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

Forrest G. Hall, Editor

Volume 102

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

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

National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

September 2000
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:

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

Josef Cihlar, Jing Chen, Jaime Nickeson, Jeffrey A. Newcomer, Fengting Huang

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. MRSC and BORIS personnel acquired, processed, and archived data from the AVHRR instruments on the NOAA-11 and -14 satellites. The AVHRR data were acquired by CCRS and were provided to BORIS for use by BOREAS researchers. These AVHRR level-4b data are gridded, 10-day composites of at-sensor radiance values produced from sets of single-day images. Temporally, the 10-day compositing periods begin 11-Apr-1994 and end 10-Sep-1994. Spatially, the data cover the entire BOREAS region. The data are stored in binary image format files.

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

Table of Contents

1) Data Set Overview
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-4b AVHRR-LAC Ten-Day Composite Images: At-sensor Radiance

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 Association (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-4b 10-day composite AVHRR-Local Area Coverage (LAC) imagery, along with the other remotely sensed images, was collected in order to provide spatially extensive information over the primary study areas 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 Center (MRSC) and CCRS processed the level-4b 10-day composite AVHRR-LAC imagery products.

1.4 Summary of Parameters
The level-4b 10-day composite AVHRR-LAC data in the BOREAS Information System (BORIS) contains the following parameters: image header and compositing information; geographic position information; scaled at-sensor radiance values for image bands 1 to 5; Normalized Difference Vegetation Index (NDVI); view and solar angle information.

1.5 Discussion
Level-4b data sets are subsets of 10-day composite images produced by Geocoding and Compositing (GEOCOMP) for the Northern Biosphere Observation and Modeling Experiment (NBIOME) (Cihlar, 1993). While the NBIOME composite covers all of Canada, a bounding rectangle encompassing the BOREAS region has been extracted for the level-4b product.

The level-4b processing starts with single-day raw data. Each image is registered to a map projection (Lambert Conformal Conic [LCC]), resampled, and incorporated into a 10-day composite using the maximum NDVI compositing criterion (e.g., each pixel is retained only if its NDVI is greater than that of the pixel already in the composite; in this manner, the composite contains fewer and fewer contaminated pixels on successive days). Once a pixel is retained, the three angles describing the acquisition geometry and the acquisition date are also saved in separate files.

The level-4b product contains the data exactly as produced by GEOCOMP. Because GEOCOMP processes the data in near-real time, the knowledge of AVHRR calibration is not always the best. In some cases, the calibration becomes known more accurately later (e.g., for NOAA-14 AVHRR). Such knowledge was not incorporated in the level-4b (or level-3b) products but was used to produce level-4c products.

1.6 Related Data Sets
BOREAS Level-3b AVHRR-LAC Imagery: Scaled At-sensor Radiance in LGSOWG Format
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
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 data collected for the BOREAS project were from instruments onboard NOAA-9, -11, and -12 polar orbiting platforms. The radiometers measured emitted and reflected radiation in the visible, near-infrared, middle-infrared, and one or two thermal channels.

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

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

* 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 (in micrometers) of the bands for the platform-specific instruments are:
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 Prince Albert Satellite Station (PASS).

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:

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Launch Date</th>
<th>Date Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOAA-B</td>
<td>29-May-1980</td>
<td>Failed to achieve orbit</td>
</tr>
<tr>
<td>NOAA-12</td>
<td>14-May-1991</td>
<td>11-Aug-1993 to present</td>
</tr>
<tr>
<td>NOAA-14</td>
<td>30-Dec-1994</td>
<td>15-May-1995 to present</td>
</tr>
</tbody>
</table>

AVHRR-LAC data used in BOREAS were collected onboard the NOAA-9, -11, and -12 polar orbiting platforms. Only NOAA-11 and -14 data were processed as level-4b products.

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 reflected and emitted radiation from Earth in the visible, near-, mid-, and thermal-infrared regions of the 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 spatial 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 reflective 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 3-5 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 and filtered.
- 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:

\[ \text{INDEX} = 10.0 \times \text{PRT TEMPERATURE} \times 1798.5 \]

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:

\[
\text{SPACEVIEW RADIANCE - BLACKBODY RADIANCE} \\
\text{SLOPE = } \frac{\text{SPACEVIEW MEAN} - \text{BLACKBODY MEAN}}{\text{SPACEVIEW RADIANCE} - \text{BLACKBODY RADIANCE}} \\
\text{INTERCEPT = SPACEVIEW RADIANCE SLOPE \times SPACEVIEW MEAN}
\]

