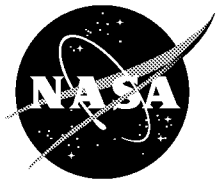
NASA/TM—2000–209891, Vol. 101



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

Forrest G. Hall, Editor

Volume 101

BOREAS Level 3-b AVHRR-LAC Imagery: Scaled At-sensor Radiance in LGSOWG Format

Jaime Nickeson and Jeffrey A. Newcomer, Raytheon ITSS,
NASA Goddard Space Flight Center, Greenbelt, Maryland
Josef Cihlar, Canada Centre for Remote Sensing, Ottawa, Ontario, Canada

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

September 2000

The NASA STI Program Office ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

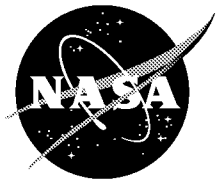
- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.
- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and mission, often concerned with subjects having substantial public interest.
- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at http://www.sti.nasa.gov/STI-homepage.html
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at (301) 621-0134
- Telephone the NASA Access Help Desk at (301) 621-0390
- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076-1320

NASA/TM—2000–209891, Vol. 101



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

Forrest G. Hall, Editor

Volume 101

BOREAS Level 3-b AVHRR-LAC Imagery: Scaled At-sensor Radiance in LGSOWG Format

Jaime Nickeson and Jeffrey A. Newcomer, Raytheon ITSS,
NASA Goddard Space Flight Center, Greenbelt, Maryland
Josef Cihlar, Canada Centre for Remote Sensing, Ottawa, Ontario, Canada

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

September 2000

Available from:

NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076-1320
Price Code: A17

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Price Code: A10

BOREAS Level-3b AVHRR-LAC Imagery: Scaled At-sensor Radiance in LGSOWG Format

Jaime Nickeson, Jeffrey A. Newcomer, Josef Cihlar

Summary

The BOREAS Staff Science Satellite Data Acquisition Program focused on providing the research teams with the remotely sensed satellite data products they needed to compare and spatially extend point results. Data acquired from the AVHRR instrument on the NOAA-9, -11, -12, and -14 satellites were processed and archived for the BOREAS region by the MRSC and BORIS. The data were acquired by CCRS and were provided for use by BOREAS researchers. A few winter acquisitions are available, but the archive contains primarily growing season imagery. These gridded, at-sensor radiance image data cover the period of 30-Jan-1994 to 18-Sep-1996. Geographically, the data cover the entire 1,000-km x 1,000-km BOREAS region. The data are stored in binary image format files.

Note: due to the large size of the images, the level-3b AVHRR-LAC data are not contained on the BOREAS CD-ROM set. An inventory listing file is supplied on the CD-ROM to inform users of what data were collected. The level-3b AVHRR-LAC image data are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC). See sections 15 and 16 for more information.

Table of Contents

1) Data Set Overview
2) Investigator(s)
3) Theory of Measurements
4) Equipment
5) Data Acquisition Methods
6) Observations
7) Data Description
8) Data Organization
9) Data Manipulations
10) Errors
11) Notes
12) Application of the Data Set
13) Future Modifications and Plans
14) Software
15) Data Access
16) Output Products and Availability
17) References
18) Glossary of Terms
19) List of Acronyms
20) Document Information

1. Data Set Overview

1.1 Data Set Identification

BOREAS Level-3b AVHRR-LAC Imagery: Scaled At-sensor Radiance in LGSOWG Format

1.2 Data Set Introduction

The BOReal Ecosystem-Atmosphere Study (BOREAS) Staff Science effort covered those activities that were BOREAS community-level activities or required uniform data collection procedures across sites and time. These activities included the acquisition of the relevant satellite data. Data from the Advanced Very High Resolution Radiometer (AVHRR) instrument on the National Oceanic and Atmospheric Administration (NOAA)-9, -11, -12, and -14 satellites were acquired by the Canada Centre for Remote Sensing (CCRS) and were provided for use by BOREAS researchers.

1.3 Objective/Purpose

For BOREAS, the level-3b AVHRR-Local Area Coverage (LAC) images, along with the other remotely sensed images, were collected in order to provide spatially extensive information over the 1,000-km x 1,000-km BOREAS region at varying spatial scales. This information includes detailed land cover and biophysical parameter maps such as Fraction of Photosynthetically Active Radiation (FPAR) and Leaf Area Index (LAI). The Manitoba Remote Sensing Centre (MRSC) and the BOREAS Information System (BORIS) processed and archived the five-band level-3b AVHRR-LAC image products.

1.4 Summary of Parameters

Level-3b NOAA AVHRR-LAC data in the BORIS contain the following parameters: original image header information; subset coordinates; summary information for the subset area; geographic position, view angle, and solar angle information; image bands 1 to 5.

1.5 Discussion

Level-3b data sets are single-date images produced by the CCRS GEOCOMP Geocoding and Compositing (GEOCOMP) system specifically for BOREAS. The major differences, when compared to the processing for the AVHRR level-4 products are:

- Projection. The level-3b data are in the Albers Equal-Area Conic (AEAC) projection; the level-4 data are in the Lambert Conformal Conic (LCC) projection.
- Calibration coefficients. For the NOAA-14 data from 1995, the calibration coefficients used for level-3b are different from those used for level-4c (but are identical to those used for level-4b).

The remainder of the processing is the same; i.e., each single-date image is registered to a map projection using high-resolution image chips, the image is then resampled, and output channels are produced. There is no compositing involved for the level-3b product. Details of the level-3b processing are described in Section 9.

BORIS staff processes the level-3b AVHRR-LAC images by: 1) extracting pertinent header information from the level-3b image product and placing it in an American Standard Code for Information Interchange (ASCII) file on disk, and 2) reading the information in the disk file and loading the online data base with information.

1.6 Related Data Sets

BOREAS Level-4b AVHRR-LAC Ten-Day Composite Images: At-sensor Radiance
BOREAS Level-4c AVHRR-LAC Ten-Day Composite Images: Surface Parameters

2. Investigator(s)

2.1 Investigator(s) Name and Title

Josef Cihlar
Canada Centre for Remote Sensing

2.2 Title of Investigation

BOREAS Staff Science Satellite Data Acquisition Program

2.3 Contact Information

Contact 1:
Josef Cihlar
Canada Centre for Remote Sensing
588 Booth Street, 4th Floor
Ottawa, Ontario
K1A0Y7 Canada
(613) 947-1265
(613) 947-1406 (fax)
Josef.Cihlar@geocan.emr.ca

Contact 2:
Jaime Nickeson
Raytheon ITSS
Code 923
NASA GSFC
Greenbelt, MD 20771
(301) 286-3373
(301) 286-0239 (fax)
Jaime.Nickeson@gsfc.nasa.gov

3. Theory of Measurements

The AVHRR is a four- or five-channel scanning radiometer capable of providing global daytime and nighttime information about ice, snow, vegetation, clouds, and the sea surface. These data are obtained on a daily basis primarily for use in weather analysis and forecasting; however, a variety of other applications are possible. The AVHRR-LAC data collected for the BOREAS project were from instruments onboard NOAA-9, -11, -12, and -14 polar orbiting platforms. The radiometers measured emitted and reflected radiation in one visible, one near-infrared, one middle-infrared, and one or two thermal channels (on some platforms the thermal channels were identical).

