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

Forrest G. Hall and Jaime Nickeson, Editors

Volume 70

BOREAS RSS-17 Dielectric Constant Profile Measurements

K.C. McDonald, R. Zimmerman, and J.B. Way

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

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BOREAS RSS-17 Dielectric Constant Profile Measurements

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BOREAS RSS-17 Dielectric Constant Profile Measurements

Kyle McDonald, Reiner Zimmermann, JoBea Way

Summary

The BOREAS RSS-17 team acquired and analyzed imaging radar data from the ESA's ERS-1 over a complete annual cycle at the BOREAS sites in Canada in 1994 to detect shifts in radar backscatter related to varying environmental conditions. This data set consists of dielectric constant profile measurements from selected trees at various BOREAS flux tower sites. The relative dielectric constant was measured at C-band (frequency = 5 GHz) as a function of depth into the trunk of three trees at each site. Measurements were made during April 1994 with an Applied Microwave Corporation field PDP fitted with a 0.358-cm (0.141-inch) diameter coaxial probe tip. The data are available in tabular ASCII files.

Table of Contents

1. Data Set Overview

1.1 Data Set Identification

BOREAS RSS-17 Dielectric Constant Profile Measurements

1.2 Data Set Introduction

The dielectric constant provides an indication of how a material responds in an electric field. Thus, it is useful to quantify this property in order to interpret radar remote sensing signatures. When considering the microwave frequency spectrum, the dielectric constant of liquid water is much higher than that of other components of a natural landscape. Thus, variations in the amount (moisture content) and state (frozen vs. thawed) of water in a vegetation canopy can significantly affect radar backscatter. The relative dielectric constant was measured as a function of depth into the trunks of three trees at each of seven treed BOReal Ecosystem-Atmosphere Study (BOREAS) tower sites. In the Northern Study Area (NSA), measurements were taken at the Old Black Spruce (OBS), Young Jack Pine (YJP),

and Old Jack Pine (OJP) sites. In the Southern Study Area (SSA), measurements were taken at the YJP, OJP, OBS, and Old Aspen (OA) sites. An Applied Microwave Corporation C-band field portable dielectric probe (PDP) was used to measure these data. Profiles were obtained during April 1994, shortly after the trees thawed.

1.3 Objective/Purpose

These measurements were taken to assist with interpretation of radar backscatter measurements obtained with the Earth Resource Satellite-1 (ERS-1) Synthetic Aperture Radar (SAR). The dielectric constant of woody vegetation varies dramatically as the vegetation transitions from a frozen to a thawed state. Because radar backscatter responds to changes in the dielectric constant, these measurements were obtained to verify that the trees had undergone the spring thaw transition. These data may also be used as parameter inputs to radar backscatter models to assist in interpretation of radar remote sensing measurements obtained at the BOREAS sites.

1.4 Summary of Parameters and Variables

Each line provides the real and imaginary parts of the relative dielectric constant at a single depth in the trunk of a selected tree of the indicated BOREAS stand. Each of these measurements represents the arithmetic mean of three samples taken at the same location in that tree. For a given tree, a measurement series represents the relative dielectric constant as a function of depth into the tree trunk.

1.5 Discussion

The dielectric constant of woody vegetation varies dramatically as the vegetation transitions from a frozen to a thawed state. Because radar backscatter responds to changes in dielectric constant, these measurements were obtained to verify that the trees had undergone the spring thaw transition.

The relative dielectric constant was measured as a function of depth into the trunks of three trees in each of seven BOREAS tower sites. An Applied Microwave Corporation C-band field PDP was used to measure these data. Profiles were obtained during April 1994, shortly after the trees thawed.