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-4b AVHRR-LAC images were provided by the CCRS. Some radiometric corrections along with geometric corrections, are applied to produce the imagery in a spatially corrected form (LCC projection). A full level-4b AVHRR-LAC image contains approximately 1,200 pixels in each of approximately 1,200 lines. Before geometric corrections, the ground resolution ranges from 1.1 km at nadir to 2.5 km x 6.8 km at the scanning extremes of 55.4 degrees. The pixel values of the images are stored in 2-byte fields. The level-4b images were processed through the CCRS GEOCOMP system, which applies both radiometric and spatial corrections to the images. Only the raw data are available from the CCRS 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 for a global (pole to pole) onboard collection of data from all 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 (sidelap) anywhere on the globe.

The BOREAS level-4b AVHRR-LAC images contain 1,200 pixels in each of the 1,200 lines and cover the entire 1,000-km x 1,000-km BOREAS region. This includes the Northern Study Area (NSA), the Southern Study Area (SSA) and the transect between the SSA and NSA.

The North American Datum of 1983 (NAD83) corner coordinates of the AVHRR images are:

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest (1,1)</td>
<td>59.36395°N</td>
<td>115.40859°W</td>
</tr>
<tr>
<td>Northeast (1,1200)</td>
<td>61.01294°N</td>
<td>93.28553°W</td>
</tr>
<tr>
<td>Southwest (1200,1)</td>
<td>48.83387°N</td>
<td>110.25229°W</td>
</tr>
<tr>
<td>Southeast (1200,1200)</td>
<td>50.02993°N</td>
<td>93.73857°W</td>
</tr>
</tbody>
</table>

The northwest corner has a distance (1109.76 km west, 7900.04 km north) from the origin (95°W and 0°N) of the LCC coordinate. The pixel size is exactly 1 km.

The NAD83 corner coordinates of the BOREAS region are:

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest</td>
<td>59.979°N</td>
<td>111.000°W</td>
</tr>
<tr>
<td>Northeast</td>
<td>58.844°N</td>
<td>93.502°W</td>
</tr>
<tr>
<td>Southwest</td>
<td>51.000°N</td>
<td>111.000°W</td>
</tr>
<tr>
<td>Southeast</td>
<td>50.089°N</td>
<td>96.970°W</td>
</tr>
</tbody>
</table>

The NAD83 corner coordinates of the SSA are:

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest</td>
<td>54.319°N</td>
<td>106.227°W</td>
</tr>
<tr>
<td>Northeast</td>
<td>54.223°N</td>
<td>104.236°W</td>
</tr>
<tr>
<td>Southwest</td>
<td>53.513°N</td>
<td>106.320°W</td>
</tr>
<tr>
<td>Southeast</td>
<td>53.419°N</td>
<td>104.368°W</td>
</tr>
</tbody>
</table>
The NAD83 corner coordinates of the NSA are:

<table>
<thead>
<tr>
<th></th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest</td>
<td>56.249°N</td>
<td>98.824°W</td>
</tr>
<tr>
<td>Northeast</td>
<td>56.083°N</td>
<td>97.241°W</td>
</tr>
<tr>
<td>Southwest</td>
<td>55.542°N</td>
<td>99.045°W</td>
</tr>
<tr>
<td>Southeast</td>
<td>55.379°N</td>
<td>97.489°W</td>
</tr>
</tbody>
</table>

7.1.2 Spatial Coverage Map
Not available.

7.1.3 Spatial Resolution
Before any geometric corrections, the spatial resolution varies from 1.1 km at nadir to approximately 2.5 km x 6.8 km at the extreme edges of the scan. The level-4b composite 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 coordinate system is the LCC, with the two standard parallels at 49°N and 77°N, respectively, and the meridian at 95°W.

7.1.5 Grid Description
The BOREAS level-4b composite images are projected into the LCC projection at a spacing of 1.0 km per pixel (grid cell) in both the X and Y directions.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage
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 NDVI imagery. Contact the Statistics Canada Crop Condition Assessment Program office for more information.

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. The seasonal time period of data acquisition for the level-4b product is nominally 11-Apr through 31-Oct. In 1994, the period was from 11-Apr through 10-Sept. BORIS contains relatively complete AVHRR-LAC coverage from NOAA-11 of central Canada during the snow-free periods in 1993 and 1994.