The primary use of each channel and spectral regions and bandwidths on the respective NOAA platforms are given in the following tables:

Channel	Wavelength [µm]	Primary Use
1*	0.57 - 0.69	Daytime Cloud and Surface Mapping
2	0.72 - 0.98	Surface Water Delineation, Vegetation Cover
3	3.52 - 3.95	Sea Surface Temperature (SST), Nighttime Cloud Mapping
4**	10.3 - 11.40	Surface Temperature, Day/Night Cloud Mapping
5***	11.4 - 12.40	Surface Temperature

* Channel 1 wavelength for the Television and Infrared Observation Satellite (TIROS)-N flight model was 0.55-0.90 µm.
** For NOAA-7 and -9, channel 4 was 10.3-11.3 µm.
*** For TIROS-N and NOAA-6, -8, -10, and -12, channel 5 duplicates channel 4.

The wavelength ranges at 50 percent relative spectral response (µm) of the bands for the platform-specific instruments are:

Band	NOAA-9	NOAA-11	NOAA-12	NOAA-14
1	0.570 - 0.699	0.572 - 0.698	0.571 - 0.684	0.570 - 0.699
2	0.714 - 0.983	0.716 - 0.985	0.724 - 0.984	0.714 - 0.983
3	3.525 - 3.931	3.536 - 3.935	3.554 - 3.950	3.525 - 3.931
4	10.334 - 11.252	10.338 - 11.287	10.601 - 11.445	10.330 - 11.250
5	11.395 - 12.342	11.408 - 12.386	10.601 - 11.445	11.390 - 12.340

The AVHRR can operate in both real-time and recorded modes. Direct readout data were transmitted to ground stations of the automatic picture transmission (APT) class at low resolution (4 x 4 km) and to ground stations of the high-resolution picture transmission (HRPT) class at high resolution (1 x 1 km). AVHRR HRPT data were received for the BOREAS region by the CCRS.

4. Equipment

4.1 Sensor/Instrument Description

The AVHRR is a cross-track scanning system featuring one visible, one near-infrared, one middle-infrared, and two thermal channels. The analog data output from the sensors is digitized onboard the satellite at a rate of 39,936 samples per second per channel. Each sample step corresponds to an angle of scanner rotation of 0.95 milliradians. At this sampling rate, there are 1.362 samples per instantaneous field of view (IFOV). A total of 2,048 samples is obtained per channel per Earth scan, which spans an angle of +/-55.4 degrees from nadir.

4.1.1 Collection Environment

The NOAA satellites orbit Earth at an altitude of 833 km. From this space platform, the data are transmitted to a ground receiving station.

4.1.2 Source/Platform

Launch and available dates for the TIROS-N series of satellites from CCRS are:

Satellite	Launch Date	Date Range
TIROS-N	13-Oct-1978	19-Oct-1978 to 30-Jan-1980
NOAA-6	27-Jun-1979	21-Aug-1984 to 23-Jan-1986
NOAA-B	29-May-1980	Failed to achieve orbit
NOAA-7	23-Jun-1981	24-Jul-1983 to 30-Dec-1984
NOAA-8	28-Mar-1983	24-Jul-1983 to 13-Aug-1985
NOAA-9	12-Dec-1984	16-Sep-1985 to 19-Mar-1995
NOAA-10	17-Sep-1986	11-Oct-1986 to 15-Nov-1993
NOAA-11	24-Sep-1988	28-Jun-1989 to 13-Sep-1994
NOAA-12	14-May-1991	11-Aug-1993 to present
NOAA-14	30-Dec-1994	15-May-1995 to present

AVHRR-LAC data used in BOREAS were collected onboard the NOAA-9, -11, and -14 polar orbiting platforms.

4.1.3 Source/Platform Mission Objectives

The AVHRR is designed for multispectral analysis of meteorologic, oceanographic, and hydrologic parameters. The objective of the instrument is to provide radiance data for investigation of clouds, land-water boundaries, snow and ice extent, ice or snow melt inception, day and night cloud distribution, temperatures of radiating surfaces, and SST. It is an integral member of the payload on the advanced TIROS-N spacecraft and its successors in the NOAA series, and as such contributes data required to meet a number of operational and research-oriented meteorological objectives.

4.1.4 Key Variables

Emitted radiation, reflected radiation.

4.1.5 Principles of Operation

The AVHRR is a four- or five-channel scanning radiometer that detects emitted and reflected radiation from Earth in the visible, near-, middle-, and thermal-infrared regions of the electromagnetic spectrum. A fifth channel was added to the follow-on instrument designated AVHRR/2 and flown on NOAA-7, -9, -11, and -14 to improve the correction for atmospheric water vapor. Scanning is provided by an elliptical beryllium mirror rotating at 360 rpm about an axis parallel to that of Earth. A two-stage radiant cooler is used to maintain a constant temperature of 95 K for the infrared detectors. The operating temperature is selectable at either 105 or 110 K. The telescope is an 8-inch afocal, all-reflective Cassegrain system. Polarization is less than 10 percent. Instrument operation is controlled by 26 commands and monitored by 20 analog housekeeping parameters.

4.1.6 Sensor/Instrument Measurement Geometry

The AVHRR is a cross-track scanning system. The IFOV of each sensor is approximately 1.4 milliradians, giving a resolution of 1.1 km at the satellite subpoint. There is about a 36 percent overlap between IFOVs (1.362 samples per IFOV). The scanning rate of the AVHRR is six scans per second, and each scan spans an angle of +/- 55.4 degrees from the nadir.

4.1.7 Manufacturer of Sensor/Instrument

ITT Aerospace
P.O. Box 3700
Fort Wayne, IN 46801-3700

4.2 Calibration

The thermal-infrared channels are calibrated in-flight using a view of a stable blackbody and space as a reference. No in-flight visible channel calibration is performed. Channel 3 data are noisy because of a spacecraft problem and may not be usable, especially when the satellite is in daylight (Kidwell, 1991).

