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*Forrest G. Hall and Jaime Nickeson, Editors*

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# BOREAS RSS-20 POLDER C-130 Measurements of Surface BRDF

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# BOREAS RSS-20 POLDER C-130 Measurements of Surface BRDF

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## Summary

This BOREAS RSS-20 data set contains measurements of surface BRDF made by the POLDER instrument over several surface types (pine, spruce, fen) of the BOREAS SSA during the 1994 IFCs. Single-point BRDF values were acquired either from the NASA ARC C-130 aircraft or from a NASA WFF helicopter. A related data set collected from the helicopter platform is available as is POLDER imagery acquired from the C-130. The data are stored in tabular ASCII files.

## Table of Contents

# 1. Data Set Overview

## 1.1 Data Set Identification
BOREAS RSS-20 POLDER C-130 Measurements of Surface BRDF

## 1.2 Data Set Introduction
The POLarization and Directionality of Earth Reflectances (POLDER) instrument measures Bidirectional Reflectance Distribution Function (BRDF) and Bidirectional Polarization Distribution Function (BPDF) of terrestrial surfaces in several visible and near-infrared spectral bands. The instrument scanned several surface types (pine, spruce, fen, and others) in the BOReal Ecosystem-Atmosphere Study (BOREAS) Southern Study Area (SSA) during the Intensive Field Campaigns (IFCs) in 1994. Single-point BRDF measurements were acquired either from the C-130 aircraft or the helicopter. POLDER images acquired from the C-130 are also available for illustration purposes.

## 1.3 Objective/Purpose

The objective of the investigation was to characterize the bidirectional reflectance properties of different cover types in boreal forests over several seasons. This characterization can then be used to retrieve biophysical parameters such as Leaf Area Index (LAI), chlorophyll content, and structural canopy parameters, either through the use of semi-empirical relations between reflectances and biophysical parameters, or through the inversion of a BRDF radiative transfer model. The overall goal is to establish methodologies for monitoring the ecological state of the boreal forest using remote sensing techniques.

## 1.4 Summary of Parameters

Surface bidirectional reflectance derived from multiangular C-130 measurements over the tower sites.

## 1.5 Discussion

The POLDER instrument measures surface reflectance as a function of wavelength and observation geometry. This data set comprises individual site measurements of surface BRDF made by the POLDER instrument over several surface types (pine, spruce, fen) in the BOREAS SSA, acquired during the 1994 IFCs.

## 1.6 Related Data Sets

BOREAS RSS-01 PARABOLA SSA Surface Reflectance and Transmittance Data
BOREAS RSS-02 Level-1b ASAS Imagery: At-sensor Radiance in BSQ Format
BOREAS RSS-03 Reflectance Measured from a Helicopter-Mounted Barnes MMR
BOREAS RSS-11 Ground Network of Sun Photometer Measurements
BOREAS RSS-20 POLDER Helicopter-Mounted Measurements of Surface BRDF

# 2. Investigator(s)

## 2.1 Investigator(s) Name and Title

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## 2.2 Title of Investigation

Estimation of Photosynthetic Capacity using POLDER Polarization

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# 3. Theory of Measurements

POLDER is an optical sensor designed to observe the surface reflectance in visible and near-infrared bands. The main characteristic of the POLDER instrument is that it can observe an area from multiple directions. POLDER has a wide field-of-view (FOV) lens with ± 51° along-track and ± 43° cross-track viewing, and a charge-coupled device (CCD) array detector to collect images.

Two principles of operation should be distinguished during the BOREAS experiment. When POLDER was mounted on the helicopter, the purpose was to collect data over the target at a low altitude, typically 300 m. One image acquired directly over a homogeneous surface provides the BRDF of the experimental site. From the National Aeronautics and Space Administration's (NASA) Ames Research Center (ARC) C-130 aircraft, at high altitude, typically 5500 m, the surface cannot be considered homogeneous. POLDER's capacity to observe an area from various view angles allows for measurement of the complete BRDF with the successive images acquired along different flight axes over the experimental site.

# 4. Equipment

## 4.1 Sensor/Instrument Description

### 4.1.1 Collection Environment
It is mandatory to operate POLDER in totally clear sky conditions, so that the distribution of irradiance does not change from one measurement to another, and so that calculation of reflectances in absolute units from radiances is possible.

