NASA/TM—2000–209891, Vol. 72

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

Forrest G. Hall and Jaime Nickeson, Editors

Volume 72

BOREAS RSS-17 Xylem Flux Density Measurements at the SSA-OBS Site

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

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

August 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. 72

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

Forrest G. Hall and Jaime Nickeson, Editors

Volume 72

BOREAS RSS-17 Xylem Flux Density Measurements at the SSA-OBS Site

Reiner Zimmerman, Bayreuth Institute for Terrestrial Ecosystem Research (BITOEK), University of Bayreuth, Bayreuth, Germany
Kyle C. McDonald, Jet Propulsion Laboratory, Pasadena, California
JoBea Way, Jet Propulsion Laboratory, Pasadena, California

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

August 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-17 Xylem Flux Density Measurements at the SSA-OBS Site

Reiner Zimmermann, Kyle McDonald, JoBea Way

Summary

As part of its efforts to determine environmental and phenological states from radar imagery, the BOREAS RSS-17 team collected in situ tree xylem flow measurements for one growing season on five Picea mariana (black spruce) trees. The data were collected to obtain information on the temporal and spatial variability in water uptake by trees in the SSA-OBS (Picea mariana) stand in the BOREAS SSA. Temporally, the data were collected in 30-minute intervals for 120 days from 31-May-1994 until 27-September-1994. The data are stored in tabular ASCII files.

Table of Contents

1. Data Set Overview

1.1 Data Set Identification

BOREAS RSS-17 Xylem Flux Density Measurements at the SSA-OBS Site

1.2 Data Set Introduction

This data set consists of continuous, in situ tree xylem sap flow measurements on five black spruce trees at the Old Black Spruce (OBS) tower site, located in the BOReal Ecosystem-Atmosphere Study (BOREAS) Southern Study Area (SSA), near Candle Lake, Saskatchewan, Canada. Xylem sap flux was measured continuously from 31-May-1994 until 27-September-1994.

The five trees measured were located near the main tower at the BOREAS SSA-OBS site in a mixed Picea mariana/Larix laricina/Pinus banksiana stand approximately 10-20 m from the main tower site hut. Picea mariana was the dominating tree species in the stand. All five trees measured were Picea mariana (black spruce) of varying tree dimensions.

Tree xylem sap flow was measured with a thermal constant energy input method (Granier et al., 1992), which consists of an inversely connected pair of copper-constantane thermocouples and a heated probe that releases 200 mWatt on a probe length of 20 mm. Tree xylem flux was measured in the tree bole between 1.55 and 1.8 m height above the moss layer. Each tree had a heated probe of 20 mm in length and 2 mm in diameter inserted horizontally into the stem. Insertion depth was from the cambium layer on 20 mm into the xylem.

The xylem sap flow measurements were logged automatically by a data logger (Delta-T DL-2). The data points stored indicate the average of measurements for a time interval between two data storage points. Storage time is indicated as the time at the end of each measurement/averaging interval. Data from the thermocouple pair were postprocessed to obtain the heat flux density of the xylem water passing the inserted heated probe.

1.3 Objective/Purpose

These measurements were taken to give information on water consumption by Picea mariana trees, the dominating tree species at SSA-OBS. In combination with the dimensional properties of the five measured trees (given in the information below) and the stand structural information, these data may be used to scale up water consumption by Picea mariana to a stand level for the time period 31-May-1994 until 27-September-1994.

In combination with meteorological and soil water content information, these data may be used to 1) analyze the climatic and pedological control of water loss by Picea mariana trees on a short-term (diurnal) and long-term (seasonal) time scale and 2) calculate canopy conductance for water vapor exchange. These data may then be used for validation of results from gas exchange and soil-vegetation-atmosphere transform (SVAT) models for water and carbon exchange from trees.

1.4 Summary of Parameters and Variables

Each line of the data file contains time and date information and xylem flux data taken at the same time for each of five trees.