4.2.1 Specifications

IFOV	1.4 mRad
RESOLUTION	1.1 km
ALTITUDE	833 km
SCAN RATE	360 scans/min (1.362 samples per IFOV)
SCAN RANGE	-55.4 to 55.4 degrees
SAMPLES/SCAN	2,048 samples per channel per Earth scan

4.2.1.1 Tolerance

The AVHRR infrared channels were designed for a Noise Equivalent Differential Temperature (NEDT) of 0.12 K (at 300 K), and a signal-to-noise ratio of 3:1 at 0.5-percent albedo.

4.2.2 Frequency of Calibration

The Naval Research Laboratory's (NRL's) TIROS-N calibration overlay performs the calibration on blocks of telemetry data. For LAC/HRPT acquisitions, a block consists of 20 scan lines. Calibration begins by reading the calibration parameters into memory. For each scan line of telemetry in a block, the following process takes place:

- Telemetry data are extracted and unpacked
- Ramp calibration data for each of the five channels are decommutated
- A single Platinum Resistor Thermometer (PRT) count is extracted
- Ten samples of internal target, or blackbody, data are decommutated
- Ten samples of space view data are decommutated and filtered

After the entire block has been decommutated, the PRTs are checked for pattern correctness. A valid PRT pattern consists of a PRT reference count whose value is less than 10 followed by 4 PRT counts whose values are greater than 10. After decommutation, the PRT counts are filtered, and the mean and standard deviation of each PRT are computed. The mean PRT counts are then converted to temperature using the formula:

$$T(1) = C(0) + C(1)M(j) + C(2)[M(j)^2] + C(3)[M(j)^3] + C(4)[M(j)^4]$$

where: T(1) = the temperature of each of the four PRTs
C(i) = the PRT coefficients from CPIDS
M(j) = the mean count of each of the four PRTs

The mean of the four PRT temperatures is then computed to get the temperature of the blackbody. The blackbody temperature is used to calculate the index of the temperature-to-radiance lookup table using the formula:

INDEX = 10.0 * PRT TEMPERATURE 1798.5

The blackbody radiances for infrared channels are extracted from the table, which was generated from CPIDS. From the decommutated blackbody data, the mean and standard deviation of the internal target are computed. This computation is also done for the mean and standard deviation of space view data. The slopes and intercepts are then calculated using the previously computed data. The slope and intercept for the visible channels are assigned constants. For each of the infrared channels, the slope and intercept are calculated using the formula:

$$\text{SLOPE} = \frac{\text{SPACEVIEW RADIANCE - BLACKBODY RADIANCE}}{\text{SPACEVIEW MEAN - BLACKBODY MEAN}}$$

INTERCEPT = SPACEVIEW RADIANCE SLOPE * SPACEVIEW MEAN

The slopes and intercepts for all five channels are then stored in each scan line in the given block. The calibration overlay then begins this process again for the next block. The final function of the calibration overlay is to determine ramp linearity or nonlinearity. This process reverses the ramp on infrared channels from descending to ascending. The ramp values are then adjusted according to data type (i.e., LAC or Global Area Coverage (GAC)).

4.2.3 Other Calibration Information

None given.

5. Data Acquisition Methods

The BOREAS level-3b AVHRR-LAC images were acquired through the CCRS. Some radiometric corrections along with geometric corrections are applied to produce the imagery in a spatially corrected form (AEAC projection). A full level-3b AVHRR-LAC image for the BOREAS region contains approximately 1,000 pixels in each of approximately 1,000 lines. Before geometric corrections, the ground resolution ranges from 1.1 km at nadir to 5 km x 6.8 km at the scanning extreme of 55.4 degrees. The raw pixel values in the images can range from 0 to 1,024.

The level-3b image pixel values are scaled radiances stored in 16-bit (2-byte) fields and can range from -32,768 to 32,767. The level-3b images were processed through the CCRS GEOCOMP system, which applies both radiometric and spatial corrections to the imagery. Because of data volume and pervasive cloudiness, only a limited number of single-date level-3b images were placed into BORIS. Raw data are available from the CCRS Prince Albert Satellite Station (PASS).

6. Observations

6.1 Data Notes

None.

6.2 Field Notes

None.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The AVHRR provides a global (pole to pole) onboard collection of data from all five spectral channels. The 110.8-degree scan equates to a swath of 27.2 degrees in longitude (at the Equator) centered on the subsatellite track. This swath width is greater than the 25.3-degree separation between successive orbital tracks and provides overlapping coverage (side lap) anywhere on the globe.

The BOREAS level-3b AVHRR-LAC images essentially cover the entire 1,000-km by 1,000-km BOREAS region. This contains both the Northern Study Area (NSA), the Southern Study Area (SSA), the transect region between the SSA and NSA, and some surrounding area. The actual coverage of each image depends on the position of the subsatellite track.

The North American Datum of 1983 (NAD83)
corner coordinates of the BOREAS region are:

	Latitude	Longitude
Northwest	59.979°N	111.000°W
Northeast	58.844°N	93.502°W
Southwest	51.000°N	111.000°W
Southeast	50.089°N	96.970°W

The NAD83 corner coordinates of the SSA are:

	Latitude	Longitude
Northwest	54.319°N	106.227°W
Northeast	54.223°N	104.236°W
Southwest	53.513°N	106.320°W
Southeast	53.419°N	104.368°W

The NAD83 corner coordinates of the NSA are:

	Latitude	Longitude
Northwest	56.249°N	98.824°W
Northeast	56.083°N	97.241°W
Southwest	55.542°N	99.045°W
Southeast	55.379°N	97.489°W

7.1.2 Spatial Coverage Map

Not available at this time.

7.1.3 Spatial Resolution

Before any geometric corrections, the spatial resolution varies from 1.1 km at nadir to approximately 4.5 km at the extreme edges of the scan. The level-3b AVHRR-LAC images have had geometric corrections applied so that the size for all pixels is 1 km in all bands.

7.1.4 Projection

The established BOREAS grid system is based on the ellipsoidal version of the AEAC projection as defined within the NAD83. The origin of the grid is at 111° W, 51° N, and the standard parallels are set to 52.5° N and 58.5° N as prescribed in "Map Projections - A Working Manual," USGS Professional Paper 1395, John P. Snyder, 1987. All of the projection equations used to calculate the BOREAS grid coordinates were taken from this manual.

7.1.5 Grid Description

The level-3b images are projected into the AEAC projection described in Section 7.1.4 at a grid cell size of 1.0 km per pixel in both the X and Y directions.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

At BOREAS latitudes, at least daily coverage is provided by a given sensor. Virtually all raw data from daytime overpasses were recorded during the BOREAS period (NOAA-11 daytime) and are archived at PASS. Only mostly cloud-free images were processed and included in BORIS.

