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Volume 29

BOREAS HYD-6 Aircraft Gamma Ray Soil Moisture Data

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BOREAS HYD-6 Aircraft Gamma Ray Soil Moisture Data

Eugene L. Peck, Thomas Carroll

Summary

The BOREAS HYD-6 team collected several data sets related to the moisture content of soil and overlying humus layers. This data set contains percent soil moisture (by weight) (and/or water content if there is a moss/humus layer) measured from aircraft using a terrestrial gamma ray instrument. There are also data that indicate the location of the aircraft at the time it collected the terrestrial gamma ray data for the various flight lines and bins. The location information contains a list of coordinates that indicate the path of the aircraft for each bin. The data were collected during four time periods from September 1993 to September 1994 over the SSA and two time periods from February to August 1994 over the NSA. The data are available in tabular ASCII files.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS HYD-06 Aircraft Gamma Ray Soil Moisture Data

1.2 Data Set Introduction

This data set contains airborne gamma radiation measurements of total available moisture. The total available moisture is the soil moisture of the mineral soil if there is not a moss/humus layer or standing water. With a moss/humus layer and/or standing water the total available moisture includes the moisture in these two variables (converted from centimeters to percent of soil moisture).

1.3 Objective/Purpose

The objectives of this research were:

- obtain improved estimates of the soil moisture conditions for the BOReal Ecosystem-Atmosphere Study (BOREAS) experimental areas
- develop techniques for measuring the water content of the moss/humus layer
- provide assistance to the Hydrology (HYD)-04 team in measuring the water equivalent of the snow cover
- provide information for validating and calibrating other remote sensing methods for measuring soil moisture
- provide information on soil moisture of the mineral soil, water content of the moss/humus layer, and (in conjunction with HYD-04) the water equivalent of the snow cover to other investigators

1.4 Summary of Parameters

The primary parameter is the airborne gamma radiation measurement of total available moisture. If there is not a moss/humus layer or standing water, the airborne estimate is the soil moisture of the mineral soil. With a moss/humus layer and/or standing water, the total available moisture includes the moisture in these two variables (converted from centimeters to percent of soil moisture).

This data set also provides flight line identifiers as well as latitudes and longitudes of the BOREAS airborne gamma radiation flight lines and for sections (bins) of the flight lines. The bins are equal divisions of the flight lines, and the number of bins is controlled primarily by the number of in situ measurements obtained for calibration of the flight lines.

1.5 Discussion

As part of the BOREAS experiment, natural terrestrial gamma radiation data over a network of 48 flight lines were collected. For each flight line, in situ measurements of the soil moisture of the mineral soil and the water content of the moss/humus were collected and used, along with other available soil moisture measurements, to establish one-time calibration of the natural terrestrial radioisotope signal for the flight lines.

1.6 Related Data Sets

BOREAS HYD-06 Moss/Humus Moisture Data
BOREAS HYD-06 Ground Gravimetric Soil Moisture Data

2. Investigator(s)

2.1 Investigator(s) Name and Title

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Dr. Thomas Carroll
National Weather Service (NWS)

2.2 Title of Investigation

Remote Sensing of Hydrologic Variables in Boreal Areas

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3. Theory of Measurements

Airborne Soil Moisture Measurements

Airborne soil moisture measurements are based on the difference between natural terrestrial gamma radiation flux measured for comparatively wet and dry soils. The presence of additional moisture in the soil, and in the moss/humus layer when it exists, increases the mass that radiation emitting from the ground has to go through to reach the radiation sensors in the aircraft. This results in increased attenuation of the gamma flux for relatively wet soil and a corresponding decrease in the attenuation of the radiation flux for dryer soil conditions. The gamma flux from the ground is a function primarily of the water mass and radioisotopes concentration near the surface of the soil (which remains constant over time). Only the mass of the moisture, not the phase, affects the attenuation of the gamma radiation. The gamma flux originates from the potassium, uranium, and thorium radioisotopes in the soil. In a typical soil, 91 percent of the gamma radiation is emitted from the top 10 cm of the soil, 96 percent from the top 20 cm, and 99 percent from the top 30 cm. Other sources of radiation, which contribute to gamma flux measurement in the aircraft, include the daughter products of radon gas in the atmosphere, high energy cosmic particles (i.e., greater than 3.0 MeV), and trace sources of radioactivity within the aircraft and the detection system itself (Carroll, 1981).

A nondifferentially corrected Global Positioning System (GPS) was used to locate the aircraft for many of the flight lines. See Section 7.3.1 for more information.

4. Equipment

4.1 Sensor/Instrument Description

The airborne detector package consists of five downward-looking 10.2- x 10.2- x 40.6-cm NaI (Tl) scintillation detectors; two 10.2- x 10.2- x 20.3-cm, upward-looking detectors (used to isolate the effects of the random gas contribution); a pulse height analyzer (PHA); a Hewlett-Packard 9825 minicomputer used to reduce and record the output data onto magnetic tape; temperature, pressure, and radar altitude sensors; and a remote control unit used by the system operator or navigator to control and monitor the data collection (Carroll and Allen, 1988).

