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

Forrest G. Hall and Shelaine Curd, Editors

Volume 157
BOREAS TE-9 NSA Photosynthetic Response Data

Q. Dang, H. Margolis, and M. Coyea

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

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BOREAS TE-9 NSA Photosynthetic Response Data

Qinglai Dang,Hank Margolis, Marie Coyea

Summary

The BOREAS TE-9 team collected several data sets related to chemical and photosynthetic properties of leaves. This data set describes (1) the response of leaf and shoot-level photosynthesis to ambient and intercellular CO_2 concentration, temperature, and incident PAR for black spruce, jack pine, and aspen during the three IFCs in 1994 in the NSA; (2) the response of stomatal conductance to vapor pressure difference throughout the growing season of 1994; and (3) a range of shoot water potentials (controlled in the laboratory) for black spruce and jack pine. The data are available in tabular ASCII files.

Table of Contents

1. Data Set Overview

1.1 Data Set Identification

BOREAS TE-09 NSA Photosynthetic Response Data

1.2 Data Set Introduction

The response of photosynthesis to ambient CO_2 concentration, temperature, light (Photosynthetically Active Radiation (PAR)), vapor pressure difference (VPD), and shoot water potential was investigated as part of an effort to construct the response surfaces of photosynthesis to different environmental factors. Samples were taken from three forest types: jack pine (Pinus banksiana Lamb.), black spruce (Picea mariana Mill. B.S.J.P), and aspen (Populus tremuloides Michx.) in the BOReal Ecosystem-Atmosphere Study (BOREAS) Northern Study Area (NSA) during each of the three Intensive Field Campaigns (IFCs) in 1994. Measurements were taken under controlled environmental conditions in the laboratory using an open gas exchange system in differential mode. Photosynthesis and related parameters all are expressed on a hemisurface area basis. The shape factors for leaf area calculation are 4 and 4.59, respectively, for black spruce and jack pine.

1.3 Objective/Purpose

This data set was collected and prepared to provide the response curves of photosynthesis to (1) ambient and intercellular CO_2 concentration, (2) temperature, and (3) PAR in jack pine, black spruce, and aspen in the NSA using a cut-branch technique. Additional data sets were collected and prepared to provide the response curves of photosynthesis and stomatal conductance to water vapor pressure difference for jack pine and black spruce to provide the response of photosynthesis to shoot water potential in jack pine and black spruce in the NSA.

1.4 Summary of Parameters

Net photosynthesis, ambient and intercellular CO_2 concentration, transpiration, stomatal conductance, temperature, PAR, VPD, water potential.

1.5 Discussion

The response of photosynthesis to ambient CO_2 concentration, temperature, and light (PAR), the response of stomatal conductance to VPD; and the response of photosynthesis and stomatal conductance to shoot water potential were investigated as part of an effort to construct the response surfaces of photosynthesis to different environmental factors. Samples were taken in the NSA during each of the three IFCs in 1994 from three forest types: old jack pine (OJP), old black spruce (OBS), and old aspen (OA). Measurements were taken under controlled environmental conditions in the laboratory using an open gas exchange system in differential mode. Photosynthesis and related parameters all are expressed on a hemisurface area basis. The shape factors for leaf area calculation are 4 and 4.59, respectively, for black spruce and jack pine.

1.6 Related Data Sets

BOREAS TE-09 NSA Photosynthetic Capacity and Foliage Nitrogen Data
BOREAS TE-09 PAR and Leaf Nitrogen Data for NSA Species
BOREAS TE-09 NSA in situ Diurnal Gas Exchange of Boreal Forest Species

2. Investigator(s)

2.1 Investigator(s) Name and Title

Dr. Hank Margolis, Associate Professor

2.2 Title of Investigation

Relationship Between Measures of Absorbed and Reflected Radiation and the Photosynthetic Capacity of Boreal Forest Canopies and Understories

2.3 Contact Information

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3. Theory of Measurements

During the process of photosynthesis, CO_2 is assimilated by green leaves (photosynthesis) while H_2O is released into the atmosphere (transpiration). The amount of water released and the amount of CO_2 absorbed can be determined by comparing the concentrations of water vapor and CO_2 in the air moving into the leaf cuvette and those in the air moving out of the cuvette at a known flow rate. The concentrations of CO_2 and water vapor in both incoming and outgoing air streams can be measured using an infrared gas analyzer (IRGA). The rates of net photosynthesis and transpiration are calculated from the difference in the concentrations of CO_2 and water vapor between the input and the output from the leaf cuvette. Stomatal conductance is calculated from transpiration rate and the water vapor gradient between the intercellular space and the bulk air in the cuvette.