The overall time period of data acquisition for BOREAS in 1994 was from 30-Jan through 06-Oct. CCRS acquired most AVHRR-LAC daytime images from NOAA-9 and -11 for each satellite pass; i.e., two images in each 24-hour cycle.

The overall time period of data acquisition for BOREAS in 1995 was from 05-Jan through 27-Sep. CCRS acquired most AVHRR-LAC daytime images from NOAA-9 and -14 for each satellite pass; i.e., two images in each 24-hour cycle.

The overall data holdings for BOREAS in 1996 are currently just two winter dates, 06-Mar and 22-Mar. CCRS acquired the AVHRR-LAC daytime images from NOAA-14 for each satellite pass; i.e., two images in each 24-hour cycle.

BORIS contains relatively complete AVHRR-LAC coverage from NOAA-11 of central Canada during the snow-free periods in 1994 and 1995. Scenes covering all or a significant part of the BOREAS region were included in BORIS.

Historical AVHRR-LAC data have been acquired by CCRS routinely since 1991 and are kept in the CCRS archive. These data can be obtained by contacting CCRS. Statistics Canada also has a historical composite data set of visible, infrared, and Normalized Difference Vegetation Index (NDVI) imagery. Contact the Statistics Canada Crop Condition Assessment Program office for more information.

7.2.2 Temporal Coverage Map

Not available.

7.2.3 Temporal Resolution

There are generally two overpasses per day per satellite at approximately 0200 or 0900 and 1400 or 2100 Greenwich Mean Time (GMT). However, not all of these data are processed and distributed because of cloud cover and other data problems. Adjacent orbits can cause double coverage at an interval of 90 minutes, increasing the number of scenes on some days.

Each scan of the AVHRR views Earth for a period of 51.282 msec. During this period each channel of the analog data output is digitized to obtain a total of 2048 samples at intervals of 25.0 microseconds (the sampling rate of the AVHRR sensors is 39,936 samples/sec/channel). Successive scans occur at the rate of 6 per second, or at intervals of 167 msec. These data provide LAC and HRPT.

For BOREAS, the level-3b scenes that are available were selected based on the amounts of cloud cover and image quality.

7.3 Data Characteristics

7.3.1 Parameter/Variable

The values in the image data files are scaled at-sensor radiance values. See Section 7.3.2 for equations to calculate radiance values. 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
BAND_QUALITY
CLOUD_COVER
ORBIT_NUM
NW_LATITUDE
NW_LONGITUDE
NE_LATITUDE
NE_LONGITUDE
SW_LATITUDE
SW_LONGITUDE
SE_LATITUDE
SE_LONGITUDE
PLATFORM_ALTITUDE
MIN_SOLAR_ZEN_ANG
MAX_SOLAR_ZEN_ANG
MIN_SOLAR_AZ_ANG
MAX_SOLAR_AZ_ANG
CRTFCN_CODE
```

7.3.2 Variable Description/Definition

At-sensor radiance is the radiant energy determined to be observed by the sensor from its position relative to the target. In this case, it is derived from the signal recorded by the AVHRR sensor, which is then calibrated by the processes described in Section 9 of this document. The following equations must be used to calculate the physical at-sensor radiance in a given band from the standardized counts given in the image files:

```
  R(1) =        (625/1023) * DN(1) -  25.0
  R(2) =        (415/1023) * DN(2) -  15.0
  R(3) = -(1.508988/1023) * DN(3) +   1.504
  R(4) =  -(175.898/1023) * DN(4) + 170.8
  R(5) =  -(183.863/1023) * DN(5) + 179.1

where R(i) is the resulting radiance for band (i), and
      DN(i) is the count from band (i) in the digital imag
```

AVHRR Band	Units	DN=0	DN=1023
1	Radiance	-25	600.0
2	Radiance	-15	400.0
3	Radiance	1.504	-0.004988
4	Radiance	170.8	-5.098
5	Radiance	179.1	-4.763

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.
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.
PATH_NUM	For Landsat and SPOT, the sequential number given to the orbital paths trending from northeast to southwest and extending around the earth.
ROW_NUM	For Landsat and SPOT, the sequential number given to the nominal scene acquisition points along the orbital paths which trend from northeast to southwest.
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 southwest 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 southeast corner of the minimum bounding rectangle for the data.
PLATFORM_ALTITUDE	The nominal altitude of the data collection plat form 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.
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

The maximum range of digital numbers in each AVHRR image band is -32,768 to 32,767 so that the values can be stored in a 2-byte field. The measurement units for the parameters contained in the inventory 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]
BAND_QUALITY	[none]
CLOUD_COVER	[none]
ORBIT_NUM	[unitless]
NW_LATITUDE	[degrees]
NW_LONGITUDE	[degrees]
NE_LATITUDE	[degrees]
NE_LONGITUDE	[degrees]
SW_LATITUDE	[degrees]
SW_LONGITUDE	[degrees]
SE_LATITUDE	[degrees]
SE_LONGITUDE	[degrees]
PLATFORM_ALTITUDE	[meters]
MIN_SOLAR_ZEN_ANG	[degrees]
MAX_SOLAR_ZEN_ANG	[degrees]
MIN_SOLAR_AZ_ANG	[degrees]

MAX_SOLAR_AZ_ANG	[degrees]
CRTFCN_CODE	[none]

7.3.4 Data Source

The source of the parameter values contained in the inventory files on the CD-ROM are:

Column Name	Data Source
SPATIAL_COVERAGE	[Assigned by BORIS]
DATE_OBS	[AVHRR image files]
START_TIME	[AVHRR image files]
END_TIME	[AVHRR image files]
PLATFORM	[AVHRR image files]
INSTRUMENT	[AVHRR image files]
NUM_BANDS	[AVHRR image files]
BAND_QUALITY	[Assigned by BORIS]
CLOUD_COVER	[Assigned by BORIS]
ORBIT_NUM	[AVHRR image files]
NW_LATITUDE	[AVHRR image files]
NW_LONGITUDE	[AVHRR image files]
NE_LATITUDE	[AVHRR image files]
NE_LONGITUDE	[AVHRR image files]
SW_LATITUDE	[AVHRR image files]
SW_LONGITUDE	[AVHRR image files]
SE_LATITUDE	[AVHRR image files]
SE_LONGITUDE	[AVHRR image files]
PLATFORM_ALTITUDE	[AVHRR image files]
MIN_SOLAR_ZEN_ANG	[AVHRR image files]
MAX_SOLAR_ZEN_ANG	[AVHRR image files]
MIN_SOLAR_AZ_ANG	[AVHRR image files]
MAX_SOLAR_AZ_ANG	[AVHRR image files]
CRTFCN_CODE	[Assigned by BORIS]

7.3.5 Data Range

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

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SPATIAL_COVERAGE	N/A	N/A	None	None	None	None
DATE_OBS	30-JAN-94	18-SEP-96	None	None	None	None
START_TIME	125	2344	None	None	None	None
END_TIME	128	2347	None	None	None	None
PLATFORM	NOAA-9	NOAA-14	None	None	None	None
INSTRUMENT	N/A	N/A	None	None	None	None
NUM_BANDS	5	5	None	None	None	None
BAND_QUALITY	N/A	N/A	None	None	None	None
CLOUD_COVER	N/A	N/A	None	None	None	None
ORBIT_NUM	1451	52655	None	None	None	None
NW_LATITUDE	55.99521	59.96559	None	None	None	None
NW_LONGITUDE	-113.05302	-110.17355	None	None	None	None
NE_LATITUDE	54.87326	60.12128	None	None	None	None
NE_LONGITUDE	-95.06478	-93.51707	None	None	None	None