7.2.2 Temporal Coverage Map
The 1994 compositing periods in this data set are as follows:

<table>
<thead>
<tr>
<th>Month</th>
<th>Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>11 - 20, 21 - 30</td>
</tr>
<tr>
<td>May</td>
<td>1 - 10, 11 - 20, 21 - 31</td>
</tr>
<tr>
<td>June</td>
<td>1 - 10, 11 - 20, 21 - 30</td>
</tr>
<tr>
<td>July</td>
<td>1 - 10, 11 - 20, 21 - 31</td>
</tr>
<tr>
<td>August</td>
<td>1 - 10, 11 - 20, 21 - 30</td>
</tr>
<tr>
<td>September</td>
<td>1 - 10</td>
</tr>
</tbody>
</table>

7.2.3 Temporal Resolution
AVHRR-LAC data processed as level-4b composite products are daytime images (afternoon passes). Most useful daily images (those containing some clear-sky regions) are used to produce the level-4b product. The daily images are composited into nominally cloud-free images over 10-day periods.
7.3 Data Characteristics

7.3.1 Parameter/Variable

The parameters contained in each image product are:

Scaled At-sensor Radiance
NDVI
View Zenith Angle
Solar Zenith Angle
Relative Azimuth Angle
Date of Acquisition

7.3.2 Variable Description/Definition

At-sensor radiance is the radiant energy measured 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 were used to calculate the radiance in a given band from the counts given:

\[
\begin{align*}
R(1) &= (625/1023) \times \text{DN}(1) - 25.0 \\
R(2) &= (415/1023) \times \text{DN}(2) - 15.0 \\
R(3) &= -(1.508988/1023) \times \text{DN}(3) + 1.504 \\
R(4) &= -(175.898/1023) \times \text{DN}(4) + 170.8 \\
R(5) &= -(183.863/1023) \times \text{DN}(5) + 179.1
\end{align*}
\]

where \( R(i) \) is the resulting radiance for band \( i \), and \( \text{DN}(i) \) is the count from band \( i \) in the digital image.

NDVI is the ratio of the difference between the near-infrared band and the visible band and the sum of the two bands \( [(\text{NIR} - \text{VIS}) / (\text{VIS} + \text{NIR})] \).

The values of the imagery have been scaled such that:

\[
\text{NDVI} = (\text{DN}/10,000) - 1.0
\]

View zenith angle is the position of the sensor relative to the nadir (subsatellite point), with 90 degrees indicating the horizontal position and 0 degrees being directly overhead. To calculate view zenith:

\[
\text{View Zenith} = \text{DN}/100
\]

Solar zenith angle is the position of the Sun relative to the horizon, with 90 degrees indicating the horizontal position and 0 degrees being directly overhead. To calculate solar zenith:

\[
\text{Solar Zenith} = \text{DN}/100
\]

Relative azimuth is equal to the solar azimuth minus the sensor view azimuth. Azimuth angles are measured from North (0 or 360 degrees) and increase clockwise to 90 degrees for east, 180 degrees for south, etc. To calculate relative azimuth:

\[
\text{Relative Azimuth} = \text{DN}/100
\]

Date of acquisition is the day of year on which that particular pixel in the level-4b composite product was acquired.

7.3.3 Unit of Measurement

At-sensor radiance units are \( \text{W/(m}^2 \text{ sr } \mu\text{m}) \) for channels 1 and 2, and \( \text{mW/(m}^2 \text{ sr cm}) \) for AVHRR channels 3, 4, and 5.
NDVI is unitless. View zenith is measured in degrees. Solar zenith is measured in degrees. Relative azimuth is measured in degrees. Date of acquisition units are days.

### 7.3.4 Data Source
The image data were acquired by CCRS and processed by the MRSC in Winnipeg, Manitoba.

### 7.3.5 Data Range
At-sensor radiance can range from:

<table>
<thead>
<tr>
<th>AVHRR Band</th>
<th>Units</th>
<th>DN=0</th>
<th>DN=1023</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Radiance</td>
<td>-25</td>
<td>600</td>
</tr>
<tr>
<td>2</td>
<td>Radiance</td>
<td>-15</td>
<td>400</td>
</tr>
<tr>
<td>3</td>
<td>Radiance</td>
<td>1.504</td>
<td>-0.004988</td>
</tr>
<tr>
<td>4</td>
<td>Radiance</td>
<td>170.8</td>
<td>-5.098</td>
</tr>
<tr>
<td>5</td>
<td>Radiance</td>
<td>179.1</td>
<td>-4.763</td>
</tr>
</tbody>
</table>

- The values of the scaled NDVI imagery range from a DN of 0 to a DN of 20,000.
- The scaled values in the view zenith image range from 0 to 9,000.
- The scaled values of solar zenith DN range from 0 to 9,000.
- The scaled values of relative azimuth range from 0 to 18,000.
- Based on a start date of 01-Jan-1970, the relative date of acquisition ranges from 8866 (11-Apr-1994) to 9018 (10-Sep-1994).