The water in the xylem is under tension. When the stem of the branch is cut, the water will retreat from the cut surface. When the cut branch is enclosed in the pressure chamber with the cut surface extruding and pressurized gradually, the xylem water will come back to the cut surface when the pressure is equal to the water potential of the shoot. The pressure inside the pressure chamber, and thus the water potential of the shoot, can be read from a pressure gauge.

4. Equipment

4.1 Sensor/Instrument Description

LI-COR 6262 IRGA, thermocouples, balance, Decagon AgVision root and leaf analysis system, PMS Model 610 pressure chamber.

4.1.1 Collection Environment

Values of major environmental variables are given in the data set for each individual measurement. Upper-canopy branch samples were harvested using a shotgun and were immediately recut under water. The samples were then transported to the laboratory for gas exchange measurement. The cut surfaces of the branches were submerged in water during transport (30 to 50 min) and in the laboratory. Measurements for each species generally took 6 to 10 hours.

All samples were kept in the dark, but prior to measurement, samples were exposed to saturated light for 2 hours to induce stomatal opening and photosynthetic activity. To test photosynthetic

response to CO_2 concentration changes, steady-state readings were taken at each CO_2 level. An independent set of two samples was used for each two CO_2 levels. Ambient CO_2 varied from 50 to 900 ppm.

To keep a continued supply of water to the branch, the cut surface was kept in contact with water during the entire course of measurement. Saturated light was supplied using two 1,000-watt high-pressure sodium lamps. When ambient CO_2 was varied, other environmental conditions were as follows: temperature = 20 +/- 0.5 °C; VPD = 0.7 +/- 0.1 kPa; CO_2 = 360 +/- 20 ppm.

To test photosynthetic response of varied temperature, the air temperature inside the leaf cuvette was controlled using a radiator that was driven by a temperature-controlled water bath. The vapor pressure inside the cuvette was controlled by passing water vapor-saturated air through a condenser whose temperature was controlled using another water bath.

An independent set of two branches was used for each temperature. The branches were from four different trees and were mixed randomly.

Saturated light for the measurement was supplied using two 1,000-watt high- pressure sodium lamps. VPD of the air was controlled at a relatively constant level except at temperatures below 10 °C, when there were some technical difficulties in getting a low enough vapor pressure to maintain the desired VPD. Input CO_2 concentration was controlled at 360 (+/- 15 ppm).

To test photosynthetic response of varied PAR, the measurements started from the highest PAR level and proceeded to darkness. Steady-state readings were taken at each light level. The light source was two 1,000-watt high-pressure sodium lamps. Different levels of light were achieved by using different neutral density filters. The environmental conditions inside the leaf cuvette were as follows: temperature 20 +/- 0.5 °C; VPD 0.7 +/- 0.2 kPa; CO_2 360 +/- 15 ppm.

To test stomatal conductance of varied VPD, all samples were kept in the dark. The samples to be measured, however, were exposed to saturated light for 2 hours prior to measurement to induce stomatal opening and photosynthetic activity.

The stability and reliability of the cut-branch technique were tested. Stable measurements for at least 24 hours are possible. Steady-state readings were taken at each VPD level.

An independent set of two samples was used for each VPD level. To keep a continued supply of water to the branch, the cut surface was kept in contact with water during the entire course of measurement.

Different VPD levels were achieved by regulating the water vapor pressure of the input air stream to the leaf cuvette. Saturated light was supplied using two 1,000-watt high-pressure sodium lamps. The CO_2 concentration in the input air was 360 (+/- 15 ppm). Measurements were taken at three temperatures (15, 25, and 35 °C) in IFC-1, two temperatures (25 and 35 °C) in IFC-2, and at 25 °C only in IFC-3.

