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

Forrest G. Hall and David E. Knapp, Editors

Volume 41

BOREAS HYD-9 Hourly and Daily Radar Rainfall Maps for the Southern Study Area

F.J. Eley and T.W. Krauss

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

July 2000

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BOREAS HYD-9 Hourly and Daily Radar Rainfall Maps for the Southern Study Area

Joe Eley, Terry Krauss

Summary

The BOREAS HYD-9 team collected data on precipitation and streamflow over portions of the NSA and SSA. This data set contains Cartesian maps of rain accumulation for 1-hour and daily periods during the summer of 1994 over the SSA only (not the full view of the radar). A parallel set of 1-hour maps for the whole radar view has been prepared and is available upon request from the HYD-09 personnel. An incidental benefit of the areal selection was the elimination of some of the less accurate data, because for various reasons the radar rain estimates degrade considerably outside a range of about 100 km. The data are available in tabular ASCII files.

Note that some of the data files on the BOREAS CD-ROMs have been compressed using the Gzip program. See Section 8.2 for details.

Table of Contents

1. Data Set Overview

1.1 Data Set Identification

BOREAS HYD-09 Hourly and Daily Radar Rainfall Maps for the Southern Study Area

1.2 Data Set Introduction

The data set documented here is a Cartesian map of rain accumulation for each 1-hour period of the summer of 1994 for the BOReal Ecosystem-Atmosphere Study (BOREAS) Southern Study Area (SSA) only (not the full view of the radar). This is an attempt to limit the size of the arrays to something of interest and convenience to most BOREAS users. A parallel set of 1-hour maps for the whole radar view has been prepared and is available on request from Eley/Krauss as noted elsewhere in this document. An incidental benefit of this areal selection is to eliminate some of the less accurate data, because for various reasons the radar rain estimates degrade considerably outside a range of about 100 km.

1.3 Objective/Purpose

The objective of analyzing these weather radar data was to define the spatial variability of precipitation during the summer of 1994 in the BOREAS SSA, and particularly in the Modeling Sub-Area (MSA).

1.4 Summary of Parameters

The data provide rainfall accumulation estimates from radar for each 1-hour period ending at the nominal file time for each 2 by 2 km of the BOREAS SSA. Additional files contain the daily accumulation for the months of May through September 1994. Each file in this data set is a geographical array of these pixels.

1.5 Discussion

The radar recorded one scan every 10 minutes. A scan takes about 15 seconds. The original scan record is in 360 radials, with an average value at each 2 km of range along the radial. The value measured by the radar is power received, from which an estimate of target radar cross-section is calculated rather directly, and from that the rain rate below the beam is estimated by a power-law relationship (see Section 3). Rain accumulation in a pixel can be estimated by accumulating the rain rate over one or several time steps.

1.6 Related Data Sets

BOREAS AFM-07 SRC Surface Meteorological and Radiation Data
BOREAS HYD-09 Belfort Rain Gauge Data
BOREAS HYD-09 Tipping Bucket Rain Gauge Data

2. Investigator(s)

2.1 Investigator(s) Name and Title

Mr. Joe Eley
Radar Specialist
Climate Research Branch

Dr. Terry W. Krauss
Canadian GEWEX Secretariat
National Hydrology Research Centre

Dr. Dennis P. Lettenmaier
Dept. of Civil Engineering
University of Washington

Dr. Nicholas Kouwen
Dept. of Civil Engineering
University of Waterloo

Dr. Eric D. Soulis
Dept. of Civil Engineering
Waterloo University

2.2 Title of Investigation

From Micro-Scale to Meso-Scale Snowmelt, Soil Moisture and Evapotranspiration from Distributed Hydrologic Models

2.3 Contact Information

Contact 1:
Joe Eley
Atmospheric Environment Service
Environment Canada
11 Innovation Blvd.
Saskatoon, Saskatchewan S7N 3H5
Canada
(306) 975-5685
(306) 975-6516 (fax)
Joe.Eley@ec.gc.ca

Contact 2:
Dr. Terry Krauss
Weather Modification, Inc.
P.O. Box 27177
Red Deer, Alberta T4N 6X8
Canada
(403) 342-5685 (phone and fax)
krausst@agt.net

