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BOREAS HYD-2 Estimated Snow Water Equivalent (SWE) from Microwave Measurements

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Summary

The surface meteorological data collected at the BOREAS tower and ancillary sites are being used as inputs to an energy balance model to monitor the amount of snow storage in the boreal forest region. The BOREAS HYD-2 team used SWE derived from an energy balance model and in situ observed SWE to compare the SWE inferred from airborne and spaceborne microwave data, and to assess the accuracy of microwave retrieval algorithms. The major external measurements that are needed are snowpack temperature profiles, in situ snow areal extent, and SWE data. The data in this data set were collected during February 1994 and cover portions of the SSA, NSA, and the transect areas. The data are available from BORIS as comma-delimited tabular ASCII files.

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1. Data Set Overview

1.1 Data Set Identification
BOREAS HYD-02 Estimated Snow Water Equivalent (SWE) from Microwave Measurements

1.2 Data Set Introduction
The estimated Snow Water Equivalent (SWE) data set contains SWE as obtained via airborne measurements. The time period of the experiment was 02-Feb to 18-Feb-1994 during the BORal Ecosystem-Atmosphere Study (BOREAS) winter focused field campaign (FFC-W). The instrumentation used was a series of microwave radiometers (specifically the 18-, 37-, and 92-GHz channels) that were mounted on a Twin Otter aircraft. The data set also contains other relevant data regarding the conditions under which each measurement was taken. For example, the temperature and dewpoint at the time of the measurement as well as the pitch and roll of the aircraft are also included.
1.3 Objective/Purpose
The objective of this investigation was to quantify the storage of water in snowpacks beneath the forest canopy. Ground water measurements were used as validation for the airborne and spaceborne SWE algorithm. This data set was created based on airborne microwave measurements to help address the question of the extent to which differences in surface cover affect snow storage.

1.4 Summary of Parameters
The specific parameters under observation for this experiment are the snowpack temperature profiles, the snow areal extent, and the SWE measured.

1.5 Discussion
During the 1994 FFC-W, 14 Twin Otter flights were made for the BOREAS project. Each of the 14 flights represents a number of different flight lines. The latitude and longitude of each data record are included with the data. Three microwave radiometers (18-, 37-, and 92-GHz) were mounted onboard the aircraft, in addition to videocameras and a PRT-5 thermal sensor. SWE was derived from the microwave radiometer data that were collected.

1.6 Related Data Sets
Nimbus-7 SMMR derived global snow depth maps (available through the National Snow and Ice Data Center (NSIDC), http://www-nsidc.colorado.edu/NASA/GUIDE/[Internet Link]).

2. Investigator(s)

2.1 Investigator(s) Name and Title

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Hydrological Sciences Branch

Co-Investigators:
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Hydrological Sciences Branch
Dr. James L. Foster
NASA GSFC
Hydrological Sciences Branch

2.2 Title of Investigation
Validation of a Passive Microwave Snow Water Equivalent Algorithm Using an Energy Balance Model
2.3 Contact Information

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3. Theory of Measurements

Microwave signatures have been used to infer SWE values over Canadian Prairie with some success (Goodison and Walker, 1993). Microwave radiation emanates from features on or near the surface of Earth at an intensity that is proportional to the product of the physical temperature and the emissivity of the surface. The measured value, referred to as the brightness temperature (TB), can simply be expressed as:

\[
TB = (R \times T_{\text{sky}} + (1 - R) \times T_{\text{surf}}e - t + T_{\text{atm}})
\]  

(1)

where e-t is the atmospheric transmissivity, R is the surface reflectivity, T<sub>sky</sub> is the sky radiation, T<sub>surf</sub> is the surface emission, and T<sub>atm</sub> is the emission from the intervening atmosphere. In the microwave region, both T<sub>sky</sub> and T<sub>atm</sub> are small and can be neglected. Thus, the observed TB is directly related to surface features.