1.6 Related Data Sets

BOREAS RSS-15 SIR-C and Landsat TM Biomass and Landcover Maps
BOREAS RSS-16 Level-3b DC-8 AirSAR CM Images
BOREAS RSS-16 Level-3b DC-8 AirSAR SY Images
BOREAS RSS-17 Stem and Air Temperature Measurements
BOREAS RSS-17 1994 ERS-1 Level-1 Backscatter Change Images
BOREAS RSS-17 Xylem Flux Density Measurements at the SSA-OBS Site

2. Investigators

2.1 Investigator(s) Name and Title

Principal Investigator
Dr. JoBea Way
Jet Propulsion Laboratory

Co-Investigator
Dr. Kyle McDonald
Jet Propulsion Laboratory

Dr. Reiner Zimmermann
Bayreuth Institute for Terrestrial Ecosystem Research (BITOEK)

2.2 Title of Investigation

Monitoring Environmental and Phenologic State and Duration of State with SAR as Input to Improved CO_2 Flux Models

2.3 Contact Information

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3. Theory of Measurements

The relative dielectric constant is monitored with an Applied Microwave Corporation field PDP. The PDP used here measures the complex reflection coefficient (magnitude and phase) at the point of contact between a material of unknown dielectric constant and a semirigid coaxial probe tip. The reflection coefficient was measured at a frequency of 5 GHz, corresponding to the C-band portion of

the electromagnetic spectrum. The real and imaginary parts of the relative dielectric constant are determined from the complex reflection coefficient through application of a calibration equation determined from measurements of reflection coefficient made on a series of reference dielectric liquids.

4. Equipment

4.1 Sensor/Instrument Description

The dielectric constant was measured with a field PDP manufactured by Applied Microwave Corporation, Lawrence, KS. These instruments are no longer in production.

4.1.1 Collection Environment

Data were collected in April 1994. Air temperature was above 0 °C. Weather conditions varied from cool and clear to rainy.

4.1.2 Source/Platform

The PDP is a hand-held, field portable device.

4.1.3 Source/Platform Mission Objectives

This study was undertaken to combine ERS-1 SAR with ecosystem CO_2 flux models. The objective is to use SAR observations as direct inputs to these models to improve their estimates of seasonal CO_2 flux.

4.1.4 Key Variables

Relative dielectric constant (C-band).

4.1.5 Principles of Operation

The PDP provides a direct measurement of the complex reflection coefficient. The relative dielectric constant is inferred through application of a calibration transformation equation determined from an equivalent circuit model applied to the coaxial probe tip. The parameters of the calibration transformation equation are determined from measurements taken on a series of liquids of known dielectric constant.

4.1.6 Sensor/Instrument Measurement Geometry

The dielectric constant was inferred from measurements of the complex reflection coefficient measured at the interface of a 0.358 cm (0.141 inch) diameter semirigid coaxial probe tip and with an unknown dielectric constant, the tree trunk.

4.1.7 Manufacturer of Sensor/Instrument

Applied Microwave Corporation
Lawrence, KS

The PDP is no longer in production.

4.2 Calibration

Calibration and processing of the dielectric data were performed with Mathematica 2.0 for the Macintosh (Wolfram Research, Inc.). The calibration technique is described in the PDP manual (1989) and by Dobson (1990).

4.2.1 Specifications

None given.

4.2.1.1 Tolerance

None given.

4.2.2 Frequency of Calibration

Calibration against a series of dielectric liquids was performed in the laboratory at the Jet Propulsion Laboratory (JPL) shortly before going to the BOREAS sites in April. In-field calibration checks are performed against an air standard immediately before each dielectric measurement.

4.2.3 Other Calibration Information

Not available.

5. Data Acquisition Methods

Profiles of the relative dielectric constant were obtained for each tree by drilling a small hole in the tree trunk to the desired depth, measuring the depth of the hole with a caliper, inserting the coaxial probe tip, and measuring the complex reflection coefficient. The process is repeated in the same hole, drilled successively deeper, until a point near the center of the tree trunk is reached, or until the probe tip cannot be inserted any further. Data are stored in a hand-held computer and loaded onto a PC for postprocessing. A series of three measurements was obtained at each depth. The values for the relative dielectric constant provided in the data file were computed by averaging the three values of dielectric constant obtained from these measurements.

6. Observations

6.1 Data Notes

The time values for the SSA-OA site on 19-April do not change except for the last few record on that day. The clock on the calculator was not set properly. The measurements acquired at time = 14.00 (20:00 Greenwich Mean Time (GMT)) were collected at approximately 14:00 +/- 15 minutes according to field notes. The calculator's internal clock was reset to correct the time problem at 14.24 (20:24 GMT). As this data set is not time-critical over the acquisition period of each profile, this will have no effect on the data quality.

6.2 Field Notes

None given.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

Each measurement is taken from one tree within a stand. Groups of three individual trees were measured at the BOREAS tower sites. The following North American Datum of 1983 (NAD83) site locations were sampled in the NSA and SSA:

Site	UTM Zone	UTM Northing (m)	UTM Easting (m)
NSA-OBS	14	6192853.4	532444.5
NSA-YJP	14	6194706.9	544583.9
NSA-OJP	14	6198176.3	523496.2
SSA-YJP	13	5969762.5	523320.2
SSA-OJP	13	5974257.5	520227.7
SSA-OBS	13	5982100.5	492276.5
SSA-OA	13	5942899.9	420790.5

7.1.2 Spatial Coverage Map
Not available.

7.1.3 Spatial Resolution
The spatial resolution of a given measurement is one tree. A series of records corresponding to a single tree and tower site corresponds to one dielectric profile.

7.1.4 Projection
Not applicable.

7.1.5 Grid Description
Not applicable.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage
Data collection took place from 19-April to 28-April-1994.

7.2.2 Temporal Coverage Map
The dates when the various sites were measured are:

```
SSA-OA   19-April-1994
SSA-OBS  20-April-1994
SSA-YJP  21-April-1994
SSA-OJP  25-April-1994
NSA-YJP  27-April-1994
NSA-OBS  28-April-1994
NSA-OJP  28-April-1994
```

7.2.3 Temporal Resolution
One measurement of dielectric constant takes less than 1 minute. Measurements at each tree were taken at 2- to 4-minute intervals. A complete profile series can be completed within 1 hour.

7.3 Data Characteristics

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

```
         Column Name
------------------------------
SITE_NAME
SUB_SITE
DATE_OBS
TIME_OBS
TREE
TREE_DIAMETER
PROBE_DEPTH
MEAN_DIELECTRIC_CONSTNT_REAL
MEAN_DIELECTRIC_CONSTNT_IMGNRY
CRTFCN_CODE
REVISION_DATE
```

7.3.2 Variable Description/Definition

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

Column Name	Description
SITE_NAME	The identifier assigned to the site by BOREAS, in the format SSS-TTT-CCCCC, where SSS identifies the portion of the study area: NSA, SSA, REG, TRN, and TTT identifies the cover type for the site, 999 if unknown, and CCCCC is the identifier for site, exactly what it means will vary with site type.
SUB_SITE	The identifier assigned to the sub-site by BOREAS, in the format GGGGG-IIIII, where GGGGG is the group associated with the sub-site instrument e.g. HYD06 or STAFF, and IIIII is the identifier for sub-site, often this will refer to an instrument.
DATE_OBS	The date on which the data were collected.
TIME_OBS	The Greenwich Mean Time (GMT) when the data were collected.
TREE	The individual tree from which measurements were taken.
TREE_DIAMETER	The diameter of the tree measured near the probe insertion point.
PROBE_DEPTH	The depth of the sensor probe into the tree trunk.
MEAN_DIELECTRIC_CONSTNT_REAL	The real portion of the relative dielectric constant, determined through application of a calibration equation applied to the reflection coefficient measured by the probe.
MEAN_DIELECTRIC_CONSTNT_IMGNRY	The imaginary portion of the relative dielectric constant, determined through application of a calibration equation applied to the reflection coefficient measured by the probe.
CRTFCN_CODE	The BOREAS certification level of the data. Examples are CPI (Checked by PI), CGR (Certified by Group), PRE (Preliminary), and CPI-??? (CPI but questionable).
REVISION_DATE	The most recent date when the information in the referenced data base table record was revised.

7.3.3 Unit of Measurement

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

Column Name	Units
SITE_NAME	[none]
SUB_SITE	[none]
DATE_OBS	[DD-MON-YY]
TIME_OBS	[HHMM GMT]
TREE	[none]
TREE_DIAMETER	[millimeters]
PROBE_DEPTH	[millimeters]

```
MEAN_DIELECTRIC_CONSTNT_REAL    [unitless]
MEAN_DIELECTRIC_CONSTNT_IMGNRY [unitless]
CRTFCN_CODE                     [none]
REVISION_DATE                   [DD-MON-YY]
```

7.3.4 Data Source

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

Column Name	Data Source
SITE_NAME	[Assigned by BORIS Staff]
SUB_SITE	[Assigned by BORIS Staff]
DATE_OBS	[RSS-17 team]
TIME_OBS	[Hand-held calculator]
TREE	[RSS-17 team]
TREE_DIAMETER	[RSS-17 team]
PROBE_DEPTH	[Caliper]
MEAN_DIELECTRIC_CONSTNT_REAL	[Dielectric probe]
MEAN_DIELECTRIC_CONSTNT_IMGNRY	[Dielectric probe]
CRTFCN_CODE	[Assigned by BORIS Staff]
REVISION_DATE	[Assigned by BORIS Staff]

7.3.5 Data Range

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

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SITE_NAME	NSA-OBS-FLXTR	SSA-YJP-FLXTR	None	None	None	None
SUB_SITE	RSS17-DIE01	RSS17-DIE01	None	None	None	None
DATE_OBS	19-APR-94	28-APR-94	None	None	None	None
TIME_OBS	1703	2345	None	None	None	None
TREE	A	C	None	None	None	None
TREE_DIAMETER	33	216	None	None	None	None
PROBE_DEPTH	0	99	None	None	None	None
MEAN_DIELECTRIC_CONSTNT_REAL	1.649	15.74	None	None	None	None
MEAN_DIELECTRIC_CONSTNT_IMGNRY	.164	6.616	None	None	None	None
CRTFCN_CODE	CPI	CPI	None	None	None	None
REVISION_DATE	17-SEP-98	17-SEP-98	None	None	None	None

```
Minimum Data Value -- The minimum value found in the column.
Maximum Data Value -- The maximum value found in the column.
Missng Data Value  -- The value that indicates missing data. This is used to
                      indicate that an attempt was made to determine the
                      parameter value, but the attempt was unsuccessful.
Unrel Data Value   -- The value that indicates unreliable data.  This is used
                      to indicate an attempt was made to determine the
                      parameter value, but the value was deemed to be
                      unreliable by the analysis personnel.
Below Detect Limit -- The value that indicates parameter values below the
                      instruments detection limits.  This is used to
```

```
                    indicate that an attempt was made to determine the
                    parameter value, but the analysis personnel determined
                    that the parameter value was below the detection
                    limit of the instrumentation.
Data Not Cllctd     -- This value indicates that no attempt was made to
                    determine the parameter value.  This usually
                    indicates that BORIS combined several similar but
                    not identical data sets into the same data base table
                    but this particular science team did not
                    measure that parameter.

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

7.4 Sample Data Record

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

