIME_OBS	The Greenwich Mean Time (GMT) when the data were collected.
OP_GRID_ID	The identifier given to the BOREAS auxiliary and tower sites during the execution of field operations. An example of this is B9B7A.
LOCATION	Specific position within the site, relative to the tower.
LAI	Leaf area index calculated from Ceptometer measurements.
FPAR	Fraction of photosynthetically active radiation measured from Ceptometer instrument.
GROUP_PLOT	Group associated with or who has defined location information.
COMMENTS	Descriptive information to clarify or enhance the understanding of the other entered data.
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:

LAI from LAI-2000:

Column Name	Units
SITE_NAME	[none]
SUB_SITE	[none]
DATE_OBS	[DD-MON-YY]
TIME_OBS	[HHMM GMT]
OP_GRID_ID	[none]
MASK	[unitless]
NUM_OBS	[counts]
LAI_STD_METHOD	[unitless]
MTA_STD_METHOD	[degrees]
LAI_LANG_METHOD	[unitless]
MTA_LANG_METHOD	[degrees]
LAI_ELLIP_METHOD	[unitless]
MTA_ELLIP_METHOD	[degrees]
LAI_CLS_METHOD	[unitless]
MTA_CLS_METHOD	[degrees]
GROUP_PLOT	[none]
COMMENTS	[none]
CRTFCN_CODE	[none]
REVISION_DATE	[DD-MON-YY]

LAI from Ceptometer:

Column Name	Units
SITE_NAME	[none]
SUB_SITE	[none]
DATE_OBS	[DD-MON-YY]
TIME_OBS	[HHMM GMT]
OP_GRID_ID	[none]
LOCATION	[none]
LAI	[unitless]
FPAR	[unitless]
GROUP_PLOT	[none]
COMMENTS	[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:

LAI from LAI-2000:

Column Name	Data Source
SITE_NAME	[Assigned by BORIS Staff]
SUB_SITE	[Assigned by BORIS Staff]
DATE_OBS	[Observer]
TIME_OBS	[Observer]
OP_GRID_ID	[BOREAS Experiment Plan]
MASK	[LAI-2000]

NUM_OBS	[LAI-2000]
LAI_STD_METHOD	[LAI-2000, calculated]
MTA_STD_METHOD	[LAI-2000, calculated]
LAI_LANG_METHOD	[LAI-2000, calculated]
MTA_LANG_METHOD	[LAI-2000, calculated]
LAI_ELLIP_METHOD	[LAI-2000, calculated]
MTA_ELLIP_METHOD	[LAI-2000, calculated]
LAI_CLS_METHOD	[LAI-2000, calculated]
MTA_CLS_METHOD	[LAI-2000, calculated]
GROUP_PLOT	[RSS04 team]
COMMENTS	[RSS04 team]
CRTFCN_CODE	[Assigned by BORIS Staff]
REVISION_DATE	[Assigned by BORIS Staff]

LAI from Ceptometer:

Column Name	Data Source
SITE_NAME	[Assigned by BORIS Staff]
SUB_SITE	[Assigned by BORIS Staff]
DATE_OBS	[Observer]
TIME_OBS	[Observer]
OP_GRID_ID	[BOREAS Experiment Plan]
LOCATION	[RSS04 team]
LAI	[Ceptometer]
FPAR	[Ceptometer]
GROUP_PLOT	[RSS04 team]
COMMENTS	[RSS04 team]
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.

LAI from LAI-2000:

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SITE_NAME	SSA-9JP-AUX02	SSA-YJP-FLXTR	None	None	None	None
SUB_SITE	RSS04-LAI01	RSS04-LAI01	None	None	None	None
DATE_OBS	14-AUG-93	05-AUG-94	None	None	None	None
TIME_OBS	122	2030	None	None	None	None
OP_GRID_ID	F5I6P	G9L0P	None	None	None	None
MASK	1111	11111	None	None	None	None
NUM_OBS	10	40	None	None	None	None
LAI_STD_METHOD	1.09	3.54	None	None	None	None
MTA_STD_METHOD	43	73	None	None	None	None
LAI_LANG_METHOD	1.03	3.82	None	None	None	None
MTA_LANG_METHOD			-999	None	None	None
LAI_ELLIP_METHOD	.92	3.69	None	None	None	None
MTA_ELLIP_METHOD	31	75	None	None	None	None
LAI_CLS_METHOD	.92	3.53	None	None	None	None
MTA_CLS_METHOD	31	69	None	None	None	None