Based on radiative transfer calculations (Chang et al., 1987), a relationship between brightness temperature and the number of snow crystals was developed for SWE retrieval. The differences between the 18- and 37-GHz horizontal polarization brightness temperature are linearly related to the SWE values when SWE is less than 200 mm. The scattering information comes largely from the 37-GHz signal. The 18-GHz signal serves as the background reference. The SWE - brightness temperature relationship of a homogeneous snow layer with crystals having a mean radius of 0.3 mm and density of 300 kg/m³ for the Scanning Multichannel Microwave Radiometer (SMMR) data can be expressed as follows (Chang et al., 1987):

\[
SWE = 4.8 \times (T_{18H} - T_{37H})
\]

(2)
where SWE is the snow water equivalent in mm of equivalent water, and T18H and T37H are the brightness temperatures for the 18- and 37-GHz horizontal polarizations, respectively. Both vertical and horizontal polarization will give generally similar results in Eq. (2). Because of the differences in the surface snow characteristics, researchers have used either vertical or horizontal polarization (Hallikainen and Jolma, 1992; Goodison and Walker, 1994) in retrieving the SWE. Rott and Aschbacher (1989) proposed a more generalized relationship of SWE and brightness temperature:

\[ \text{SWE} = A + B \times \text{DTB} \quad (3) \]

where A and B are the offset and slope for brightness temperature difference and DTB is the brightness temperature difference between a high-scattering channel (37- or 85-GHz) and a low-scattering channel (18- or 19-GHz) for vertical or horizontal polarization channels. Based on ground measurements of SWE in forests, A and B were determined for the airborne sensor in the boreal region. For this experiment, A and B are 0.0 and 1.7, respectively, when using the 18- and 37-GHz vertical polarization data.

The brightness temperature difference for forest-covered areas will cancel out if the emissivities of forest for both the high-scattering and the low-scattering channels are approximately the same. This is based on the findings that the emissivities for forest in Finland at 37 and 18 GHz are very similar and have the values of 0.9 to 0.92 (Hallikainen et al., 1988). Thus, only the snow-covered fraction contributes to the brightness temperature difference. For a footprint with a fraction of forest cover (f) and fraction snow cover (1-f), Eq. (3) will become

\[ \text{SWE} = 1.7 \times \text{DTB} / (1 - f) \quad (4) \]

Over the forested pixels, Eq. (3) would underestimate the SWE if not corrected for the forest cover. The amount of underestimation depends on the fraction of forest cover in Eq. (4). This equation was derived by Hallikainen for boreal forests in Finland that have similar forest conditions as the BOREAS sites. Because of the low sun angles for early February in the BOREAS test sites, accurate forest cover determination is difficult to obtain from the video. Therefore, fractional forest cover corrections were not included in this data set and f was set equal to 0. Data users may compute an estimate of the fractional forest cover from other BOREAS data sources and apply Eq. (4) to correct for the forest cover.

4. Equipment

4.1 Sensor/Instrument Description
Three dual polarization microwave radiometers at 18, 37, and 92 GHz were mounted onto a Canadian Twin Otter aircraft. Thermal radiation in the microwave region was measured using Dicke-type radiometers with two reference sources in 18, 37, and 92 GHz. The microwave radiation was received by square wave detectors. A PRT-5 infrared (IR) radiometer was also mounted on the aircraft.

4.1.1 Collection Environment
The data were collected during the BOREAS experiment FFC-W, which occurred from 02-Feb to 18-Feb-1994. The areas over which the data were collected included the BOREAS Northern Study Area (NSA), BOREAS Southern Study Area (SSA), and other surrounding areas. There were 14 flyovers for this particular investigation.

4.1.2 Source/Platform
Radiometers were mounted on the right side of the Twin Otter aircraft with a 45-degree look-angle.
4.1.3 Source/Platform Mission Objective
The mission of the Twin Otter was to serve as a platform for the brightness temperature measurements.

4.1.4 Key Variables
Brightness temperatures, IR temperature, and aircraft locations.

4.1.5 Principles of Operation
Dicke-type radiometers with two reference sources were used to measure brightness temperature. The 18-, 37-, and 92-GHz were Dicke radiometers (Ulaby et al., 1981). It was basically a total-power radiometer with (1) Dicke switch connected at the receiver input and used to modulate the input signal, and (2) a synchronous demodulator placed between the square-law detector and the low-pass filter. The predetection section consisted of the radio frequency (RF) amplifier, mixer, and intermediate frequency (IF) amplifier. It operated like a super-heterodyne radio receiver.

To stabilize the gain of the receiver, two internal microwave references were used, a warm load and a cold load, respectively. The warm loads were the ambient temperatures of the instrument, about 285 K. A noise diode was used as a cold load for the 18- and 37-GHz radiometers. For the 92-GHz radiometer, outside air was used to cool the cold load to about 240 K. Thus, the dynamic range of the 92-GHz radiometer is not optimum.

4.1.6 Instrument Measurement Geometry
The radiometers were set up such that a 45-degree angle looking out of the aircraft to the right was achieved. The pitch and roll of the aircraft were also recorded.

4.1.7 Manufacturer of Instrument
The radiometers were assembled at Goddard Space Flight Center (GSFC) using commercial parts. An Intel 486 IBM-compatible personal computer (PC) was used as the data logger.

4.2 Calibration
For the Dicke radiometer, a warm and a cold reference load are used to stabilize the gain. These international calibration load readings were taken once each minute. During the calibration cycle, no scene data were taken. External calibrations were performed by aiming the radiometer to known brightness temperature targets. Liquid nitrogen (77 K) and ambient Ecosorb target (290 K) were used as references. These calibrations were performed on the ground, while the instruments were mounted on the Twin Otter aircraft, before, during, and after the flight mission. Before and after shipping the instrument package, external calibrations were also done at GSFC. These calibrations were performed to make sure that there was no drift of the instrument during the BOREAS experiment.

4.2.1 Specifications
Radiometers were calibrated with clear sky, liquid nitrogen, and warm ecosorb targets.

4.2.1.1 Tolerance
Accuracy of the radiometers is about 2 K in nominal temperature range.

4.2.2 Frequency of Calibration
During a flight, calibration was done for 6 seconds out of every minute of data recording. External calibration was done twice during the mission.

4.2.3 Other Calibration Information
Losses for each component were measured in the laboratory in 1992.
5. Data Acquisition Methods

Microwave brightness temperatures were taken by aircraft from takeoff to landing, nominally lasting about 2 hours. Data were collected in 1-minute blocks, which included 6 seconds of calibration and 54 seconds of data from target. Data were recorded on the hard disk of a PC and were copied to other computers for further processing.

6. Observations

6.1 Data Notes

At the beginning of February 1994, the temperatures were very cold (about -40 °C), and the snowpack should have been dry. The temperature warmed up slowly during the 2 weeks of experimentation. During Flight 14, the air temperatures were close to 0 °C; thus, surface melting was possible. Data were taken over the NSA and SSA sites during the winter FFC.

6.2 Field Notes

None.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

Data were taken over the BOREAS NSA, SSA, and transect areas. The North American Datum of 1983 (NAD83) coordinates of the areas are:

**NSA**

<table>
<thead>
<tr>
<th>Corner</th>
<th>Longitude</th>
<th>Latitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest</td>
<td>98.82° W</td>
<td>56.247° N</td>
</tr>
<tr>
<td>Northeast</td>
<td>97.24° W</td>
<td>56.081° N</td>
</tr>
<tr>
<td>Southeast</td>
<td>97.49° W</td>
<td>55.377° N</td>
</tr>
<tr>
<td>Southwest</td>
<td>99.05° W</td>
<td>55.540° N</td>
</tr>
</tbody>
</table>

**SSA**

<table>
<thead>
<tr>
<th>Corner</th>
<th>Longitude</th>
<th>Latitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest</td>
<td>106.23° W</td>
<td>54.319° N</td>
</tr>
<tr>
<td>Northeast</td>
<td>104.24° W</td>
<td>54.223° N</td>
</tr>
<tr>
<td>Southeast</td>
<td>104.37° W</td>
<td>53.419° N</td>
</tr>
<tr>
<td>Southwest</td>
<td>106.30° W</td>
<td>53.513° N</td>
</tr>
</tbody>
</table>

The following table indicates the study area at which data were collected. 'REGION' indicates that the data were not collected in the SSA, NSA, nor in the area in between; the data for this flight were likely collected south of the SSA, in an agricultural area. 'TRANSECT' indicates that the data were collected in the transect area between the NSA and SSA.
<table>
<thead>
<tr>
<th>SPATIAL_COVERAGE</th>
<th>DATE_OBS</th>
<th>START_TIME</th>
<th>END_TIME</th>
<th>FLIGHT_NUM</th>
</tr>
</thead>
<tbody>
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<td>1723</td>
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</tr>
<tr>
<td>REGION</td>
<td>06-FEB-1994</td>
<td>1808</td>
<td>1942</td>
<td>FLIGHT #2</td>
</tr>
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<td>SSA</td>
<td>06-FEB-1994</td>
<td>2018</td>
<td>2237</td>
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</tr>
<tr>
<td>SSA</td>
<td>07-FEB-1994</td>
<td>1537</td>
<td>1758</td>
<td>FLIGHT #4</td>
</tr>
<tr>
<td>SSA</td>
<td>07-FEB-1994</td>
<td>1943</td>
<td>2134</td>
<td>FLIGHT #5</td>
</tr>
<tr>
<td>SSA</td>
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<td>1456</td>
<td>1621</td>
<td>FLIGHT #6</td>
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<td>TRANSECT</td>
<td>08-FEB-1994</td>
<td>1834</td>
<td>2006</td>
<td>FLIGHT #7</td>
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<td>2213</td>
<td>FLIGHT #8</td>
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<td>09-FEB-1994</td>
<td>1558</td>
<td>1806</td>
<td>FLIGHT #9</td>
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<td>NSA</td>
<td>09-FEB-1994</td>
<td>1856</td>
<td>2012</td>
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<tr>
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<td>2308</td>
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<td>SSA</td>
<td>13-FEB-1994</td>
<td>1957</td>
<td>2221</td>
<td>FLIGHT #14</td>
</tr>
</tbody>
</table>

7.1.2 Spatial Coverage Map
Not available.

7.1.3 Spatial Resolution
These data were taken from an aircraft altitude of 2,500 feet, which resulted in a spatial resolution of approximately 350 feet at the 45-degree viewing angle. The spatial resolution of a microwave radiometer depends on the beam width of the antenna. The beam width of the antenna is 6°, which is roughly about one tenth of a radian. Thus, the field of view (FOV) is about one tenth of the aircraft altitude. Normally, the radiometers were looking at 45° to the left side of the aircraft. When the aircraft pitches or rolls, the FOV size and position could be changed greatly. Data with large pitch and roll angles should not be used for SWE study.

7.1.4 Projection
Not applicable.

7.1.5 Grid Description
Not applicable.

7.2 Temporal Characteristics
Most of the 14 flight lines were covered once during the mission.

7.2.1 Temporal Coverage
The data were collected from 06-Feb-1994 to 13-Feb-1994.

7.2.2 Temporal Coverage Map
Not available.

7.2.3 Temporal Resolution
In each minute, data values were collected once per second for 53 seconds; the remaining time was used for instrument calibration. Some data gaps exist.
7.3 Data Characteristics

7.3.1 Parameter/Variable
The data contained in the data files are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMT</td>
<td>Greenwich mean time</td>
</tr>
<tr>
<td>18V</td>
<td>18 GHz brightness temperature (V)</td>
</tr>
<tr>
<td>18H</td>
<td>18 GHz brightness temperature (H)</td>
</tr>
<tr>
<td>37V</td>
<td>37 GHz brightness temperature (V)</td>
</tr>
<tr>
<td>37H</td>
<td>37 GHz brightness temperature (H)</td>
</tr>
<tr>
<td>92V</td>
<td>92 GHz brightness temperature (V)</td>
</tr>
<tr>
<td>92H</td>
<td>92 GHz brightness temperature (H)</td>
</tr>
<tr>
<td>SWE</td>
<td>Estimated snow water equivalent</td>
</tr>
<tr>
<td>Evet</td>
<td>Flight line marker</td>
</tr>
<tr>
<td>Ralt</td>
<td>Radar Altitude</td>
</tr>
<tr>
<td>PsAlt</td>
<td>Pressure Altitude</td>
</tr>
<tr>
<td>AcLat</td>
<td>Latitude of aircraft</td>
</tr>
<tr>
<td>AcLong</td>
<td>Longitude of aircraft</td>
</tr>
<tr>
<td>FltLat</td>
<td>Latitude of measurement location</td>
</tr>
<tr>
<td>FltLong</td>
<td>Flight line marker</td>
</tr>
<tr>
<td>TAS</td>
<td>Flight speed</td>
</tr>
<tr>
<td>GS</td>
<td>Ground speed</td>
</tr>
<tr>
<td>Hdg</td>
<td>Heading</td>
</tr>
<tr>
<td>Wind</td>
<td>Wind speed</td>
</tr>
<tr>
<td>Temp</td>
<td>Temperature</td>
</tr>
<tr>
<td>DewP</td>
<td>Dew point temperature</td>
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<tr>
<td>PRT5</td>
<td>PRT5 value</td>
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<tr>
<td>Sun</td>
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<tr>
<td>Roll</td>
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</tr>
<tr>
<td>DX</td>
<td>Distance</td>
</tr>
<tr>
<td>DY</td>
<td>Distance</td>
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7.3.2 Variable Description/Definition
The descriptions of the parameters in the data files are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
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<tbody>
<tr>
<td>GMT</td>
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<td>92 GHz brightness temperature (V)</td>
</tr>
<tr>
<td>92H</td>
<td>92 GHz brightness temperature (H)</td>
</tr>
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<td>Estimated snow water equivalent</td>
</tr>
<tr>
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<td>Radar Altitude</td>
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<td>PsAlt</td>
<td>Pressure Altitude</td>
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<td>Latitude of aircraft</td>
</tr>
<tr>
<td>AcLong</td>
<td>Longitude of aircraft</td>
</tr>
<tr>
<td>FltLat</td>
<td>Latitude of measurement location</td>
</tr>
</tbody>
</table>
FltLong  Longitude of measurement location
TAS     True air speed
GS      Ground speed
Hdg     Aircraft heading
Wind    Wind direction and speed
Temp    Air temperature
DewP    Dewpoint temperature
PRT5    IR surface temperature
Sun     Solar input
Ptch    Aircraft Pitch angle
Roll    Aircraft Roll angle
DX      x offset
DY      y offset

7.3.3 Unit of Measurement

The descriptions of the units in the data files are:

<table>
<thead>
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<tbody>
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<td>[Kelvin]</td>
</tr>
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<td>[Kelvin]</td>
</tr>
<tr>
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<tr>
<td>PsAlt</td>
<td>[meters]</td>
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</tr>
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<tr>
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<td>[degrees]</td>
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<td>[degrees][meters][second^-1]</td>
</tr>
<tr>
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<td>[degrees Celsius]</td>
</tr>
<tr>
<td>DewP</td>
<td>[degrees Celsius]</td>
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<tr>
<td>PRT5</td>
<td>[degrees Celsius]</td>
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<tr>
<td>Sun</td>
<td>[Watts][meter^-2]</td>
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<td>[degrees]</td>
</tr>
<tr>
<td>Roll</td>
<td>[degrees]</td>
</tr>
<tr>
<td>DX</td>
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<tr>
<td>DY</td>
<td>[meters]</td>
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</table>
### 7.3.4 Data Source

The descriptions of the source of the data files are:

<table>
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<tr>
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<td>radiometer</td>
</tr>
<tr>
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<td>radiometer</td>
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<td>radiometer</td>
</tr>
<tr>
<td>SWE</td>
<td>inferred</td>
</tr>
<tr>
<td>Ever</td>
<td>1 flight line</td>
</tr>
<tr>
<td></td>
<td>0 non-flight line</td>
</tr>
<tr>
<td>Ralt</td>
<td>radar</td>
</tr>
<tr>
<td>PsAlt</td>
<td>Barometer</td>
</tr>
<tr>
<td>AcLat</td>
<td>GPS</td>
</tr>
<tr>
<td>AcLong</td>
<td>GPS</td>
</tr>
<tr>
<td>FltLat</td>
<td>GPS</td>
</tr>
<tr>
<td>FltLong</td>
<td>GPS</td>
</tr>
<tr>
<td>TAS</td>
<td>INS</td>
</tr>
<tr>
<td>GS</td>
<td>INS</td>
</tr>
<tr>
<td>Hdg</td>
<td>INS</td>
</tr>
<tr>
<td>Wind</td>
<td>INS</td>
</tr>
<tr>
<td>Temp</td>
<td>Rosemount</td>
</tr>
<tr>
<td>DewP</td>
<td>Hygrometer</td>
</tr>
<tr>
<td>PRT5</td>
<td>Barnes PRT5</td>
</tr>
<tr>
<td>Sun</td>
<td>Pyrometer</td>
</tr>
<tr>
<td>Ptcch</td>
<td>INS</td>
</tr>
<tr>
<td>Roll</td>
<td>INS</td>
</tr>
<tr>
<td>DX</td>
<td>GPS</td>
</tr>
<tr>
<td>DY</td>
<td>GPS</td>
</tr>
</tbody>
</table>

### 7.3.5 Data Range

The descriptions of the ranges of the data files are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMT</td>
<td>00:00:00 - 23:59:59 hours</td>
</tr>
<tr>
<td>18V</td>
<td>0-300</td>
</tr>
<tr>
<td>18H</td>
<td>0-300</td>
</tr>
<tr>
<td>37V</td>
<td>0-300</td>
</tr>
<tr>
<td>37H</td>
<td>0-300</td>
</tr>
<tr>
<td>92V</td>
<td>0-300</td>
</tr>
<tr>
<td>92H</td>
<td>0-300</td>
</tr>
<tr>
<td>SWE</td>
<td>0-250 mm</td>
</tr>
<tr>
<td>Ever</td>
<td>0-1</td>
</tr>
<tr>
<td>Ralt</td>
<td>None given.</td>
</tr>
<tr>
<td>PsAlt</td>
<td>None given.</td>
</tr>
<tr>
<td>AcLat</td>
<td>None given.</td>
</tr>
<tr>
<td>AcLong</td>
<td>None given.</td>
</tr>
<tr>
<td>FltLat</td>
<td>None given.</td>
</tr>
<tr>
<td>FltLong</td>
<td>None given.</td>
</tr>
</tbody>
</table>
TAS 0-150
GS 0-150
Hdg 0-360
Wind Dir. 0-360
Wind Sp. 0-200
Temp None given.
DewP None given.
PRT5 None given.
Sun None given.
Ptch -90 to 90
Roll -90 to 90
DX None given.
DY None given.

7.4 Sample Data Record
The following are wrapped versions of sample data records from one of the data files:

```
GMT,AMMR 18-V, AMMR 18-H, AMMR 37-V, AMMR 37-H, AMMR 92-V, AMMR 92-H, SWE, Evnt,
RadAlt (m), PsAlt (m), AcLat (Deg), AcLon (Deg), FtpLat (Deg), FtpLon (Deg), AirSpd (m/s),
GrSpd (m/s), Hdg (Deg), WinDir (Deg), WinSpd (m/s), AirTemp (C), DewPt (C), PRT5 (C),
SolarIn (W/m2), AcPitch (Deg), AcRoll (Deg), XOff (m), YOff (m)
19:57:41,.........,0,2,429,53.2178, 105.684,53.2178, 105.684,-0.4,0.2,89,251,0.4,
-2,-11.7,-15.3,297,-0.8,-0.4,0,-2
19:57:42,.........,0,2,429,53.2178,105.684,53.2178,105.684,-0.4,0.2,89,251,0.4,
-2,-11.8,-15.3,297,-1,-0.5,0,-2
19:57:43,.........,0,2,429,53.2178,105.684,53.2178,105.684,-0.4,0.2,89,251,0.4,
-1.9,-11.8,-15.3,297,-1.1,-0.5,0,-2
```

8. Data Organization

8.1 Data Granularity
The smallest amount of data that can be ordered from this data set is the data from one flight.

8.2 Data Format
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. 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.

The SWE data set contains 28 columns of data. It is written in ASCII text with two header lines describing the contents of the column beneath it. The data columns are comma delimited. The columns in left-to-right order are:

```
GMT  - Greenwich Mean Time, the time at which the observation was made
18-V  - The 18-GHz vertical channel reading in Kelvin
18-H  - The 18-GHz horizontal channel reading in Kelvin
37-V  - The 37-GHz vertical channel reading in Kelvin
37-H  - The 37-GHz horizontal channel reading in Kelvin
92-V  - The 92-GHz vertical channel reading in Kelvin
92-H  - The 92-GHz horizontal channel reading in Kelvin
```
9. Data Manipulations

9.1 Formulae
Measured radiometric units have been converted to brightness temperature using the following equations:

\[ TB = TH - \frac{(dc-hc)}{(cc-hc)}(TH-TC) \]

where:
- \( dc \) = data counts
- \( cc \) = cold counts
- \( hc \) = hot counts
- \( TC \) = cold load temperature
- \( TH \) = hot load temperature

9.1.1 Derivation Techniques and Algorithms
Radiometer calibration was done by pointing the antenna to cold sky and a liquid nitrogen bucket as the cold references; ecosorb at ambient temperature is used as the warm reference target.

9.2 Data Processing Sequence

9.2.1 Processing Steps
The data collected during the flights were processed using the following steps:
- The raw data counts from each radiometer were read from the collected data file.
- These data were then converted to antenna temperature using the calibration equations derived.
- Loss corrections were applied to the antenna temperature to create brightness temperature.
- SWE was derived from equations.
- SWE was merged with aircraft navigation data and PRT-5 IR data.
- Output was saved on 8-mm tape cartridge.
- BOREAS Information System (BORIS) staff read the files from tape, added commas to delimit the different columns, and wrote the data back to tape.
9.2.2 Processing Changes
None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments
None given.

9.3.2 Calculated Variables
Please refer to Eq. (3) in Section 3 of this document for the equation used to infer the SWE values.

9.4 Graphs and Plots
Brightness temperatures for each flight are plotted as a function of time, as a quick-look product. Please contact personnel at the Hydrological Sciences Branch at GSFC.

10. Errors

10.1 Sources of Error
Errors in the calibrated brightness temperature data may arise from several sources:
- Instrumentation operation temperature: Because of the cold ambient temperature, the instrument temperature could not be controlled accurately.
- Stability of the noise diode.

10.2 Quality Assessment

10.2.1 Data Validation by Source
Comparisons were made with Special Sensor Microwave Imager (SSM/I) data over the same area and available water targets.

10.2.2 Confidence Level/Accuracy Judgment
The 18- and 37-GHz radiometers are believed to be accurate to about +/-3 K. The 92-GHz radiometer may be accurate to approximately +/-10 K. For SWE value, the accuracy is approximately 5 mm.

10.2.3 Measurement Error for Parameters
None given.

10.2.4 Additional Quality Assessments
None given.

10.2.5 Data Verification by Data Center
None given.

11. Notes

11.1 Limitations of the Data
During the aircraft flights, it was found that the 92-GHz brightness temperature was not very stable because of the instability in the cold reference load temperature. There was also a problem with the 37-GHz horizontal polarization data. Therefore, the quality of these data is somewhat uncertain.
11.2 Known Problems with the Data
None given.

11.3 Usage Guidance
None given.

11.4 Other Relevant Information
None given.

12. Application of the Data Set
This data set may be used to study the energy balance for the BOREAS sites.

13. Future Modification and Plans
There are no reprocessing plans at this time.

14. Software

14.1 Software Description
None given.

14.2 Software Access
None given.

15. Data Access
The SWE 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].

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15.3 Procedures for Obtaining Data
Users may obtain data directly through the ORNL DAAC online search and order system [http://www-eosdis.ornl.gov/] and the anonymous FTP site [ftp://www-eosdis.ornl.gov/data/] or by contacting User Services by electronic mail, telephone, fax, letter, or personal visit using the contact information in Section 15.1.

15.4 Data Center Status/Plans
The ORNL DAAC is the primary source for BOREAS field measurement, image, GIS, and hardcopy data products. The BOREAS CD-ROM and data referenced or listed in inventories on the CD-ROM are available from the ORNL DAAC.

16. Output Products and Availability

16.1 Tape Products
The data can be made available on 8-mm tape.

16.2 Film Products
None.

16.3 Other Products
These data are available on the BOREAS CD-ROM series. Videotapes from the Twin Otter flights are also available.

17. References

17.1 Platform/Sensor/Instrument/Data Processing Documentation
None given.

17.2 Journal Articles and Study Reports


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
- FFC-W - Focused Field Campaign - Winter
- FOV - Field of View
- GIS - Geographic Information System
- GMT - Greenwich Mean Time
- GPS - Global Positioning System
- GSFC - Goddard Space Flight Center
- HTML - HyperText Markup Language
- HYD - Hydrology
- INS - Inertial Navigation System
- IR - InfraRed
- MTPE - Mission to Planet Earth
- MW - MicroWave
- NASA - National Aeronautics and Space Administration
- NSA - Northern Study Area
- NSIDC - National Snow and Ice Data Center
- ORNL - Oak Ridge National Laboratory
- PANP - Prince Albert National Park
- PC - Personal Computer
- PRT5 - Borneo Model PRT-5 radiation thermometer
- SMMR - Scanning Multichannel Microwave Radiometer
- SSA - Southern Study Area
- SSM/I - Special Sensor Microwave Imager
- SWE - Snow Water Equivalent
- URL - Uniform Resource Locator
20. Document Information

20.1 Document Revision Date
Written: 23-Jan-1997
Revised: 26-Jul-1999

20.2 Document Review Date
BORIS Review: 02-Jul-1998
Science Review: 06-Jul-1998

20.3 Document ID

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

The microwave brightness temperature data set was intended to provide accurate measurements of thermal microwave radiation from snow fields. This data set was developed with support from NASA's Mission to Planet Earth (MTPE) BOREAS Project. Thanks are due to BORIS at GSFC for distributing the data and to Drs. Chang, Hall, and Foster of the Hydrological Sciences Branch, NASA GSFC, for producing these data products.

If using data from the BOREAS CD-ROM series, also reference the data as:


Also, cite the BOREAS CD-ROM set as:

20.5 Document Curator

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

BOREAS HYD-2 Estimated Snow Water Equivalent (SWE) from Microwave Measurements

Hugh Powell and Alfred T.C. Chang
Forrest G. Hall and David E. Knapp, Editors

Goddard Space Flight Center
Greenbelt, Maryland 20771

National Aeronautics and Space Administration
Washington, DC 20546-0001

The surface meteorological data collected at the BOREAS tower and ancillary sites are being used as inputs to an energy balance model to monitor the amount of snow storage in the boreal forest region. The BOREAS HYD-2 team used SWE derived from an energy balance model and in situ observed SWE to compare the SWE inferred from airborne and spaceborne microwave data, and to assess the accuracy of microwave retrieval algorithms. The major external measurements that are needed are snowpack temperature profiles, in situ snow areal extent, and SWE data. The data in this data set were collected during February 1994 and cover portions of the SSA, NSA, and the transect areas. The data are available from BORIS as comma-delimited tabular ASCII files.