### 7.4 Sample Data Record
Sample data records are not applicable to image data.

### 8. Data Organization

#### 8.1 Data Granularity
The smallest unit of data for the level-4b AVHRR-LAC composite is the set of parameters for a given compositing period.

#### 8.2 Data Format(s)

##### 8.2.1 Uncompressed Data Files
A single level-4b AVHRR-LAC composite image product produced by CCRS contains the following 10 files:

- File 1 -- Channel 1 radiance
- File 2 -- Channel 2 radiance
- File 3 -- Channel 3 radiance
- File 4 -- Channel 4 radiance
- File 5 -- Channel 5 radiance
- File 6 -- NDVI
- File 7 -- View zenith angle
- File 8 -- Solar zenith angle
- File 9 -- Relative azimuth angle
- File 10 -- Date of acquisition
8.2.2 Compressed CD-ROM Files

On the BOREAS CD-ROMs, the image files have been compressed with the Gzip (GNU zip) compression program (file_name.gz). These data have been compressed using gzip version 1.2.4 and the high compression (-9) option (Copyright (C) 1992-1993 Jean-loup Gailly). Gzip uses the Lempel-Ziv algorithm (Welch, 1994) also used in the zip and PKZIP programs. The compressed files may be uncompressed using gzip (with the -d option) or gunzip. Gzip is available from many Web sites (for example, the ftp site prep.ai.mit.edu/pub/gnu/gzip-*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

9. Data Manipulations

9.1 Formulae

9.1.1 Derivation Techniques and Algorithms

The level-4b composite product uses the level-3 AVHRR-LAC product in LCC projection as input. Daily level-4b products are combined to select the most cloud-free pixels during the 10-day compositing period. By definition, this is the pixel with the highest NDVI value. Once a pixel is selected, it is retained in the composite image, as are the three associated angles, NDVI, and the day of year in which the pixel was imaged. The components are created for three separate periods within a month: 1-10, 11-20, and 21-end of month.

The daily data are not corrected for atmospheric effects prior to creating composites. This is done to avoid selection of pixels with high view zenith angles (Cihlar and Huang, 1994). Only data for view zenith angles 57 degrees or less were used in the composite (except for 1993, when data were used from all zenith angles).

It is important to note that level-4b images were composited from level-3b images processed separately from the level-3b images contained in BORIS. This is because of the differences in projections Albers Equal-Area Conic (AEAC) vs. LCC. However, the same calibration and processing sequences were used, except as noted (e.g., difference in 1995 calibrations).

9.2 Data Processing Sequence

9.2.1 Processing Steps

GEOCOMP created the level-4b composite image by:
- Specifying input parameters for generating the composite image (source images, geographic region, compositing criterion, compositing period)
- Inputting imagery
- Comparing the NDVI of every pixel of the input level-3 image with that of the corresponding composite pixel
- If appropriate, replacing values of a composite pixel by those in the daily image for all channels
- Repeating steps 3 and 4 for all daily images during the compositing period
- Outputting imagery
BORIS staff processed the data by:
- Developing and using software to verify the content of and extract needed information from the image files,
- Compressing the binary files for release on CD-ROM.

9.2.2 Processing Changes
None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments
None.

9.3.2 Calculated Variables
See Section 7.

9.4 Graphs and Plots
None.

10. Errors

10.1 Sources of Error
The major source of error is due to two geometric effects, IFOV and image registration. Because the IFOV size at large view zenith angles varies for adjacent level-4 pixels on different dates, the composite pixels represent varying areas (in size and location, thus creating overlaps or gaps) on Earth's surface. This effect can be assessed using the angular information in the level-4 product. The other geometric effect is caused by pixel misregistration. Although the registration of level-3b images is typically done with subpixel accuracy (root mean square [rms]<0.8 km for pixels within 45 degrees of nadir), the accuracy of the composite products accumulates errors from individual images and suffers from the reduced accuracy for pixels farther from nadir. This effect is difficult to quantify as it varies both within the composite image and between composite periods.

The level-4b product is not corrected for atmospheric or bidirectional effects; thus, the composites have numerous radiometric artifacts caused by these phenomena. The level-4b product also suffers from errors in the level-3b product (see level-3b product documentation).