Contact 3:
David Knapp
Raytheon ITSS
NASA GSFC
Code 923
Greenbelt, MD 20771
(301) 286-1424
(301) 286-0239 (fax)
David.Knapp@gsfc.nasa.gov

3. Theory of Measurements

A portable C-band weather radar (Enterprise WSR-100) with an 8-foot dish was operated at a location on the southern boundary of the SSA during the summer of 1994. The radar made azimuthal sweeps at a rate of four revolutions per minute with an elevation of 1.1 to 1.5 degrees above the horizon. Trees near the radar in the southeast sector were unavoidable, and that sector shows no rain. The SSA is within the range at which radar can give quantitative estimates of precipitation. The MSA is between the inner and outer range limits (about 30 and 80 km) for best quantitative rainfall estimates.

The radar sends out a pulse of energy with a short duration (2 microseconds) 260 times per second and receives energy from the various scatterers in the radar beam. The detector determines the elapsed time of the round trip to each target and the power received with a time resolution of somewhat better than the transmitted pulse length. The distance resolution is thus on the order of the transmitted pulse length, or about 300×10^6 m/s x 2×10^{-6} s, or approximately 600 m. The digitizer samples at least once each 1 km equivalent time (round trip 2 km/300,000 km/s, or 6.7 microseconds).

The Digitizer and Video Integrator-Processor (DVIP) acquires these samples for every pulse emitted and integrates them by averaging the logarithmic values over the specified angular range resolution. The BOREAS rain radar was set to integrate over 1-degree and 2-km intervals. Because the azimuthal scan rate was approximately 15 seconds per scan, there were 15*260/360 = 10.8 pulses per degree of azimuth, or approximately 20 samples per output integrated value. Values were output with a least significant digit of 1/3 dB, where decibel means 10 times the common log of a value.

The response curve of the receiver to the digitizer is log-linear over much of its operating range, but is in general S-shaped with a lower difference in response per input change at the extremes. Because investigators are interested in weather targets from below the detection capability of the radar to very intense (strong and near), the lower leg of the S-curve was often used, and occasionally the upper part was seen. This curve was applied as a first stage in transforming the data from radar response to estimated target intensity. The second stage of processing was to adjust for an assumed attenuation due to the beam spread in both directions with the result that power received varies as the inverse square of range from the radar. The archived raw data are taken after these two stages of processing. The archived value is in units of 1/3 dBZ, where Z is rain target cross-section in mm^6/m^3 (summation of the 6th power of raindrop diameters per cubic meter of space).

The radar was carefully calibrated in the conventional manner of weather radars, and loss estimates were taken from literature and the experience base of the investigators, including a 2.5-dB adjustment for averaging the log (mentioned above). Rainfall rates were estimated from the cross-section Z by the physically based Marshall-Palmer relationship:

$$Z = 200\,R^{1.6}$$

where R is rain rate in mm/hour. The rate was mapped from the range/bearing (R-theta) coordinates of the original scan to Cartesian maps by taking the R-theta pixel nearest the center of the Cartesian pixel.

The rain rate is estimated for each recorded scan, once every 10 minutes, and this is summed for the scans at 10, 20, 30, 40, and 50 minutes after the previous hour and at 00 of the nominal hour. The values in the file for each pixel are in units of mm with a resolution of 0.01 mm per hour.

The density structure of the atmosphere and consequent refraction of electromagnetic waves varies with weather and time of day. The radar is mapped in the vertical on the assumption of a model atmosphere, which is adequate for most weather radar interpretation. Changes in refraction can cause the beam to be above or below the intended height. The largest effect of this occurs when the beam follows the ground and targets on the surface, which can be quite strong, are logged as if they were rain. A lesser effect will occur if the beam completely overshoots the raining low cloud.

The bright band at the melting level does occur in this data set and no compensation has been made. Preliminary stratification of the data by freezing level indicated that this effect could not be isolated from other effects, and thus no compensation factor could be assigned.

Refer to Sections 10 and 11 for further discussion relating to the theory of these measurements.

4. Equipment

4.1 Sensor/Instrument Description

The equipment for this project was a weather radar system built by Enterprise Electronics Corp. of Enterprise, AL, and owned by Weather Modification, Inc., of Fargo, ND. This is a mobile system, with all the electronics mounted in a Winnebago and the antenna mounted on a portable tower. System specifications are:

```
Model                    WR 100
Wavelength               5.4 cm
Peak pulse power         250 kW
Pulse repetition freq.   260 Hz
Pulse duration           2.0 microseconds
Min. detectable signal   -104 dBm
     (10 dBZ at 100 km range,
      or 0.15 mm/h at 100 km)
Beam width               1.65 degrees pencil beam
Antenna gain             40 dB (2.44-m dish)
```

The radar system includes a preprocessor (DVIP) that digitizes the video signal from logarithmic amplifier output of the receiver and performs averaging along range and between pulses to achieve a lower variability in the estimate of radar reflectivity.

An IBM PC-based radar processing system was used to acquire the DVIP output, archive it in its original 8-bit resolution, and convert it into Cartesian displayable rain maps. A horizontal sweep of the radar was acquired and stored once every 10 minutes, and a map was produced. A second stage processor stored the displayable maps and once per hour produced and stored a displayable 1-hour rainfall accumulation map.

4.1.1 Collection Environment

The radar operated in ambient outdoor conditions during the days of data collection.

4.1.2 Source/Platform

Radar antenna mounted on a portable tower.

4.1.3 Source/Platform Mission Objectives

The objective was to gather spatial data on rainfall.

4.1.4 Key Variables

Rainfall maps of the BOREAS SSA.

4.1.5 Principles of Operation

See Section 3.

4.1.6 Sensor/Instrument Measurement Geometry

The radar made an azimuthal scan at a rate of four revolutions per minute with an elevation of 1.1 to 1.5 degrees above the horizon.

4.1.7 Manufacturer of Sensor/Instrument

Enterprise Electronics Corporation
Enterprise, AL

4.2 Calibration

The electronics of the radar system were checked as much as possible at the beginning of the season, before the second Intensive Field Campaign (IFC), and at the end of the season. The gain and offset of the radar receiver's final amplifier was mistakenly set quite inappropriately on 16-July-1994, so the gain and the consequent lookup table for the processor were reestablished on 18-July-1994. (The spurious data from this period have not been included in the data posted to the BOREAS Information System [BORIS].) The recheck at the end of the season indicated that the receiver response was stable to within 1 dB.

The radar was carefully calibrated in the conventional manner of weather radars, and loss estimates were taken from literature and the experience base of the investigators, including a 2.5-dB adjustment for averaging the log.

The second form of calibration is comparison of rain rates with rain gauges. In comparisons of six gauges and the overlying radar pixel, the radar appeared to overestimate on average 25 to 40 percent using the Marshall-Palmer relation. A comparison of the radar average for the MSA versus the average of all the Hydrology (HYD)-09 tipping bucket gauges in the area for 01-July-1994 to 31-Jul-1994 showed a radar overestimate of 9 percent.

4.2.1 Specifications

None given.

4.2.1.1 Tolerance

None given.

4.2.2 Frequency of Calibration

The equipment was calibrated on 29-Apr-1994, 18-Jul-1994, and 22-Sep-1994.

4.2.3 Other Calibration Information

None.

5. Data Acquisition Methods

The radar scanned at an elevation of 1.3 to 1.5 degrees above the horizon in order to have the whole beam above all obstructions except tall, very local trees in the sector between azimuths 103 and 135 degrees true north. The higher elevation was set for the later part of the season when it was discovered in July that a group of trees at about 2-km range had leafed out and caused a partial beam blockage at azimuth 45 degrees. This partial beam blockage can be seen by inspection of storm rain accumulations during June and early July 1994.

The radar was located at the midpoint of the southern boundary of the SSA, latitude 53.4835 degrees N, longitude 105.4753 degrees W, elevation 479 m above sea level.

6. Observations

6.1 Data Notes

None given.

6.2 Field Notes

The radar system was fully operational and logging data from 05-May/1840 Universal Time Code (UTC) to 23-Sep/2000 UTC in 1994 with the exceptions noted below. During this time, the real-time processing system archived a single 360-degree scan every 10 minutes in range-bearing (R-theta) format and in a Cartesian display rain map format. At the end of each hour, a 1-hour rain map was derived from the six single-scan rain maps. Brief shutdowns during fine weather for servicing are not all noted. The following dates are all in 1994.

```
Outages in the field notes:
11-May/2250-12/2230UTC    Computer failure.
13-May/1300-15/0030UTC    Radar transmitter failure.
24-May/1640,1650,1730-1750,1830  Servicing.
30-May/0020-1600UTC       Computer problem.  Data available in R-theta.
09-June/2010-10/1510UTC   Computer problem.  Data available in R-theta.
23-June/0800-28/2000UTC   Hourly rain map scale stuck on 3 mm/step.  Light rains
                           shown as 3 mm (1 scale step).
02-July/1620-1810UTC      Computer servicing.
06-July/1840-2310UTC      Computer servicing.
15-July/1950-2140UTC      Computer servicing.
16-July/1730-18-July/2030UTC  See below, erroneous data.
21-July/2220-2350UTC      Computer servicing.
25-July/2110-2150UTC      Computer servicing.
29-July/0120-1550UTC      Operator error.  Significant weather missed in SSA.
12-Aug/2010-2200UTC       Radar servicing.
31-Aug/1720-1820, 2020-2350UTC  Radar servicing.
```

Erroneous Data Produced:
July 16/1730-18/2030UTC Wrong radar calibration curve.
All maps overestimated (not sent to BORIS).

Other field problems are noted in other sections of this report. The two main concerns were:

- Beam reduction due to trees near 45 degrees azimuth, which reduced the rain estimate slightly in late June and early July.
- Total beam blockage between azimuth 103 and 135 degrees.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The original full data set contains rays of radar reflectivity at each 1 degree of azimuth, at the nominal elevation angle of 1.5 degrees above the horizon. There are 110 values along each ray at a 2-km interval. These are transformed to a Cartesian map with a 2- x 2-km pixel, choosing the highest coincident value for near ranges (inside 80 km) and replicating the nearest neighbor for outer ranges. The radar was located at North American Datum of 1983 (NAD83) coordinates (by Global Positioning System [GPS]):

```
Radar site     53.4835 deg N     105.4753 deg W
```

A rectangular map of radar data covers the following area:

```
NW corner      54.26667 deg N     106.28500 deg W
NE corner      54.27000 deg N     104.31333 deg W
SE corner      53.51333 deg N     104.33000 deg W
SW corner      53.51667 deg N     106.26833 deg W
```

7.1.2 Spatial Coverage Map

None.

7.1.3 Spatial Resolution

Each grid cell is 2 km by 2 km in size.

7.1.4 Projection

These data were gridded based on a transverse Mercator projection centered on the site where the radar instrument was located.

7.1.5 Grid Description

These data were gridded into 2- by 2-km pixels based on a transverse Mercator projection centered on the site where the radar instrument was located.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

The radar was operated nearly continuously from 13-May-1994 to 23-Sep-1994. All outages are listed in Section 6.2.

7.2.2 Temporal Coverage Map

None.

7.2.3 Temporal Resolution

A scan was logged every 10 minutes (the radar was scanning at approximately four turns per minute). The system integrated the scans into 1-hour rain maps at the end of each hour.

7.3 Data Characteristics

7.3.1 Parameter/Variable

The parameter contained in the rain radar images is the amount of rainfall for that area.The parameters contained in the inventory listing file on the CD-ROM are:

Column Name
SPATIAL_COVERAGE
START_DATE
END_DATE
NUM_IMAGES
DATA_TYPE
CRTFCN_CODE
REVISION_DATE

7.3.2 Variable Description/Definition

The parameter contained in the rain radar images is the amount of rainfall for that area.The descriptions of the parameters contained in the inventory listing file on the CD-ROM are:

Column Name	Description
SPATIAL_COVERAGE	The general term used to denote the spatial area over which the data were collected.
START_DATE	The date on which the collection of the reference data commenced.
END_DATE	The date on which the collection of the referenced data was terminated.
NUM_IMAGES	The number of daily and hourly radar images that exist for a day.
DATA_TYPE	The type of data contained in the data unit. Examples include SRC_AMS_SUITE_A, LANDSAT_TM, AVHRR_LAC, TOWER_FLUX, and SOIL_MOISTURE.
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 rainfall amounts in each rainfall image are expressed as millimeters.The measurement units for the parameters contained in the inventory listing file on the CD-ROM are:

Column Name	Units
SPATIAL_COVERAGE	[none]
START_DATE	[DD-MON-YY]
END_DATE	[DD-MON-YY]
NUM_IMAGES	[counts]

DATA_TYPE	[none]
CRTFCN_CODE	[none]
REVISION_DATE	[DD-MON-YY]

7.3.4 Data Source

The rainfall amounts in each rainfall image were supplied by the investigator.The sources of the parameter values contained in the inventory listing file on the CD-ROM are:

Column Name	Data Source
SPATIAL_COVERAGE	[Supplied by Investigator]
START_DATE	[Supplied by Investigator]
END_DATE	[Supplied by Investigator]
NUM_IMAGES	[Assigned by BORIS]
DATA_TYPE	[Supplied by Investigator]
CRTFCN_CODE	[Assigned by BORIS]
REVISION_DATE	[Assigned by BORIS]

7.3.5 Data Range

The range of values in the rainfall maps was not determined.The following table gives information about the parameter values found in the inventory table on the CD-ROM.

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SPATIAL_COVERAGE	N/A	N/A	None	None	None	None
START_DATE	12-MAY-94	23-SEP-94	None	None	None	None
END_DATE	12-MAY-94	23-SEP-94	None	None	None	None
NUM_IMAGES	1	29	None	None	None	None
DATA_TYPE	N/A	N/A	None	None	None	None
CRTFCN_CODE	CPI	CPI	None	None	None	None
REVISION_DATE	07-JAN-97	07-JAN-97	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 data record from the inventory list of rain maps that are available in the data base.

```
SPATIAL_COVERAGE,START_DATE,END_DATE,NUM_IMAGES,DATA_TYPE,CRTFCN_CODE,
REVISION_DATE
'SSA',12-MAY-94,31-MAY-94,12,'DAILY RAIN RADAR','CPI',07-JAN-97
```

The following is an example of the header lines and the northwest corner of the rain map array.

```
BSCAN AREA RAIN ACCUMS FOR PDK 47030110.arc TO 47030200.arc

GRID CELLS (83,65) TO (147,107)

grid point value (mm)
    2.24    1.95    1.26    1.09    1.08    1.07    0.97  ..............
    2.00    1.66    1.30    1.12    1.05    1.07    1.11  ..............
    2.02    1.71    1.31    1.20    1.27    1.23    1.11  ..............
```

8. Data Organization

8.1 Data Granularity

The smallest amount of data that can be ordered is the entire data set.

8.2 Data Format(s)

8.2.1 Uncompressed Data Files

The data are contained in American Standard Code for Information Interchange (ASCII) files that contain multiple daily or hourly images. The data are organized into daily and hourly files. The daily rainfall data are stored in five files (one for each month in which the radar was operating). The hourly rainfall data are stored in 128 files (one for each day of data).

Each of the five daily and 128 hourly data files contains several daily or hourly images that have been concatenated. One daily or hourly image consists of 47 records. The first four records contain header information as shown in Section 7.4. Records 5 through 47 contain the 43 data records. Each data record contains 65 numeric values presented as ASCII characters, separated by blank spaces.

BSCAN AREA RAIN ACCUMS FOR PDK 47231110.arc TO 47231200.arc GRID CELLS (83,65) TO (147,107) grid point value (mm)

The first line indicates the first and last 10-minute periods that were used to determine the accumulation of rain for a given hour. For example:

```
47231110.arc                               47231200.arc
4 = year (1994)                            4 = year (1994)
7 = month (July)                           7 = month (July)
23 = day                                  23 = day
1110 = Greenwich Mean Time (GMT)        1200 = GMT
```

Thus, the image data from which this header was extracted contains the accumulation of rain for the period from 1100 to 1200 GMT on 07-Jul-1994.

8.2.2 Compressed CD-ROM Files

On the BOREAS CD-ROMs, each of the daily and hourly data files has been compressed with the GNU zip (Gzip) compression program (file name *.gz). These data have been compressed using Gzip Version 1.2.4 and the high compression (-9) option (copyright 1992-93 Jean-loup Gailly). Gzip uses the Lempel-Ziv algorithm (Welch, 1994) used in the zip and PKZIP programs. The compressed files can be uncompressed using Gzip (-d option) or Gunzip. Gzip is available from many Web sites (for example, ftp site prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

9. Data Manipulations

9.1 Formulae

See Section 3.

9.1.1 Derivation Techniques and Algorithms

See Section 3.

9.2 Data Processing Sequence

9.2.1 Processing Steps

The following data-gathering steps were performed:

- Operate the radar equipment, collect raw rain target reflectivity (archive a scan each 10 minutes, each scan has 360 radials, with a value for each 2 km of range to 220 km).
- The preprocessing incorporated in the above sequence includes digital averaging of logarithmic data for approximately 10 radials by 2 ranges in the DVIP.
- Estimate rain-rates with the Marshall-Palmer relationship.
- Remap to a Cartesian 2- x 2-km grid selecting the nearest point from the range-bearing data and integrate over a 1-hour or 1-day period, resulting in an ASCII map in mm accumulation over the period.

BORIS staff performed the following processing of the data:

- Reviewed the files for format and content.
- Merged the numerous individual hourly and daily data files.
- Copied the ASCII and compressed the binary files for release on CD-ROM.

9.2.2 Processing Changes

None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

None.

9.3.2 Calculated Variables

Rainfall amounts.

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

This is a conventional weather radar system, as described in textbooks on the subject. Principal sources of error are:

Variability of reflected power due to the inherent characteristics of a distributed scatterer such as a cloud of moving droplets. Evaporation or condensation of droplets between the height at which they are observed by radar and the ground. Drift of the rain between radar observation height and the ground. Enhanced radar reflectivity of melting ice crystals at the freezing level, when the freezing/melting level of a cloud is in the radar beam.

10.2 Quality Assessment

These are conventional rain radar data. There is considerable scatter in individual gauge-radar pixel comparisons, especially near the threshold of detection of either instrument. There are erroneous radar indications of rain due to anomalous propagation (AP) of the radar beam near the ground, although this is rare in the northeast sector, which covers the MSA.

Several attempts were made to assess a local radar cross-section to rain rate transform, but these varied considerably between situations. No general transform (Z-R relation) was found that worked well throughout the season. Thus, the physically based Marshall-Palmer relationship was used as a good first estimate, and users are advised to use caution in applying these data in any case study.

Because this is a non-Doppler system, ground clutter removal was accomplished only through elevation of the beam. This does not remove clutter when the refraction is especially strong. During rain, this type of clutter is infrequent and relatively weak. With other weather information, the secondary clutter removal mechanism can be to ignore radar map times when it is known that precipitation was not occurring.

10.2.1 Data Validation by Source

In comparisons between six gauges and the overlying radar pixel, the radar appeared to overestimate on average 25 to 40 percent using the Marshall-Palmer relationship. A comparison of the radar average for the MSA versus the average of all the HYD-09 tipping bucket gauges in the area for 01- to 31-Jul-1994 showed a radar overestimate of 9 percent.

10.2.2 Confidence Level/Accuracy Judgment

None given.

10.2.3 Measurement Error for Parameters

See Section 10.2.1.

10.2.4 Additional Quality Assessments

None.

10.2.5 Data Verification by Data Center

BORIS staff spot checked the data set to ensure that it was what was described by the investigators and that it contained reasonable values.

11. Notes

11.1 Limitations of the Data

None given.

11.2 Known Problems with the Data

There is a "dead sector" in these data, because trees near the site were too tall to be avoided to the southeast, causing a blank sector from about 105 to 132 degrees on the rain maps.

The beam is swept as low as possible to measure rain as near to the ground as possible. This means that near the site, there is some return from objects on the ground in all maps. Ground clutter extends to 12 to 14 km south to northwest, less in other sectors. The following matrix shows the permanent ground clutter for the BOREAS rain radar site. Each pixel is 2 by 2 km, and the matrix is north-up.

```
    x     clutter
    Z     heavy clutter
    .     (dot)  no clutter
    R      radar site

  x Z x . . . . . . Z x . .
  x Z x . . . x . x x Z . .
  Z x . x . . x . . . Z . .
  Z Z x . . x x . x x Z Z Z
  Z x x . . . x x x . Z Z Z
  Z . . x . . x . . . Z Z x
  x . . . . . x x x x Z Z Z
  x x . . . x x Z Z Z R Z x
  x Z . . . Z Z Z Z x Z X .
  x Z x . x Z Z Z x x x x .
  . Z Z x . x x Z Z Z x x .
  . . Z x x Z Z Z Z Z . . .
  . . x . x x Z x x . . . .
```

The structure of the atmosphere varies with time of day, different advection at different heights, etc. There is AP (the same as optical 'miraging'), which can cause large areas of ground clutter to appear at times. At this site, this appeared commonly in the sector from 200 to 330 degrees, extending to long ranges. The northeast sector over the MSA seldom had AP. AP can be recognized and edited with a high degree of confidence by human intervention. This data set is offered "as-is" with no editing as a first cut.

The radar data are limited at the outer ranges by the loss of power as the energy returned from targets is scattered in all directions and by loss of transmitted power as the beam passes through weather in its path. At long ranges, the beam may also overshoot all weather or the part of the cloud that is a best estimator of rain rate, because the beam rises with range. The usual estimate of beam height is to assume that it is a straight line, but that Earth's radius is 4/3 of the real Earth. With a 1.5-degree elevation this gives an estimated beam height of 3.2 km above ground at 100 km, and 7.7 km at 200-km range. For the ranges covered in the SSA, and for most rain intensities encountered in 1994, this radar covered the entire area.

11.3 Usage Guidance

These rain accumulations are a good estimate of the spatial and temporal distribution of rain in the area. Individual pixels integrated over 1 hour, as in this case, can vary considerably from a single underlying rain gauge and on average they will disagree by some 50 percent for a single reading.

Viewing the data with a system capable of map animation helps greatly in identifying areas of ground clutter, which does not move, but scintillates in place, as distinct from rain, which moves consistently. Hourly and 10-minute maps and such a viewer are available on request.

Before uncompressing the Gzip files on CD-ROM, be sure that you have enough disk space to hold the uncompressed data files. Then use the appropriate decompression program provided on the CD-ROM for your specific system.

11.4 Other Relevant Information

None given.

12. Application of the Data Set

These data could be used to investigate spatial rainfall patterns or used as inputs to spatial soil and vegetation models.

13. Future Modifications and Plans

None.

14. Software

14.1 Software Description

Gzip uses the Lempel-Ziv algorithm (Welch, 1994) used in the zip and PKZIP commands.

14.2 Software Access

Gzip is available from many Web sites across the Internet (ftp prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

15. Data Access

The HYD-09 hourly and daily radar rainfall maps for the SSA 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
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
Welch, T.A. 1984. A Technique for High Performance Data Compression. IEEE Computer, Vol. 17, No. 6, pp. 8-19.

17.2 Journal Articles and Study Reports
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Schnur, R., T.W. Krauss, F.J. Eley, and D.P. Lettenmaier. 1997. Spatiotemporal analysis of radar-estimated precipitation during the BOREAS summer 1994 field campaigns. Journal of Geophysical Research, 102(D24):29,417-29,427.

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.

Wilson, J.W. and E.A. Brandes. 1979. Radar measurement of rainfall: A summary. Bulletin of the American Met. Society, 60(9):1048-1058.

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

```
AES      - Atmospheric Environment Service
AFM      - Airborne Fluxes and Meteorology
AP       - Anomalous Propagation
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
DVIP     - Digital Video Integrator-Processor
EOS      - Earth Observing System
EOSDIS   - EOS Data and Information System
GIS      - Geographic Information System
GMT      - Greenwich Mean Time
GPS      - Global Positioning System
GSFC     - Goddard Space Flight Center
Gzip     - GNU zip
HYD      - Hydrology
IBM-PC   - International Business Machines - Personal Computer
IFC      - Intensive Field Campaign
MSA      - Modeling Sub-Area
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
SSA      - Southern Study Area
URL      - Uniform Resource Locator
UTC      - Universal Time Code
```

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The BOREAS HYD-9 team collected data on precipitation and streamflow over portions of the NSA and SSA. This data set contains Cartesian maps of rain accumulation for 1-hour and daily periods during the summer of 1994 over the SSA only (not the full view of the radar). A parallel set of 1-hour maps for the whole radar view has been prepared and is available upon request from the HYD-09 personnel. An incidental benefit of the areal selection was the elimination of some of the less accurate data,because for various reasons the radar rain estimates degrade considerably outside a range of about 100 km. The data are available in tabular ASCII files.

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