A video camera is used to obtain recording of the area immediately under the aircraft. Video tapes are available for lines flown in September 1993 and during Intensive Field Campaign (IFC)-2 and IFC-3 in 1994. Overview pictures at different altitudes were obtained for the area near the Old Black Spruce (OBS), Old Jack Pine (OJP), Young Aspen (YA), and flight line BP114 during IFC-3 in the Southern Study Area (SSA).

4.1.1 Collection Environment

During data acquisitions, the nominal altitude for the Aero Commander aircraft is 150 m Above Ground Level (AGL).

4.1.2 Source/Platform

The sensing platform is a twin-engine Aero Commander Aircraft.

4.1.3 Source/Platform Mission Objectives

The mission objective was to collect spectral gamma radiation information along established flight lines to provide estimates of the mean areal soil moisture, the water content of the moss/humus layer, and the water equivalent of the snow cover (in support of HYD-04).

4.1.4 Key Variables

The key variable is the airborne gamma radiation measurement of total available moisture. This is the soil moisture of the mineral soil if there is not a moss/humus layer or standing water. With a moss/humus layer and/or standing water, the total available moisture includes the moisture in these two variables (converted from centimeters to percent of soil moisture).

4.1.5 Principles of Operation

The 48 flight lines surveyed for the BOREAS investigation averaged 10.7 km in length. Data collected during calibration surveys, in which background gamma radiation data and ground-based soil moisture data are collected simultaneously, are used to calibrate each flight line. Once a flight line is calibrated, airborne soil moisture measurements can be made with no future ground-based data support required. Reliable, real-time, mean areal soil moisture measurements can be made for the upper 20 cm of soil (and of the water content of the moss/humus layer) along the flight line once both the background and current, uncollided terrestrial gamma count rates and background soil moisture data are available. To separate the change in the reduction of the radiation due to the moisture in the soil moisture and the water content of the moss/humus layer, an estimate of the average of one or the other is required. Detailed information on the operation of the airborne gamma radiation system can be found in the users guide (Carroll and Allen, 1988).

4.1.6 Sensor/Instrument Measurement Geometry

The aircraft flies at an altitude of 150 m AGL and measures natural terrestrial gamma radiation over a path 305 m wide. Consequently, radiation data collected over each BOREAS flight line are mean areal measurements over approximately 3.3 km^2.

4.1.7 Manufacturer of Sensor/Instrument

The radiation sensors onboard the aircraft have been customized by the NWS, National Oceanic and Atmospheric Administration (NOAA), Minneapolis, MN. The manufacturer of the GPS unit used

to locate the flight lines is unknown.

4.2 Calibration

4.2.1 Specifications

Calibration of the airborne gamma radiation equipment is accomplished by collecting radiation data at different altitudes and using the changing airmass as an attenuation medium. A reliable calibration can be generated in one area and used in another with a different radioisotope concentration. During the calibration procedure, stripping equations are derived for isolating other extraneous sources of radiation (Carroll, 1987).

4.2.1.1 Tolerance

The radioisotope concentration in the soil does not significantly change with time; consequently, there is no need for additional background data collection once a radiation spectrum has been collected for a particular flight line.

4.2.2 Frequency of Calibration

The airborne technique requires a one-time flight line calibration in which background gamma radiation data and ground-based soil moisture data are collected simultaneously and used to calibrate each flight line.

4.2.3 Other Calibration Information

None given.

5. Data Acquisition Methods

Airborne Radiation Flight Lines

Radiation information was collected for 48 flight lines during the BOREAS field experiment (four of the flight lines were established after the first flights in September 1993). Maps showing locations of all of the 48 established flight lines (except for BP121 over the OJP tower site in the SSA, BP122 a north-south line east of the north-south highway to the east of the Young Jack Pine (YJP) and Fen tower sites in the SSA, and BP123 established over the YA tower site in the SSA) are shown in Figures 5.2.1.4a, 5.2.1.4b, and 5.2.1.4c of Version 3.0 of the BOREAS Experimental Plan. Revised computerized maps of all of the 48 flight lines prepared by the National Operational Hydrologic Remote Sensing Center (NOHRSC) have been submitted to the BOREAS Information System (BORIS).

Location of Flight Lines

Maps showing locations of most of the established flight lines are presented on Figures 5.2.1.4a, 5.2.1.4b, and 5.2.1.4c of Version 3.0 of the BOREAS Experimental Plan. Flight lines BP121, BP122, and BP123 were added later.

The flight lines are numbered BP100 to BP123 and CR954 to CR960 in the SSA and BP201 to BP213 in the Northern Study Area (NSA). Flight lines BP301 to BP305 are located along the transect between the SSA and NSA. The CR lines in the SSA are part of the operational snow measurement program of the Atmospheric Environment Service (AES) of Canada.

6. Observations

6.1 Data Notes

None.

6.2 Field Notes

Computer tapes of the airborne gamma radiation data for all airborne flights are available (from NOHRSC) but are not in BORIS. A large number of complex computer programs are required for processing the data to obtain the airborne soil moisture estimates.

Ground measurements were collected during September 1993 for a proposed north-south flight line on the western side of the highway directly east of the YJP and Fen tower sites in the SSA. Ground and airborne observations clearly indicated that the vegetation over the area to be measured by the airborne gamma surveys was highly variable, so much so that any reasonable number of measurements could not provide acceptable information on average conditions along the flight line. Information collected for this proposed line is listed under flight line BP140 in the ground measurements of soil moisture.

Very High Cosmic Radiation Observed

During the 3-day period from 08- to 10-Sep-1994, very unusual high cosmic radiation was observed during the soil moisture airborne surveys in the SSA. A paper was presented at the March 1995 BOREAS workshop in Ellicott City, MD (Peck and Carroll, 1995), describing the collection and analyses of the observed data. The high solar protons that apparently originated from solar flares had not been observed during the entire year of airborne BOREAS surveys. A review of 15 years of approximately 14,000 records for 7 provinces of Canada and 25 states in the United States maintained by NOHRSC of NWS found no case with cosmic radiation as high as that observed during each day of the 3-day period. Fortunately, procedures developed during the First International Satellite Land Surface Climatology Project (ISLSCP) Field Experiment (FIFE) permit the computation of soil moisture (total moisture) estimates using only radiation collected by the airborne system that are not affected by the high radiation. All BOREAS airborne gamma estimates have been derived using the FIFE procedure. The primary question raised in the paper is "Does the high cosmic radiation observed affect measurements by other BOREAS scientists?"

7. Data Description

7.1 Spatial Characteristics

The two BOREAS study areas cover over a million square kilometers in the Canadian provinces of Saskatchewan and Manitoba. Each of the principal study areas (NSA and SSA) is approximately 50 by 100 km.

The flight line locational information provides latitude and longitude (in decimal form) for each flight line. Each flight line is divided into a specific number (varying from 2 to 6) of equally spaced bins (sections). The latitude and longitude of the start and end point of each leg of each bin are provided. The first leg of the first bin begins at the start of the flight line, and the final leg of the final bin extends to the end of the flight line. An example is shown in Section 7.4.

The latitude and longitude given in these data were read automatically by the GPS aboard the aircraft during aerial surveys in February 1995 for all but the following flight lines: BP123, BP301, BP302, BP303, BP304, and BP305. Location values for BP123 were read from U.S. Geological Survey (USGS) maps in North American Datum of 1983 (NAD83). Values for the BP300s lines were read from USGS maps in North American Datum of 1927 (NAD27) and converted to NAD83 values. All longitude and latitude values in the data base are equivalent to NAD83. For each of the four categories of flight lines (BPxxx lines in the SSA, BPxxx lines in the NSA, BPxxx lines along the transect, and the CRxxx lines in the SSA), the number of flight lines and the number of bins are shown in the table in Section 7.1.3 (with the average length and the average areal coverage).

7.1.1 Spatial Coverage

These data were collected at the two BOREAS study areas, which are located within a large area of interest covering over a million square kilometers in the Canadian provinces of Saskatchewan and Manitoba. Each of the study areas is approximately 50 by 100 km.

The aircraft flies at an altitude of 150 m AGL and measures natural terrestrial gamma radiation, on average, over an average path 10.7 km long and 305 m wide, or an areal extent of 3.3 km^2. Soil moisture and water content of the moss/humus layer samples were collected at various points along the flight. The number and timing of the flight lines flown each day were determined by the need for ground calibration and on the basis of need for other studies (priority was given where possible to obtaining measurements over flight lines associated with ground tower sites) and the amount of flight hours remaining for the aircraft before required maintenance.

These measurements were made within the NSA and SSA and along a transect that is between these two study areas. There is a reference table called HYD06_TRANSECT_REF that contains information about the location of the various flight lines.

NSA Spatial Coverage (NAD83)

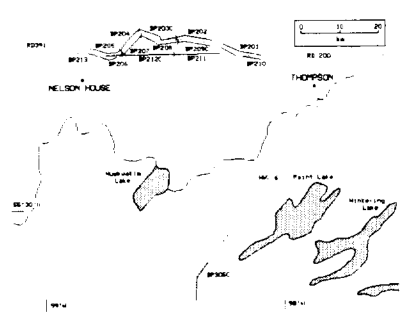
	Longitude	Latitude
Northwest	98.82 W	56.247 N
Northeast	97.24 W	56.081 N
Southeast	97.49 W	55.377 N
Southwest	99.05 W	55.54 N

SSA Spatial Coverage

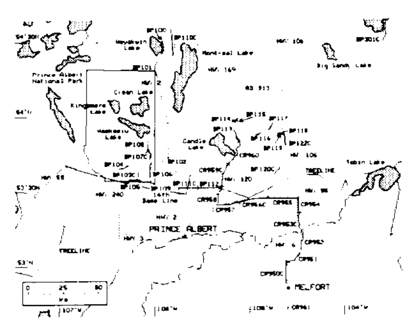
	Longitude	Latitude
Northwest	106.23 W	54.319 N
Northeast	104.24 W	54.223 N
Southeast	104.37 W	53.419 N
Southwest	106.32 W	53.513 N

7.1.2 Spatial Coverage Map

The following maps are provided courtesy of the HYD-04 BOREAS team, led by Dr. Barry Goodison.