```
SW_LATITUDE          47.00085       50.9955        None    None    None    None
SW_LONGITUDE         -110.99289     -109.13777     None    None    None    None
SE_LATITUDE          46.07361       50.97096       None    None    None    None
SE_LONGITUDE         -97.46993      -95.05019      None    None    None    None
PLATFORM_ALTITUDE    827754         870733         None    None    None    None
MIN_SOLAR_ZEN_ANG    27.3           117.5          None    None    None    None
MAX_SOLAR_ZEN_ANG    36.6           129.6          None    None    None    None
MIN_SOLAR_AZ_ANG     32             292.3          None    None    None    None
MAX_SOLAR_AZ_ANG     51.8           309.8          None    None    None    None
CRTFCN_CODE          PRE            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-3b AVHRR 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,
BAND_QUALITY,CLOUD_COVER,ORBIT_NUM,NW_LATITUDE,NW_LONGITUDE,NE_LATITUDE,
NE_LONGITUDE,SW_LATITUDE,SW_LONGITUDE,SE_LATITUDE,SE_LONGITUDE,
PLATFORM_ALTITUDE,MIN_SOLAR_ZEN_ANG,MAX_SOLAR_ZEN_ANG,MIN_SOLAR_AZ_ANG,
MAX_SOLAR_AZ_ANG,CRTFCN_CODE
'REGION',30-JAN-94,2202,2206,'NOAA-11','AVHRR',5,'NOT ASSESSED','NOT ASSESSED',
27582,59.96559,-110.99107,58.83186,-93.51707,50.9955,-110.99289,50.08562,
-96.97773,858222.0,76.2,88.6,216.4,231.1,'PRE'
```

8. Data Organization

8.1 Data Granularity

The smallest unit of data for level-3b AVHRR-LAC is an image. The level-3b AVHRR-LAC images from CCRS are stored in band interleaved by line (BIL) form. General information on this format is provided in the subsequent sections. Detailed information on this can be obtained from the CCRS documents referenced in Section 17.1.

8.2 Data Format(s)

The 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.

The AVHRR-LAC level-3b data are supplied in Landsat Ground Station Operational Working Group (LGSOWG) BIL format.

File 1 -- Physical Volume Directory
File 2 -- Logical Volume Directory
File 3 -- Leader File Bands 1-5
File 4 -- Image Data File for AVHRR-LAC Bands 1-5
File 5 -- Trailer
File 6 -- Null Volume File

If there are multiple scenes on a tape, the subsequent scene would occupy files 7-11 (five files), as files 2-6 above (there is only one physical volume directory per physical tape). The image files in BIL format contain image data for all five spectral bands.

8.2.1 BIL Logical Volume Directory File

This file contains:

- Volume descriptor record
- File pointer records for the leader, image data, and trailer files
- Text record

8.2.2 BIL Leader Files

The contents of leader files have been defined in detail by the LGSOWG Technical Working Group (LTWG). The contents of the leader files are as follows:

- File descriptor record
- Scene header record
- Ancillary records (map projection, ground control points, ephemeris, and radiometric transformation)

All leader files contain fixed-length records of 2,520 bytes and contain both ASCII and binary data. For specific details, see the CCRS documentation referenced in Section 17.1.

8.2.3 BIL Imagery File

The single BIL image file has 5,001 records, with each record containing 2,808 bytes. The first record in the file is the file descriptor record, followed by 5,000 image records for a total of 1,000 lines of the scene for all five bands (1,000 lines x 5 bands = 5,000 records). In a BIL image file, the first five image records are line 1, bands 1-5, respectively; the next five image records are line 2, bands 1-5, respectively; and so on. Each image record contains 36 bytes (18 pixels) of prefix data, 2,000 bytes (1,000 pixels) of image data, and 772 bytes of suffix data (36 + 2,000 + 772 = 2,808 bytes).

The image is oriented so that pixel 1, line 1 is in the upper left-hand corner (i.e., northwest) of the screen display. Pixels and lines progress from left to right and top to bottom so that pixel n, line n is in the lower right-hand corner. Each pixel value is contained in a 2-byte (16-bit) field ordered as most significant (high-order) byte first.

8.2.4 BIL Trailer File

The trailer file contains information associated with the image data that is not always available before writing the image data, such as data and recording quality and data summaries. Each trailer file contains a file descriptor record and trailer records for all bands of imagery in the associated imagery file. All trailer files contain fixed length records of 4,140 bytes and contain both ASCII and binary data. For specific details, see the CCRS documentation referenced in Section 17.1.

8.2.5 BIL Null Volume File

The null volume file contains one record that designates the end of the data volume. The BOREAS level-3b AVHRR-LAC tapes contain null volume files after each image because multiple scenes were copied to a tape from several original tapes.

9. Data Manipulations

9.1 Formulae

9.1.1 Derivation Techniques and Algorithms

The AVHRR-LAC processing is carried out by GEOCOMP (Robertson et al., 1992). Designed to produce AVHRR-LAC composite images over continental areas, GEOCOMP operates in two steps. First, individual images are registered and resampled to coregister with one another and with a baseline map. Second, the images are composited to find the most cloud-free pixels for the period of interest. Level-3b images are the result of step 1. The requirement for high throughput was handled in GEOCOMP by giving the operator an option to divide the orbit into smaller scenes (thus reducing the number of empty pixels after geometric correction). Buffam (1994) provides detailed documentation of the GEOCOMP products from the user viewpoint.

All five AVHRR-LAC channels are calibrated by GEOCOMP. Channels 3-5 are calibrated using onboard calibration data (Planet, 1979). Data for the reflective channels i (i = 1,2) are calibrated in two steps (Teillet and Holben, 1994): first by converting the raw digital signal level (DSL) Di(raw) into apparent sensor radiance L*i, and then by representing the resulting L*i on a fixed 10-bit output scale as calibrated DSL Di(cal). The formulas used are:

$$Li^* = (Di(raw) - D0I(d))/Gi(d) \quad [1]$$

$$Di(cal) = Gi(cal) * (Li^*) + D0I(cal) \quad [2]$$

$$Gi(cal) = 1023/(Li^*max - Li^*min) \quad [3]$$

$$D0i(cal) = -Gi(cal) * Li^*min \quad [4]$$

where: Li* is the radiance at the top-of-the-atmosphere in channel i (i=1,2) [(W/(m^2 sr µm)].
Di(raw) is the measured value for channel i (in 10 bits) [counts].
D0i(d) is the calibration offset coefficient on day d [counts].
Gi(d) is the calibration gain coefficient on day d [(counts m^2 sr µm)/W].
Di(cal) is the final digital signal level (DSL) on GEOCOMP product for channel i.