### 4.1.2 Source/Platform
During IFC-1 and IFC-2, the POLDER instrument was installed alternatively on the NASA ARC C-130 aircraft or the NASA Wallops Flight Facility (WFF) helicopter. The POLDER instrument was deployed on the C-130 only in the SSA. The data described in this document were collected from the C-130 platform.

### 4.1.3 Source/Platform Mission Objectives

The POLDER mission objective was to collect multiangle and multispectral bidirectional reflectance data over flux tower and auxiliary sites to study the boreal forest canopy.

### 4.1.4 Key Variables

POLDER measures multispectral radiance in the visible and near infrared domain as a function of solar and view geometry.

### 4.1.5 Principles of Operation

The POLDER optical system consists of a telecentric lens, a filter wheel, and a CCD array as a detector. The light is almost vertically incident on the filter wheel after passing the telecentric lens. The CCD array (288 x 384 elements) can collect 2-D images. The filter wheel contains 10 slots for spectral filters and polarizers. The first channel is reserved for dark current measurement, while the others allow measurements in five spectral bands (443, 550, 670, 864, and 910 nm). Two spectral bands (443 and 864 nm) are associated with three polarized filters oriented by steps of 60°. A 10-channel image, corresponding to the 10 positions of the filter wheel, is collected within 3 seconds, and this acquisition is repeated every 10 seconds.

The POLDER optical system was installed in the forward bay of the C-130. Aircraft position and attitude parameters provided by the onboard navigation system were recorded by the POLDER electronics subsystem for data postprocessing. Typical flight altitude was 5500 m. Different flight lines were flown on each site to collect images in the principal, perpendicular, and 45° solar planes.

### 4.1.6 Sensor/Instrument Measurement Geometry

The long axis of the CCD array was set parallel to the aircraft longitudinal axis. An inclinometer was used to record the initial bias between the optical axis and true nadir.

### 4.1.7 Manufacturer of Sensor/Instrument

The instrument was designed and manufactured by
Laboratoire d'Optique Atmosphèrique (LOA)
59655 Villeneuve d'Ascq Cedex
Lille, France

### 4.2 Calibration

Radiometric calibration data were acquired at LOA by J.-Y. Balois before and after the BOREAS experiment (11-May-1994, 24-Oct-1994) using a calibrated integration sphere. The whole exit port of the integration sphere is used to derive the equalization coefficients $g_{ij}{}^{ka}$ (see definition in Section 9.2.1). For absolute calibration, the exit port is reduced by a diaphragm to illuminate only a small circular area in the center of the CCD array. Readings of 15 x 15 pixel windows are corrected for dark current and averaged to obtain the absolute calibration coefficients $A^{ka}$(see Section 9.2.1)

Other calibration experiments were made during the BOREAS experiment using a 30-inch (0.76-m) diameter portable hemisphere that is owned and operated by NASA's Goddard Space Flight Center (GSFC). This portable hemisphere was made available to Remote Sensing Science (RSS)-20 by Brian Markham and John Schaffer. The calibration of POLDER was performed at the Prince Albert airport when POLDER was installed in C-130 aircraft on 27-May-1994 and 21-Jul-1994.

There is a good agreement between the LOA calibration and the first in situ calibration. The second in situ calibration shows discrepancies greater than 10% for all channels. The reasons for such discrepancies are still unknown.

### 4.2.1 Specifications

The general specifications of calibration accuracy were 5% absolute accuracy, 3% interband relative calibration accuracy, and 2% multitemporal relative calibration accuracy.

### 4.2.1.1 Tolerance

A general rise of the sensitivity was noted between the two calibration experiments made at LOA (11-May-1994, 24-Oct-1994): 8% in the blue (443 nm), 3.5% in the green (550 nm) and in the red (670 nm), 5.5% for the 864-nm channel, and 5% for the 910-nm channel. For subsequent processing, mean coefficients obtained at LOA are used.

### 4.2.2 Frequency of Calibration

The instrument is generally calibrated once before an experimental campaign and once after the campaign. Calibration was performed at LOA on 11-May-1994 and 24-Oct-1994. Onsite calibration was performed on 27-May-1994 and 21-Jul-1994.