Map of flight lines in the BOREAS Northern Study Area (NSA)



Map of flight lines in the BOREAS Southern Study Area (SSA)

7.1.3 Spatial Resolution

Table 1: Number and average coverage of flight lines and bins of flight lines

Category		Number of Flight Lines	Average Length km	Average Area km^2		Number of Bins	Average Length km	Average Area km^2
BP100-BP123		24	8.0	2.4		80	2.4	0.7
BP201-BP213		13	10.3	3.1		33	4.0	1.2
BP301-BP305		5	17.0	5.2		15	5.7	1.7
CR954		7	16.1	4.9		24	4.7	1.4

7.1.4 Projection

The geographic coordinates are NAD83 latitude and longitude values.

7.1.5 Grid Description

Not applicable.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

The data were collected for as many flight lines as possible during the following periods:

```
08-Sep-1993 to 11-Sep-1993 in the SSA
07-Feb-1994 to 11-Feb-1994 in the SSA and NSA (in cooperation with HYD-04)
24-Jul-1994 to 05-Aug-1994 in the SSA and NSA
30-Aug-1994 to 10-Sep-1994 in the SSA
```

7.2.2 Temporal Coverage Map

See Section 7.2.1.

7.2.3 Temporal Resolution

Airborne surveys were conducted on a daily basis. The timing of the aerial surveys was controlled by BOREAS operations.

7.3 Data Characteristics

7.3.1 Parameter/Variable

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

AIRCRAFT SOIL MOISTURE DATA

Column Name
HYD06_SITE_ID
DATE_OBS
TIME_OBS
FLIGHT_LINE
HYD06_BIN
TOTAL_MOISTURE
MEAN_WATER_CONTENT_MOSS_HUMUS
CRTFCN_CODE
REVISION_DATE

AIRCRAFT TRANSECT REFERENCE DATA

The flight line locational information provides latitude and longitude (in decimal form) for each flight line. Each flight line is divided into a specific number (varying from 2 to 6) of equally spaced bins (sections). The latitude and longitude of the start and end point of each leg of each bin are listed. The first leg of the first bin begins at the start of the flight line and the final leg of the final bin extends to the end of the flight line. An example of these data is shown in Section 7.4.

The latitude and longitude given in these data were read automatically by the GPS aboard the aircraft during aerial surveys in February 1995 for all but the following flight lines, BP123, BP301, BP302, BP303, BP304, and BP305. Locations values for BP123 were read off of USGS maps in NAD83. Values for the BP300s lines were read off USGS maps in NAD27 and converted to NAD83 values. All longitude and latitude values in the data base are equivalent to NAD83.

Column Name
HYD06_SITE_ID
FLIGHT_LINE
HYD06_BIN
HYD06_LEG_NUM
START_LATITUDE
START_LONGITUDE
END_LATITUDE
END_LONGITUDE
START_BOREAS_X
START_BOREAS_Y
END_BOREAS_X
END_BOREAS_Y
REVISION_DATE

7.3.2 Variable Description/Definition

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

AIRCRAFT SOIL MOISTURE DATA

Column Name	Description
HYD06_SITE_ID	The identifier assigned to the site by BOREAS, in the format AAA-FFF-GGGGG-SMAC01 where AAA is the study area, FFF is the flight line number, GGGGG is the science group, and SMAC01 stands for Soil Moisture Aircraft.
DATE_OBS	The date on which the data were collected.
TIME_OBS	The Greenwich Mean Time (GMT) when the data were collected.
FLIGHT_LINE	The designation for the line/transect over which the aircraft flew.
HYD06_BIN	The HYD-06 designation for the part of the flight line over which the soil moisture measurement was derived.
TOTAL_MOISTURE	The percent moisture of mineral soil and moss layer (if present) derived from gamma ray emissions for the bin or flight line.
MEAN_WATER_CONTENT_MOSS_HUMUS	The average water content of the moss/humus layer for the in situ bin measurements.
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.

AIRCRAFT TRANSECT REFERENCE DATA

Column Name	Description
HYD06_SITE_ID	The identifier assigned to the site by BOREAS, in the format AAA-FFF-GGGGG-SMAC01 where AAA is the study area, FFF is the flight line number, GGGGG is the science group, and SMAC01 stands for Soil Moisture Aircraft.
FLIGHT_LINE	The designation for the line/transect over which the aircraft flew.
HYD06_BIN	The HYD-06 designation for the part of the flight line over which the soil moisture measurement was derived.
HYD06_LEG_NUM	The HYD-06 designation for a portion of the bin.
START_LATITUDE	The NAD83 based latitude coordinate at the start of the measurement set.
START_LONGITUDE	The NAD83 based longitude coordinate at the start of the measurement set.
END_LATITUDE	The NAD83 based latitude coordinate at the end of the measurement set.
END_LONGITUDE	The NAD83 based longitude coordinate at the end of the measurement set.
START_BOREAS_X	The x component of the BOREAS grid coordinate at

	the start of the measurement set.
START_BOREAS_Y	The y component of the BOREAS grid coordinate at the start of the measurement set.
END_BOREAS_X	The x component of the BOREAS grid coordinate at the end of the measurement set.
END_BOREAS_Y	The y component of the BOREAS grid coordinate at the end of the measurement set.
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:

AIRCRAFT SOIL MOISTURE DATA

Column Name	Units
HYD06_SITE_ID	[none]
DATE_OBS	[DD-MON-YY]
TIME_OBS	[HHMM GMT]
FLIGHT_LINE	[none]
HYD06_BIN	[none]
TOTAL_MOISTURE	[percent]
MEAN_WATER_CONTENT_MOSS_HUMUS	[millimeters]
CRTFCN_CODE	[none]
REVISION_DATE	[DD-MON-YY]

AIRCRAFT TRANSECT REFERENCE DATA

Column Name	Units
HYD06_SITE_ID	[none]
FLIGHT_LINE	[none]
HYD06_BIN	[none]
HYD06_LEG_NUM	[none]
START_LATITUDE	[degrees]
START_LONGITUDE	[degrees]
END_LATITUDE	[degrees]
END_LONGITUDE	[degrees]
START_BOREAS_X	[kilometers]
START_BOREAS_Y	[kilometers]
END_BOREAS_X	[kilometers]
END_BOREAS_Y	[kilometers]
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:

AIRCRAFT SOIL MOISTURE DATA:

Column Name	Data Source
HYD06_SITE_ID	[Assigned by BORIS]
DATE_OBS	[Supplied by Investigator]
TIME_OBS	[Supplied by Investigator]
FLIGHT_LINE	[Supplied by Investigator]
HYD06_BIN	[Supplied by Investigator]

TOTAL_MOISTURE	[Supplied by Investigator]
MEAN_WATER_CONTENT_MOSS_HUMUS	[Supplied by Investigator]
CRTFCN_CODE	[Assigned by BORIS]
REVISION_DATE	[Assigned by BORIS]

AIRCRAFT TRANSECT REFERENCE DATA

Column Name	Data Source
HYD06_SITE_ID	[Assigned by BORIS]
FLIGHT_LINE	[Supplied by Investigator]
HYD06_BIN	[Supplied by Investigator]
HYD06_LEG_NUM	[Supplied by Investigator]
START_LATITUDE	[Supplied by Investigator]
START_LONGITUDE	[Supplied by Investigator]
END_LATITUDE	[Supplied by Investigator]
END_LONGITUDE	[Supplied by Investigator]
START_BOREAS_X	[Calculated by BORIS from LATITUDE and LONGITUDE]
START_BOREAS_Y	[Calculated by BORIS from LATITUDE and LONGITUDE]
END_BOREAS_X	[Calculated by BORIS from LATITUDE and LONGITUDE]
END_BOREAS_Y	[Calculated by BORIS from LATITUDE and LONGITUDE]
REVISION_DATE	[Assigned by BORIS]

7.3.5 Data Range

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

AIRCRAFT SOIL MOISTURE DATA

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
HYD06_SITE_ID	N/A	N/A	None	None	None	None
DATE_OBS	01-AUG-93	10-SEP-94	None	None	None	None
TIME_OBS	0	2355	None	None	None	None
FLIGHT_LINE	BP100	CR960	None	None	None	None
HYD06_BIN	1	S	None	None	None	None
TOTAL_MOISTURE	1	361.5	None	-888	None	Blank
MEAN_WATER_CONTENT_MOSS_HUMUS	0	164	None	-888	None	Blank
CRTFCN_CODE	CPI	CPI-???	None	None	None	None
REVISION_DATE	11-JUL-95	10-APR-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.

AIRCRAFT TRANSECT REFERENCE DATA

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
HYD06_SITE_ID	N/A	N/A	None	None	None	None
FLIGHT_LINE	BP100	CR960	None	None	None	None
HYD06_BIN	1	6	None	None	None	Blank
HYD06_LEG_NUM	1	13	None	None	None	Blank
START_LATITUDE	49.596	55.94	None	None	None	None
START_LONGITUDE	-107.2165	-98.093	None	None	None	None
END_LATITUDE	49.596	55.94	None	None	None	None
END_LONGITUDE	-107.2165	-98.09515	None	None	None	None
START_BOREAS_X	269.472	802.191	None	None	None	None
START_BOREAS_Y	-134.599	619.148	None	None	None	None
END_BOREAS_X	269.472	802.281	None	None	None	None
END_BOREAS_Y	-134.599	619.141	None	None	None	None
REVISION_DATE	10-JUL-95	03-MAR-97	None	None	None	Blank

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

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                    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 Records

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

```
AIRCRAFT SOIL MOISTURE DATA

HYD06_SITE_ID,DATE_OBS,TIME_OBS,FLIGHT_LINE,HYD06_BIN,TOTAL_MOISTURE,
MEAN_WATER_CONTENT_MOSS_HUMUS,CRTFCN_CODE,REVISION_DATE
'SSA-108-HYD06-SMAC01',01-AUG-93,0,'BP108','1',15.2,,'CPI',11-JUL-95
'SSA-108-HYD06-SMAC01',01-AUG-93,0,'BP108','2',15.2,,'CPI',11-JUL-95
'SSA-108-HYD06-SMAC01',01-AUG-93,0,'BP108','3',12.5,,'CPI',11-JUL-95
'SSA-108-HYD06-SMAC01',01-AUG-93,0,'BP108','S',14.3,,'CPI',11-JUL-95

AIRCRAFT TRANSECT REFERENCE DATA

HYD06_SITE_ID,FLIGHT_LINE,HYD06_BIN,HYD06_LEG_NUM,START_LATITUDE,
START_LONGITUDE,END_LATITUDE,END_LONGITUDE,START_BOREAS_X,START_BOREAS_Y,
END_BOREAS_X,END_BOREAS_Y,REVISION_DATE
'SSA-100-HYD06-SMAC01','BP100','1',1,54.44102,-105.94402,54.4441,-105.93901,
327.366,394.836,327.665,395.201,10-JUL-95
'SSA-100-HYD06-SMAC01','BP100','1',2,54.4441,-105.93901,54.44705,-105.93304,
327.665,395.201,328.027,395.557,10-JUL-95
'SSA-100-HYD06-SMAC01','BP100','1',3,54.44705,-105.93304,54.45112,-105.92707,
328.027,395.557,328.38,396.038,10-JUL-95
'SSA-100-HYD06-SMAC01','BP100','1',4,54.45112,-105.92707,54.45504,-105.9211,
328.38,396.038,328.734,396.502,10-JUL-95
```

8. Data Organization

8.1 Data Granularity

The smallest amount of data that can be ordered from this data set is a day's worth of data.

8.2 Data Format(s)

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

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

9. Data Manipulations

9.1 Formulae

See Section 9.3.

9.1.1 Derivation Techniques and Algorithms

See Section 9.3.

9.2 Data Processing Sequence

The airborne radiation data are processed by NOHRSC to compute the calibration radiation window data used for computing the estimates of total moisture for days without observed ground data. The calibration ground data were prepared in table format with average values for flight lines (and each bin of flight lines) of the observed soil moisture of the mineral soil and the water content of the moss/humus layer.

9.2.1 Processing Steps

The airborne radiation data are recorded on the aircraft computer for each 5 seconds of flight time. The airborne radiation data are processed by NOHRSC to compute the radiation window values for each flight line and bin. Average flight line and bins values of in situ measurements of the soil moisture of the mineral soil and the water content of the moss/humus layer are used with the airborne radiation data in calibrating each flight line. The radiation window counts per minute are used with the calibration data for computing the airborne estimates of total moisture.

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 conversions on measurements into System International (SI) units.
- Working with the HYD-06 team to document the data set.
- Extracting the standardized data into logical files.

9.2.2 Processing Changes

None.

9.3 Calculations

Soil moisture is computed using the current uncollided terrestrial gamma count rate for each of the photopeak windows used by the following equation:

$$\text{soil moisture} = ((C_0/C)(100 + 1.11 * M_0) - 100)/(1.11)$$

where: C = current uncollided terrestrial gamma count for each of the three photopeak windows used.

C_0 = Background uncollided terrestrial gamma count rate in each of the three photopeak windows used.

M and M_0 = current (airborne) and background (ground-based) soil moisture for the upper 20 centimeters. Soil moisture is defined as soil moisture weight divided by dry sample weight.

Incorporated in the above equation are two coefficients: 1.11 represents the ratio of gamma radiation attenuation in water to air; and 100 is used because the percent soil moisture (by weight) is reported as a percentage.

The estimated soil moisture for the BOREAS airborne gamma radiation surveys is determined by weighing the estimates computed using the potassium ^{40}K and thallium ^{208}Tl windows with the First ISLSCP Field Experiment (FIFE) weighing factors (see Table 2, Section 9.3.1) by the following

equation:

soil moisture = 0.565 * (Potassium ^{40}K estimate + 0.435) * Thallium ^{208}Tl estimate

9.3.1 Special Corrections/Adjustments

The standard NWS operational procedure uses weighing factors for the potassium (40K, 1.26-1.56 MeV), thallium (208Tl, 2.41-2.81 MeV) and gross count (0.41-3.0 MeV) windows to compute estimates computed for each window to a single weighted estimate of the total moisture. Under normal cosmic radiation activity, the computed estimates are not significantly different from estimates computed using weighing factors developed during FIFE (Carroll et al., 1988). The FIFE procedure uses only the potassium and thallium radiation windows values. Since the very high cosmic radiation on 08-Sep-1994 through 10-Sep-1994 had a very large effect on the gross count window measurements and not on the potassium and thallium windows, the FIFE weighing factors have been used for all BOREAS airborne estimates. The NWS standard and FIFE weighing factors are shown in Table 2.

Table 2: NWS and FIFE radiation windows weighting factors

Radiation Window	NWS Weighing Factors	FIFE Weighing Factors
Potassium ^{40}K	0.346	0.565
Thallium ^{208}Tl	0.518	0.435
Gross Count	0.136	0.000

9.3.2 Calculated Variables

See other portions of Section 9.

