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BOREAS RSS-20 POLDER Radiance Images from the NASA C-130

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BOREAS RSS-20 POLDER Radiance Images from the NASA C-130

Marc Leroy

Summary

These BOREAS RSS-20 data are a subset of images collected by the POLDER instrument over tower sites in the BOREAS study areas during the IFCs in 1994. The POLDER images presented here from the NASA ARC C-130 aircraft are made available for illustration purposes only. The data are stored in binary image-format files.

Note that some of the data files on the BOREAS CD-ROMs have been compressed using the Gzip program. See Section 8.2 for details.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS RSS-20 POLDER Radiance Images from the NASA C-130

1.2 Data Set Introduction

POLarization and Directionality of Earth Reflectances (POLDER) is an instrument that 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) study areas during the various Intensive Field Campaigns (IFCs) in 1994. Single-point BRDF measurements were acquired either from the National Aeronautics and Space Administration (NASA) C-130 aircraft or from a NASA helicopter. POLDER images acquired from the C-130 are made available for illustration purposes.

1.3 Objective/Purpose

The objective of this investigation was to characterize the bidirectional reflectance properties of different cover types in boreal forests over several seasons (IFC-1, -2, and -3). 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 semiempirical relations between reflectances and biophysical parameters or through the inversion of a BRDF radiative transfer model. The overall goal is to establish methodologies of monitoring the ecological state of the boreal forest using remote sensing techniques.

1.4 Summary of Parameters

This data set contains POLDER images acquired from the C-130 at approximately 5500 m over the various tower sites.

1.5 Discussion

Warning: The C-130 POLDER images are given as a qualitative information only. Although the measurements have been calibrated, no geometric correction has been applied.

1.6 Related Data Sets

BOREAS RSS-01 PARABOLA Surface Reflectance and Transmittance Data
BOREAS RSS-02 Level-1b ASAS Imagery: At-sensor Radiance in BSQ Format
BOREAS RSS-03 Helicopter-Mounted MMR Reflectance Data
BOREAS RSS-11 Airborne Tracking Sun Photometer Data
BOREAS RSS-20 POLDER BRDF Measurements of Tower Flux Sites
BOREAS RSS-20 POLDER Helicopter-Mounted Measurements of Surface BRDF

2. Investigator(s)

2.1 Investigator(s) Name and Title

Dr. Marc Leroy
Dr. François-Marie Brèon
Patrice Bicheron
Olivier Hautecoeur

2.2 Title of Investigation

Airborne Remote Sensing Measurements with the POLDER Instrument

2.3 Contact Information

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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. Its main characteristic is that it can observe an area from various 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.

From the NASA Ames Research Center (ARC) C-130 aircraft at an altitude of approximately 5500 m, the surface cannot be considered homogeneous. POLDER's capacity to observe an area from various view angles is used to constitute 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 only under totally clear sky conditions, so that the distribution of irradiance does not change from one measurement to the next, 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 C-130 aircraft, or on the helicopter. During IFC-3, the instrument flew only on the helicopter. POLDER C-130 data were acquired only in the Southern Study Area (SSA) (Prince Albert).

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 Sun-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. Each image acquisition is repeated every 10 seconds.

The POLDER optical system was installed on the C-130 aircraft in the forward bay. Aircraft position and attitude parameters provided by the onboard navigation system were recorded by POLDER electronics subsystem for data postprocessing. Typical flight altitude was 5500 m. Flight lines were designed 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's 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 and 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 window 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 GSFC. It was made available to the Remote Sensing Science (RSS)-20 team by Brian Markham and John Schaffer from NASA GSFC. The POLDER sensor was calibrated at the airport when POLDER was installed in the 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 results. 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: 8% in the blue, 3.5% in the green and in the red, 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.

4.2.3 Other Calibration Information

Having the spectral radiance at the outport of the sphere or the hemisphere, 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 (λ_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 POLDER images were acquired over various tower site locations. The North American Datum of 1983 (NAD83) coordinates are:

Site	West Longitude	North Latitude	UTM Easting	UTM Northing	UTM Zone
SSA Fen	104.61797	53.80206	525190.7	5961344.0	13
SSA Old Aspen (OA)	106.19779	53.62890	420821.8	5942678.0	13
SSA Old Black Spruce (OBS)	105.11779	53.98718	492306.1	5981879.0	13
SSA Old Jack Pine (OJP)	104.69203	53.91634	520257.0	5974035.0	13
SSA Young Jack Pine (YJP)	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 is approximately 35 meters when POLDER is on the C-130.

7.1.4 Projection
Each image is supplied in its original geometry with no geometric rectification or registration performed. Users will need to at least rotate the images for a coarse registration. The images are nearly centered on the tower sites.

7.1.5 Grid Description
Not applicable.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage
POLDER image data exist only for C-130 acquisitions taken from 26-May-1994 to 24-July-1994. Most experiments took place in the morning, except the following: 21-July: OJP (around noon), YJP, Fen.

7.2.2 Temporal Coverage Map
Images from the C-130 exist for the following dates:

Site	IFC-1	IFC-2
Fen	24-Jul	
OA	26-May, 31-May	
OBS	31-May, 01-Jun	21-Jul
OJP	31-May, 01-Jun	21-Jul, 24-Jul
YJP	01-Jun	21-Jul

7.2.3 Temporal Resolution
Most sites were visited more than once in 1994.

7.3 Data Characteristics

7.3.1 Parameter/Variable
Raw radiometric POLDER image data.

7.3.2 Variable Description/Definition
They are essentially normalized radiances.

7.3.3 Unit of Measurement
Unitless digital numbers.

7.3.4 Data Source
POLDER instrument mounted on the NASA C-130 aircraft.

7.3.5 Data Range
None given.

7.4 Sample Data Record
Not applicable to image data.

8. Data Organization

8.1 Data Granularity

The smallest unit of data tracked by the BOREAS Information System (BORIS) is a given image file.