GROUP_PLOT	None	TE-13	None	None	None	None
COMMENTS	N/A	N/A	None	None	None	Blank
CRTFCN_CODE	CPI	CPI	None	None	None	None
REVISION_DATE	03-AUG-95	25-OCT-96	None	None	None	None

LAI from Ceptometer:

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SITE_NAME	SSA-9BS-AUX01	SSA-YJP-FLXTR	None	None	None	None
SUB_SITE	RSS04-LAI01	RSS04-LAI01	None	None	None	None
DATE_OBS	19-AUG-93	04-AUG-94	None	None	None	None
TIME_OBS	0	2357	None	None	None	None
OP_GRID_ID	D0H6S	G9L0P	None	None	None	None
LOCATION	0	90 m	None	None	None	None
LAI	.11	7.81	None	None	None	None
FPAR	.04	.96	None	None	None	None
GROUP_PLOT	RSS-1	TE-6	None	None	None	None
COMMENTS	N/A	N/A	None	None	None	Blank
CRTFCN_CODE	CPI	CPI	None	None	None	None
REVISION_DATE	07-AUG-95	25-OCT-96	None	None	None	None

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

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

7.4 Sample Data Record

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

LAI from LAI-2000:

```
SITE_NAME,SUB_SITE,DATE_OBS,TIME_OBS,OP_GRID_ID,MASK,NUM_OBS,LAI_STD_METHOD,
MTA_STD_METHOD,LAI_LANG_METHOD,MTA_LANG_METHOD,LAI_ELLIP_METHOD,MTA_ELLIP_METHOD,
LAI_CLS_METHOD,MTA_CLS_METHOD,GROUP_PLOT,COMMENTS,CRTFCN_CODE,REVISION_DATE
'SSA-YJP-FLXTR','RSS04-LAI01',14-AUG-93,1500,'F8L6T',11111,37,1.09,63,1.15,-999,
1.08,65,1.07,62,'RSS-4','','CPI',03-AUG-95
'SSA-YJP-FLXTR','RSS04-LAI01',14-AUG-93,1500,'F8L6T',11111,22,1.23,61,1.2,-999,
1.22,62,1.21,59,'RSS-4','','CPI',03-AUG-95
```

LAI from Ceptometer:

```
SITE_NAME,SUB_SITE,DATE_OBS,TIME_OBS,OP_GRID_ID,LOCATION,LAI,FPAR,GROUP_PLOT,
COMMENTS,CRTFCN_CODE,REVISION_DATE
'SSA-9JP-AUX08','RSS04-LAI01',30-JUL-94,1502,'G8L6P','3N',2.23,.71,'RSS-4','',
'CPI',25-OCT-96
'SSA-9JP-AUX08','RSS04-LAI01',30-JUL-94,1507,'G8L6P','3W',2.12,.69,'RSS-4','',
'CPI',25-OCT-96
```

8. Data Organization

8.1 Data Granularity

The smallest unit of data tracked by the BOREAS Information System (BORIS) is all the data collected at a site on a given day or for a given time period.

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

LAI-2000 method:

In calculation of LAI with the LAI-2000, the foliage density is derived by measurement of the contact frequency over the azimuthal averaged zenith bin represented by each viewing ring. Foliage density is calculated as:

$$\mu = (2 \text{ x pi}) - \ln(T(Ø))\sin Ø/S(Ø)\ dØ$$

where T(Ø) is the probability of noninterception, Ø is zenith angle, and S(Ø) is the path length. If there is a homogeneous cover, foliage density μ is related to LAI by canopy height and path length S is dependent on canopy height and zenith angle:

$$LAI = \mu z \text{ and } S(Ø) = z/\cos(Ø)$$

Thus, LAI can be calculated by summation of the azimuthal averaged transmission over the five zenith bins:

$$LAI = (2 \times pi) - \ln(T(Ø))\sin Ø \cos Ø$$

For boreal forest canopies where the cover is not homogeneous (i.e., the foliage distribution is not random, and a proportion of the intercepting elements are not foliage), the measurement is of effective LAI (see Chen et al., 1997). To derive LAI, it is necessary to adjust the effective LAI for the woody-to-total area ratio and the foliage clumping both within conifer shoots and at large scales. A discussion of the derivation of such correction factors is given in Chen et al. (1997), with values provided for the tower flux sites.

