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

Forrest G. Hall and Jaime Nickeson, Editors

Volume 74

BOREAS RSS-18 Level-1B AVIRIS Imagery: At-sensor Radiance in BIL Format

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Greenbelt, Maryland 20771

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BOREAS RSS-18 Level-1b AVIRIS Imagery: At-Sensor Radiance in BIL Format

Jeffrey A. Newcomer, Robert O. Green

Summary

These data were collected and processed by the BOREAS RSS-18 team at NASA JPL. Data were acquired for BOREAS with NASA's AVIRIS. This optical sensor measures images that consist of spectra from 400 to 2500 nm at 10-nm sampling. These spectra are acquired as images with 20-meter spatial resolution, 11-km swath width and up to 800-km length. The measurements are spectrally, radiometrically, and geometrically calibrated. Spatially, the data are focused on the BOREAS NSA and SSA near Thompson, Manitoba, and Candle Lake, Saskatchewan, Canada, respectively. AVIRIS data were collected in 1994 during the Thaw campaign at the NSA and SSA, at the SSA in IFC-1, and at the NSA and SSA in both IFC-2 and IFC-3. In 1996, AVIRIS was deployed in the winter and summer campaigns in the SSA only.

Note that the AVIRIS images are not contained on the BOREAS CD-ROM set. An inventory file of the available images is provided on the CD-ROM to inform users of the data that are available. See Section 15 for information on how to acquire the data.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS RSS-18 Level-1b AVIRIS Imagery: At-Sensor Radiance in BIL Format

1.2 Data Set Introduction

These data were collected and processed by the BOReal Ecosystem-Atmosphere Study (BOREAS) Remote Sensing Science (RSS)-18 team at the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL). The Airborne Visible/Infrared Imaging Spectrometer

(AVIRIS) Data Facility (ADF) is responsible for processing AVIRIS data to level-b products (at-sensor radiance), archiving and distributing data, and assisting with judging the instrument performance. AVIRIS data have been used in a wide variety of atmospheric, land, and ocean studies. For BOREAS, AVIRIS data were collected along with other remotely sensed images to spatially characterize the state of various atmospheric, vegetative, and aquatic components for use in integrated modeling studies.

1.3 Objective/Purpose

AVIRIS spectral images record the interaction of atmospheric and surface matter with the solar reflected spectrum through processes of absorption and scattering. Analysis of the measured radiance spectra enables determination of atmospheric and surface constituents. Many of the questions posed in BOREAS are related to the distribution and change of constituents of the atmosphere and surface.

1.4 Summary of Parameters

The AVIRIS images provide the total spectral radiance [$\mu W/(cm^2\ sr\ nm)$] recorded at the sensor position.

1.5 Discussion

AVIRIS measures the total incident spectral radiance from 400 to 2500 nm through 224 channels at nominally 10-nm spectral sampling and response function. These data are acquired in 11-km by up to 800-km images with nominal 20- by 20-m resolution.

Spectral and radiometric calibrations are determined for AVIRIS at JPL prior to each period of operations. With an accurate calibration, AVIRIS radiance data may be analyzed quantitatively to retrieve surface reflectance and derived atmospheric and ecological parameters using radiative transfer codes. Accurate calibration will allow comparison of data acquired at the different BOREAS sites. Analysis with time series of AVIRIS data at the BOREAS sites will also require an accurate calibration of the sensor data. Finally, analysis of AVIRIS data in conjunction with other measurements or physical models requires calibrated data.

1.6 Related Data Sets

BOREAS RSS-18 Sunphotometer Data
BOREAS level-0 ER-2 Navigation Data
BOREAS Level-1b MAS Imagery: At-sensor Radiance in BSQ Format
BOREAS Level-1b ASAS Imagery: At-sensor Radiance in BSQ Format

2. Investigator(s)

2.1 Investigator(s) Name and Title

Dr. Robert O. Green, AVIRIS Experiment Scientist

2.2 Title of Investigation

Surface and Atmosphere Measurements and Radiative Transfer Modeling for the Calibration and Validation of the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) for Quantitative Data Analysis at BOREAS

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3. Theory of Measurements

An imaging spectrometer measures a continuous spectrum of light for each spatial element of an image. From these spectra, the constituents of Earth's surface and atmosphere are identified and measured quantitatively based on the fundamental molecular absorption features and particle-scattering characteristics. Spectra measured in the range of 400 to 2500 nm contain important molecular absorptions for many constituents of Earth's surface and atmosphere. Scientific investigations are ongoing using imaging spectrometry data in the disciplines of Ecology, Oceanography, Coastal and Inland Waters, Geology and Soils, Snow Hydrology, the Atmosphere, etc.

4. Equipment

4.1 Sensor/Instrument Description

4.1.1 Collection Environment

The BOREAS AVIRIS spectral images were acquired largely under clear sky conditions.

4.1.2 Source/Platform

AVIRIS is installed in the Q-bay of the NASA ER-2 aircraft, which flies nominally at approximately 20 km altitude.

4.1.3 Source/Platform Mission Objectives

The BOREAS Experiment Plans (1994 and 1996) give information about the overall ER-2 flight patterns. The AVIRIS mission objectives for BOREAS were to acquire high spatial and hyperspectral resolution digital imagery over selected BOREAS areas during optimally clear days of the BOREAS field efforts in 1994 and 1996.

4.1.4 Key Variables

The AVIRIS images provide the total spectral radiance [$\mu W/(cm^2\ sr\ nm)$] at the sensor.

4.1.5 Principles of Operation

Light enters AVIRIS from a 10- by 20-cm scan mirror driven by a 70-percent-efficient whiskbroom scan drive at a rate of 12 scans per second. Significant engineering effort was required to develop a scan drive to sweep linearly across the 30-degree (10.4 km at nominal altitude of 19,800 m) field of view (FOV) and then return at nearly twice the speed to start the next imaging scan. The instantaneous FOV (IFOV) of AVIRIS is 1 milliradian (19.8 m at altitude of 19,800 m) and translates to 614 cross-track spatial elements per scan. In the foreoptics, the energy reflected from the scan mirror is magnified and focused on four 200-micron-diameter optical fibers. The fibers transmit the light from the foreoptics to one each of four spectrometers. Silica glass fibers with numerical apertures of 0.55 are used to cover the spectral range from 400 to 1200 nanometers. Zirconium fluoride glass fibers with a beryllium fluoride cladding with a 0.55 numerical aperture are used from 1200 to 2500 nm. These high numerical aperture zirconium fluoride fibers were specifically developed for AVIRIS and were the first of their kind. The Zirconium fluoride fibers were found to be less robust than silica. However, initial difficulties were overcome, and the use of fibers was essential to allow independent alignment of the foreoptics and spectrometers as well as meet the compact sensor packaging requirements.

AVIRIS uses four off-axis Schmidt spectrometers (A, B, C, and D) to measure the light across the wavelength range at maximum grating efficiencies. Light enters the spectrometers from the optical fibers and a spherical mirror collimates and directs it to a diffraction grating where the light is dispersed into its spectral components. The grating is designed with a second-order aspheric correction surface. The dispersed light is refocused by the spherical mirror onto the detector focal plane. For the range 400 to 700 nm, a linear silicon detector array of 32 elements is used in spectrometer A. Spectrometers B, C, and D use 64 element arrays of indium antimonide. Each spectrometer and detector array is optimized for the appropriate spectral range. The signal measured by each detector in the array is multiplexed in the focal plane and then amplified. The amplified signal is then digitized at 12 bits. The digital signal is buffered and then merged with engineering, navigation, and dark signal data. Navigation data include the X, Y, and Z position of the platform from a Global Positioning System (GPS) as well as the roll, pitch, and yaw at 1-second intervals. This data stream is then recorded on a 10.4-gigabyte digital high-density tape at a rate of 20.4 megabits per second.