```
SITE_NAME,SUB_SITE,DATE_OBS,TIME_OBS,TREE,TREE_DIAMETER,PROBE_DEPTH,
MEAN_DIELECTRIC_CONSTNT_REAL,MEAN_DIELECTRIC_CONSTNT_IMGNRY,CRTFCN_CODE,
REVISION_DATE
'NSA-OBS-FLXTR','RSS17-DIE01',28-APR-94,1703,'A',116,0.0,1.714,.242,'CPI',
17-SEP-98
'NSA-OBS-FLXTR','RSS17-DIE01',28-APR-94,1705,'A',116,3.0,8.367,5.034,'CPI',
17-SEP-98
'NSA-OBS-FLXTR','RSS17-DIE01',28-APR-94,1708,'A',116,4.0,8.049,3.259,'CPI',
17-SEP-98
'NSA-OBS-FLXTR','RSS17-DIE01',28-APR-94,1710,'A',116,5.5,9.644,3.618,'CPI',
17-SEP-98
```

8. Data Organization

8.1 Data Granularity

The smallest unit of data tracked by BOREAS Information System (BORIS) is all of the measurements for a given site on a given day.

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
None given.

9.1.1 Derivation Techniques and Algorithms
None given.

9.2 Data Processing Sequence

9.2.1 Processing Steps
None given.

9.2.2 Processing Changes
Not applicable.

9.3 Calculations

9.3.1 Special Corrections/Adjustments
Not applicable.

9.3.2 Calculated Variables
None given.

9.4 Graphs and Plots
Not available.

10. Errors

10.1 Sources of Error
Instabilities in the electronics of the PDP are taken into account by repeated calibration of the PDP with free space as the calibration standard. Accuracy of the dielectric constant measurement is limited by the range of the dielectric constant of the liquid standards used in laboratory calibration of the PDP.

10.2 Quality Assessment

10.2.1 Data Validation by Source
None given.

10.2.2 Confidence Level/Accuracy Judgment
Accuracy of the dielectric constant is estimated to be +/- 10% when the real portion, Re(eps), is less than 15 and when the imaginary portion, Im(eps), is less than 4. The accuracy of the dielectric constant decreases to +/- 30% when Re(eps) is greater than 15 and Im(eps) is greater than 4, where eps is the complex relative dielectric constant.

10.2.3 Measurement Error for Parameters
Not available.

10.2.4 Additional Quality Assessments
Not applicable.

10.2.5 Data Verification by Data Center
Data have been checked for content as described and for format.

11. Notes

11.1 Limitations of the Data

None given.

11.2 Known Problems with the Data

None given.

11.3 Usage Guidance

These data are typically used to estimate the gross vegetation dielectric constant for application to radar remote sensing studies (e.g., Way et al., 1997).

11.4 Other Relevant Information

Not available.

12. Application of the Data Set

These data can be used for site-level observations related to the state of the stand or the forest, either frozen or thawed.

13. Future Modifications and Plans

None.

14. Software

14.1 Software Description

Data collection and preprocessing of the PDP data files were performed with custom software written for the HP hand-held computer at the University of Michigan radiation laboratory. Calibration and processing of the dielectric data were performed with Mathematica 2.0 for the Macintosh (Wolfram Research, Inc.).

14.2 Software Access

None given.

15. Data Access

The dielectric constant profile 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
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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/ [Internet Link].

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

Applied Microwave Corporation. 1989. Manual for Portable Dielectric Probe. Applied Microwave Corporation. Lawrence, KS.

17.2 Journal Articles and Study Reports

Brunfeldt, D.R. 1997. Theory and Design of a Field-Portable Dielectric Measurement System. Proc. of the 1987 International Geoscience and Remote Sensing Symposium. Ann Arbor, MI, May 18-21, pp. 559-563.

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Hogg, E.H., T.A. Black, G. den Hartog, H.H. Neumann, R. Zimmerman, P.A. Hurdle, P.D. Blanken, Z. Nesic, P.C. Yang, R.M. Staebler, K.C. McDonald, and R. Oren. 1997. A comparison of sap flow and fluxes of water vapor from a boreal deciduous forest. Journal of Geophysical Research 102(D24): 28,929-28,937.

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.

Sellers, P. and F. Hall. 1994. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1994-3.0, NASA BOREAS Report (EXPLAN 94).

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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.

Way, J.B., R. Zimmermann, E. Rignot, K. McDonald, and R. Oren. 1997. Winter and spring thaw as observed with imaging radar at BOREAS. Journal of Geophysical Research 102(D24): 29,673-29,684.

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

ASCII	- American Standard Code for Information Interchange
BOREAS	- BOReal Ecosystem-Atmosphere Study
BORIS	- BOREAS Information System
CD-ROM	- Compact Disk-Read-Only Memory
DAAC	- Distributed Active Archive Center
EOS	- Earth Observing System
EOSDIS	- EOS Data and Information System
ERS-1	- Earth Resources Satellite-1
GIS	- Geographic Information System
GMT	- Greenwich Mean Time
GSFC	- Goddard Space Flight Center
HTML	- HyperText Markup Language
JPL	- Jet Propulsion Laboratory
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
PDP	- Portable Dielectric Probe
RSS	- Remote Sensing Science
SAR	- Synthetic Aperture Radar
SSA	- Southern Study Area
URL	- Uniform Resource Locator
UTM	- Universal Transverse Mercator
YJP	- Young Jack Pine

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The BOREAS RSS-17 team acquired and analyzed imaging radar data from the ESA's ERS-1 over a complete annual cycle at the BOREAS sites in Canada in 1994 to detect shifts in radar backscatter related to varying environmental conditions. This data set consists of dielectric constant profile measurements from selected trees at various BOREAS flux tower sites. The relative dielectric constant was measured at C-band (frequency = 5 GHz) as a function of depth into the trunk of three trees at each site. Measurements were made during April 1994 with an Applied Microwave Corporation field PDP fitted with a 0.358-cm (0.141-inch) diameter coaxial probe tip. The data are available in tabular ASCII files.

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