### 4.2.3 Other Calibration Information

Having the spectral radiance at the outport of the sphere or the hemisphere and knowing the sensitivity of the various filters and the spectral value of the solar exoatmospheric irradiance, the normalized radiance is computed using:

$$L_{norm} = \pi \frac{\sum_{i=1}^{n} L(\lambda_i) S(\lambda_i) \delta\lambda_i}{\sum_{i=1}^{n} E(\lambda_i) S(\lambda_i) \delta\lambda_i}$$

where:  L : spectral radiance (W/m$^2$/sr/µm) as a function of wavelength ($\lambda_i$)
S : spectral sensitivity as a function of wavelength
E : spectral exoatmospheric solar irradiance (W/m$^2$/µm) as a function of wavelength

The normalized radiance is used (see Section 9.2.1) to derive the absolute calibration coefficient A[ka].

# 5. Data Acquisition Methods

For the C-130 data, the onboard navigation system gives information on the viewing geometry of each pixel. Therefore, the location and attitude data yield an approximate position of a given surface target in all POLDER images. There is a time lag of 10 seconds between each image acquisition sequence. For a typical C-130 flight altitude and speed, an angular resolution of approximately 10 degrees is obtained.

# 6. Observations

### 6.1 Data Notes
None.

### 6.2 Field Notes
None.

# 7. Data Description

## 7.1 Spatial Characteristics

### 7.1.1 Spatial Coverage
The following are North American Datum of 1983 (NAD83) coordinates of locations that were visited:

| Site | BORIS Grid ID | West Longitude | North Latitude | UTM Easting | UTM Northing | UTM Zone |
|------|---------------|----------------|----------------|-------------|--------------|----------|
| SSA Fen | FOL9T | 104.61797 | 53.80206 | 525190.7 | 5961344.0 | 13 |
| SSA Old Aspen (OA) | C3B7T | 106.19779 | 53.62890 | 420821.8 | 5942678.0 | 13 |
| SSA Old Black Spruce (OBS) | G8I4T | 105.11779 | 53.98718 | 492306.1 | 5981879.0 | 13 |
| SSA Old Jack Pine (OJP) | G2L3T | 104.69203 | 53.91634 | 520257.0 | 5974035.0 | 13 |
| SSA Young Jack Pine (YJP) | F8L6T | 104.64527 | 53.87581 | 523350.7 | 5969540.0 | 13 |

### 7.1.2 Spatial Coverage Map
Not available.

### 7.1.3 Spatial Resolution
The pixel size for POLDER images from the C-130 at an altitude of 5500 m is 35 m.

### 7.1.4 Projection
Not applicable.

### 7.1.5 Grid Description
Not applicable.

## 7.2 Temporal Characteristics

### 7.2.1 Temporal Coverage
POLDER data were collected on one of two platforms during the three 1994 IFCs. Dates are indicated in Section 7.2.2. Most experiments took place in the morning, except the following: 21-Jul: OJP (around noon), YJP, Fen.

### 7.2.2 Temporal Coverage Map

| Site | BORIS Grid | IFC-1 | IFC-2 | IFC-3 |
|------|-----------|-------|-------|-------|
| Fen | FOL9T | 07/24 | | |
| OA | G3B7T | 05/26,05/31 | | |
| OBS | G8I4T | 05/31,06/01 | 07/21 | |
| OJP | G2L3T | 05/31,06/01 | 07/21, 07/24 | |
| YJP | F8L6T | 06/01 | 07/21 | |

### 7.2.3 Temporal Resolution
See Section 7.2.1.

## 7.3 Data Characteristics

### 7.3.1 Parameter/Variable
The parameters contained in the data files on the CD-ROM are:

```
          Column Name
-------------------------------
SITE_NAME
SUB_SITE
DATE_OBS
WAVELENGTH
SOLAR_ZEN_ANG
VIEW_ZEN_ANG
RELATIVE_VIEW_AZ_ANG
MEAN_REFL
MEAN_SURF_REFL
CRTFCN_CODE
REVISION_DATE
```

### 7.3.2 Variable Description/Definition
The descriptions of the parameters contained in the data files on the CD-ROM are:

| Column Name | Description |
| --- | --- |
| SITE_NAME | The identifier assigned to the site by BOREAS, in the format SSS-TTT-CCCCC, where SSS identifies the portion of the study area: NSA, SSA, REG, TRN, and TTT identifies the cover type for the site, 999 if unknown, and CCCCC is the identifier for site, exactly what it means will vary with site type. |
| SUB_SITE | The identifier assigned to the sub-site by BOREAS, in the format GGGGG-IIIII, where GGGGG is the group associated with the sub-site instrument e.g. HYD06 or STAFF, and IIIII is the identifier for sub-site, often this will refer to an instrument. |
| DATE_OBS | The date on which the data were collected. |
| WAVELENGTH | Spectral wavelength at which the measurement was acquired. |
| SOLAR_ZEN_ANG | The angle from the surface normal (straight up) to the sun during the data collection. |
| VIEW_ZEN_ANG | The angle from the surface normal (straight up) to the observing instrument during the data collection. |
| RELATIVE_VIEW_AZ_ANG | The azimuthal angle at which the radiant energy was traveling when measured by the sensor, relative to the solar azimuth. The relative view azimuth angle increases in a clockwise direction from the solar position. |
| MEAN_REFL | The mean reflectance factor. |
| MEAN_SURF_REFL | The mean surface reflectance factor (atmospherically corrected). |
| CRTFCN_CODE | The BOREAS certification level of the data. |

Examples are CPI (Checked by PI), CGR (Certified
by Group), PRE (Preliminary), and CPI-??? (CPI
but questionable).

```
REVISION_DATE                           The most recent date when the information in the
                                        referenced data base table record was revised.
```

## 7.3.3 Unit of Measurement
The measurement units for the parameters contained in the data files on the CD-ROM are:

```
          Column Name                         Units
---------------------------------  ----------------------------------------------
SITE_NAME                          [none]
SUB_SITE                           [none]
DATE_OBS                           [DD-MON-YY]
WAVELENGTH                         [micrometers]
SOLAR_ZEN_ANG                      [degrees]
VIEW_ZEN_ANG                       [degrees]
RELATIVE_VIEW_AZ_ANG               [degrees]
MEAN_REFL                          [percent]
MEAN_SURF_REFL                     [percent]
CRTFCN_CODE                        [none]
REVISION_DATE                      [DD-MON-YY]
```

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

```
          Column Name                         Data Source
---------------------------------  ----------------------------------------------
SITE_NAME                          [Assigned by BORIS Staff]
SUB_SITE                           [Assigned by BORIS Staff]
DATE_OBS                           [RSS20 team]
WAVELENGTH                         [POLDER instrument]
SOLAR_ZEN_ANG                      [Calculated using position and time]
VIEW_ZEN_ANG                       [Calculated using geometry]
RELATIVE_VIEW_AZ_ANG               [Calculated using geometry]
MEAN_REFL                          [POLDER instrument]
MEAN_SURF_REFL                     [POLDER instrument and atmospheric correction]
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.

```
                         Minimum        Maximum        Missng  Unrel  Below    Data
                         Data           Data           Data    Data   Detect   Not
Column Name              Value          Value          Value   Value  Limit    Cllctd
-----------------------  -------------  -------------  ------  -----  ------  ------
SITE_NAME                SSA-90A-FLXTR  SSA-YJP-FLXTR  None    None   None    None
SUB_SITE                 RSS20-BRF01    RSS20-BRF01    None    None   None    None
DATE_OBS                 26-MAY-94      24-JUL-94      None    None   None    None
WAVELENGTH               0.443          0.910          None    None   None    None
SOLAR_ZEN_ANG            33.4           56.6           None    None   None    None
VIEW_ZEN_ANG             .3             55.5           None    None   None    None
RELATIVE_VIEW_AZ_ANG     0              360            None    None   None    None
```

| | | | | | | |
|---|---|---|---|---|---|---|
| MEAN_REFL | 2 | 77 | -999 | None | None | None |
| MEAN_SURF_REFL | .1 | 96.7 | None | None | None | None |
| CRTFCN_CODE | CPI | CPI | None | None | None | None |
| REVISION_DATE | 15-JAN-99 | 15-JAN-99 | None | None | None | None |

```
-------------------------------------------------------------------
Minimum Data Value -- The minimum value found in the column.
Maximum Data Value -- The maximum value found in the column.
Missng Data Value  -- The value that indicates missing data. This is used to
                      indicate that an attempt was made to determine the
                      parameter value, but the attempt was unsuccessful.
Unrel Data Value   -- The value that indicates unreliable data. This is used
                      to indicate an attempt was made to determine the
                      parameter value, but the value was deemed to be
                      unreliable by the analysis personnel.
Below Detect Limit -- The value that indicates parameter values below the
                      instruments detection limits. This is used to
                      indicate that an attempt was made to determine the
                      parameter value, but the analysis personnel determined
                      that the parameter value was below the detection
                      limit of the instrumentation.
Data Not Cllctd    -- This value indicates that no attempt was made to
                      determine the parameter value. This usually
                      indicates that BORIS combined several similar but
                      not identical data sets into the same data base table
                      but this particular science team did not
                      measure that parameter.
Blank -- Indicates that blank spaces are used to denote that type of value.
N/A   -- Indicates that the value is not applicable to the respective column.
None  -- Indicates that no values of that sort were found in the column.
-------------------------------------------------------------------
```

## 7.4 Sample Data Record

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