10.2 Quality Assessment

10.2.1 Data Validation by Source
Not available.

10.2.2 Confidence Level/Accuracy Judgment
Refer to the level-3b product specification.

10.2.3 Measurement Error for Parameters
None.

10.2.4 Additional Quality Assessments
Composites are assessed visually.

10.2.5 Data Verification by Data Center
BORIS personnel extracted header information, inventoried the AVHRR data acquisition information in the data base, and viewed some of the imagery to confirm the use of scaling information provided in Section 7.3.2. Lastly, BORIS staff compressed the image data files for distribution on CD-ROM.
11. Notes

11.1 Limitations of the Data
None.

11.2 Known Problems with the Data
None.

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

11.4 Other Relevant Information
None.

12. Application of the Data Set
None given.

13. Future Modifications and Plans
None.

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

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

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

The level-4b AVHRR-LAC 10-day composite images are available from the Earth Observing 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

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 AVHRR-LAC level-4b 10-day composite data can be made available on 8-mm media.

16.2 Film Products
None.

16.3 Other Products
These data are available on the BOREAS CD-ROM series.
17. References

17.1 Platform/Sensor/Instrument/Data Processing Documentation


17.2 Journal Articles and Study Reports


17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEAC</td>
<td>Albers Equal-Area Conic</td>
</tr>
<tr>
<td>APC</td>
<td>Automatic Picture Transmission</td>
</tr>
<tr>
<td>ASCII</td>
<td>American Standard Code for Information Interchange</td>
</tr>
<tr>
<td>AVHRR</td>
<td>Advanced Very High Resolution Radiometer</td>
</tr>
<tr>
<td>BOREAS</td>
<td>BOReal Ecosystem-Atmosphere Study</td>
</tr>
<tr>
<td>BORIS</td>
<td>BOREAS Information System</td>
</tr>
<tr>
<td>BPI</td>
<td>Bytes per inch</td>
</tr>
<tr>
<td>CCRS</td>
<td>Canada Centre for Remote Sensing</td>
</tr>
<tr>
<td>CCT</td>
<td>Computer-Compatible Tape</td>
</tr>
<tr>
<td>CD-ROM</td>
<td>Compact Disk-Read-Only Memory</td>
</tr>
<tr>
<td>CPIDS</td>
<td>Calibration Parameter Input Dataset</td>
</tr>
<tr>
<td>DAAC</td>
<td>Distributed Active Archive Center</td>
</tr>
<tr>
<td>DAT</td>
<td>Digital Archive Tape</td>
</tr>
<tr>
<td>DN</td>
<td>Digital Number</td>
</tr>
<tr>
<td>EOS</td>
<td>Earth Observing System</td>
</tr>
<tr>
<td>EOSDIS</td>
<td>EOS Data and Information System</td>
</tr>
<tr>
<td>EROS</td>
<td>Earth Resources Observation System</td>
</tr>
<tr>
<td>FPAR</td>
<td>Fraction of Photosynthetically Active Radiation</td>
</tr>
<tr>
<td>GAC</td>
<td>Global Area Coverage</td>
</tr>
<tr>
<td>GEOCOMP</td>
<td>Geocoding and Compositing System</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>GSFC</td>
<td>Goddard Space Flight Center</td>
</tr>
<tr>
<td>HRPT</td>
<td>High-Resolution Picture Transmission</td>
</tr>
<tr>
<td>IFC</td>
<td>Intensive Field Campaign</td>
</tr>
<tr>
<td>IFOV</td>
<td>Instantaneous Field-of-View</td>
</tr>
<tr>
<td>LAC</td>
<td>Local Area Coverage</td>
</tr>
<tr>
<td>LAI</td>
<td>Leaf Area Index</td>
</tr>
<tr>
<td>LCC</td>
<td>Lambert Conformal Conic</td>
</tr>
<tr>
<td>LGSWG</td>
<td>Landsat Ground Station Operational Working Group</td>
</tr>
<tr>
<td>MRSC</td>
<td>Manitoba Remote Sensing Centre</td>
</tr>
</tbody>
</table>
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 data were acquired by CCRS and processed by the 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:

Also, cite the BOREAS CD-ROM set as:

20.5 Document Curator

20.6 Document URL
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. MRSC and BORIS personnel acquired, processed, and archived data from the AVHRR instruments on the NOAA-11 and -14 satellites. The AVHRR data were acquired by CCRS and were provided to BORIS for use by BOREAS researchers. These AVHRR level-4b data are gridded, 10-day composites of at-sensor radiance values produced from sets of single-day images. Temporally, the 10-day compositing periods begin 11-Apr-1994 and end 10-Sep-1994. Spatially, the data cover the entire BOREAS region. The data are stored in binary image format files.