Ceptometer Method:

The derivation of LAI from Ceptometer measurements uses the formula derived by Norman (1988) to convert from PAR transmission to LAI. This approach was derived from simulation results from a radiative transfer model under assumptions of a spherical leaf angle distribution and random leaf positioning. It does not involve gap fraction analysis and can be used with any beam fraction from clear sky to overcast. Although it does not require a series of solar angles, averaging across a range of solar zenith angles is recommended. The empirical fit of LAI to PAR transmission is:

$$LAI = [\{f_b(1-\cos Ø<_s)-1\} \ln(Ei</E_a)]/(0.72-0.337f_b)$$
$$f_b = (E_a - E_{ad})/E_a$$

where f_b is the beam fraction, Ei is incident PAR under the canopy, E_a is incident PAR above the canopy, E_{ad} is the diffuse incident PAR, and $Ø_s$ is solar zenith angle.

Descriptions of these and other methods of LAI estimation can be found in the cited literature (Section 17.2) and a review by Welles (1990).

FPAR is calculated using the following formula:

$$FPAR = (PAR_0 - PAR_r - (PAR_t - PAR_s))/PAR_0$$

The subscripts 0, r, t, and s refer to the incoming PAR, PAR reflected by the canopy, PAR transmitted through the canopy, and PAR reflected by the substrate, respectively. The measurements in all cases are the average of eight azimuthal measurements to eliminate azimuthal bias.

9.1.1 Derivation Techniques and Algorithms

None given.

9.2 Data Processing Sequence

9.2.1 Processing Steps

See Section 9.1.

9.2.2 Processing Changes

None.

9.3 Calculations

i) LAI from LAI-2000

LAI was calculated using the LAI-2000 operating in one-sensor mode with one run constituting 10 B measurements separated by A measurements at the start and end of each run. Linear interpolation between the A values was used to calculate A values for each B measurement. B values were rejected if the B:A ratio was greater than 1 in any of the five rings.

ii) LAI from Ceptometer

Determined using the method of Norman (1988), a typical Ceptometer run comprised:

- Total incoming
- Diffuse incoming
- Canopy
- Measurement 1
- Substrate at Measurement 1
- Diffuse at Measurement 1
- Measurement 2
- Measurement 3....
- Measurement 10
- Total incoming
- Diffuse incoming

Linear interpolation based on time (decimal) for Total and Diffuse incoming was used to calculate incoming for each measurement. Solar zenith angle was calculated based on the time and site latitude/longitude obtained from the BOREAS Auxiliary Site Guide.

iii) FPAR from Ceptometer

FPAR calculations used the same data set and methods as ii) to determine the incoming. The canopy and substrate components were as a percentage of incoming at each sample point.

9.3.1 Special Corrections/Adjustments

None given.

9.3.2 Calculated Variables

LAI, FPAR.

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

None given.

10.2 Quality Assessment

10.2.1 Data Validation by Source

Checks were made prior to storage to make sure anomalous values were not stored. In the case of LAI-2000, measurements were acquired only before sunrise and after sunset and in the absence of significant amounts of cloud, or where the cloud was fast moving. Measurements were redone if the number of invalid data points (indicated by an instrument beep) was higher than 2 on a standard run. These data sets were discarded.

Similarly, where a single Ceptometer measurement contributing to the average was unexpectedly high or low, for example in the case of diffuse measurements, where the shadowing device was not completely over the instrument, the average was recalculated using an additional eight samples.

10.2.2 Confidence Level/Accuracy Judgment

It is difficult to draw conclusions on the subjective quality of the data; however, it is clear that such estimates are only as good as the assumptions made in derivation. The Chen et al. (1997) paper discusses these assumptions for LAI and compares a range of instrument measurements. The cause and effects of error on the representativeness of measurements varies with instrument and tree species, and particularly with clumping at a range of scales. Nevertheless, the estimates are consistent with alternative approaches.

10.2.3 Measurement Error for Parameters

Error in LAI from LAI-2000 and Ceptometer from Chen et al. (1997) varies with tree species, but is in the range of 15-30%. This error is comparable but not necessarily the same as for allometry.

Error (n=10) in FPAR varies with the degree of clumping in a canopy but is typically less than 10% for FPAR of greater than 0.7. The error increases and may reach 30% where the canopy is highly variable. There is no consistent pattern in error variation with solar geometry.

10.2.4 Additional Quality Assessments

None given.

10.2.5 Data Verification by Data Center

BORIS staff reviewed the data during the data base loading process for clarity and consistency.

11. Notes

11.1 Limitations of the Data

None given.

11.2 Known Problems with the Data

i) LAI from LAI-2000

The data set is exclusively of an incomplete conifer canopy. The assumptions in translating from transmission to LAI may not strictly apply. In particular, the assumption of random arrangement of needles in space is not true, which leads to underestimation of LAI. An empirical correction to convert from shoot projected area to needle projected area has been suggested to adjust for this effect (Gower and Norman, 1990). These empirical corrections, however, have not been applied to the data. Representative correction values can be found in Chen et al. (1997), along with a discussion of their use.

The irradiance measurement was constrained by access to an open area. In most cases, this was the road. Edge effects were reduced by limiting the view azimuth and standing on a raised platform; however, it is anticipated that there may still be some influence caused by the reduction in representativeness of the azimuth average.

ii) LAI from Ceptometer

The azimuth averages of incoming PAR could potentially be biased by the presence of tree trunks or gaps near the sample point. Variations in averages were noted by repeated sampling near the central grid point. Absolute values of PAR are not given because cross comparison with the TRAC instrument (Chen et al. 1997)(RSS-7) revealed a consistent discrepancy of approximately 230 counts.

iii) FPAR from Ceptometer

All values were calculated as an average of eight azimuth measurements. In the case of canopy and substrate measurements, low incoming values resulted in null returns as an average. In these cases, the percentage reflectance was derived from repeat measurements of the site.

The canopy measurement was not derived under ideal conditions because it was not possible to obtain PAR reflectance from the real canopy. Measurements of short trees at the roadside were substituted. The average values were not azimuth independent because of problems with the bias introduced from direct irradiance incident on the Ceptometer in the antisolar direction; therefore, canopy values may not be truly representative.

The average values were computed and stored by the instrument, so no record of the eight values that generated the average is available.

11.3 Usage Guidance

None given.

11.4 Other Relevant Information

None.

12. Application of the Data Set

This data set can be used for model parameterization and to test empirical relationships hypothesized between biophysical parameters and remotely sensed data.

13. Future Modifications and Plans

None.

14. Software

14.1 Software Description

None given.

14.2 Software Access

None given.

15. Data Access

The SSA jack pine LAI and FPAR 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

Campbell, G.S. 1986. Extinction coefficients for radiation in plant canopies calculated using an ellipsoidal inclination angle distribution. Agric. For. Meteorol. 36, 317-321.

Chen, J.M., P.M. Rich, S.T. Gower, J.M. Norman, and S.E. Plummer. 1997. Leaf area index of boreal forests: Theory, techniques, and measurements. Journal of Geophysical Research 102(D24): 29,429-29,443.

Gower, S.T. and J.M. Norman. 1990. Rapid estimation of leaf area index in conifer and broad-leaf plantations. Ecology, 72, 1896-1900

Lang, A.R.G. 1987. Simplified estimate of leaf area index from transmittance of the sun's beam. Agric. For. Meteorology, 41, 179-186.

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. 1988. Crop canopy photosynthesis and conductance from leaf measurements. Workshop prepared for LI-COR, Inc., Lincoln, NE.

Norman, J.M. and G.S. Campbell. 1989. Canopy structure. In: Plant Physiological Ecology: Field methods and instrumentation. (eds. R.W. Pearcy, J. Ehleringer, H.A. Mooney, and P.W. Rundel). Chapman and Hall, London and New York. 301-325.

North, P.R. 1995. A three-dimensional forest light interaction model using a Monte-Carlo method. IEEE Trans. Geosci. and Rem. Sens., 34, 946-956.

North, P.R. and S.E. Plummer. 1994. Estimation of conifer bi-directional reflectance using a Monte Carlo method. IGARSS'94, IEEE, Piscataway, NJ, Vol. I, 114-116.

Plummer, S.E. and N. Lucas. 1993. Report of the BOREAS Intensive Field Campaign 1993. Remote Sensing Applications Development Unit, Report No. 93/5.

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.

Walker, G.K., R.E. Blackshaw, and J. Dekker. 1988. Leaf area and competition for light between plant species using direct transmission. Weed Technology, 2, 159-165.

Welles, J.M. 1990. Some indirect methods of estimating canopy structure. In: Instrumentation for Studying Vegetation Canopies for Remote Sensing in Optical and Thermal Infrared Regions. Remote Sensing Reviews 5(1) (eds. N. S. Goel and J. M. Norman). Harwood Academic Publishers, London and New York.

Welles, J.M. and J.M. Norman. 1991. Instrument for indirect measurement of canopy architecture. Agronomy Journal, 83: 818-825.

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

```
APAR    - Absorbed Photosynthetically Active Radiation
ASCII   - American Standard Code for Information Interchange
AVIRIS  - Airborne Visible and Infrared Imaging Spectrometer
BNSC    - British National Space Centre
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
FFC     - Focused Field Campaign
FPAR    - Fraction of absorbed Photosynthetically Active Radiation
GIS     - Geographic Information System
GMT     - Greenwich Mean Time
GSFC    - Goddard Space Flight Center
HTML    - HyperText Markup Language
IFC     - Intensive Field Campaign
IPAR    - Incident PAR
LAI     - Leaf Area Index
NAD83   - North American Datum of 1983
NASA    - National Aeronautics and Space Administration
NSA     - Northern Study Area
OBS     - Old Black Spruce
OJP     - Old Jack Pine
ORNL    - Oak Ridge National Laboratory
PANP    - Prince Albert National Park
PAR     - Photosynthetically Active Radiation
PI      - Principal Investigator
RSADU   - Remote Sensing Applications Development Unit
RSS     - Remote Sensing Science
SSA     - Southern Study Area
TE      - Terrestrial Ecology
TRAC    - Tracing Radiation and Architecture of Canopies
URL     - Uniform Resource Locator
UTM     - Universal Transverse Mercator
YA      - Young Aspen
YJP     - Young Jack Pine
```

20. Document Information

20.1 Document Revision Dates
Written: 02-Aug-1995
Last Updated: 30-Jul-1999

20.2 Document Review Dates
BORIS Review: 10-Aug-1998
Science Review: 03-Aug-1998

20.3 Document ID

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

LAI-2000 and Ceptometer data were gathered by Dr. Stephen Plummer (British National Space Centre/Remote Sensing Applications Development Unit) and Mr. Neil Lucas (University College of Swansea).

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

Plummer, S. and P. Curran, "RSS-04: Coupling Remotely Sensed Data to Ecosystem Simulation Models." 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
	July 2000	Technical Memorandum

4. TITLE AND SUBTITLE

Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)
BOREAS RSS-4 1994 Southern Study Area Jack Pine LAI and FPAR Data

5. FUNDING NUMBERS

923
RTOP: 923-462-33-01

6. AUTHOR(S)

Stephen Plummer
Forrest G. Hall and Jaime Nickeson, 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. 49

11. SUPPLEMENTARY NOTES

S. Plummer: Institute for Terrestrial Ecology; J. Nickeson: Raytheon ITSS

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 RSS-4 team collected several data sets related to leaf, plant, and stand physical, optical, and chemical properties. This data set contains leaf area indices and FPAR measurements that were taken at the three conifer sites in the BOREAS SSA during August 1993 and at the jack pine tower flux and a subset of auxiliary sites during July and August 1994. The measurements were made with LAI-2000 and Ceptometer instruments. The measurements were taken for the purpose of model parameterization and to test empirical relationships that were hypothesized between biophysical parameters and remotely sensed data. The data are stored in tabular ASCII files.

14. SUBJECT TERMS

BOREAS, remote sensing science, FPAR measurements.

15. NUMBER OF PAGES

27

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