An onboard calibrator is an additional component of the AVIRIS sensor. This subsystem contains a stabilized quartz halogen lamp that provides light to the foreoptics end of the optical fibers. AVIRIS data are collected from the onboard calibrator before and after each flight line. A silicon detector feedback circuit has been developed specifically to maintain the stability of the light from the onboard calibrator. In addition, light from the onboard calibrator is sent sequentially through eight different filters providing both radiometric and spectral calibration sources.

The AVIRIS sensor and onboard calibrator system are calibrated in the laboratory preceding and following each flight season. During laboratory calibration, the spectral, radiometric, and geometric characteristics of AVIRIS are determined with respect to laboratory standards.

In the 6-month period each year when AVIRIS is not collecting airborne data, the sensor is maintained and improved at JPL. Since its first flight in 1986, almost every subsystem of AVIRIS has been upgraded. Through these continuous improvements, AVIRIS has continued to incorporate new technology and remain a unique state-of-the-art imaging spectrometer.

4.1.6 Sensor/Instrument Measurement Geometry

AVIRIS Instrument/Platform Specifications

Platform:	NASA Ames ER-2
Altitude:	19,800 meters (nominal)
Ground Speed:	440 knots (814.88 kilometers/hr)
Pixel Spatial Resolution:	19.8 meters (at 19,800 meters altitude)
Pixels per Scan Line:	614
Scan Rate:	12 scans/second
Swath width:	10.4 km at 19,800 m altitude
Total Field of View:	30 (plus or minus 15) degrees
Instantaneous Field of View:	1.0 milliradian
Bits per Channel:	10 through 1994; 12 since 1995
Data Rate:	17 Megabytes/second through 1994; 20.4 since 1995
Visible Calibration:	Direct view of Standard Lamp
Infrared Calibration:	Direct view of Standard Lamp
Other Calibration Standards	Inflight validation, Quantum Efficient Detector, Cavity Blackbody

4.1.7 Manufacturer of Sensor/Instrument

AVIRIS was proposed, developed, and is maintained at the NASA JPL.

4.2 Calibration

4.2.1 Specifications

4.2.1.1 Tolerance

Several calibration standards are used both in the laboratory and in the field to support calibration of AVIRIS.

Spectral calibration of AVIRIS is derived from krypton and mercury low-pressure emission lamps. Known emission line features from these lamps are used to spectrally calibrate a monochromator. The monochromator is used as a calibrated source to establish for each instrument the channel spectral positions and channel spectral response functions.

Radiometric calibration, stability, linearity, and noise equivalent radiance are derived from the National Institute of Standards and Technology (NIST) standard lamp maintained within the AVIRIS calibration laboratory. Two Spectralon panels calibrated at the 0.5-percent reflectance accuracy are used as the reflectance standards.

4.2.2 Frequency of Calibration

AVIRIS is calibrated at the beginning and end of the flight season in the laboratory. In-flight calibration of AVIRIS occurs at the beginning, middle, and end of the flight season. The onboard calibrator is observed by AVIRIS at the beginning and end of each flight line and is used to trace the calibration in detail through the flight season.

4.2.3 Other Calibration Information

AVIRIS spectral, radiometric, and geometric calibration are provided with each flight line.

5. Data Acquisition Methods

As part of the BOREAS aircraft data collection effort, the ADF personnel provided the AVIRIS data to the BOREAS Information System (BORIS) for use in science investigations. The AVIRIS was flown on NASA's ER-2 aircraft during BOREAS. Maintenance and operation of the instrument are the responsibility of NASA JPL.

6. Observations

6.1 Data Notes

AVIRIS operated nominally for BOREAS. The following sections were extracted from the errata files (full errata files exist as part of the data set) on the 1994 and 1996 Format A AVIRIS data tapes.

1994 Errata File

- Operations Period: from 93-05-17
  - Single channel and spatial element noise spikes continue through this period in all spectrometers. Rate: 1 in 300,000 samples. In calibrated data, the spikes are replaced with values computed from spatial neighbors.
  - All values in the vignetting file are 1.0. In 1993 and later the vignetting effect is less than 2% and below our ability to accurately measure.
- Operations Period: from 94-03-01
  - A tendency for the least significant 1 or 2 bits to be flipped in the data was observed. The noise was detected because it occurs in the minor frame sync words, which should have uniform values. The magnitude of the noise (typically 1, 2, or 4) is not large enough to be observed in most channels' data, so it is not known how frequently a data value is affected. In channels with low enough signal to notice these spikes, an average of perhaps 10 in a scene were observed. In calibrated data these noise values may be replaced by the same spike replacement algorithm used on the spikes described in 1) a), but usually their magnitude is not big enough to trip that detection mechanism.

Normally in calibrating the data, lines with minor sync errors are dropped. For this period however they are not because this would have resulted in throwing away a lot of good data. Because minor sync errors are ignored in this data, there will occasionally be a line in which the science data is corrupted or missing.

1996 Errata File

- Operations from 95-10-26 to 96-10-10
  - The detector slew rate artifact that first appeared in the 1995 flight season has been reduced. It may be seen in ratios of bands in and out of strong atmospheric absorptions.
  - Occasional downward spikes occur in the spectra about every 15000 spectra. These are replaced when detected in the calibration process. Radiometrically calibrated data undergo spike replacement. Please note that, since this is the only (known) type of spikes in the 1996 data and since the spike filtering algorithm used to detect these spikes differs substantially compared to previous years, the old spike filtering algorithms and the spike thresholds file are no longer used. The spike thresholds file is nevertheless included on the PG tapes for 1996 (for consistency reasons), but all threshold values are set to zero and should not be used.
  - Spectral calibration shifts of up to 1.0 nm may occur in 1996 data. This is comparable to previous years and will be corrected in 1997. Radiometric calibration is the best ever at better than 96.5 percent.
  - All values in the vignetting file are 1.0. Vignetting effect is less than 2% and below our ability to accurately measure.

    - When uncalibrated data is requested, no On-board Calibrator (OBC) correction is applied to the data set. As a result, no OBC correction coefficients are calculated. The OBC correction coefficients file (OCC) written to the PG tape is filled with ones and is not applicable to the uncalibrated data set.
- Operations from 94-04-04 to 94-11-30
    - Single channel and spatial element noise spikes occur through this period in all spectrometers. Rate: 1 in 300,000 samples. In calibrated data, the spikes are replaced with values computed from spatial neighbors.
    - All values in the vignetting file are 1.0. Vignetting effect is less than 2% and below our ability to accurately measure.
    - A tendency for the least significant 1 or 2 bits to be flipped in the data was observed.
    - Normally in calibrating the data, lines with minor sync errors are dropped. For this period however they are not. Because minor sync errors are ignored in this data, there will occasionally be a line in which the science data is corrupted or missing.

6.2 Field Notes

None.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The cross-track coverage of an AVIRIS image is nominally 11 km. The length of the images is determined from the start and stop latitude and longitude flown. For BOREAS, the images were collected over the Southern Study Area (SSA) and Northern Study Area (NSA) with some data also collected over the transect between the SSA and the NSA.

```
The North American Datum of 1983 (NAD83)
corner coordinates of the SSA are:
             Latitude     Longitude
             --------     ---------
Northwest    54.321 N     106.228 W
Northeast    54.225 N     104.237 W
Southwest    53.515 N     106.321 W
Southeast    53.420 N     104.368 W

The NAD83 corner coordinates of the NSA are:

             Latitude     Longitude
             --------     ---------
Northwest    56.249 N      98.825 W
Northeast    56.083 N      97.234 W
Southwest    55.542 N      99.045 W
Southeast    55.379 N      97.489 W
```

7.1.2 Spatial Coverage Map

Each record or flight line name in the following table represents one to several AVIRIS scenes. See the BOREAS Experiment Plan for graphics depicting the general location of flight lines. For specific information about flux tower site coverage, see Section 7.2.2.

#Lines	Flight line Name	Start Latitude	End Latitude	Start West Long	End West Long	Start GMT	End GMT
10-Apr-1994							
1954	SSA-cal-W	53:07:08	53:20:58	105:41:58	105:41:58	18:01:54	18:03:56
5769	SSA-West-B	53:28:53	54:17:39	106:15:54	106:15:54	18:10:41	18:18:00
3334	SSA-West-Thaw	54:02:30	53:35:28	106:05:22	106:13:56	18:22:12	18:26:08
5761	SSA-West-C	53:28:53	54:17:59	106:07:00	106:06:41	18:32:13	18:39:32
3258	SSA-East-Thaw	53:59:32	53:52:56	105:19:33	104:36:02	18:46:23	18:50:13
4245	SSA-East-J	54:12:23	53:36:08	104:40:59	104:40:59	18:59:14	19:04:27
4447	SSA-East-H	53:35:28	54:12:03	104:58:07	104:58:07	19:10:08	19:15:37
4266	SSA-East-F	54:12:23	53:36:08	105:15:16	105:15:36	19:20:52	19:26:07
4381	SSA-East-K	53:35:28	54:12:03	104:32:25	104:32:25	19:33:18	19:38:42
4290	SSA-EAST-I	54:12:23	53:36:08	104:49:33	104:49:33	19:44:09	19:49:24
4382	SSA-EAST-G	53:35:28	54:12:03	105:06:42	105:06:42	19:54:32	19:59:55
4331	SSA-East-E	54:12:23	53:36:08	105:24:10	105:24:10	20:07:39	20:12:57
5679	SSA-West-D	53:29:12	54:17:39	105:57:47	105:57:47	20:21:33	20:28:44
20-Apr-1994							
8294	Transect-T	54:59:31	55:54:33	101:40:42	100:15:00	17:52:33	18:03:21
8960	Transect-U	55:54:53	55:54:33	100:15:20	97:49:59	18:11:00	18:22:45
2342	NSA-Q	56:03:08	55:44:40	98:07:27	98:07:27	18:30:42	18:33:16
2550	NSA-O	55:44:01	56:02:48	98:25:15	98:25:35	18:38:28	18:41:19
2315	NSA-M	56:02:48	55:44:40	98:44:02	98:44:22	18:46:45	18:49:16
2556	NSA-L	55:44:01	56:02:48	98:52:56	98:52:56	18:55:21	18:58:14
2360	NSA-N	56:03:08	55:45:00	98:35:08	98:35:08	19:03:27	19:06:01
2537	NSA-P	55:44:01	56:02:48	98:16:21	98:16:21	19:11:32	19:14:22
2415	NSA-R	56:03:27	55:44:40	97:58:14	97:58:14	19:19:36	19:22:17
3514	NSA-thaw-X	55:53:14	55:53:14	98:04:10	98:55:15	19:29:14	19:33:26
13829	Transect S	39:22:30	54:07:07	101:39:03	104:59:07	19:49:30	20:07:59
28-Apr-1994							
3567	NSA-Thaw	55:53:14	55:53:14	98:56:34	98:05:29	17:00:20	17:04:35
1597	NSA-Q	55:57:51	55:46:59	98:07:08	98:07:27	17:12:22	17:13:53
1923	NSA-O	55:46:59	56:00:10	98:25:35	98:25:35	17:19:24	17:21:22
1777	NSA-M	56:00:10	55:47:38	98:44:02	98:44:02	17:26:32	17:28:17
1869	NSA-L	55:47:18	56:00:10	98:52:56	98:53:16	17:33:43	17:35:36
1861	NSA-N	56:00:29	55:47:18	98:34:49	98:34:49	17:40:49	17:42:44
1876	NSA-P	55:46:59	56:00:10	98:16:41	98:16:21	17:48:05	17:50:00
1789	NSA-R	56:00:10	55:47:38	97:58:14	97:58:14	17:55:35	17:57:22
1936	NSA -Q	55:46:59	56:00:10	98:07:08	98:07:08	18:03:11	18:05:11
9125	Transect-U	55:54:53	55:54:53	97:49:20	100:15:20	18:12:55	18:24:54
8112	Transect-T	55:54:53	54:59:51	100:15:00	101:40:02	18:31:58	18:42:32
5764	Transect-S	54:59:51	54:40:04	101:38:43	102:58:29	18:49:44	18:57:03
08-Jun-1994							
4241	NSA-Thaw-X	55:53:14	55:53:14	99:05:08	98:03:30	15:59:04	16:04:16
2842	NSA-R	55:45:20	56:06:25	97:57:54	97:57:34	16:12:17	16:15:33
1872	NSA-P	56:00:49	55:47:18	98:16:21	98:16:41	16:20:05	16:22:01
2101	NSA-N	55:45:20	56:00:10	98:34:49	98:34:49	16:27:19	16:29:33
1867	NSA-L	56:01:09	55:47:38	98:53:16	98:53:16	16:35:11	16:37:06
2076	NSA-M	55:45:39	56:00:29	98:44:02	98:44:02	16:43:49	16:46:01
1890	NSA-O	56:01:09	55:47:38	98:25:55	98:25:55	16:51:20	16:53:15
10479	Boreas	55:54:53	55:54:53	97:48:20	100:41:22	17:09:40	17:23:31
7267	Boreas	55:47:58	54:58:51	100:26:13	101:41:41	17:30:40	17:40:05

#Lines	Flight line Name	Start Latitude	End Latitude	Start West Long	End West Long	Start GMT	End GMT
21-Jul-1994							
1995	SSA-Cal-W	53:06:28	53:20:58	105:41:58	105:41:58	16:29:31	16:31:35
3757	SSA-Thaw-Y	53:51:37	53:59:12	104:28:08	105:18:34	16:54:23	16:58:55
4485	SSA-East-G	54:10:05	53:31:31	105:06:42	105:06:42	17:05:55	17:11:27
4138	SSA-Easy-I	53:36:08	54:10:05	104:49:33	104:49:33	17:15:42	17:20:46
3741	SSA-East-K	54:10:44	53:39:06	104:32:25	104:32:25	17:25:59	17:30:28
4040	SSA-East-J	53:37:07	54:10:05	104:40:59	104:40:59	17:35:55	17:40:49
3630	SSA-East-H	54:08:46	53:38:46	104:58:07	104:58:07	17:46:43	17:51:05
4171	SSA-East-F	53:36:08	54:09:45	105:15:16	105:15:16	17:56:24	18:01:29
3514	SSA-Thaw-Z	54:04:09	53:35:08	106:05:02	106:13:56	18:08:07	18:12:19
5207	SSA-West-B	54:18:39	53:32:30	106:15:54	106:15:54	18:29:08	18:35:39
5495	SSA-West-D	53:30:32	54:17:20	105:57:47	105:56:47	18:40:59	18:47:56
5511	SSA-West-C	54:20:18	53:50:58	106:07:00	106:07:00	18:56:46	19:01:01
04-Aug-1994							
3905	NSA-Thaw-X	47:58:18	55:53:14	120:39:26	98:04:49	19:52:41	15:29:31
2139	NSA - R	55:45:00	55:59:50	97:57:54	97:57:54	15:39:41	15:41:56
1978	NSA - P	56:02:08	55:47:18	98:16:21	98:16:21	15:47:38	15:49:41
2065	NSA - N	55:45:39	56:00:10	98:34:49	98:34:49	15:54:57	15:57:07
1875	NSA - L	56:00:49	55:47:18	98:53:16	98:53:16	16:02:27	16:04:22
1904	NSA - M	55:46:59	56:00:10	98:44:02	98:44:02	16:09:48	16:11:46
1835	NSA - O	56:00:49	55:47:58	98:25:55	98:25:35	16:16:53	16:18:45
9352	Transect U	55:54:53	55:54:53	97:44:03	100:15:40	16:33:56	16:46:13
8296	Transect T	55:57:12	55:12:02	100:11:23	101:21:35	16:53:50	17:02:21
08-Aug-1994							
3889	NSA-Thaw-X	55:53:14	55:53:14	99:02:10	98:03:50	15:23:36	15:28:19
2262	NSA_R	55:43:41	56:00:29	97:57:54	97:58:14	15:36:19	15:38:47
2180	NSA-P	56:03:27	55:47:18	98:16:01	98:16:21	15:44:12	15:46:32
2292	NSA-N	55:44:01	56:00:29	98:34:49	98:34:49	15:52:30	15:55:00
2175	NSA-L	56:03:08	55:46:39	98:53:36	98:53:16	16:01:24	16:03:43
2120	NSA-M	55:45:00	56:00:29	98:44:02	98:44:02	16:11:52	16:14:06
1973	NSA-O	56:00:29	55:45:59	98:25:55	98:25:35	16:20:25	16:22:28
2105	NSA-Q	55:44:40	56:00:10	98:07:27	98:07:08	16:28:38	16:30:51
8967	Transect U	55:54:53	55:55:13	97:49:20	99:34:48	16:39:20	16:47:51
8290	Transect-T	55:55:53	54:59:51	100:13:41	101:40:22	16:58:55	17:09:45
16-Sep-1994							
1760	SSA-Cal-W	53:08:46	53:20:58	105:41:38	105:41:58	16:39:15	16:41:00
3953	SSA-East-K	53:38:26	54:11:04	104:37:41	104:32:05	16:47:20	16:52:07
4061	SSA-East-I	54:11:04	53:38:46	104:49:33	104:49:33	17:02:21	17:07:18
3883	SSA-East-G	53:37:47	54:10:05	105:06:42	105:06:42	17:14:50	17:19:33
3726	SSA-East-F	54:08:46	53:38:26	105:15:36	105:15:36	17:28:38	17:33:07
3875	SSA-East-H	53:38:26	54:10:24	104:57:48	104:58:07	17:41:13	17:45:53
4003	SSA-East-J	54:11:24	53:38:26	104:40:59	104:40:59	17:53:26	17:58:17
3391	SSA-E-Thaw-Y	53:52:56	53:59:32	104:36:22	105:18:53	18:05:49	18:09:50
5165	SSA-West-D	54:16:20	53:32:30	105:58:07	105:58:07	18:18:54	18:25:24
5088	SSA-West-B	53:33:10	54:16:20	106:15:54	106:15:35	18:32:45	18:39:07
5077	SSA-West-C	54:16:01	53:32:50	106:07:00	106:07:00	18:48:21	18:54:43

#Lines	Flight line Name	Start Latitude	End Latitude	Start West Long	End West Long	Start GMT	End GMT
17-Sep-1994							
8423	BOREAS-Tran-T	54:58:32	55:54:53	101:41:41	100:15:00	15:54:16	16:05:16
1615	NSA - L	55:58:31	55:47:38	98:53:16	98:53:16	16:14:26	16:16:01
2237	NSA - N	55:44:01	55:59:50	98:34:29	98:34:49	16:21:09	16:23:34
1877	NSA - P	56:01:09	55:47:58	98:16:21	98:16:41	16:28:41	16:30:34
2091	NSA - R	55:45:20	55:59:50	97:57:34	97:57:54	16:35:41	16:37:53
2105	NSA - M	56:03:08	55:47:38	98:44:02	98:44:22	16:54:24	16:56:38
2061	NSA - O	55:45:20	55:59:50	98:25:35	98:25:35	17:01:45	17:03:54
2098	NSA - Q	56:03:08	55:47:38	98:07:27	98:07:27	17:09:12	17:11:26
9914	NSA-Thaw-X/Trn	55:53:14	55:53:14	97:45:03	100:15:20	17:21:11	17:34:14
30000	Transect S	55:00:30	53:45:02	101:37:24	106:15:15	17:45:37	18:13:14
07-Mar-1996							
6376	Prince Albert	53:26:01	54:17:48	106:15:56	106:17:56	19:09:40	19:17:43
5463	Prince Albert	54:19:45	53:30:25	105:57:47	105:57:46	19:23:04	19:29:52
6478	Prince Albert	53:25:35	54:17:40	106:06:33	106:06:37	19:36:25	19:44:36
4260	Prince Albert	54:14:24	53:36:21	105:06:42	105:06:37	19:51:44	19:56:52
5143	Prince Albert	53:31:35	54:12:01	104:57:38	104:57:55	20:03:49	20:10:10
4703	Prince Albert	54:11:17	53:29:00	104:49:16	104:49:28	20:16:37	20:22:23
5225	Prince Albert	53:31:18	54:12:06	104:32:16	104:32:10	20:25:51	20:32:18
5148	Prince Albert	54:16:06	53:28:57	104:40:55	104:40:54	20:38:14	20:44:34
08-Aug-1996							
5945	P.A. West	53:27:05	54:17:46	106:24:35	106:24:36	16:24:39	16:32:07
5565	P.A. West	54:19:00	53:30:27	106:06:54	106:06:49	16:37:17	16:44:14
5830	P.A. West	53:28:48	54:18:10	106:15:38	106:15:36	16:49:24	16:56:43
5593	P.A. West	54:18:42	53:30:24	105:57:46	105:57:49	17:01:45	17:08:43
4566	P.A. East	54:14:56	53:36:29	105:23:50	105:23:54	17:22:26	17:28:00
4428	P.A. East	53:34:55	54:12:02	105:06:35	105:06:29	17:33:57	17:39:18
4486	P.A. East	54:13:46	53:44:23	105:15:07	105:15:18	17:43:05	17:47:21
4535	P.A. East	53:33:58	54:03:20	104:57:56	104:57:53	17:53:18	17:57:33
4476	P.A. East	54:14:01	53:36:24	104:40:53	104:40:54	18:03:32	18:08:59
4512	P.A. East	53:34:30	54:03:48	104:49:09	104:49:12	18:14:28	18:18:43

7.1.3 Spatial Resolution

At the nominal ER-2 operating altitude of 19,800 m, the AVIRIS provides across-track pixel resolutions of 19.5 m at nadir to 21.4 m at the scanning extremes. The along-track resolution is dependent on the forward velocity of the aircraft and the scan rate, which is usually 12 scans per second.

7.1.4 Projection

The images covering the BOREAS areas are stored in their raw spatial form with pixel size increasing from nadir to the scanning extremes of 15 degrees. Navigation and position data are delivered with AVIRIS that allow ephemeris-based projection of the spectral images.

7.1.5 Grid Description

Not applicable.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

AVIRIS data were acquired on the following dates:

```
19-Apr-1994
20-Apr-1994
28-Apr-1994
08-Jun-1994
21-Jul-1994
04-Aug-1994
16-Sep-1994
17-Sep-1994
07-Mar-1996
14-Aug-1996
```

7.2.2 Temporal Coverage Map

flight	run	scene	site_name	BOREAS sites
940419	2	1,2,3	SSA-Cal-W	
940419	3	2	SSA-West-B	Old Aspen (OA)
940419	4	6	SSA-West-Thaw	OA
940419	6	2	SSA-East-Thaw	Old Black Spruce (OBS)
940419	6	5	SSA-East-Thaw	Old Jack Pine (OJP)
940419	6	6	SSA-East-Thaw	Young Jack Pine (YJP)
940419	7	4	SSA-East-J	OJP
940419	7	5,6	SSA-East-J	YJP,FEN (FEN tower in 5, Wind-Aligned Blob (WAB) extends into 6)
940419	12	5	SSA-East-G	OBS (site near edge, may also want scene 6)
940420	6	2	NSA-O	OBS
940420	6	3	NSA-O	FEN
940420	9	?	NSA-N	QUICKLOOK NOT AVAILABLE
940420	10	?	NSA-P	QUICKLOOK NOT AVAILABLE
940420	12	2	NSA-THAW	YJP
940420	12	3	NSA-THAW	FEN,OBS
940420	12	4	NSA-THAW	OJP
940428	2	3	NSA-THAW	OJP
940428	2	4	NSA-THAW	FEN,OBS
940428	4	2	NSA-O	FEN,OBS
940428	7	1,2	NSA-N	OJP (tower in 2, WAB may extend into 2)
940428	8	2	NSA-P	YJP
940608	2	4	NSA-THAW	OJP
940608	2	5	NSA-THAW	FEN,OBS
940608	2	6	NSA-THAW	YJP
940608	4	2	NSA-P	YJP
940608	5	3	NSA-N	OJP
940608	8	2	NSA-O	FEN,OBS
940721	2	1,2,3	SSA-Cal-W	
940721	3	?	SSA-THAW-EAST	(quicklook for scenes 7 and 8, found no sites, did not find quicklook for scenes 1-6)
940721	4	3	SSA-EAST-G	OBS
940721	7	3	SSA-EAST-J	FEN
940721	7	4	SSA-EAST-J	YJP,OJP

```
940721 10    6    SSA-WEST-THAW  OASP
940721 11    9    SSA-WEST-B     OASP

940804  2    3    NSA-THAW       OJP
940804  2    4    NSA-THAW       OBS
940804  2    5    NSA-THAW       FEN
940804  2    6    NSA-THAW       YJP
940804  4    2    NSA-P          YJP
940804  5    3    NSA-N          OJP
940804  8    2    NSA-O          OBS

940808  1    3    NSA-THAW       OJP
940808  1    4    NSA-THAW       OBS
940808  1    5    NSA-THAW       FEN
940808  1    6    NSA-THAW       YJP (cloud shadow over tower)
940808  3   2,3   NSA-P          YJP (near edge of scene 2, clouds all over,
                                     tower apparently clear)
940808  4    3    NSA-N          OJP
940808  7    2    NSA-O          FEN,OBS (large cloud next to OBS)

940916  2  1,2,3  SSA-Cal-W
940916  5    5    SSA-EAST-G     OBS
940916  8    4    SSA-EAST-J     OJP,YJP
940916  9    1    SSA-THAW-EAST  OJP,YJP
940916  9    5    SSA-THAW-EAST  OBS
940916 11    1    SSA-WEST-B     OA

940917  5    3    NSA-N          OJP
940917  9    2    NSA-O          FEN, OBS
940917 10    7    NSA-P          OJP
940917 11 4,5,6,7 NSA-Thaw-X     YJP,FEN,OBS,OJP (respectively)
```

Additional AVIRIS imagery is available over the SSA on 07-Mar and 14-Aug-1996 however.

7.2.3 Temporal Resolution

See Section 7.1.2.

7.3 Data Characteristics

7.3.1 Parameter/Variable

Scaled at-sensor radiance AVIRIS data contains numerous additional parameters. For further tape content detail, see Section 8, the Description File on a data tape, and the software noted in Section 14. The parameters contained in the data files on the CD-ROM are:

```
         Column Name
-----------------------------
SPATIAL_COVERAGE
DATE_OBS
START_TIME
END_TIME
PLATFORM
INSTRUMENT
NUM_BANDS
PLATFORM_ALTITUDE
```

MIN_SOLAR_ZEN_ANG
MAX_SOLAR_ZEN_ANG
MIN_SOLAR_AZ_ANG
MAX_SOLAR_AZ_ANG
ER2_MISSION_ID
AVIRIS_FLIGHT_ID
AVIRIS_RUN_NUM
AVIRIS_SCENE_NUM
BAND_QUALITY
CLOUD_COVER
NUM_GOOD_LINES
NUM_SYNC_LINES
NUM_MISSING_LINES
NUM_INV_CNT_LINES
NUM_INV_FRAME_LINES
NW_LATITUDE
NW_LONGITUDE
NE_LATITUDE
NE_LONGITUDE
SW_LATITUDE
SW_LONGITUDE
SE_LATITUDE
SE_LONGITUDE
CRTFCN_CODE

7.3.2 Variable Description/Definition

Scaled At-sensor radiance: Scaled values of the derived radiant energy incident on the sensor aperture at the time of data collection in the specific AVIRIS wavelength regions. The descriptions of the parameters contained in the data files 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.
DATE_OBS	The date on which the data were collected.
START_TIME	The starting Greenwich Mean Time (GMT) for the data collected.
END_TIME	The ending Greenwich Mean Time (GMT) for the data collected.
PLATFORM	The object (e.g., satellite, aircraft, tower, person) that supported the instrument.
INSTRUMENT	The name of the device used to make the measurements.
NUM_BANDS	The number of spectral bands in the data.
PLATFORM_ALTITUDE	The nominal altitude of the data collection platform above the target.
MIN_SOLAR_ZEN_ANG	The minimum angle from the surface normal (straight up) to the sun during the data collection.
MAX_SOLAR_ZEN_ANG	The maximum angle from the surface normal (straight up) to the sun during the data collection.
MIN_SOLAR_AZ_ANG	The minimum azimuthal direction of the sun during data collection expressed in clockwise increments

	from North.
MAX_SOLAR_AZ_ANG	The maximum azimuthal direction of the sun during data collection expressed in clockwise increments from North.
ER2_MISSION_ID	The mission identifier assigned to the ER2 mission in the form of YY-DDD where YY is the last two digits of the fiscal year, and DDD is the deployment number. An example would be 94-120.
AVIRIS_FLIGHT_ID	Flight ID as assigned in the header files.
AVIRIS_RUN_NUM	Each flight contains about 5-15 Runs. Each Run is an image which is later sliced up into Scenes.
AVIRIS_SCENE_NUM	Each AVIRIS run's image is sliced up into small manageable Scenes as each image has 224 bands.
BAND_QUALITY	The data analyst's assessment of the quality of the spectral bands in the data.
CLOUD_COVER	The data analyst's assessment of the cloud cover that exists in the data.
NUM_GOOD_LINES	Each image line has a flag indicating the status of the line. This number indicates the number of lines that were flagged as good data.
NUM_SYNC_LINES	Each image line has a flag indicating the status of the line. This number indicates the number of lines that were dropped due to a bad sync pattern.
NUM_MISSING_LINES	Each image line has a flag indicating the status of the line. This number indicates the number of actual lines of science data missing when the data were archived.
NUM_INV_CNT_LINES	Each image line has a flag indicating the status of the line. This number indicates the number of lines that were dropped because of an invalid count flag.
NUM_INV_FRAME_LINES	Each image line has a flag indicating the status of the line. This number indicates the number of lines that were dropped because of an invalid frame somewhere in the line.
NW_LATITUDE	The NAD83 based latitude coordinate of the north west corner of the minimum bounding rectangle for the data.
NW_LONGITUDE	The NAD83 based longitude coordinate of the northwest corner of the minimum bounding rectangle for the data.
NE_LATITUDE	The NAD83 based latitude coordinate of the north-east corner of the minimum bounding rectangle for the data.
NE_LONGITUDE	The NAD83 based longitude coordinate of the north east corner of the minimum bounding rectangle for the data.
SW_LATITUDE	The NAD83 based latitude coordinate of the south west corner of the minimum bounding rectangle for the data.
SW_LONGITUDE	The NAD83 based longitude coordinate of the south west corner of the minimum bounding rectangle for

	the data.
SE_LATITUDE	The NAD83 based latitude coordinate of the south east corner of the minimum bounding rectangle for the data.
SE_LONGITUDE	The NAD83 based longitude coordinate of the south east corner of the minimum bounding rectangle for the data.
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).

7.3.3 Unit of Measurement

Scaled At-sensor radiance - Scaled microwatts/ (square centimeter * steradian * nanometer).

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

Column Name	Units
SPATIAL_COVERAGE	[none]
DATE_OBS	[DD-MON-YY]
START_TIME	[HHMM GMT]
END_TIME	[HHMM GMT]
PLATFORM	[none]
INSTRUMENT	[none]
NUM_BANDS	[counts]
PLATFORM_ALTITUDE	[meters]
MIN_SOLAR_ZEN_ANG	[degrees]
MAX_SOLAR_ZEN_ANG	[degrees]
MIN_SOLAR_AZ_ANG	[degrees]
MAX_SOLAR_AZ_ANG	[degrees]
ER2_MISSION_ID	[none]
AVIRIS_FLIGHT_ID	[none]
AVIRIS_RUN_NUM	[none]
AVIRIS_SCENE_NUM	[none]
BAND_QUALITY	[none]
CLOUD_COVER	[none]
NUM_GOOD_LINES	[counts]
NUM_SYNC_LINES	[counts]
NUM_MISSING_LINES	[counts]
NUM_INV_CNT_LINES	[none]
NUM_INV_FRAME_LINES	[none]
NW_LATITUDE	[degrees]
NW_LONGITUDE	[degrees]
NE_LATITUDE	[degrees]
NE_LONGITUDE	[degrees]
SW_LATITUDE	[degrees]
SW_LONGITUDE	[degrees]
SE_LATITUDE	[degrees]
SE_LONGITUDE	[degrees]
CRTFCN_CODE	[none]

7.3.4 Data Source

The AVIRIS instrument, the ER-2 Navigation system, and Product Generation software. The sources of the parameter values contained in the data files on the CD-ROM are:

Column Name	Data Source
SPATIAL_COVERAGE	[Determined by BORIS software from header information]
DATE_OBS	[Determined by BORIS software from header information]
START_TIME	[Determined by BORIS software from header information]
END_TIME	[Determined by BORIS software from header information]
PLATFORM	[Determined by BORIS software from header information]
INSTRUMENT	[Constant software value]
NUM_BANDS	[Determined by BORIS software from header information]
PLATFORM_ALTITUDE	[Determined by BORIS software from header information]
MIN_SOLAR_ZEN_ANG	[Calculated from latitude and longitude and time information given in the header]
MAX_SOLAR_ZEN_ANG	[Calculated from latitude and longitude and time information given in the header]
MIN_SOLAR_AZ_ANG	[Calculated from latitude and longitude and time information given in the header]
MAX_SOLAR_AZ_ANG	[Calculated from latitude and longitude and time information given in the header]
ER2_MISSION_ID	[Determined by BORIS software from header information]
AVIRIS_FLIGHT_ID	[Determined by BORIS software from header information]
AVIRIS_RUN_NUM	[Determined by BORIS software from header information]
AVIRIS_SCENE_NUM	[Determined by BORIS software from header information]
BAND_QUALITY	[Not Assessed]
CLOUD_COVER	[Not Assessed]
NUM_GOOD_LINES	[Determined by BORIS software from header information]
NUM_SYNC_LINES	[Determined by BORIS software from header information]
NUM_MISSING_LINES	[Determined by BORIS software from header information]
NUM_INV_CNT_LINES	[Determined by BORIS software from header information]
NUM_INV_FRAME_LINES	[Determined by BORIS software from header information]
NW_LATITUDE	[Determined by BORIS software from header information]
NW_LONGITUDE	[Determined by BORIS software from header information]
NE_LATITUDE	[Determined by BORIS software from header information]
NE_LONGITUDE	[Determined by BORIS software from header information]
SW_LATITUDE	[Determined by BORIS software from header information]
SW_LONGITUDE	[Determined by BORIS software from header information]
SE_LATITUDE	[Determined by BORIS software from header information]
SE_LONGITUDE	[Determined by BORIS software from header information]
PLATFORM_ALTITUDE	[Determined by BORIS software from header information]
CRTFCN_CODE	[Assigned by BORIS]

7.3.5 Data Range

Scaled At-sensor radiance: Dependent on the particular AVIRIS band of interest due to the wavelength region, the scaling factor, and the ground surface being imaged. The maximum range of values based on the storage format is -32768 to 32767 (16-bit data). 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
DATE_OBS	19-APR-94	14-AUG-96	None	None	None	None
START_TIME	1525	2043	None	None	None	None
END_TIME	1525	2044	None	None	None	None
PLATFORM	ER2	ER2	None	None	None	None
INSTRUMENT	N/A	N/A	None	None	None	None
NUM_BANDS	224	224	None	None	None	None
PLATFORM_ALTITUDE	2282.2	20266.1	None	None	None	None
MIN_SOLAR_ZEN_ANG	17.7	61.8	None	None	None	None
MAX_SOLAR_ZEN_ANG	30.8	62	None	None	None	None
MIN_SOLAR_AZ_ANG	109.9	206.7	None	None	None	None
MAX_SOLAR_AZ_ANG	116.4	206.9	None	None	None	None
ER2_MISSION_ID	94-079	96-161	None	None	None	None
AVIRIS_FLIGHT_ID	940419B	960814B	None	None	None	None
AVIRIS_RUN_NUM	01	13	None	None	None	None
AVIRIS_SCENE_NUM	01	20	None	None	None	None
BAND_QUALITY	N/A	N/A	None	None	None	None
CLOUD_COVER	N/A	N/A	None	None	None	None
NUM_GOOD_LINES	179	512	None	None	None	None
NUM_SYNC_LINES	0	0	None	None	None	None
NUM_MISSING_LINES	0	0	None	None	None	None
NUM_INV_CNT_LINES	0	45	None	None	None	None
NUM_INV_FRAME_LINES	0	333	None	None	None	None
NW_LATITUDE	53.19646	56.11626	None	None	None	None
NW_LONGITUDE	-106.37844	-97.93204	None	None	None	None
NE_LATITUDE	53.18896	56.09806	None	None	None	None
NE_LONGITUDE	-106.21561	-97.78588	None	None	None	None
SW_LATITUDE	39.43284	56.07188	None	None	None	None
SW_LONGITUDE	-107.52661	-97.96779	None	None	None	None
SE_LATITUDE	39.32808	56.0537	None	None	None	None
SE_LONGITUDE	-106.21941	-97.82201	None	None	None	None
CRTFCN_CODE	CPI	CPI-PRE	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

A sample data record for the level-1b AVIRIS images is not available here. The following is a sample of the first few records from the data table on the CD-ROM:

```
SPATIAL_COVERAGE,DATE_OBS,START_TIME,END_TIME,PLATFORM,INSTRUMENT,NUM_BANDS,
PLATFORM_ALTITUDE,MIN_SOLAR_ZEN_ANG,MAX_SOLAR_ZEN_ANG,MIN_SOLAR_AZ_ANG,
MAX_SOLAR_AZ_ANG,ER2_MISSION_ID,AVIRIS_FLIGHT_ID,AVIRIS_RUN_NUM,AVIRIS_SCENE_NUM,
BAND_QUALITY,CLOUD_COVER,NUM_GOOD_LINES,NUM_SYNC_LINES,NUM_MISSING_LINES,
NUM_INV_CNT_LINES,NUM_INV_FRAME_LINES,NW_LATITUDE,NW_LONGITUDE,NE_LATITUDE,
NE_LONGITUDE,SW_LATITUDE,SW_LONGITUDE,SE_LATITUDE,SE_LONGITUDE,CRTFCN_CODE
'SSA',19-APR-94,1801,1802,'ER2','AVIRIS',224,19477.1,47.3,47.4,158.6,158.8,
'94-079','940419B','02','01','NOT ASSESSED','NOT ASSESSED',349,0,0,0,163,
53.22423,-105.76718,53.21731,-105.61618,53.10208,-105.78247,53.09519,
-105.63192,'CPI'
```

8. Data Organization

8.1 Data Granularity

The smallest obtainable unit of data for level-1b AVIRIS images is a single flight line. Each flight line is broken up into one to several scenes. A scene represents AVIRIS image data collected over a portion of a site during one flight line.

8.2 Data Format(s)

The Compact Disk-Read-Only Memory (CD-ROM) inventory listing file consists of 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.

There are two AVIRIS data formats currently in the BORIS archive. The AVIRIS data format was changed in July 1997. The old format is referred to as PG, and the new format is referred to as Calibrated AVIRIS Spectral Image. All data at the ADF back to 1992 are being reprocessed to the newer format. Most of the BOREAS data are in the PG format; only the summer 1996 data arrived in the newer format.

Old (PG) Format

A full description of the AVIRIS data will not be given here since the format is rather involved. It is given in the Description File on each tape, and software is available to read the tapes. Instead, an overall product description follows.

All the BOREAS level-1b AVIRIS data are in what the ADF calls 'VAX format with fixed length file headers.' The VAX format refers to the byte ordering of certain (but not all) binary multibyte

fields. The fixed-length file headers are included at the start of a majority of the files and are described in detail in the description file and software. The tape records contain a variable number of bytes, with the largest records containing 32,768 bytes.

A given tape of level-1b AVIRIS images contains one set of introductory files followed by up to six sets of image files. The introductory files for 1994 and 1996 differed in that the March 1996 data contained an additional file.

The 1994 data contained 10 introductory files:

- Description File (ASCII)
- Errata File (ASCII)
- Spectral Calibration File (ASCII and binary)
- Radiometric Calibration File (ASCII and binary)
- Geometric Correction (ASCII and binary)
- Vignetting File (ASCII and binary)
- Onboard Calibration File (ASCII and binary)
- Spike Threshold File (ASCII and binary)
- Precal File (ASCII and binary)
- Postcal File (ASCII and binary)

The March 1996 data contained 11 introductory files:

- Description File (ASCII)
- Errata File (ASCII)
- Spectral Calibration File (ASCII and binary)
- Radiometric Calibration File (ASCII and binary)
- Geometric Correction (ASCII and binary)
- Vignetting File (ASCII and binary)
- Onboard Calibration File (ASCII and binary)
- Spike Threshold File (ASCII and binary)
- Precal File (ASCII and binary)
- Postcal File (ASCII and binary)
- Onboard Calibration Correction Coefficient File (ASCII and binary) (present for 1996 data tapes only)

Following the introductory files on a tape, the 1994 and March 1996 AVIRIS data contain one or more sets of eight image-related files. These files are:

- Engineering File (ASCII and binary)
- Navigation File (ASCII and binary)
- Offset File (ASCII and binary)
- Dark Current File (ASCII and binary)
- Noise Spike Replace List (ASCII and binary)
- Dropped Line List (ASCII and binary)
- Auxiliary File (Contents Varies)
- Image Data (ASCII and binary)

New Format

The new software puts entire runs on each tape, in tar format. The important info is the same, flight and run, but all scenes from a run are now included. When extracted, the following files should be found:

PER FLIGHT LINE (i.e., occurs once per tar file/tape):

*.avhdr general information about the flight line,
*.brz browse image of the complete flight line,
*.gain multiplication factors, radiance to 16-bit integer,
*.geo geometric calibration data,
*.log log information of the distribution processing,
*.occ onboard calibration correction coefficients,
*.post postflight line onboard calibrator data,
*.pre preflight line onboard calibrator data,
*.rcc radiometric calibration coefficients,
*.readme this file,
*.spc spectral calibration file.

PER SCENE (i.e., occurs once or several times per tar file/tape):

*.drk1 first part of summed dark signal,
*.drk2 second part of summed dark signal,
*.eng engineering data,
*.nav navigation data,
*.img calibrated AVIRIS radiance (image) data,

This listing, as well as more detailed information about the files, including formats, can be found in the *.readme file contained within each flight line.

9. Data Manipulations

9.1 Formulae

None given.

9.1.1 Derivation Techniques and Algorithms

None given.

9.2 Data Processing Sequence

9.2.1 Processing Steps

The JPL ADF is responsible for low-level processing (up to level-1b), data archiving, and data distribution, along with assisting the hardware team in judging the performance of the AVIRIS instrument and modeling instrument anomalies.

Upon receipt of an AVIRIS tape, the ADF first processes the first and last science runs (as opposed to preflight, runway, Dewar check, or other runs) to determine whether or not the instrument performed properly over the course of the flight. If not, then AVIRIS is grounded until the anomaly or anomalies can be found and analyzed. This performance evaluation stage is mainly a subset of normal processing, but must be performed on the first and last science runs on a tape before normal processing can commence.

The first step in processing a new tape is scanning the tape to make sure it matches the hardcopy list of runs provided by the AVIRIS Experiment Coordinator. Sometimes problems will result in short

'throwaway' or missing runs. These problems must be detected so that the proper site names can be matched with the good data.

AVIRIS processing is done on a per run or per scene (512 lines) basis. However, as the AVIRIS archive media have limited storage space, no more than six scenes are processed at one time.

Normal processing begins with downloading and decommutating the data, known as the download process. AVIRIS data are collected as 10-bit (12-bit for 1995 and later) fields, but computers do not have any standard 10-bit data structures. Thus, the first processing reads the data from the tape, pads it with leading zeroes for storage in 16-bit integers, and writes it to disk.

All data are stored in 16-bit integers, but some data (e.g., navigation) are actually encoded 32-bit floating point data. The ADF archiving process "expands" these fields to their proper size for easier understanding. In addition, the image data are reversed (within each scan line), since the data coming from the AVIRIS instrument, if displayed directly, are actually reversed from how the data would look from the aircraft. Each line of data is expanded and reversed, with any bad data marked as such, and then written to ADF archive media (currently 4-mm tapes).

The AVIRIS archiving process also compiles information about the image, navigation, and engineering data and stores it in the ADF data base. This stored data are extracted at will with the Performance Evaluation Programs (PEPs), which also plot the data to model instrument behavior graphically.

The AVIRIS quicklook images are also created during the archive process. These are initially stored as 2048 x 1536 SUN raster files, and show band 36 of each of the scenes in the run (up to the maximum of six scenes; longer runs will have more than one quicklook). These are printed and stored in folders in the ADF. Then they are processed to reduce them to 307 x 1536 strips with no header or separating data. These reduced quicklooks are then stored on the AVIRIS anonymous FTP site.

When a request is made, the data must go through the Product Generation (PG) software. If the investigator wishes raw data, then PG only copies the data from archive tape to the desired distribution medium. However, most of the time the investigator wishes radiometrically corrected data.

In addition to radiometric correction, the PG process performs detector readout delay correction when necessary. The data from the instrument's detectors are not read simultaneously. For each of the four spectrometers, the bands are read in order, so that the last band is read somewhat later than the first. As the instrument is scanning, the later bands are looking over a slightly different ground position than the first bands. Therefore, PG does a weighted average to "slide" the data back to the proper position, ensuring that for each pixel each of its 224 bands contains data from the same area on the ground. However, for the 1995 flight season, the instrument hardware was improved so that there is no delay in 1995 data.

The ADF also has software for general image processing that is used for image display and creation of pictures for the JPL Public Information Office and any technical conferences or presentations that ADF members are involved in. This software is also used by for detailed anomaly analysis.

BORIS processing of the level-1b AVIRIS image products includes:

- Using developed software to extract and summarize information from each of the images on tape into ASCII files on disk.
- Performing a visual review of the ASCII summary and log files for anomalous items.
- Interacting with the ADF staff regarding any anomalies.
- Using developed software to inventory the images and descriptive information in the relational data base.

9.2.2 Processing Changes

None given.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

None given.

9.3.2 Calculated Variables
None given.

9.4 Graphs and Plots
None given.

10. Errors

10.1 Sources of Error
Uncertainty in AVIRIS calibration results from knowledge of the standards of calibration and stability of the AVIRIS sensor system.

10.2 Quality Assessment
The spectral calibration is assessed to be within 5% in both spectral channel position and spectral response function full width, half maximum (FWHM). The radiometric calibration is assessed at better than 5%. The geometric calibration is assessed to be at the 7% of the reported along-track and cross-track spatial response function. The precision of the AVIRIS measurements is approximately 1 DN RMS.

10.2.1 Data Validation by Source
In-flight calibration experiments are used to validate the calibration of AVIRIS. These are reported at the JPL Airborne Earth Science Workshops.

10.2.2 Confidence Level/Accuracy Judgment
See Section 10.2.

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
Based on tape format information in the description file of the AVIRIS tapes and interactions with the ADF staff, BORIS staff developed software that calculates and extracts summary information from each AVIRIS tape. The summary information was reviewed visually and any anomalies were communicated to the ADF staff for assessment.

11. Notes

11.1 Limitations of the Data
None given.

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

Scientific investigations are ongoing using imaging spectrometry data in the disciplines of Ecology, Oceanography, Coastal and Inland Waters, Geology and Soils, Snow Hydrology, the Atmosphere, etc.

13. Future Modifications and Plans

The signal-to-noise of AVIRIS and the absolute calibration are improved every year. In the 6-month period each year when AVIRIS is not collecting airborne data, the sensor is maintained and improved at JPL. Since its first flight in 1986, almost every subsystem of AVIRIS has been upgraded. Through these continuous improvements, AVIRIS has continued to incorporate new technology and remain a unique state-of-the-art imaging spectrometer.

14. Software

14.1 Software Description

```
vtodxx:     Transfers flight tape data to disk
expxx:      Expands data to 16-bit words
peyy0:      Evaluates performance of AVIRIS after flight
tryy0:      Performs trend analysis of AVIRIS data
calyy0:     Calibrates data to at sensor radiance
distyy0:    Distributes data

xx: 10 or 12 bit data
yy: 92,93,94,95,96,97,98...
```

Software is Unix, C, Fortran

The proprietary software packages used by the ADF are:

- IDL (Interactive Display Language) from Research Systems Inc. (RSI)
- ENVI (ENvironment for the Visualization of Images), also from RSI
- SQL Server and Open Client from Sybase

BORIS personnel developed software and command procedures to:

- Decode, check, and summarize the various level-1b AVIRIS data files,
- Log the level-1b AVIRIS tapes into the BORIS database.

The BORIS software is written in the C language and is operational on VAX 6410 and MicroVAX 3100 systems at NASA GSFC. The primary dependencies in the software are the tape I/O library and the Oracle data base utility routines.

14.2 Software Access

Proprietary software used by the ADF can be obtained by the respective commercial companies that produce the software packages. The ADF plans to make AVIRIS software available upon request after it is formally coded and finalized. All of the described BORIS software is available upon request.

15. Data Access

The RSS-18 level-1b AVIRIS imagery is available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services
Oak Ridge National Laboratory
P.O. Box 2008 MS-6407
Oak Ridge, TN 37831-6407
Phone: (423) 241-3952
Fax: (423) 574-4665
E-mail: ornldaac@ornl.gov or ornl@eos.nasa.gov

15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics http://www-eosdis.ornl.gov/.

15.3 Procedures for Obtaining Data

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

15.4 Data Center Status/Plans

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

16. Output Products and Availability

16.1 Tape Products

The BOREAS Level-1b AVIRIS data can be made available on 8-mm or Digital Archive Tape (DAT) media.

16.2 Film Products

Color aerial photographs were taken from the ER-2 during AVIRIS data collection. The BOREAS data base contains an inventory of available BOREAS aircraft flight documentation, such as flight logs, video tapes, and photographs.

16.3 Other Products

Although the inventory is contained on the BOREAS CD-ROM set, the actual level-1b AVIRIS images are not. See Section 15 for information about how to obtain the data.

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17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

Hyperspectral - Refers to image data that contains several image bands, usually 30 to hundreds.

19. List of Acronyms

ADF - AVIRIS Data Facility
ARC - Ames Research Center
ASAS - Advanced Solid-state Array Spectrometer
ASCII - American Standard Code for Information Interchange
AVIRIS - Airborne Visible/Infrared Imaging Spectrometer
BIL - Band Interleaved by Line
BOREAS - BOReal Ecosystem-Atmosphere Study
BORIS - BOREAS Information System
BSQ - Band Sequential
CD-ROM - Compact Disk-Read-Only Memory
DAAC - Distributed Active Archive Center
DAT - Digital Archive Tape
ENVI - ENvironment for the Visualization of Images
EOS - Earth Observing System
EOSDIS - EOS Data and Information System
FOV - Field of View
FWHM - Full Width, Half Maximum
GIS - Geographic Information System
GPS - Global Positioning System
GSFC - Goddard Space Flight Center
HDF - Hierarchical Data Format
I/O - Input/Output
IDL - Interactive Display Language
IFC - Intensive Field Campaign
IFOV - Instantaneous Field of View
JPL - Jet Propulsion Laboratory
MAS - MODIS Airborne Simulator
MODIS - MODerate Imaging Spectroradiometer
MODLAND - MODIS Land Group
NAD83 - North American Datum of 1983
NASA - National Aeronautics and Space Administration
NIST - National Institute of Standards and Technology
NSA - Northern Study Area
OA - Old Aspen
OBS - Old Black Spruce
OJP - Old Jack Pine
ORNL - Oak Ridge National Laboratory
PANP - Prince Albert National Park
PEP - Performance Evaluation Program
PG - Product Generator
RSI - Research Systems Inc.
RSS - Remote Sensing Science
SQL - Structured Query Language
SSA - Southern Study Area
URL - Uniform Resource Locator
WAB - Wind-Aligned Blob
YJP - Young Jack Pine

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These data were collected and processed by the BOREAS RSS-18 team at NASA JPL. Data were acquired for BOREAS with NASA's AVIRIS. This optical sensor measures images that consist of spectra from 400 to 2500 nm at 10-nm sampling. These spectra are acquired as images with 20-meter spatial resolution, 11-km swath width and up to 800-km length. The measurements are spectrally, radiometrically, and geometrically calibrated. Spatially, the data are focused on the BOREAS NSA and SSA near Thompson, Manitoba, and Candle Lake, Saskatchewan, Canada, respectively. AVIRIS data were collected in 1994 during the Thaw campaign at the NSA and SSA, at the SSA in IFC-1, and at the NSA and SSA in both IFC-2 and IFC-3. In 1996, AVIRIS was deployed in the winter and summer campaigns in the SSA only.

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