```
SITE_NAME,SUB_SITE,DATE_OBS,WAVELENGTH,SOLAR_ZEN_ANG,VIEW_ZEN_ANG,
RELATIVE_VIEW_AZ_ANG,MEAN_REFL,MEAN_SURF_REFL,CRTFCN_CODE,REVISION_DATE
'SSA-OBS-FLXTR','RSS20-BRF01',21-JUL-94,.443,33.6,51.9,350.5,12.0,5.0,'CPI',
15-JAN-99
'SSA-OBS-FLXTR','RSS20-BRF01',21-JUL-94,.443,33.6,47.1,349.6,12.0,5.0,'CPI',
15-JAN-99
'SSA-OBS-FLXTR','RSS20-BRF01',21-JUL-94,.443,33.6,40.8,348.6,11.0,5.2,'CPI',
15-JAN-99
'SSA-OBS-FLXTR','RSS20-BRF01',21-JUL-94,.443,33.6,33.7,346.9,11.0,5.5,'CPI',
15-JAN-99
'SSA-OBS-FLXTR','RSS20-BRF01',21-JUL-94,.443,33.6,25.0,342.5,10.0,4.7,'CPI',
15-JAN-99
'SSA-OBS-FLXTR','RSS20-BRF01',21-JUL-94,.443,33.6,15.1,333.3,8.0,3.9,'CPI',
15-JAN-99
```

# 8. Data Organization

## 8.1 Data Granularity
The smallest amount of data that can be ordered from this data set is a day's worth of data for a given site.

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

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

# 9. Data Manipulations

## 9.1 Formulae
See Section 9.2.

## 9.1.1 Derivation Techniques and Algorithms
See Section 9.2.

## 9.2 Data Processing Sequence

## 9.2.1 Processing Steps

## 9.2.1.1 Level 1 Images
The raw radiometric data are digital numbers noted $CN_{ij}{}^{ka}$, where i, j are indices of pixel location on the CCD matrix, k is the wavelength, and a is the polarizer number for spectral bands comprising three polarizers. For the other spectral bands, a is meaningless. The processing from level 0 to level 1 data consists of the transformation of raw data into data proportional to normalized radiances $S_{ij}{}^{ka}$, according to the equation:

$$ S_{ij}^{ka} = \frac{t_0 \; (CN_{ij}^{ka} - \overline{CN_{j}^{0}})}{t \; A^{ka} \; g_{ij}^{ka} \; e^{-\beta^{k}(T - T_0)}} $$

where:   $t_0$ -- reference exposure time, used in calibration : 100 ms
         t -- exposure time during operation
         $CN_{j}{}^{0}$ -- average of line j of dark current
         $A^{ka}$ -- calibration coefficient
         $g_{ij}{}^{ka}$ -- relative sensitivity (high and low frequency) of instrumental (optics + CCD) transmission. It is normalized such that the local average of $g_{ij}{}^{ka}$ at the matrix center equals 1.
         $\beta^{k}$ -- sensitivity of absolute calibration to CCD temperature
         $T_0$ -- CCD temperature during calibration
         T -- CCD temperature in operation

$S_{ij}^{ka}$ -- is a digital number proportional to the observed normalized radiance (for the channels without polarizers)

$$S_{ij}^{ka} = 10000 \frac{\pi L_{ij}^k}{E^k}$$

where:  $L_{ij}^k$ -- observed radiance (W/m²/sr/μm) for pixel i, j in band k

$E^k$ -- exoatmospheric solar irradiance in band k (W/m²/μm)

For polarized bands, the aircraft displacement between successive channel acquisition must be taken into account to obtain a normalized spectral radiance from the three polarized channels

$$\frac{1}{3} \sum_{a=1}^{3} S_{xy}^{ka} = 10000 \frac{\pi L_{xy}^k}{E^k}$$

where (x,y) are surface coordinates that refer to CCD pixels coordinates (i,j) in each of the polarized channels viewing the same ground point (x,y). The level 1 images provide data that for each band are equal to the right-hand side of the two previous equations. They are essentially normalized radiances.

## 9.2.1.2 BRDF Over Tower Sites

**Radiance to Reflectance:**
   The radiance is converted to reflectance $R_{ij}^k$ according to

$$R_{ij}^k = \frac{\pi L_{ij}^k}{E^k \cos\theta_s}$$

where $\emptyset_s$ is the solar zenith angle.

**Image Coregistration (for C-130 data):**
   The POLDER electronics subsystem recorded the aircraft position and attitude parameters during the flights. The initial bias between the inertial reference system and the POLDER optical axis was measured before each flight. Attitude and location data should be sufficient to correct POLDER images for geometry. However, the uncertainty in the aircraft position was too large. A ground control point technique was therefore used to fine-tune the geometric multi-image registration of the whole set.
   To derive the BRDF over tower sites, a simple translation was made on geocoded images. The reflectance measurements were then averaged on a 5 x 5 pixel window (175 x 175 m²) around each tower site to minimize residual misregistration effects.

**Atmospheric corrections:**
   The atmospheric correction algorithm, the Second Simulation of the Satellite Signal in the Solar Spectrum (6S) (Vermote et al., 1997) was applied to the measured reflectances to produce corrected reflectances. This was performed only on the C-130 data, not to helicopter data. A mid-Arctic summer atmospheric model and a continental aerosol model were selected to characterize the atmosphere above

the BOREAS sites. Moreover, the total aerosol optical depth for the full atmosphere and the below-aircraft aerosol optical depth, both at 550 nm, are necessary inputs of the algorithm. These optical thickness measurements were obtained from the BORIS Information System (BORIS) data base: total optical depth was retrieved from RSS-11 (Markham/Schafer) sunphotometer data at Prince Albert airport and YJP sites; above-aircraft thicknesses come from RSS-12 (Wrigley/Spanner); interpolations were made to derive values at 550 nm. Aerosol optical depths are given in the following table for each date and site. All flight days of IFC-1 and IFC-2 were very clear, with an average value of the total optical aerosol depth of 0.10 at 550 nm.

The following table summarizes the C-130 and solar and atmospheric conditions during POLDER data acquisitions:

| Site | Date | Sun Zenith angle (deg) | Aerosol thickness at 550 nm (total/below aircraft) |
|------|------|------------------------|----------------------------------------------------|
| Fen | 24-Jul | 44.4 - 49.3 | 0.080/0.020 |
|     | 03-May | 38.4 - 42.8 | 0.130/0.055 |
| OJP | 01-Jun | 48.4 - 51.4 | 0.095/0.050 |
|     | 21-Jul | 33.8 - 35.0 | 0.120/0.095 |
|     | 24-Jul | 40.5 - 43.3 | 0.095/0.020 |
|     | 26-May | 39.4 - 41.8 | 0.115/0.075 |
| OA | 31-May | 6.5 - 52.5 | 0.070/0.025 |
|    | 01-Jun | 44.0 - 47.0 | 0.095/0.050 |
| YJP | 21-Jul | 35.5 - 37.2 | 0.115/0.090 |
|     | 31-May | 35.5 - 37.4 | 0.135/0.070 |
| OBS | 01-Jun | 53.5 - 56.4 | 0.060/0.030 |
|     | 21-Jul | 33.4 - 33.7 | 0.115/0.090 |

## 9.2.2 Processing Changes
None.

## 9.3 Calculations

## 9.3.1 Special Corrections/Adjustments
None.

## 9.3.2 Calculated Variables
Radiance and reflectance were calculated.

## 9.4 Graphs and Plots
None.

# 10. Errors

## 10.1 Sources of Error
For images and BRDF data, there is some uncertainty in the absolute calibration coefficient, as illustrated by the calibration tables shown above. For the BRDF data, an additional source of error results from image registration. In the processing, it is assumed that the position of the site is the same for all images of the sequence, which can induce a error in the location of less than 1 pixel. These errors are lessened with the spatial averaging procedure. The smoothing aspect of the BRDF data tends to show that the misregistration errors are not critical.

## 10.2 Quality Assessment

### 10.2.1 Data Validation by Source
The POLDER data have been tested against the four-scale BRDF reflectance model (Leblanc et al., 1997) as well as against the PARABOLA data and the DART 3-D BRDF model (Gastellu-Etchegorry et al., 1997).

### 10.2.2 Confidence Level/Accuracy Judgment
The uncertainty associated with POLDER spectral reflectances values, taking into account only error in the absolute calibration coefficient, is approximately less than 0.005 for the visible channels and 0.01 for the near-infrared channel. The confidence level in these measurements is good because of their reproducibility for different axes during the same flight.

### 10.2.3 Measurement Error for Parameters
Not available.

### 10.2.4 Additional Quality Assessments
The directional reflectances obtained with POLDER data corrected from atmospheric effects for the flux tower or auxiliary sites can be compared to similar data made by other instruments.

### 10.2.5 Data Verification by Data Center
BORIS staff has looked at some of the POLDER imagery from the C-130. It appears that there are some registration problems between bands in some of the imagery.

# 11. Notes

## 11.1 Limitations of the Data
None.

## 11.2 Known Problems with the Data
None.

## 11.3 Usage Guidance
Not applicable.

## 11.4 Other Relevant Information
None.

# 12. Application of the Data Set

This data set can be used for BRDF model inversion and BRDF direct model cross-checking.

# 13. Future Modifications and Plans

None.

# 14. Software

## 14.1 Software Description
None given.

## 14.2 Software Access
Raw data and processing software may be available upon request. See Section 2.3.


# 15. Data Access

The POLDER C-130 measurements of surface BRDF are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

## 15.1 Contact Information
For BOREAS data and documentation please contact:

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

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

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

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


# 16. Output Products and Availability

## 16.1 Tape Products
None.

## 16.2 Film Products
None.

## 16.3 Other Products
These data are available on the BOREAS CD-ROM series.

# 17. References

## 17.1 Platform/Sensor/Instrument/Data Processing Documentation
None.

## 17.2 Journal Articles and Study Reports

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

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

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

Vermote E.F., D. Tanre, J.L. Deuze, M. Herman, and J.J. Morcrette. 1997. Second Simulation of the Satellite Signal in the Solar Spectrum, 6S: An overview. IEEE Transactions On Geoscience And Remote Sensing 35: (3) 675-686.

## 17.3 Archive/DBMS Usage Documentation
None.

# 18. Glossary of Terms

None.

# 19. List of Acronyms

| | | |
|---|---|---|
| 6S | – | Second Simulation of the Satellite signal in the Solar Spectrum |
| ARC | – | Ames Research Center |
| ASCII | – | American Standard Code for Information Interchange |
| BOREAS | – | BOReal Ecosystem-Atmosphere Study |
| BORIS | – | BOREAS Information System |
| BPDF | – | Bidirectional Polarization Distribution Function |
| BRDF | – | Bidirectional Reflectance Distribution Function |
| CCD | – | Change Coupled Device |
| CD-ROM | – | Compact Disk-Read-Only Memory |
| DAAC | – | Distributed Active Archive Center |
| EOS | – | Earth Observing System |
| EOSDIS | – | EOS Data and Information System |
| FOV | – | Field of View |
| GIS | – | Geographic Information System |
| GSFC | – | Goddard Space Flight Center |
| HTML | – | HyperText Markup Language |
| IFC | – | Intensive Field Campaign |
| LAI | – | Leaf Area Index |
| LOA | – | Laboratoire d'Optique Atmospherique |
| 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 |
| POLDER | – | POLarization and Directionality of Earth's Reflectances |
| RSS | – | Remote Sensing Science |
| SSA | – | Southern Study Area |
| URL | – | Uniform Resource Locator |
| UTM | – | Universal Transverse Mercator |
| WFF | – | Wallops Flight Facility |
| YJP | – | Young Jack Pine |

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

Leroy, M., F.-M. Brèon, P. Bicheron, and O. Hautecoeur, "Estimation of Photosynthetic Capacity using POLDER Polarization." In Collected Data of The Boreal Ecosystem-Atmosphere Study. Eds. J. Newcomer, D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers. CD-ROM. NASA, 2000.

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## 20.5 Document Curator

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13. ABSTRACT *(Maximum 200 words)*

This BOREAS RSS-20 data set contains measurements of surface BRDF made by the POLDER instrument over several surface types (pine, spruce, fen) of the BOREAS SSA during the 1994 IFCs. Single-point BRDF values were acquired either from the NASA ARC C-130 aircraft or from a NASA WFF helicopter. A related data set collected from the helicopter platform is available as is POLDER imagery acquired from the C-130. The data are stored in tabular ASCII files.

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