8.2 Data Format(s)

8.2.1 Uncompressed Data Files

The image parameter is S_{ij}^{ka}, a digital number proportional to the observed normalized radiance for the channels without polarizers (see Section 9.2). The image data are stored in a Band Sequential (BSQ) format (9 bands, 288 lines by 384 pixels, 16 bits per pixel).

Description/Name	Format	Bytes Per Pixel	Npixels	Nlines	Nbands	Size (Bytes)
SSA-FEN_940724	Raw Binary	2	384	288	9	1990656
SSA-OA_940526	Raw Binary	2	384	288	9	1990656
SSA-OA_940531	Raw Binary	2	384	288	9	1990656
SSA-OBS_940531	Raw Binary	2	384	288	9	1990656
SSA-OBS_940601	Raw Binary	2	384	288	9	1990656
SSA-OBS_940721	Raw Binary	2	384	288	9	1990656
SSA-OJP_940531	Raw Binary	2	384	288	9	1990656
SSA-OJP_940601	Raw Binary	2	384	288	9	1990656
SSA-OJP_940721	Raw Binary	2	384	288	9	1990656
SSA-OJP_940724	Raw Binary	2	384	288	9	1990656
SSA-YJP_940601	Raw Binary	2	384	288	9	1990656
SSA-YJP_940721	Raw Binary	2	384	288	9	1990656

The table of the attitude parameters for these images follows:

			Mean attitude parameters				Sun position	
Site	Date	Hour	roll	pitch	heading	altitude	zenith	azimuth
FEN	940724	15:49:07	0.7	3.0	191.0	5645.2	49.3	114.3
OA	940526	16:47:03	-0.1	1.8	82.4	5482.44	41.8	127.7
OA	940531	15:31:45	0.4	2.6	263.2	5457.75	51.0	107.0
OBS	940531	17:19:52	-0.3	1.6	209.8	5489.75	37.3	139.5
OBS	940601	14:49:48	0.0	2.5	349.1	5552.54	53.4	98.6
OBS	940721	17:39:30	-0.4	1.1	16.8	5493.41	36.8	147.3
OJP	940531	16:27:49	-0.3	1.9	329.0	5461.41	42.9	123.4
OJP	940601	15:44:48	-0.2	2.3	68.0	5601.0	48.4	111.7
OJP	940721	18:27:14	-0.2	2.2	198.9	5558.03	33.9	166.7
OJP	940724	16:48:45	-1.6	1.4	229.0	5595.21	42.0	131.0
YJP	940601	15:53:55	0.1	1.4	194.0	5630.57	47.1	114.1
YJP	940721	19:25:35	0.1	2.3	331.2	5567.78	33.7	191.4

8.2.2 Compressed CD-ROM Files

On the BOREAS CD-ROMs, each of the 12 image files been compressed with the Gzip (GNU zip) compression program (file_name.gz). These data have been compressed using gzip version 1.2.4 and the high compression (-9) option (Copyright (C) 1992-1993 Jean-loup Gailly). Gzip uses the Lempel-Ziv algorithm (Welch, 1994) also used in the zip and PKZIP programs. The compressed files may be uncompressed using gzip (with the -d option) or gunzip. Gzip is available from many Web

sites (for example, the ftp site prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

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

BORIS staff compressed the binary files for release on CD-ROM.

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:

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

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.
β^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 ($W/m^2/sr/\mu m$) for pixel i, j in band k
E^k-- exoatmospheric solar irradiance in band k ($W/m^2/\mu m$)

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

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

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.

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

Site	Date	Sun zenith angle degrees	Aerosol optical 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	0.070/0.025
	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
Not applicable.

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 an 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 4-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

Based on a visual review of the images by BORIS staff, it appears that there are some registration problems between bands in the imagery.

11.3 Usage Guidance

Before uncompressing the Gzip files on CD-ROM, be sure that you have enough disk space to hold the uncompressed data files. Then use the appropriate decompression program provided on the CD-ROM for your specific system.

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 models cross-check.

13. Future Modifications and Plans

None.

14. Software

14.1 Software Description

Gzip (GNU zip) uses the Lempel-Ziv algorithm (Welch, 1994) used in the zip and PKZIP commands.

14.2 Software Access

Raw data and processing software might be available upon request; see Section 2.3. Gzip is available from many Web sites across the Internet (for example, FTP site prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

15. Data Access

The POLDER radiance images 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

The image data are stored on 8-mm media as BSQ raw images (9 bands, 288 lines by 384 pixels, 16 bits per pixel).

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

Welch, T.A. 1984. A Technique for High Performance Data Compression. IEEE Computer, Vol. 17, No. 6, pp. 8-19.

17.2 Journal Articles and Study Reports

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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.

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 System
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
BSQ	- Band Sequential
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
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

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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
YJP     - Young Jack Pine
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These BOREAS RSS-20 data are a subset of images collected by the POLDER instrument over tower sites in the BOREAS study areas during the IFCs in 1994. The POLDER images presented here from the NASA ARC C-130 aircraft are made available for illustration purposes only. The data are stored in binary image-format files.

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