9.4 Graphs and Plots

Maps of the BOREAS flight lines, digitized by NOHRSC, have been submitted to BORIS.

10. Errors

10.1 Sources of Error

There are many possible sources of error in the airborne estimates of soil moisture. Some of these result from abnormally high radon activity, especially if the percent of soil moisture is very low. The largest errors results from nonrepresentative calibration data (Peck et al., 1992). Fritzsche (1979) discusses the errors associated with the calibration of the gamma radiation system.

Errors in the locations of the flight lines and bins are primarily associated with the difficulty in reading the GPS values at the start and end points of the flight lines while flying at 150 meters. Maintaining the aircraft exactly over the flight line during an aerial survey is difficult. Some of the variations in the latitude and longitude values along the flight lines are due to the difficulty of maintaining the aircraft over the flight line.

10.2 Quality Assessment

10.2.1 Data Validation by Source

Confidence in the airborne gamma radiation estimates of the total moisture depends on many factors regarding the accuracy of the flight line in respect to the flight line flown during calibration of the line.

10.2.2 Confidence Level/Accuracy Judgment

The confidence level varies with the experience of the person selecting the flight line or marking the location of the ground measurement for collection of ground calibration data. In very flat areas, the exact location of a ground measurement site is more difficult to identify on a map than a location near a stream or in areas of variable terrain. Soil moisture measurements over nonforested areas during the FIFE experiments had a root mean square error of approximately 2.5 percent (Peck et al., 1990).

10.2.3 Measurement Error for Parameters

The start and end points of flight lines are generally associated with visual ground locations that can be readily located by the aircraft flight crew (roads, trails, streams, or edges of clearings). No error can be determined for locating ground measurement sites from the flight line selected for airborne measurement.

The calibration of the flight line is very important in the accuracy of the airborne estimates. The principal objective of calibration is to obtain measurements along the flight line that are representative of the average conditions of the area measured by the system. The selection of the sites for in situ measurements of the soil moisture and the water content of the moss/humus layer is very critical to the usefulness of measured values. During the development of the airborne system in the United States, it was clear that using a grid method to collect soil moisture samples over farmland in Minnesota was not viable. One or more measurements taken in shallow, low ravines subject to high soil moisture following periods of runoff-producing precipitation would result in average soil moisture values for sections of farmland that would not correlate with the airborne estimates. In Minnesota, soil moisture observations of average land slope (i.e., 1 to 2 percent) of corn fields or other crops were found to be best correlated with airborne measurements (Peck et al., 1975).

10.2.4 Additional Quality Assessments

Experience with the airborne gamma radiation system during FIFE illustrated the need to obtain ground measurements representative of the average of the area from which ground-based gamma are received by the airborne detectors. During FIFE, a few lines were established in areas where permission to traverse the entire line on foot was not possible. Airborne estimates for other days without ground truth measurements showed that the estimated values tended to be reasonable when the average soil moisture of the future flight was approximately equal to that obtained during calibration. However, during periods when the average soil moisture departed significantly, either high or low, from the calibration average, the estimates for one or more bins along the line would appear to be exceptionally high or low (Peck, 1992).

During the BOREAS field experiments, careful attention has been given to obtaining as representative measurements of in situ soil moisture along the flight lines as possible. Most of the originally established flight lines were located over areas having as consistent vegetative cover as possible (i.e., all old aspen). However, in some areas, due to heterogeneous conditions, it was not possible to judge what measurements would provide representative averages.

Initially, a flight line on the west side of the north-south highway just east of the Fen and YJP sites in the SSA was considered. While collecting soil moisture and moss/humus measurements along the proposed line, it was clear that the large variability in the vegetative cover (from open areas, to burned areas, to heavy forested areas) made it impractical to obtain representative measurements, and the attempt to establish a line was given up. The ground data for this proposed line are in BORIS under flight line BP140. Later, a request was received for a north-south line east of the same highway. Flight line BP122 was established and flown for most of the 1994 field experiment. Review of the estimates obtained for line BP122 indicate that the soil moisture estimates are inconsistent with expected conditions, and most, if not all, of the estimates have been disregarded.

When the flight and bin estimates are consistently in line with other measurements, for all ranges of conditions, it is clear that the calibration of the line is representative. The calibration of most of the flight lines in the SSA appears to be very good, and the soil moisture estimates are considered to be very representative.

The experience of the person selecting the in situ sites and the consistency of the vegetative cover over the flight line are the two most important factors for obtaining representative calibrations of flight

lines and maintaining quality control. Even with careful attention to selection of the ground measurement sites for calibration, the airborne estimates for a few bins along some flight lines have been found to be nonrepresentative. For these lines, the estimated values for soil moisture conditions that varied considerably from those during calibration are either much higher or lower than those for nearby bins or flight lines. During evaluation of the airborne estimate, it is generally evident which bin calibration data are not representative. Estimates for bins (or flight lines) that are clearly out of line have been disregarded. When the data are questionable, the data have been labeled as nonrepresentative with a CRTFCN_CODE of CPI-??? and -888 as the data value.

All of the airborne estimates are being checked by comparison with available soil moisture measurements along the same and nearby lines. As additional soil moisture values become available, additional quality control will be done.

10.2.5 Data Verification by Data Center

These data were reviewed to make sure that data were loaded properly.

11. Notes

11.1 Limitations of the Data

None given.

11.2 Known Problems with the Data

See Section 10.

11.3 Usage Guidance

The airborne gamma radiation soil moisture estimates are only representative for the soil and vegetative conditions of the measured flight line. Considerable change in soil conditions may be found over short distances, even for the same vegetative cover. Careful review of the soil and vegetative conditions is necessary to transfer the soil moisture estimates to nearby areas. However, the use of the airborne estimates for flux analyses and other studies can add considerable information on the spatial and temporal variation in the soil moisture of the mineral soil and of the water content of the moss/humus layer. Maps and digital values of average soil moisture for each one-half square kilometer for the entire FIFE area have been prepared using all available soil moisture information (Peck and Hope, 1995). The report by Peck and Hope indicates the difficulty in preparing such maps but also presents cases showing the utility of such information.

11.4 Other Relevant Information

None.

12. Application of the Data Set

The use of the airborne estimates for flux analyses and other studies can add considerable information on the spatial and temporal variation in the soil moisture of the mineral soil and of the water content of the moss/humus layer. Maps and digital values of average soil moisture for each one-half square kilometer for the entire FIFE area have been prepared using all available soil moisture information (Peck and Hope, 1995). Similar information can be developed from the BOREAS data. The report by Peck and Hope indicates the difficulty in preparing such maps but also presents cases showing the utility of such information.

13. Future Modifications and Plans

None.

14. Software

14.1 Software Description

None given.

14.2 Software Access

None given.

15. Data Access

The HYD-06 aircraft gamma ray soil moisture 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/ [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

Video tapes taken over each flight line during calibration showing the area directly under the aircraft are available at NOHRSC. At the present time, no decision has been made on storing these tapes in BORIS.

16.3 Other Products

Maps showing the flight lines for which gamma data were obtained have been digitized by NOHRSC and submitted to BORIS. These maps appear as figures 5.2.1.4a, 5.2.1.4b, and 5.2.1.4c in version 3.0 of the BOREAS 1994 Experiment Plan. These data are available on the BOREAS CD-ROM series.

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17.2 Journal Articles and Study Reports

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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.

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

AES	- Atmospheric Environment Service of Canada
AGL	- Above Ground Level
ASCII	- American Standard Code for Information Interchange
BOREAS	- BOReal Ecosystem-Atmosphere Study
BORIS	- BOREAS Information System
BPI	- Bytes Per Inch
CCT	- Computer Compatible Tape
CD-ROM	- Compact Disk - Read-Only Memory
DAAC	- Distributed Active Archive Center
EOS	- Earth Observing System
EOSDIS	- EOS Data and Information System
EXP	- Experiment
FIFE	- First ISLSCP Field Experiment
FIS	- FIFE Information System (NASA)
GIS	- Geographic Information System
GMT	- Greenwich Mean Time
GPS	- Global Positioning System
GSFC	- Goddard Space Flight Center
HTML	- Hyper-Text Markup Language
HYD	- Hydrology (BOREAS science team)
IFC	- Intensive Field Campaign
ISLSCP	- International Satellite Land Surface Climatology Project
MeV	- Million Electronic Volts
NAD27	- North American datum of 1927
NAD83	- North American datum of 1983
NASA	- National Aeronautics and Space Administration
NOAA	- National Oceanic and Atmospheric Administration
NOHRSC	- National Operational Hydrologic Remote Sensing Center
NSA	- Northern Study Area
NWS	- National Weather Service
OA	- Old Aspen
OBS	- Old Black Spruce
OJP	- Old Jack Pine
ORNL	- Oak Ridge National Laboratory
PANP	- Prince Albert National Park
PHA	- Pulse Height Analyzer
SI	- System International
SM	- Soil moisture, percent by weight, of the mineral soil
SSA	- Southern Study Area
URL	- Uniform Resource Locator
USGS	- U.S. Geological Survey
WC	- Water content of the moss/humus layer
WE	- Water equivalent of the snow layer
YJP	- Young Jack Pine

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When using these data, please include the following acknowledgment as well as citations of relevant papers in Section 17.2:

Eugene L. Peck, President, Hydex Corporation Thomas Carroll, Chief, NOHRSC

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Peck, E.L. and T. Carroll, "Remote Sensing of Hydrologic Variables in Boreal Areas." 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 HYD-6 team collected several data sets related to the moisture content of soil and overlying humus layers. This data set contains percent soil moisture (by weight) (and/or water content if there is a moss/humus layer) measured from aircraft using a terrestrial gamma ray instrument. There are also data that indicate the location of the aircraft at the time it collected the terrestrial gamma ray data for the various flight lines and bins. The location information contains a list of coordinates that indicate the path of the aircraft for each bin. The data were collected during four time periods from September 1993 to September 1994 over the SSA and two time periods from February to August 1994 over the NSA. The data are available in tabular ASCII files.

14. SUBJECT TERMS
BOREAS, hydrology, terrestrial gamma ray instrument.

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