Gi(cal) is time-independent calibration gain coefficient [(counts m^2 sr µm)/W].
D0i(cal) is time-independent calibration offset coefficient [counts].
Li*max, Li*min are the (time-independent) maximum and minimum Li* values.

The values of Li* used in GEOCOMP are [W/(m^2 sr µm)])

L1*min = -25
L2*min = -15
L1*max = 600
L2*max = 400

GEOCOMP uses time-dependent (defined as days since launch) correction of the AVHRR-LAC gain Gi and offset D0i of each of the channels 1 and 2 (Teillet and Holben, 1994) as seen above, and onboard blackbody calibration targets for channels 3, 4, and 5. The resulting values are in radiance units [W/(m^2 sr μm)] for channels 1 and 2, and mW/(m^2 sr cm) for channels 3-5. Thus, for channel i, i=1,2 the gain and offset are:

$$Gi(d) = A*d + B \quad [5]$$
$$D0I(cal) = Gi(cal) * (Li*) + D0i(cal) \quad [6]$$

where A, B, D, E are channel-dependent coefficients.

The coefficients A, B, D, and E in equations [5] and [6] describing the temporal dependence of Gi(d) and D0i(d) are stored in a separate GEOCOMP data base. The values used for processing 1994 AVHRR-LAC data for BOREAS by Cihlar and Teillet (1995) for NOAA-9 and -11 are reproduced below. Coefficients for NOAA-14 were based on prelaunch calibration supplied by NOAA. Rws A1-D1 represent channel 1, and rows A2-D2 represent Channel 2.

Calibration coefficients used to produce level-3 and products:

	NOAA-9 1994 Level-3b	NOAA-11 Levels-3,-4	NOAA-14 1995 Levels-3b,-4b	NOAA-14 1995 Level-4c	NOAA-14 1996 Levels-3,-4
A1	-1.721E-04	-5.601E-05	0	-3.527E-04	-3.047E-04
B1	1.6376157	1.815337	1.81	1.795	1.778
C1	0	0	0	0	0
D1	37	40	35.8	41.0	41.0
A2	-1.828E-04	-1.331E-0	0	-6.16E-04	-5.088E-04
B2	2.503063	2.700631	2.80	2.364	2.324
C2	0	0	0	0	0
D2	39.6	40	33.7	41.0	41,0

Note: For NOAA-14 in 1995, a distinction needs to be made between data processed as level-3b, which used prelaunch calibration, and as levels-4b and -4c, which used postlaunch with sensor degradation.

Angular information is encoded in the GEOCOMP format to allow calculation of the solar zenith, view zenith, and relative azimuth angles for each resampled pixel. This information is located in the suffix of the image file. In each image line, 65 tie-points are encoded for the four angles: solar zenith, solar azimuth, satellite zenith, and satellite azimuth. After extracting these angles on tie-point pixels (65 pixels within each image line), linear interpolation is applied to get the angles for each pixel within the line. The relative azimuth angle is given by:

Relative Azimuth = abs(Solar Zenith - Satellite Zenith)

9.2 Data Processing Sequence

9.2.1 Processing Steps

GEOCOMP created the level-3b HRPT image by:

- Inputting the geocoding work order and associated auxiliary data
- Inputting raw image data from 8-mm tape
- Viewing the input image and defining products interactively (optional)
- Generating a spacecraft model
- Generating image correction parameters
- Correcting imagery (sensor calibration, three-pass image resampling)
- Estimating quality or allowing the image to be viewed
- Outputting imagery

BORIS processed a level-3b AVHRR-LAC image by:

- Extracting pertinent header information from the level-3 image product and writing it to a disk file
- Reading the information in the disk file and loading the online data base with needed information

9.2.2 Processing Changes

None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

None.

9.3.2 Calculated Variables

None.

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

There has been a serious noise problem caused by a spacecraft malfunction with data from channel 3 on the TIROS-N series spacecraft. This problem is especially obvious when the satellite is in daylight, and may render some data unusable. See Section 4.2.

Users of LAC/HRPT data should be aware that the satellite's onboard clock experiences a small drift in time over a period of several months. Specifically, that time drift may be defined by dt, where dt is the spacecraft clock time minus the actual GMT. Satellite Operations Control Center (SOCC) monitors this time error and corrects dt to +0.5 second when it reaches -0.5 second. The Earth data that are appended to the level-0 data are based on the spacecraft clock time. Therefore, an error in dt will be reflected as an error in Earth location. The error in Earth location caused by this timing error could be as much as 4 kilometers at the satellite subpoint. SOCC applies the correction to dt just before an orbital recording begins, so a user would never see a jump in the Earth location of a particular data set. This does not influence the accuracy of the level-3b data; the effect is taken out during GEOCOMP registration and processing.

Some uncertainties remain in the geometric location of the level-3b resampled pixels. The root mean square (rms) error in the location of control points is most often less than 1,000 meters (typically 600-800 meters rms).

10.2 Quality Assessment

10.2.1 Data Validation by Source

Not available.

10.2.2 Confidence Level/Accuracy Judgment

The AVHRR reflective channels 1 and 2 are designed to accommodate a dynamic range of 200 to 1. A full-scale signal corresponds to 100 percent albedo; that is, the radiance from a diffuse (Lambertian) reflector (a bright cloud) under full solar illumination. A minimum detectable signal corresponds to 0.5 percent albedo with a signal-to-noise ratio of at least 3 to 1. The thermal channels 3, 4, and 5 are calibrated in-flight using a view of a stable blackbody and space as a reference. These channels are designed to measure emitted thermal radiation with an accuracy better than 0.14 °C for a source blackbody temperature of 300 K.

10.2.3 Measurement Error for Parameters

The sensor view zenith and azimuth angles calculated for use in atmospheric correction have a resolution of 0.01 degrees.

10.2.4 Additional Quality Assessments

GEOCOMP uses the information embedded in the downlinked data stream to perform a partial evaluation of input data quality. The operator checks the general quality of the input and output images. Band quality is judged and the quality level is included in the BORIS database inventory table. Images are screened for cloud cover, and different levels of cover are assigned in processing.

10.2.5 Data Verification by Data Center

BORIS staff has extracted header information and inventoried the AVHRR data acquisition information in the data base. BORIS staff has also viewed some of the imagery and confirmed the use of scaling information provided in Section 7.3.2.

11. Notes

11.1 Limitations of the Data

None.