In the laboratory, the branches were taken out of the water, the cut surfaces of the branches were dried and sealed using silicon grease. The branches were then exposed to light and let transpire freely. At certain time intervals, the gas exchange of the branches (two at a time) was measured. The water potential of the branches was measured immediately after the gas exchange measurement.

Gas exchange was measured at saturated light conditions. Other environmental conditions in the leaf cuvette were as follows: temperature 20 +/- 0.5 °C; VPD 0.7 +/- 0.2 kPa; CO_2 of input air 360 +/-15 ppm.

4.1.2 Source/Platform

Branch samples were harvested in the early morning using a shotgun and transported to the laboratory in Thompson for gas exchange measurement.

4.1.3 Source/Platform Mission Objectives

The mission objectives were:

- To obtain the response curves of photosynthesis to ambient and intercellular CO_2 concentration, temperature, PAR, leaf-to-air VPD, and shoot water potential.
- To examine interspecific differences in photosynthetic response to CO_2, temperature, PAR, leaf-to-air VPD and shoot water potential.
- To examine seasonal variations in photosynthetic response to CO_2, temperature, PAR, leaf-to-air VPD, and shoot water potential.

4.1.4 Key Variables

Net photosynthesis, stomatal conductance, transpiration, ambient and intercellular CO_2 concentration, temperature, PAR flux density, VPD, water potential.

4.1.5 Principles of Operation

The stems of samples were connected to a water reservoir during the measurement to keep a continuous supply of water to the foliage. Independent samples were used for each temperature level, and each sample was measured for two CO_2 levels. Samples were exposed to saturated light for 2 hours prior to measurement to induce photosynthetic activity and stomatal opening.

Upper-canopy branch samples were harvested using a shotgun and were immediately recut under water. The samples were then transported to the laboratory for gas exchange measurement. The cut surfaces of the branches were submerged in water during transportation (30 to 50 min).

In the laboratory, the branches were taken out of the water and the cut surfaces were dried and sealed using silicon grease. The branches were then exposed to light and let transpire freely. At certain time intervals, the gas exchange of the branches (two at a time) was measured. The water potential of the branches was measured immediately after the gas exchange measurement.

Gas exchange was measured at saturated light conditions. Other environmental conditions in the leaf cuvette were as follows: temperature 20 +/- 0.5 °C; VPD 0.7 +/- 0.2 kPa; CO_2 of input air 360 +/-15 ppm.

4.1.6 Sensor/Instrument Measurement Geometry

All samples were taken from the upper third of the forest canopy. Efforts were made to keep the amount of foliage relatively consistent from sample to sample. The leaf chamber for the measurement is about 1,300 in^3.

4.1.7 Manufacturer of Sensor/Instrument

LI-6200 portable gas exchange system
LI-COR
P.O. Box 4425
4421 Superior St.
Lincoln, NE 68504
(800) 447-3576

Leaf area measurement system/optical image analysis system (AgVision, monochrome system, root and leaf analysis)
Decagon Devices, Inc.
P.O. Box 835
Pullman, WA 99163
(800) 755-2751

Pressure Chamber, Model 610
PMS Instrument Co.
480 SW Airport Avenue
Corvallis, OR 97333
(503) 752-7926

4.2 Calibration

The LI-COR 6262 gas analyzer was calibrated using a standard gas at the beginning of each field campaign. The standard gas had been calibrated against the prime CO_2 standard in the NSA laboratory in Thompson, Manitoba, using gas chromatography technique. The stability of gas exchange and the reliability of the cut branch technique were also tested (see Dang et al., 1997a, for details).

4.2.1 Specifications

The weighing balance was accurate to within 0.0001 g. The leaf area system was accurate to within 1%. The gas exchange system was accurate to 1 ppm CO_2.

The shape factor used for black spruce was 4, in accordance with the BOREAS Experiment Plan, Appendix K, Version 3.0. Based on observations of two cross- sections of two needles per fascicle for five fascicles for six jack pine trees from Thompson, Manitoba, an average shape factor of 4.59 (+/- 0.07) was calculated.

4.2.1.1 Tolerance

No tolerance level was set for these measurements.

4.2.2 Frequency of Calibration

The LI-COR 6262 IRGA was calibrated at the beginning of each IFC.

4.2.3 Other Calibration Information

Calibrations were performed according to each manufacturer's instructions.

5. Data Acquisition Methods

Upper-canopy branch samples were harvested using a shotgun and were immediately recut under water. The samples were then transported to the laboratory for gas exchange measurement. The cut surfaces of the branches were submerged in water during transport (30 to 50 min) and in the laboratory. Measurements for each species generally took 6 to 10 hours.

CO_2 concentration variation:

All samples were kept in the dark, but prior to measurement, samples were exposed to saturated light for 2 hours to induce stomatal opening and photosynthetic activity. Steady-state readings were taken at each CO_2 level, and an independent set of two samples was used for each two CO_2 levels. Ambient CO_2 varied from 50 to 900 ppm.

To keep a continued supply of water to the branch, the cut surface was kept in contact with water during the entire course of measurement. Saturated light was supplied using two 1,000-watt high-pressure sodium lamps. Other environmental conditions were as follows: temperature = 20 +/- 0.5 °C; VPD = 0.7 +/- 0.1 kPa; CO_2 = 360 +/- 20 ppm.

Temperature variation:

The air temperature inside the leaf cuvette was controlled using a radiator that was driven by a temperature-controlled water bath. The vapor pressure inside the cuvette was controlled by passing water vapor-saturated air through a condenser whose temperature was controlled using another water bath.

Saturated light for the measurement was supplied using two 1,000-watt high-pressure sodium lamps. VPD of the air was controlled at a relatively constant level except at temperatures below 10 °C, when there were some technical difficulties in getting a low enough vapor pressure to maintain the desired VPD. Input CO_2 concentration was controlled at 360 (+/- 15 ppm).

An independent set of two branches was used for each temperature. The branches were from four different trees and were mixed randomly.

PAR variations:

The measurements started from the highest PAR level and proceeded to darkness. Steady-state readings were taken at each light level. The light source was two 1,000-watt high-pressure sodium lamps. Different levels of light were achieved by using different neutral density filters. The environmental conditions inside the leaf cuvette were as follows: temperature 20 +/- 0.5 °C; VPD 0.7 +/- 0.2 kPa; CO_2 360 +/- 15 ppm.

Vapor pressure variation:

All samples were kept in the dark, but prior to measurement, samples were exposed to saturated light for 2 hours to induce stomatal opening and photosynthetic activity. The stability and reliability of the cut-branch technique were tested. Stable measurements for at least 24 hours are possible. Steady-state readings were taken at each VPD level.

An independent set of two samples was used for each VPD level. To keep a continued supply of water to the branch, the cut surface was kept in contact with water during the entire course of measurement.

Different VPD levels were achieved by regulating the water vapor pressure of the input air stream to the leaf cuvette. Saturated light was supplied using two 1,000-watt high-pressure sodium lamps. The CO_2 concentration in the input air was 360 (+/- 15 ppm). Measurements were taken at three temperatures (15, 25, and 35 °C) in IFC-1, two temperatures (25 and 35 °C) in IFC-2, and at 25 °C only in IFC-3.

Shoot water potential variations:

In the laboratory, the branches were taken out of the water and the cut surfaces were dried and sealed using silicon grease. The branches were then exposed to light and let transpire freely. At certain time intervals, the gas exchange of the branches (two at a time) was measured. The water potential of the branches was measured immediately after the gas exchange measurement.

Gas exchange was measured at saturated light conditions. Other environmental conditions in the leaf cuvette were as follows: temperature 20 +/- 0.5 °C; VPD 0.7 +/- 0.2 kPa; CO_2 of input air 360 +/-15 ppm.

6. Observations

6.1 Data Notes

Three to four leaves per sample for aspen.