1.5 Discussion

Xylem sap flux density (XFD, unit: grams of H_2O per square meter of hydroactive xylem per second = $g/m^2/s$) in the youngest, distal part of the hydroactive xylem was derived from continuous measurements of heat dissipation properties in the hydroactive xylem of tree boles at approximately 1.6 to 1.8 m height above the ground. A constant thermal energy input method with a point source heating device of 20 mm in length and a diameter of 2 mm (Granier, 1985) was used. The apparent temperature difference between the stem tissue and a heated probe (constant heat dissipation of the sensor: 200 mWatt) inserted in the outer xylem was monitored every 30 seconds, and a 30-minute mean was stored for each sensor. The sensor setup was covered with a radiation shield to avoid external radiative thermal load on the setup. The tree dimensions, diameter at breast height, height, and projected canopy area, were measured for the five trees .

1.6 Related Data Sets

BOREAS RSS-17 Dielectric Constant Profile Measurements
BOREAS RSS-17 Stem and Air Temperature Measurements
BOREAS RSS-17 1994 ERS-1 Level-1 Backscatter Change Images

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

Contact 1:
Dr. Reiner Zimmermann
Bayreuth Institute for Terrestrial Ecosystem Research (BITOEK)
Plant Ecology II
University of Bayreuth
D-95445 Bayreuth
GERMANY
+49-921-555624
+49-921-555799 (fax)
reiner.zimmermann@bitoek.uni-bayreuth.de

Contact 2:
Dr. JoBea Way
Jet Propulsion Laboratory
Mail Stop 300-233
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109
USA
(818) 354-8225
(818) 354-9476 (fax)
way@lor.jpl.nasa.

Contact 3:
Dr. Kyle McDonald
Jet Propulsion Laboratory
Mail Stop 300-233
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109
USA
(818) 354-3263
(818) 354-9476 (fax)
kyle.mcdonald@jpl.nasa.gov

Contact 4:
Prof. Dr. Ram Oren
Duke University
Nicholas School of the Environment
Durham, NC 27706
USA
ramoren@duke.edu

Contact 5:
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

Calculation of Xylem Flux with the Granier Method

The following discussion depends to a large extent on Gülpen (1996) and Granier (1985):

3.1 General Principles of Measurement

The constant current heating of a wire wrapped around the upper needle of the xylem sensor setup causes a constant warming of the wood around the needle.

The constant electrical current applied to a constant electrical resistance causes a constant energy release. Combining the equation for Ohms law (1):

$$U = R * I \qquad (1)$$

U = Electrical voltage (Volts)
R = Electrical resistance (Ohms)
I = Electrical current (Amps)

and the equation for electrical power (2):

$$P = U * I \qquad (2)$$

P = Electrical power (Watt)

results in equation (3):

$$P = R * I * I \qquad (3)$$

The electrical resistance of the heated wire coil that is inserted into the wood is determined by the dimensions and electrical properties of the wire type.

The sensors used were 20 mm in length; the electrical resistance of the heating coil is typically 10.2 Ohm. The constant current controller unit supplies the wire with 0.140 mAmpere. Thus, the energy release for this type of sensor can be calculated by using equation (3):

$$P = 10.2 * 0.140 * 0.140 = 0.200$$

The total energy release of this sensor type is 200 mW at a length of 20 mm. This is 10 mW per mm of sensor length.

The preference of constant current control over constant voltage control for the heating coil power supply has a practical reason: the variation of the electrical resistance in the connecting cables between the power supply and the heated sensor coil (caused by varying cable length, changes in environmental temperature conditions, direct radiation load from the Sun, or corrosion) does not affect the heating coil energy release when constant current is applied to the entire setup.

The warming at the heated sensor needle is at its maximum if no water transport takes place. Thus, the temperature difference between the heated sensor and the reference sensor will be at its maximum at no flow conditions in the xylem. If xylem flux starts, the heated sensor will be cooled by the xylem water, which is at average stem temperature passing by the heated sensor. In this case, the measured temperature difference between the heated sensor and the reference sensor will decrease. The degree of cooling at the heated sensor is proportional to the intensity of xylem sap flow. This is the underlying principle of calculating the xylem sap flow with this sensor arrangement from a measured temperature difference between a heated sensor and a reference sensor.

The formula obtained is based on a study by Granier (1985). For the calculation of the xylem flow, two parameters must be defined. The term XYLEM FLUX is a quantitative expression of xylem water passing through a single tree or through an entire stand of trees (=transpiration), while XYLEM FLUX DENSITY is the xylem flow related to an area through which the xylem sap is passing at a given point. The area is typically the cross-sectional area of hydroactive xylem in a tree stem. The xylem flux density (grams of H_2O per square meter of hydroactive xylem per second = $g/m^2/s$) is the measured parameter obtained by using the Granier method in the data set included here.

The xylem flux density measured can then be scaled up to a tree or stand level if the tree or whole stand cross-sectional areas of the trees are known. At this point of scaling up water flow in trees, it has to be taken into account that the xylem flux density varies with microclimatic conditions, tree water status, tree size, and xylem depth as well as tree species. For scaling up purposes, it is typically necessary to measure and analyze the above-mentioned parameters before the transpiration of trees and entire stands can be calculated.

3.2 Theory of Heat Exchange Between Heated Sensor and Xylem Tissue

It is assumed that the energy that is produced by the heated sensor will be entirely transferred by the surrounding aluminum tube to the xylem tissue:

$$h * S * (T - T_{inf}) = R * I * I \qquad (4)$$

h = Heat exchange coefficient ($W/m^2/°C$)
S = Heat exchange surface (m^2)
T = Temperature of heated sensor (°C)
T_{inf} = Temperature of unheated wood material (°C)
R = Electric resistance (Ohm)
I = Electric current (A)

This means that the heat loss from the heated sensor to the wood depends on both: a) the contact surface between the heated sensor to the wood and b) the temperature difference between the heated sensor and the surrounding wood material.

The contact surface area S remains a constant because it is given by the size of the sensor and by the surrounding aluminum tube. The exchange of heat energy between the heated sensor and the wood material, however, is determined by the heat exchange coefficient h.

The heat exchange coefficient h can be calculated according to equation (5):

$$h = R * I * I / S (T - T_{inf}) \qquad (5)$$

At zero xylem sap flow condition, the temperature of the heated sensor is at its maximum. The heat exchange coefficient at zero xylem sap flow condition (hzero) can be calculated according to equation (3):

$$h_{zero} = R * I * I / S (T_{max} - T_{inf}) \qquad (6)$$

T_{max} = Temperature of the heated sensor at zero xylem sap flow (maximum temperature measured at sensor).

The actual heat exchange coefficient h changes with the onset of xylem sap flow:

$h = h_{zero} (1 + alpha * u^{beta})$ (7)

u = xylem flux density (mass of xylem water per area of hydroactive xylem in $g/m^2/s$)

h_{zero} = Heat exchange coefficient at u = 0 (zero xylem flow)

The variables alpha and beta are empirically measured calibration factors for a material (in this example, xylem woody tissue) that describe at a given xylem flow density the change of the relationship of the actual heat exchange coefficient, h, at any given xylem flow to the heat exchange coefficient at zero flow, h_{zero}.

For the calculation of the xylem flux density, u, the equation (7) can be rearranged:

$u = (1/ alpha * (h - h_{zero}) / h_{zero})^{(1/beta)}$ (8)

Integration of equations (5) and (6) into equation (8) results in:

$u = (1 / alpha * (T_{max}-T_{inf})-(T-T_{inf}) / (T-T_{inf}))^{(1/beta)}$ (9)

This means:

$u = (1 / alpha * (T_{max} - T) / (T-T_{inf}))^{(1/beta)}$ (10)

Within equation (10) the term (11) is a measure of the degree of cooling of the heated sensor. The term is also proportional to the xylem sap flux.

$(T_{max}-T) / (T-T_{inf})$ (11)

Granier (1985) calls this term (11) the "flow index, K."

The Granier sensor method does not measure absolute temperatures at the heated or the reference sensor. Rather, it measures the temperature difference between both sensors.

Technically, this temperature difference is measured by a pair of copper-constantane thermocouples that are connected at the constantane ends. The inverted thermocouple array produces a predictable voltage output at the two copper ends when both thermocouple junctions are exposed to different temperatures. For copper-constantane thermocouples the voltage output increases at approximately 40 microvolts per degree Celsius within ambient temperatures for plant life.

For the temperature difference measurements, the equations (12) and (13) are valid:

$T_{max} = T_{deltaMax} + T_{inf}$ (12)

$T = T_{deltaActual} + T_{inf}$ (13)

$T_{deltaMax}$ = Temperature difference at u = 0 (zero xylem flow) when the probe temperature is at its maximum temperature elevation above ambient material (wood) temperature.

$T_{deltaActual}$ = Actual measured temperature difference

From this, the flux index K according to Granier (1985) can be calculated:

$$K = \frac{(T_{deltaMax} + T_{inf}) - (T_{deltaActual} + T_{inf})}{(T_{deltaActual} + T_{inf}) - T_{inf}} \qquad (14)$$

This can be rearranged as:

$$K = (T_{deltaMax} - T_{deltaActual}) / T_{deltaActual} \qquad (15)$$

The derivation of a flux index K from the theoretical consideration of heat exchange between an inserted and actively heated xylem flux probe and the surrounding xylem tissue demonstrates the characteristics of the xylem flux measurement method according to Granier (1985):

- The measurement of xylem flow is achieved by calculation of the xylem flux density u, which is proportional to the flux index K.
- The flux index K is calculated by using the factors alpha and beta. These two factors can be empirically derived by experiments for woody xylem tissue. The factors are independent of the ambient temperature conditions.

3.3 Determination of the Calibration Factors Alpha and Beta

Because the flux index K is proportional to the xylem flux density u (equation (10)), the following relationship exists:

$$K = alpha * u^{beta} \qquad (16)$$

The variation of the flux index K was experimentally investigated for obtaining a calibration for his system. Because of large anatomical differences, the calibration factors were determined for various xylem types and tree species by Granier (1985). Data were obtained for Pseudotsuga menziesii, Pinus nigra and Quercus pedunculata, and Picea abies (Granier, 1985), and for Quercus robur, Malus domestica, and Castanea sativa (Lu, 1992). The aim of these studies was to obtain a relationship between K and the gravimetrically measured xylem flux density in order to be able to calculate the factors alpha and beta. The experiments were performed using stem segments through which water was percolated by applying various hydrostatic pressures. The xylem flow was measured gravimetrically, and the xylem flux density was recalculated from the xylem flow. The xylem flux density was then compared with the measured flux index K.

The relationship between K and u was determined by a linear regression model that delivered the factors alpha and beta. It was found that all tree species studied showed the same relationship between u and K. The regression model had a r^2 of 0.92 and a replication of $n = 53$ samples (Granier, 1985). Further studies supported the general validity of this model (Granier, 1989; Lu, 1992).

From these experiments, the following relationship between K and u ($g/m^2/s$) was derived:

$$K = 0.0206\, u^{0.8124} \qquad (16a)$$

For u ($g/m^2/s$), the following equation is obtained:

$$u = 118.99 * K^{1.234} \qquad (17)$$

This is the general form of the equation used for calculation of xylem flux density when the flux index K is measured with the Granier method.

3.4 Calculation of Tree and Stand Transpiration

The xylem flux density is related to the xylem flow (transpiration) of a whole stem or an entire stand of trees as follows:

$u = F / SA$ (18)

u = xylem flux density ($g/m^2/s$)
F = xylem flow (transpiration) (g/s)
SA = hydroactive sapwood cross sectional area (m^2)

Equation (16) is valid if the hydroactive xylem depth is equal to or larger than the sensor insertion depth. If the hydroactive xylem depth is smaller than the sensor depth (e.g., with most ring porous trees), the flux density must be corrected to its actual and higher value.

The xylem flow for a tree or an entire stand can be calculated from the knowledge of the xylem flux density u and the total hydroactive sapwood area of the tree or the forest stand. This assumption implies that no xylem flux density variations exist with tree dimensions, canopy structure, and xylem depth.

$F = u * SA$ (19)

4. Equipment

4.1 Sensor/Instrument Description

Technically, the heated sensor consists of two units:

- A Teflon-insulated constantane wire with a known electrical resistance that is wrapped around a steel syringe. The wire releases a constant amount of heat energy. The external size of the sensor is a 2-mm diameter, 20-mm length of inserted heating coil.
- A thermocouple of a pair of copper and constantane wires connected together at its tip. The tip is at the center of the sensor setup inside the steel syringe. The thermocouple measures the temperature of the sensor and is electrically insulated from the heated wire and the steel syringe.

An external direct current power supply with a controller for constant current output is connected to the heating wire coil. The heated wire has a known and constant electrical resistance. Furthermore, a constantane wire, a nickel-copper alloy, does not change its electrical resistance at varying temperatures as regular metal wires typically do.

4.1.1 Collection Environment

Data were collected from May 1994 until September 1994. Air temperature was typically above 0 °C, and conditions varied widely diurnally from cool and clear to overcast and rain.

4.1.2 Source/Platform

Black spruce trees.

4.1.3 Source/Platform Mission Objectives

This study was undertaken to obtain water flux information from the tree canopy in order to allow validation of water exchange models.

4.1.4 Key Variables

Xylem flux density (XFD) in grams of water per square meter of hydroactive xylem per second.

4.1.5 Principles of Operation

Continuous thermal measurement with constant power input.

4.1.6 Sensor/Instrument Measurement Geometry

Insertion depth of sensors was horizontal and central with a depth of 20 mm into the outer ring of the hydroactive xylem from the cambium layer on.

4.1.7 Manufacturer of Sensor/Instrument

Custom made by:

B. Stumpf
Technical Precision Instruments
Trebgest, Germany

4.2 Calibration

No field calibration of the sensors is necessary. Constant current power supply of sensors was checked during installation and removal of the sensors. All constant current source controllers were stable during operation and varied within less than 1% of 140 mAmp.

4.2.1 Specifications

Sensors were running on 140 mAmp at 10.204-Ohm heating wire resistance. Energy release over 20 mm in sensor length was thus 200 mAmp.

Thermocouple wires used are copper-constantan. Two thermocouples were connected copper-constantan-copper and given 40 µVolt per 1 °C of temperature difference measured at the two joints at 20 °C ambient temperature.

4.2.1.1 Tolerance

Measurement depends on the accuracy of thermocouple measurements and natural temperature gradients in the measured stem.

4.2.2 Frequency of Calibration

Not applicable.

4.2.3 Other Calibration Information

Not applicable.

5. Data Acquisition Methods

Temperature difference from the xylem flux sensors was automatically logged on a data logger (DL-2 with LAC-1) in double ended mode, autoranging on (Delta-T Devices, England).

Data were downloaded on a PC laptop and processed using Dataman (Ce Huang, Duke University, USA), Sigmaplot 4.0 (Jandel Inc., USA), SPSS (USA), and Excel 4.0 (Microsoft, USA).

6. Observations

6.1 Data Notes

All sensors worked without problems for the entire time period of observation. There was a period from 16-July through 27-July when the data were reported every 10 minutes instead of every half hour.

6.2 Field Notes

None given.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The five trees measured had the following dimensional properties:

```
------------------------------------------------------------
Tree# = Tree number
DBH = Stem diameter at breast height including bark (mm)
TH = Tree height (m)
PCA = Projected canopy area (m2)
------------------------------------------------------------
Tree# , DBH ,  TH  , PCA
Tree1 , 138 , 10.0 , 2.12
Tree2 ,  90 ,  6.5 , 2.00
Tree3 ,  99 ,  8.2 , 1.22
Tree4 ,  45 ,  6.9 , 0.57
Tree5 , 180 , 12.7 , 5.30
```

The measurement site was located at the SSA OBS flux tower site, approximately 20 meters northeast of the tower. The North American Datum of 1983 (NAD83) coordinates of the SSA-OBS flux tower are given below:

Site Id	Grid Id	Longitude	Latitude	UTM Easting	UTM Northing	UTM Zone
SSA-OBS-XYL01	G8I4T	105.11779°W	53.98717°N	492276.5	5982100.5	13

7.1.2 Spatial Coverage Map

Not available.