11.2 Known Problems with the Data

None.

11.3 Usage Guidance

None.

11.4 Other Relevant Information

None.

12. Application of the Data Set

These data could be used to investigate regional land cover and land cover change over the BOREAS time period.

13. Future Modifications and Plans

Not available.

14. Software

14.1 Software Description

The GEOCOMP software is written in Pascal and FORTRAN and runs on Digital's VAX computers. Special code also exists for the GEOCOMP array processor. The GEOCOMP software is proprietary.

BORIS staff has developed software and command procedures for:

- Extracting header information from level-3 AVHRR-LAC images on tape and writing it to ASCII files on disk
- Reading the ASCII disk file and logging the level-3 AVHRR-LAC image products into the Oracle data base tables
- 3) Converting between the geographic systems of (latitude, longitude), Universal Trans verse Mercator (UTM) (northing, easting), and BOREAS (x,y) grid locations

The software mentioned under items 1 and 2 is written in C and is operational on VAX 6410 and MicroVAX 3100 systems at Goddard Space Flight Center (GSFC). The primary dependencies in the software are the tape input/output (I/O) library and the Oracle data base utility routines.

The geographic coordinate conversion utility developed for BOREAS (BOR_CORD) has been tested and used on Macintosh, IBM PC, VAX, Silicon Graphics, and Sun workstations.

14.2 Software Access

Most of the GEOCOMP software is proprietary. For further information, contact:

MacDonald Dettwiler and Associates 13800 Commerce Parkway Richmond, BC VGV2J3 (604) 278-3411

All the software described above is available upon request. BORIS staff would appreciate knowing of any problems discovered with the software, but cannot promise to fix them.

15. Data Access

The level-3b AVHRR-LAC 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 level-3b AVHRR imagery can be made available on 8-mm magnetic media.

16.2 Film Products

None.

16.3 Other Products

Although the inventory is contained on the BOREAS CD-ROM set, the actual AVHRR-LAC imagery is not. See Section 15 for information about how to obtain the data.

17. References

17.1 Platform/Sensor/Instrument/Data Processing Documentation

Buffam, A. 1994. GEOCOMP User Manual. Internal Report, Canada Centre for Remote Sensing, Ottawa, Ontario.

Cihlar, J. and F. Huang. 1993. User guide for the 1993 GEOCOMP products. NBIOME Internal Report, Canada Centre for Remote Sensing, Ottawa, Ontario. 9 p.

Hussey, J.W. 1977. The TIROS-N NOAA Operational Satellite System. U.S. Department of Commerce, NOAA/NESS.

Kidwell, K. 1991. NOAA Polar Orbiter Data User's Guide, NCDC/SDSD. (Updated from original 1984 edition.)

Lauritson, et al. 1979. Data Extraction and Calibration of TIROS N/NOAA Radiometers. NOAA Technical Memorandum NESS 107, U.S. Department of Commerce, NOAA/NESS.

Snyder, J.P. 1987. Map Projections - A Working Manual. USGS Professional Paper 1395.

17.2 Journal Articles and Study Reports

Brown, O.B., J.W. Brown, and R.H. Evans. 1985. Calibration of Advanced Very High Resolution Radiometer Infrared Observations. Journal of Geophysical Research, 90:11,667-11,677.

Brown, R.J., Bernier, and G. Fedosejevs. 1982. Geometric and Radiometric Considerations of NOAA AVHRR Imagery. Proc. of the 8th International Symposium on Machine Processing of Remotely Sensed Data. Purdue University, Indiana. p. 374-381.

Cicone, R.C. and M.D. Metzer. 1982. Comparisons of Landsat MSS, Nimbus-7 CZCS, and NOAA-6/7 AVHRR sensors for Land Use Analysis. Proc. of the 8th International Symposium on Machine Processing of Remotely Sensed Data. Purdue University, Indiana. p. 291-297.

Cihlar, J. and F. Huang. 1994. Effect of atmospheric correction and viewing angle restriction on AVHRR composites. Canadian Journal for Remote Sensing 20: 132-137.

Cihlar, J. and P.M. Teillet. 1995. Forward piecewise linear calibration model for quasi-real time processing of AVHRR data. Canadian Journal of Remote Sensing 21: 22-27.

Duggin, M.J., D. Piwinshi, V. Whitehead, and G. Tyland. 1982. Evaluation of NOAA-AVHRR Data for Crop Assessment. Appl. Opt. 21:1873-1875.

Gray, T.I. and D.G. McCrary. 1981. Meteorological Satellite Data - A Tool to Describe the Health of the World's Agriculture. AgRISTARS Report EW-N1-04042. NASA/JSC. Houston, Texas. 7 p.

Greegor, D.H. and J. Norwine. 1981. A Gradient Model of Vegetation and Climate Utilizing NOAA Satellite Imagery - Phase I: Texas Transect. AgRISTARS Report JSC-17435. FC-J1-04176. NASA/JSC. Houston, Texas. 58 p.

Inoue, T. 1987. A Cloud Type Classification with NOAA-7 Split-Window Measurements. Journal of Geophysical Research 92:3,991-4,000.

Newcomer, J., D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers, eds. 2000. Collected Data of The Boreal Ecosystem-Atmosphere Study. NASA. CD-ROM.

Ormsby, J.P. 1982. Classification of Simulated and Actual NOAA-6 AVHRR Data for Hydrological Land-Surface Feature Definition. IEEE Transactions on Geoscience and Remote Sensing. GE-20:262-268.

Robertson, B., A. Erickson, J. Friedel, B. Guindon, T. Fisher, R. Brown, P. Teillet, M. D'Iorio, J. Cihlar, and A. Sancz. 1992. GEOCOMP, a NOAA AVHRR geocoding and compositing system. Proceedings of the ISPRS Conference, Commission 2, Washington, DC, 223-228.

Schneider, S.R. and D.F. McGinnis. 1982. The NOAA/AVHRR: A New Satellite Sensor for Monitoring Crop Growth. Proc. of the 8th International Symposium on Machine Processing of Remotely Sensed Data. Purdue University, Indiana. p. 281-290.

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.

Taconet, O., R. Bernard, and D. Vidal-Madja. 1986. Evapotranspiration Over an Agricultural Region Using a Surface Flux/Temperature Model Based on NOAA-AVHRR Data. J. Climate Appl. Meteor. 25:284-307.

Teillet, P.M. and B.N. Holben. 1994. Towards operational radiometric calibration of NOAA AVHRR imagery in the visible and near-infrared channels. Canadian Journal of Remote Sensing 20: 1-10.

Townshend, J. (Ed.). 1995. Global data sets for the land from AVHRR. International Journal of Remote Sensing 15: 3315-3639 (special issue).

Townshend, J.R.G. and C.J. Tucker. 1981. Utility of AVHRR of NOAA-6 and -7 for Vegetation Mapping. In Matching Remote Sensing Technologies and their Applications Proceedings. Remote Sensing Society. London. p. 97-109.

Yates, H.W. and J.D. Tarpley. 1982. The Role of Meteorological Satellites in Agricultural Remote Sensing. Proc. of the 8th International Symposium on Machine Processing of Remotely Sensed Data. Purdue University, Indiana. p. 23-32.

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