6.2 Field Notes

Samples were taken from trees of relatively consistent vigor. See pages 2-23 and 2-24 in the BOREAS Experiment Plan, Version 3.0, for a description of site conditions.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

At each site, branch samples were taken from four different trees that were at least 10 m apart from one another. Sampling was done within a 100 m^2 area. The North American Datum of 1983 (NAD83) coordinates for each site are:

- NSA-OJP flux tower site, Lat/Long:55.92842°N, 98.62396°W; UTM Zone 14, N:6198176.3, E:523496.2
- NSA-OASP canopy access tower site (auxiliary site number T2Q6A, BOREAS Experiment Plan, Version 3), Lat/Long 55.88691°N, 98.67479°W; UTM Zone 14, N: 6193540.7, E: 520342
- NSA-OBS flux tower site, Lat/Long: 55.88007°N, 98.48139°W; UTM Zone 14, N: 6192853.4 E: 532444.5

7.1.2 Spatial Coverage Map
None.

7.1.3 Spatial Resolution
These data are point source measurements from the sampled trees.

7.1.4 Projection
Not applicable.

7.1.5 Grid Description
Not applicable.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage
All data were collected between 24-May-1994 and 19-Sep-1994. Samples were taken between 6:00 and 7:00 a.m. Measurements in the laboratory generally took 6 to 8 hours. An independent data set was taken during each of the three field campaigns. The specific dates for each data set are given in the data table.

7.2.2 Temporal Coverage Map

CO2 concentration:

Site	Sample Dates (day-month) 1994
NSA-OBS	04-JUN, 09-AUG, 06-SEP
NSA-OJP	02-JUN, 06-AUG, 07-SEP
NSA-OA	01-JUN, 07-AUG, 30-AUG

Temperature:

Site	Sample Dates (day-month) 1994
NSA-OBS	23-MAY, 26-JUL, 15-SEP
NSA-OJP	13-MAY, 27-JUL, 16-SEP
NSA-OA	14-JUN, 28-JUL, 10-SEP

PAR:

Site	Sample Dates (day-month) 1994
NSA-OBS	25-MAY, 23-JUL, 14-SEP
NSA-OJP	26-MAY, 24-JUL, 13-SEP
NSA-OA	10-JUN, 25-JUL, 09-SEP

VPD:

Site	Sample Dates (day-month) 1994
NSA-OBS	30-MAY, 25-MAY, 28-MAY, 29-AUG, 30-AUG, 12-SEP
NSA-OJP	24-MAY, 27-MAY, 29-MAY, 01-AUG, 03-AUG, 17-SEP

Water Shoot Potential:

Site	Sample Dates (day-month) 1994
NSA-OBS	23-JUL, 06-SEP
NSA-OJP	02-AUG, 07-SEP

7.2.3 Temporal Resolution
The measurements can be considered to be single point in time measurements since the same trees were not repeatedly sampled.

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
START_DATE
END_DATE
SPECIES
PARAM_VARIED
LEAF_TEMP
AIR_TEMP
CO2_CONC
TRANSPIRATION_RATE
PHOTOSYNTHETIC_RATE
DOWN_PPFD
INTERCELL_CO2_CONC
STOMATAL_CONDUCT_CO2
WATER_USE_EFF
WATER_POTENTIAL
VAPOR_PRESS_DEFICIT
VAPOR_PRESS_DEFICIT_AIR_TEMP
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.
START_DATE                     The date on which the collection of the
                               referenced data commenced.
END_DATE                       The date on which the collection of the
                               referenced data was terminated.
SPECIES                        Botanical (Latin) name of the species
                               (Genus species).
PARAM_VARIED                   The parameter varied to study photosynthetic
                               response to BOREAL tree species. i.e. CO2
```

	CONCENTRATION=CO2 varied; LIGHT=light varied; TEMPERATURE=temperature varied; VAPOR PRESS DEFICIT = vapor pressure deficit varied; WATER POTENTIAL = Water potential varied; DARK RESPIRATION=temperature varied in dark; HUMIDITY=humidity varied; CONSTANT CONDITIONS=nothing varied; STOMATAL MODEL=many things varied for model calibration.
LEAF_TEMP	The measured leaf or shoot temperature
AIR_TEMP	The measured air temperature.
CO2_CONC	CO2 concentration.
TRANSPIRATION_RATE	Transpiration rate (E)
PHOTOSYNTHETIC_RATE	Measured Net Photosynthesis
DOWN_PPFD	The downward photosynthetic photon flux density.
INTERCELL_CO2_CONC	Intercellular CO2 concentration
STOMATAL_CONDUCT_CO2	Stomatal conductance to CO2 (gs)
WATER_USE_EFF	Water use efficiency
WATER_POTENTIAL	Water Potential
VAPOR_PRESS_DEFICIT	Vapor Pressure Deficit (VPD)
VAPOR_PRESS_DEFICIT_AIR_TEMP	The air temperature when vapor pressure deficit was varied.
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]
START_DATE	[DD-MON-YY]
END_DATE	[DD-MON-YY]
SPECIES	[none]
PARAM_VARIED	[none]
LEAF_TEMP	[degrees Celsius]
AIR_TEMP	[degrees Celsius]
CO2_CONC	[parts per million]
TRANSPIRATION_RATE	[millimoles][meter^-2][second^-1]
PHOTOSYNTHETIC_RATE	[micromoles][meter^-2][second^-1]
DOWN_PPFD	[micromoles][meter^-2][second^-1]
INTERCELL_CO2_CONC	[parts per million]
STOMATAL_CONDUCT_CO2	[millimoles][meter^-2][second^-1]
WATER_USE_EFF	[micromoles CO2][millimole H2O^-1]
WATER_POTENTIAL	[megaPascals]
VAPOR_PRESS_DEFICIT	[kiloPascals]
VAPOR_PRESS_DEFICIT_AIR_TEMP	[degrees Celsius]
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	BORIS Designation
SUB_SITE	BORIS Designation
START_DATE	BORIS Designation
END_DATE	BORIS Designation
SPECIES	Human Observer
PARAM_VARIED	Human Observer
LEAF_TEMP	Thermometer
AIR_TEMP	Thermometer
CO2_CONC	Laboratory Equipment
TRANSPIRATION_RATE	Laboratory Equipment
PHOTOSYNTHETIC_RATE	Laboratory Equipment
DOWN_PPFD	PPFD Sensor
INTERCELL_CO2_CONC	Laboratory Equipment
STOMATAL_CONDUCT_CO2	Laboratory Equipment
WATER_USE_EFF	Laboratory Equipment
WATER_POTENTIAL	Laboratory Equipment
VAPOR_PRESS_DEFICIT	Laboratory Equipment
VAPOR_PRESS_DEFICIT_AIR_TEMP	Thermometer
CRTFCN_CODE	BORIS Designation
REVISION_DATE	BORIS Designation

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-9OA-9TETR	NSA-OJP-FLXTR	None	None	None	None
SUB_SITE	9TE09-PHR01	9TE09-PHR01	None	None	None	None
START_DATE	24-MAY-94	30-AUG-94	None	None	None	None
END_DATE	16-JUN-94	19-SEP-94	None	None	None	None
SPECIES	N/A	N/A	None	None	None	None
PARAM_VARIED	N/A	N/A	None	None	None	None
LEAF_TEMP	-4.94	44.22	None	None	None	None
AIR_TEMP	-6.94	43.9	None	None	None	None
CO2_CONC	47.53	872	None	None	None	None
TRANSPIRATION_RATE	.004843	8	None	None	None	None
PHOTOSYNTHETIC_RATE	-4.55426	25.8703	None	None	None	None
DOWN_PPFD	0	1452	None	None	None	None
INTERCELL_CO2_CONC	31.526	667.147	None	None	None	None
STOMATAL_CONDUCT_CO2	.5891	149.8545	None	None	None	None
WATER_USE_EFF	-20.842	85.604	None	None	None	None
WATER_POTENTIAL	.15	3.95	None	None	None	Blank
VAPOR_PRESS_DEFICIT	.04	5.368694	None	None	None	None
VAPOR_PRESS_DEFICIT_AIR_TEMP	1	25	None	None	None	Blank
CRTFCN_CODE	CPI	CPI	None	None	None	None
REVISION_DATE	03-SEP-96	03-SEP-96	None	None	None	None

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

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

7.4 Sample Data Record

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

```
SITE_NAME,SUB_SITE,START_DATE,END_DATE,SPECIES,PARAM_VARIED,LEAF_TEMP,AIR_TEMP,
CO2_CONC,TRANSPIRATION_RATE,PHOTOSYNTHETIC_RATE,DOWN_PPFD,INTERCELL_CO2_CONC,
STOMATAL_CONDUCT_CO2,WATER_USE_EFF,WATER_POTENTIAL,VAPOR_PRESS_DEFICIT,
VAPOR_PRESS_DEFICIT_AIR_TEMP,CRTFCN_CODE,REVISION_DATE
'NSA-OBS-FLXTR','9TE09-PHR01',24-MAY-94,16-JUN-94,'Picea mariana','LIGHT',19.8,
19.8,359.3,.081231,-.58655,0.0,424.4152,7.836619,-7.22077,,.618614,,'CPI',
03-SEP-96
'NSA-OBS-FLXTR','9TE09-PHR01',24-MAY-94,16-JUN-94,'Picea mariana','LIGHT',20.3,
20.3,333.1,.195906,1.968549,1007.0,254.9745,20.48158,10.04844,,.570307,,'CPI',
03-SEP-96
```

8. Data Organization

8.1 Data Granularity

The smallest unit of orderable data is data collected on one day at one site.

8.2 Data Format(s)

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

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

9. Data Manipulations

9.1 Formulae

9.1.1 Derivation Techniques and Algorithms

A, E, gs-CO_2, and Ci were calculated according to von Caemmerer and Farquhar (1981), Planta 153: 376-387.

WUE = A/E

where: WUE = photosynthetic water use efficiency
A = net photosynthesis
E = transpiration rate

VPD = VPsat - Vpamt

where: VPD = vapor pressure difference
VPsat is saturated vapor pressure in the chamber
VPamt is measured vapor pressure in the chamber

9.2 Data Processing Sequence

9.2.1 Processing Steps

Data were recorded automatically by a computer and also printed on a printer. Subsequent calculations of different parameters were performed using MS Excel for Windows 5.0.

BOREAS Information System (BORIS) staff processed the data by:

- Reviewing the initial data files and loading them online for BOREAS team access.
- Designing relational data base tables to inventory and store the data.
- Loading the data into the relational data base tables.
- Performing the following conversions on measurements into System International (SI) units: - Changing PAR flux from (mol/m^2/s) to DOWN_PPFD (µmol/m^2/s)
- Working with the Terrestrial Ecology (TE)-09 team to document the data set.
- Extracting the standardized data into logical files.

9.2.2 Processing Changes

None.

9.3 Calculations

A, E, gs-CO_2, and Ci were calculated according to von Caemmerer and Farquhar (1981), Planta 153: 376-387.

WUE = A/E
VPD = VPsat - Vpamt

where: VPsat and VPamt are saturated vapor pressure and measured vapor pressure in the chamber.

9.3.1 Special Corrections/Adjustments

None.

9.3.2 Calculated Variables

A, E, gs-CO_2, and Ci were calculated according to von Caemmerer and Farquhar (1981), Planta 153: 376-387.

WUE = A/E
VPD = VPsat - Vpamt

where: VPsat and VPamt are saturated vapor pressure and measured vapor pressure in the chamber.

9.4 Graphs and Plots

Net photosynthesis versus ambient and internal CO_2 concentration. A, gs, WUE vs. P

10. Errors

10.1 Sources of Error

During photosynthetic response to temperature differences, condensation sometimes formed on the radiator inside the cuvette when the temperature went below 10 °C.

Possible genetic differences between trees and possible differences in physiological conditions between branches could cause inconsistencies in the data.

There are no other known sources of error.

10.2 Quality Assessment

Please contact Dr. Hank Margolis and Dr. Qinglai Dang if these data are used for publication (see Section 2.3, Contact Information).

10.2.1 Data Validation by Source

After each measurement, the sample was removed from the leaf cuvette and a base measurement (i.e., when cuvette contained no sample) was taken. The previous measurement was adjusted by this base value, if necessary.

10.2.2 Confidence Level/Accuracy Judgment

No statistical confidence level is yet available. However, the investigators are very confident that these data are reliable. Results are consistent with field measurements.

10.2.3 Measurement Error for Parameters

Unknown.

10.2.4 Additional Quality Assessments

Calculated results were plotted, and the patterns were examined. Obvious outliers (determined visually) were eliminated from the data set.

10.2.5 Data Verification by Data Center

Data were examined for general consistency and clarity

11. Notes

11.1 Limitations of the Data
None given.

11.2 Known Problems with the Data
None.

11.3 Usage Guidance
Parameters derived from this data set will be more applicable to aggregated foliage on the shoot as a whole than to individual needles or leaves.

11.4 Other Relevant Information
None.

12. Application of the Data Set

Data can be used to examine the influence of different factors on the photosynthetic process.

13. Future Modifications and Plans

None.

14. Software

14.1 Software Description
Calculations were performed using MS Excel for Windows 5.0.

14.2 Software Access
Contact Microsoft Corp.

15. Data Access

The NSA photosynthetic response 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

LI-COR 6262 Infrared gas analyzer manual.

17.2 Journal Articles and Study Reports

Dang, Q.L., H. Margolis, M.R. Coyea, M. Sy, and G.J. Collatz. 1997a. Regulation of branch-level gas exchange of boreal trees: roles of shoot water potential and vapor pressure difference. Tree Physiology, BOREAS Special Issue 17(8/9):521-535.

Dang, Q.L., H. Margolis, G.J. Collatz, et al. Parameterization and testing of a coupled photosynthesis stomatal conductance model for the boreal forest. Tree Physiology (in preparation).

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.

von Caemmerer, S. and G.D. Farquhar. 1981. Some relationships between biochemistry of photosynthesis and the gas exchange of leaves. Planta 153: 376-387.

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

A	- net photosynthesis (µmol $CO_2/m^2/s$)
A-Ci curve	- photosynthetic response to CO_2
Ci	- intercellular CO_2 concentration (ppm)
CO_2	- ambient CO_2 concentration (ppm)
E	- transpiration rate (mmol $H_2O/m^2/s$)
gs CO_2	- stomatal conductance to CO_2 (mmol/m^2/s)
P	- shoot water potential (MPa)
Tleaf	- leaf temperature (°C)
Tair	- air temperature (°C)
WUE	- photosynthetic water use efficiency (mmol CO_2/mol H_2O)

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
CGI	- Certified by Group
CPI	- Checked by Principal Investigator
DAAC	- Distributed Active Archive Center
EOS	- Earth Observing System
EOSDIS	- EOS Data and Information System
GIS	- Geographic Information System
GSFC	- Goddard Space Flight Center
HTML	- Hyper-Text Markup Language

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IFC     - Intensive Field Campaign
IRGA    - Infrared Gas Analyzer
NAD83   - North American Datum of 1983
NASA    - National Aeronautics and Space Administration
NSA     - Northern Study Area
ORNL    - Oak Ridge National Laboratory
PANP     - Prince Albert National Park
PAR      - Photosynthetically Active Radiation
PRE      - Preliminary
SSA      - Southern Study Area
URL      - Uniform Resource Locator
UTM      - Universal Transverse Mercator
VPD      - Vapor Pressure Difference (kPa)
```

20. Document Information

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When using these data, please contact one of the individuals listed in Section 2.3 as well as citations of relevant papers in Section 17.2.

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H. Margolis, "Relationship Between Measures of Absorbed and Reflected Radiation and the Photosynthetic Capacity of Boreal Forest Canopies and Understories." In Collected Data of The Boreal Ecosystem-Atmosphere Study. Eds. J. Newcomer, D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers. CD-ROM. NASA, 2000.

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13. ABSTRACT *(Maximum 200 words)*

The BOREAS TE-9 team collected several data sets related to chemical and photosynthetic properties of leaves. This data set describes (1) the response of leaf and shoot-level photosynthesis to ambient and intercellular CO_2 concentration, temperature, and incident PAR for black spruce, jack pine, and aspen during the three IFCs in 1994 in the NSA; (2) the response of stomatal conductance to vapor pressure difference throughout the growing season of 1994; and (3) a range of shoot water potentials (controlled in the laboratory) for black spruce and jack pine. The data are available in tabular ASCII files.

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