7.1.3 Spatial Resolution

The spatial resolution of a given measurement is one tree.

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 continuously from 31-May-1994 to 27-September-1994.

7.2.2 Temporal Coverage Map

Not applicable.

7.2.3 Temporal Resolution

Sap flux was measured every 1 minute and averaged into 30-minute ensembles. The 30-minute ensembles are presented. There was a period from 17-July through 27-July when the fluxes were reported every 10 minutes instead of every half 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
MEAN_XYLEM_FLUX_DENSITY_T1
MEAN_XYLEM_FLUX_DENSITY_T2
MEAN_XYLEM_FLUX_DENSITY_T3
MEAN_XYLEM_FLUX_DENSITY_T4
MEAN_XYLEM_FLUX_DENSITY_T5
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) at the end of the period when the data were collected.
MEAN_XYLEM_FLUX_DENSITY_T1	The mean xylem sap flux density aggregated from one minute measurements made at the SSA-OBS site at tree 1, which has a dbh of 138 mm, a height of 10 m, and a projected canopy area of 2.12 m^2.
MEAN_XYLEM_FLUX_DENSITY_T2	The mean xylem sap flux density aggregated from one minute measurements made at the SSA-OBS site at tree 2, which has a dbh of 90 mm, a height of 6.5 m, and a projected canopy area of 2.0 m^2.
MEAN_XYLEM_FLUX_DENSITY_T3	The mean xylem sap flux density aggregated from one minute measurements made at the SSA-OBS site at tree 3, which has a dbh of 99 mm, a height of 8.2 m, and a projected canopy area of 1.22 m^2.
MEAN_XYLEM_FLUX_DENSITY_T4	The mean xylem sap flux density aggregated from one minute measurements made at the SSA-OBS site

	at tree 4, which has a dbh of 45 mm, a height of 6.9 m, and a projected canopy area of 0.57 m^2.
MEAN_XYLEM_FLUX_DENSITY_T5	The mean xylem sap flux density aggregated from one minute measurements made at the SSA-OBS site at tree 5, which has a dbh of 180 mm, a height of 12.7 m, and a projected canopy area of 5.30 m^2.
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]
MEAN_XYLEM_FLUX_DENSITY_T1	[grams][meter^-2][second^-1]
MEAN_XYLEM_FLUX_DENSITY_T2	[grams][meter^-2][second^-1]
MEAN_XYLEM_FLUX_DENSITY_T3	[grams][meter^-2][second^-1]
MEAN_XYLEM_FLUX_DENSITY_T4	[grams][meter^-2][second^-1]
MEAN_XYLEM_FLUX_DENSITY_T5	[grams][meter^-2][second^-1]
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	[Datalogger]
TIME_OBS	[Datalogger]
MEAN_XYLEM_FLUX_DENSITY_T1	[Measurement probe/Datalogger]
MEAN_XYLEM_FLUX_DENSITY_T2	[Measurement probe/Datalogger]
MEAN_XYLEM_FLUX_DENSITY_T3	[Measurement probe/Datalogger]
MEAN_XYLEM_FLUX_DENSITY_T4	[Measurement probe/Datalogger]
MEAN_XYLEM_FLUX_DENSITY_T5	[Measurement probe/Datalogger]
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	SSA-OBS-FLXTR	SSA-OBS-FLXTR	None	None	None	None
SUB_SITE	RSS01-XYL01	RSS01-XYL01	None	None	None	None
DATE_OBS	31-MAY-94	28-SEP-94	None	None	None	None
TIME_OBS	0000	2350	None	None	None	None
MEAN_XYLEM_FLUX_DENSITY_T1	.001	17.737	None	None	None	None
MEAN_XYLEM_FLUX_DENSITY_T2	.001	19.602	None	None	None	None
MEAN_XYLEM_FLUX_DENSITY_T3	.001	30.61	None	None	None	None
MEAN_XYLEM_FLUX_DENSITY_T4	.001	15.176	None	None	None	None
MEAN_XYLEM_FLUX_DENSITY_T5	.001	12.407	None	None	None	None
CRTFCN_CODE	CPI	CPI	None	None	None	None
REVISION_DATE	17-JUL-98	17-JUL-98	None	None	None	None

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

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

7.4 Sample Data Record

The following are wrapped versions of data record from a sample data file on the CD-ROM.

```
SITE_NAME,SUB_SITE,DATE_OBS,TIME_OBS,MEAN_XYLEM_FLUX_DENSITY_T1,
MEAN_XYLEM_FLUX_DENSITY_T2,MEAN_XYLEM_FLUX_DENSITY_T3,MEAN_XYLEM_FLUX_DENSITY_T4,
MEAN_XYLEM_FLUX_DENSITY_T5,CRTFCN_CODE,REVISION_DATE
'SSA-OBS-FLXTR','RSS17-XYL01',01-JUL-94,0,3.252,3.218,6.049,1.514,5.602,'CPI',
17-JUL-98
'SSA-OBS-FLXTR','RSS17-XYL01',01-JUL-94,30,3.418,4.088,5.528,2.036,5.633,'CPI',
17-JUL-98
'SSA-OBS-FLXTR','RSS17-XYL01',01-JUL-94,100,3.244,4.005,5.207,.935,5.745,'CPI',
17-JUL-98
'SSA-OBS-FLXTR','RSS17-XYL01',01-JUL-94,130,3.409,3.922,5.26,1.35,6.022,'CPI',
17-JUL-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

Data of xylem flux density do not need further processing.

9.1.1 Derivation Techniques and Algorithms

See Section 3.

9.2 Data Processing Sequence

9.2.1 Processing Steps

See Section 5.

9.2.2 Processing Changes

None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

Not applicable.

9.3.2 Calculated Variables

See Section 3.

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

Human errors while staring into the tube and passing out and hitting the keyboard.

10.2 Quality Assessment

10.2.1 Data Validation by Source

The data were checked for consistency and outliers

10.2.2 Confidence Level/Accuracy Judgment

Good.

10.2.3 Measurement Error for Parameters

None given.

10.2.4 Additional Quality Assessments

We provided only those data that were of good quality. Faulty data and data acquired during time periods for which our measurement technique was not robust (e.g., data acquired during periods when the tree was frozen or undergoing freeze/thaw transitions) were not included in the supplied data set.

10.2.5 Data Verification by Data Center

BORIS staff reviewed the data files during the data base loading process.

11. Notes

11.1 Limitations of the Data

None.

11.2 Known Problems with the Data

None, as long as no frost condition in the tree bole occurs. Data from periods of frost in the tree boles are not presented.

11.3 Usage Guidance

None given.

11.4 Other Relevant Information

None given.

12. Application of the Data Set

These measurements were taken to give information on water consumption by Picea mariana (black spruce) trees, the dominating tree species at SSA-OBS.

In combination with the dimensional properties of the five measured trees (given in Section 7.1) and the stand structural information, these data may be used to scale up water consumption by Picea mariana to a stand level for the time period from 31-May-1994 until 27-September-1994.

In combination with meteorological and soil water content information, these data may be used to:

- Analyze the climatic and pedological control of water loss by Picea mariana trees on a short-term (diurnal) and long-term (seasonal) time scale.
- Calculate canopy conductance for water vapor exchange.

These data may then be used for validation of results from gas exchange models for water and carbon exchange from trees.

13. Future Modifications and Plans

No modifications are planned.

14. Software

14.1 Software Description

Data were downloaded on a PC laptop and processed using Dataman (Ce Huang, Duke University, USA), Sigmaplot 4.0 (Jandel Inc., USA), SPSS (USA), and Excel 4.0 (Microsoft, USA).

Data collection and transformation from binary data to ASCII data were performed in the field with software from Delta-T, Cambridge, UK.

Processing of the data was performed by Reiner Zimmermann with custom software Dataman written by Huang Ce for a PC-DOS computer in TURBOBASIC at Duke University, North Carolina, USA.

Data transformation, data check, and data visualization were done with customized program routines for SIGMAPLOT 4.0 (Jandel Scientific) for DOS by Reiner Zimmermann at BITOEK, Bayreuth, Germany.

14.2 Software Access

Dataman is available upon request from Huang Ce, Nicholas School of the Environment, Duke University, North Carolina, USA.

15. Data Access

The xylem flux 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

Granier, A. 1985. Une nouvelle methode pour la mesure du flux de seve brute dans le tronc des arbres. Ann. Sci. For. 42 (2) 81-88.

Granier, A. 1987. Evaluation of Transpiration in a Douglas-fir Stand by means of Sap Flow Measurements. Tree Physiology. Vol. 3, pp. 309-319.

Granier, A., R. Huc, and F. Colin. 1992. Transpiration and stomatal conductance of two rain forest species growing in plantations (Simarouba amara and Goupia glabra) in French Guyana. Ann. Sci. For. 49, 17-24.

Gülpen, M. 1996. Xylemfluss, Elementtransport und Bindung von Calcium und Magnesium in Fichten (Picea abies (L.) Karst.) von den ARINUS- Versuchsflächen im Schwarzwald. Freiburg. Bodenk. Abh. 36, Freiburg, Germany, 163 pp.

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.

Lu, P. 1992. Ecophysiologie et reaction a la secheresse de trois especes de coniferes (Abies alba Miller, Picea abies (L.) Karsten et Pinus sylvestris L.); effet de l age. Dissertation, University of Nancy, France, 116 pp.

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).

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.

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
GIS     - Geographic Information System
GMT     - Greenwich Mean Time
GSFC    - Goddard Space Flight Center
HTML    - HyperText Markup Language
NAD83   - North American Datum of 1983
NASA    - National Aeronautics and Space Administration
NSA     - Northern Study Area
OBS     - Old Black Spruce
ORNL    - Oak Ridge National Laboratory
PANP    - Prince Albert National Park
PDP     - Portable Dielectric Probe
RSS     - Remote Sensing Science
SSA     - Southern Study Area
SVAT    - Soil-Vegetation-Atmosphere Transfer
URL     - Uniform Resource Locator (a World Wide Web address)
UTM     - Universal Transverse Mercator
XFD     - Xylem Flux Density
```

20. Document Information

20.1 Document Revision Date(s)
Written: 01-Jun-1997
Last Updated: 05-Aug-1999

20.2 Document Review Date(s)
BORIS Review: 10-Sep-1997
Science Review: 11-Jul-1998

20.3 Document ID

20.4 Citation
When using these data, please acknowledge the efforts of R. Zimmermann, K.C. McDonald, J.B. Way, and R. Oren and include citations of relevant papers in Section 17.2.

If using data from the BOREAS CD-ROM series, also reference the data as:
Way, J.B., K. McDonald, and R. Zimmermann, "Monitoring Environmental and Phenologic State and Duration of State with SAR as Input to Improved CO_2 Flux 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
August 2000

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)
BOREAS RSS-17 Xylem Flux Density Measurements at the SSA-OBS Site

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

6. AUTHOR(S)
Reiner Zimmerman, Kyle C. McDonald, and JoBea Way
Forrest G. Hall amd 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. 72

11. SUPPLEMENTARY NOTES
R. Zimmerman: Bayreuth Institute for Terrestrial Ecosystem Research (BITOEK), University of Bayreuth, Bayreuth, Germany; K.C. McDonald and J.B. Way: Jet Propulsion Laboratory, Pasadena, California; J. Nickerson: 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)*

As part of its efforts to determine environmental and phenological states from radar imagery, the BOREAS RSS-17 team collected in situ tree xylem flow measurements for one growing season on five Picea mariana (black spruce) trees. The data were collected to obtain information on the temporal and spatial variability in water uptake by trees in the SSA-OBS (Picea mariana) stand in the BOREAS SSA. Temporally, the data were collected in 30-minute intervals for 120 days from 31-May-1994 until 27-September-1994. The data are stored in tabular ASCII files.

14. SUBJECT TERMS
BOREAS, remote sensing science, tree xylum flow measurements.

15. NUMBER OF PAGES
20

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