```
AEAC    - Albers Equal-Area Conic
APT     - Automatic Picture Transmission
ASCII   - American Standard Code for Information Interchange
AVHRR   - Advanced Very High Resolution Radiometer
BIL     - Band Interleaved by Line
BOREAS  - BOReal Ecosystem-Atmosphere Study
BORIS   - BOREAS Information System
BPI     - Bytes Per Inch
CCRS    - Canada Centre for Remote Sensing
CCT     - Computer Compatible Tape
CD-ROM  - Compact Disk-Read-Only Memory
CPIDS   - Calibration Parameter Input Dataset
DAAC    - Distributed Active Archive Center
DAT     - Digital Archive Tape
DSL     - Digital Signal Level
EOS     - Earth Observing System
EOSDIS  - EOS Data and Information System
EROS    - Earth Resources Observation System
FPAR    - Fraction of Photosynthetically Active Radiation
GAC     - Global Area Coverage
GEOCOMP - Geocoding and Compositing System
GIS     - Geographic Information System
GMT     - Greenwich Mean Time
GSFC    - Goddard Space Flight Center
HRPT    - High-Resolution Picture Transmission
```

```
I/O      - Input/Output
IFC      - Intensive Field Campaign
IFOV     - Instantaneous Field-Of-View
LAC      - Local Area Coverage
LAI      - Leaf Area Index
LCC      - Lambert Conformal Conic
LGSOWG   - Landsat Ground Station Operational Working Group
LTWG     - LGSAWG Technical Working Group
MRSC     - Manitoba Remote Sensing Centre
NAD83    - North American Datum of 1983
NASA     - National Aeronautics and Space Administration
NDVI     - Normalizes Difference Vegetation Index
NEdT     - Noise Equivalent Differential Temperature
NOAA     - National Oceanic and Atmospheric Administration
NRL      - Naval Research Laboratory
NSA      - Northern Study Area
ORNL     - Oak Ridge National Laboratory
PANP     - Prince Albert National park
PASS     - Prince Albert Satellite Station
PRT      - Platinum Resistor Thermometer
RMS      - Root Mean Square
SOCC     - Satellite Operations Control Center
SSA      - Southern Study Area
SST      - Sea Surface Temperature
TIROS    - Television and Infrared Observation Satellite
URL      - Uniform Resource Locator
UTM      - Universal Transverse Mercator
```

20. Document Information

20.1 Document Revision Date

Written: 25-Jul-1995
Last Updated: 16-Jul-1999

20.2 Document Review Date(s)

BORIS Review: 11-Sep-1997
Science Review: 05-Jan-1998

20.3 Document ID

20.4 Citation

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

The AVHRR-LAC level-3b images resulted from a joint development and processing effort between BOREAS staff at CCRS and NASA GSFC. The data were acquired by CCRS and processed by MRSC in Winnipeg, Manitoba. The respective contributions of the above individuals and agencies to completing this data set are greatly appreciated.

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

Cihlar, J., "BOREAS Staff Science Satellite Data Acquisition Program." In Collected Data of The Boreal Ecosystem-Atmosphere Study. Eds. J. Newcomer, D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers. CD-ROM. NASA, 2000.

Also, cite the BOREAS CD-ROM set as:

Newcomer, J., D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers, eds. Collected Data of The Boreal Ecosystem-Atmosphere Study. NASA. CD-ROM. NASA, 2000.

20.5 Document Curator

20.6 Document URL

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 2000

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)
BOREAS Level 3-b AVHRR-LAC Imagery: Scaled At-sensor Radiance in LGSOWG Format

5. FUNDING NUMBERS
923
RTOP: 923-462-33-01

6. AUTHOR(S)
Jaime Nickeson, Jeffrey A. Newcomer, and Josef Cihlar
Forrest G. Hall, Editor

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS (ES)
Goddard Space Flight Center
Greenbelt, Maryland 20771

8. PEFORMING ORGANIZATION REPORT NUMBER
2000-03136-0

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS (ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
TM—2000–209891
Vol. 101

11. SUPPLEMENTARY NOTES
J. Nickeson, J.A. Newcomer: Raytheon ITSS, Greenbelt, Maryland;
J. Cihlar: Canada Centre for Remote Sensing, Ottawa, Ontario, Canada

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified–Unlimited
Subject Category: 43
Report available from the NASA Center for AeroSpace Information,
7121 Standard Drive, Hanover, MD 21076-1320. (301) 621-0390.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The BOREAS Staff Science Satellite Data Acquisition Program focused on providing the research teams with the remotely sensed satellite data products they needed to compare and spatially extend point results. Data acquired from the AVHRR instrument on the NOAA-9, -11, -12, and -14 satellites were processed and archived for the BOREAS region by the MRSC and BORIS. The data were acquired by CCRS and were provided for use by BOREAS researchers. A few winter acquisitions are available, but the archive contains primarily growing season imagery. These gridded, at-sensor radiance image data cover the period of 30-Jan-1994 to 18-Sep-1996. Geographically, the data cover the entire 1,000-km x 1,000-km BOREAS region. The data are stored in binary image format files.

14. SUBJECT TERMS
BOREAS, remote sensing science, AVHRR.

15. NUMBER OF PAGES
24

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL