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Forrest G. Hall, Editor

Volume 97

BOREAS Level-3b Landsat TM Imagery: At-sensor Radiances in BSQ Format

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September 2000

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BOREAS Level-3b Landsat TM Imagery: At-sensor Radiance in BSQ Format

Jaime Nickeson, David Knapp, Jeffrey A. Newcomer, Josef Cihlar

Summary

For BOREAS, the level-3b Landsat TM data, along with the other remotely sensed images, were collected in order to provide spatially extensive information over the primary study areas. This information includes radiant energy, detailed land cover, and biophysical parameter maps such as FPAR and LAI. Although very similar in content to the level-3a Landsat TM products, the level-3b images were created to provide users with a directly usable at-sensor radiance image. Geographically, the level-3b images cover the BOREAS NSA and SSA. Temporally, the images cover the period of 22-Jun-1984 to 09-Jul-1996. The images are available in binary, image format files.

Note that the level-3b Landsat TM images are not contained on the BOREAS CD-ROM set. An inventory listing file is supplied on the CD-ROM to inform users of the data that were collected. See Sections 15 and 16 for information about how to acquire the data.

Also note that the ground control points for the NSA were updated after many of the scenes covering the NSA had already been processed to level-3a. Thus, the longitude and latitude coordinates contained in many of the ASCII header files for the NSA scenes are outdated and not as precise as the new coordinates. Please see Section 11.2 for details and updated coordinates.

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 Landsat TM Imagery: At-sensor Radiance in BSQ 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 and processing procedures across sites and time. These activities included the acquisition of the relevant satellite data. Data from the Landsat Thematic Mapper (TM) instruments on the Landsat satellites were acquired by the Canada Centre for Remote Sensing (CCRS) and provided for use by BOREAS researchers. BOREAS Information System (BORIS) and CCRS personnel subsequently processed the acquired images to the level-3b products described here.

1.3 Objective/Purpose

For BOREAS, the Landsat TM imagery, along with the other remotely sensed images, was collected in order to provide spatially extensive information over the primary study areas. This information includes detailed land cover and biophysical parameter maps such as biomass, Fraction of Photosynthetically Active Radiation (FPAR), and Leaf Area Index (LAI). The BOREAS Information System (BORIS) processed the level-3a Landsat TM imagery to the level-3b product so the BOREAS research teams had directly usable at-sensor radiance products for remote sensing and atmospheric correction research.

1.4 Summary of Parameters

Landsat TM level-3b data in BORIS contain the following parameters:

Original image header information, image coordinates, gains and offsets for each band, georeferencing information summary, control point coordinates used to georeference the image, and at-sensor radiance values for image bands 1-7.

1.5 Discussion

Use and distribution of the level-3b Landsat TM images are subject to copyright restrictions. CCRS and Radarsat International (RSI) granted permission to BOREAS to place a subset of the level-3a Landsat TM images on the BOREAS CD-ROM series; however, none of the level-3b images are included. The level-3b images may not be available for public access. Please see Sections 15 and 16 for further details.

BORIS staff created the Landsat TM level-3b data by:

- Extracting pertinent header information from the level-3a image product and placing it in the level-3b American Standard Code for Information Interchange (ASCII) header file.
- Calculating at-sensor radiance values for each band and scaling them to 16-bit (2-byte) integer values on disk.
- Applying the geometric transformation coefficients from the level-3b header to update geographic coverage information for the image.
- Writing the level-3b ASCII header file and seven image bands to tape.
- Inventorying the image product in the online data base.

1.6 Related Data Sets

BOREAS Level-3a Landsat TM Imagery: Scaled At-sensor Radiance in BSQ Format
BOREAS Level-3p Landsat TM Imagery: Geocoded and Scaled At-sensor Radiance
BOREAS Level-3s Landsat TM Imagery: Scaled At-sensor Radiance in LGSOWG Format
BOREAS Level-3s SPOT Imagery: Scaled At-sensor Radiance in LGSOWG Format

2. Investigator(s)

2.1 Investigator(s) Name and Title

BOREAS Staff Science

2.2 Title of Investigation

BOREAS Staff Science Satellite Data Acquisition Program

2.3 Contact Information

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3. Theory of Measurements

The Landsat series of satellites began with the Earth Resources Technology Satellite (ERTS) launched in July 1972. This satellite was renamed Landsat 1 in 1975 to reflect its primary use as a land resource observatory. Through its onboard instruments, Landsat monitors Earth's mountain ranges, deserts, forests, and crops by measuring the light waves they reflect.

The second generation of Landsat satellites (4 and 5) marked a significant advance in remote sensing through the addition of the more sophisticated TM sensor, with higher spectral and spatial resolution, and faster data processing at a highly automated data processing facility at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) in Greenbelt, MD. For BOREAS, the CCRS receiving station in Prince Albert, Saskatchewan, collected the raw data. Processing of the raw data to the imagery used as input for the BOREAS level-3a processing was performed with the Geocoded Image Correction System (GICS; Friedel, 1992) at the CCRS facility in Ottawa.

As Landsat's instrument mirrors scan Earth's surface, light enters the instrument optics, where it is focused on specially calibrated detector arrays. Onboard electronics encode the detector voltage as binary digits or bits. These digital image data are then relayed back to Earth to be processed into film and Computer-Compatible Tape (CCT) products, which are subsequently used for Earth resources analysis.

4. Equipment

4.1 Sensor/Instrument Description

The TM sensor system records radiation from seven bands in the electromagnetic spectrum. It has a telescope that directs the incoming radiant flux obtained along a scan line through a scan line collector to the visible and near-infrared focal plane, or to the mid-infrared and thermal-infrared cooled focal plane. The detectors for the visible and near-infrared bands (1 to 4) are four staggered linear arrays, each containing 16 silicon detectors. The two mid-infrared detectors are 16 indium-antimonide cells in a staggered linear array, and the thermal-infrared detector is a four-element array of mercury-cadmium-telluride cells. The spectral regions, band widths, and primary use of each channel are given in the following table:

Channel	Wavelength (µm)	Primary Use
1	0.451 - 0.521	Coastal water mapping, soil vegetation differentiation, deciduous/coniferous differentiation.
2	0.526 - 0.615	Green reflectance by healthy vegetation.
3	0.622 - 0.699	Chlorophyll absorption for plant species differentiation.
4	0.771 - 0.905	Biomass surveys, water body delineation.
5	1.564 - 1.790	Vegetation moisture measurement, snow and cloud differentiation.
6	10.450 - 12.460	Plant heat stress measurement, other thermal mapping.
7	2.083 - 2.351	Hydrothermal mapping.

4.1.1 Collection Environment

The Landsat satellite orbits Earth at an altitude of 705 km. The BOREAS level-3s and 3p Landsat TM images were acquired through the CCRS. A full TM image contains 6,920 pixels in each of 5,728 lines (see Section 11.1). Before any geometric corrections, the instantaneous field of view (IFOV) is 30 m for bands 1, 2, 3, 4, 5, and 7 and 120 m for band 6 at nadir. The pixel values of the level-3a images can range from 0 to 255. This allows each pixel to be stored in a single-byte field. The level-3a images from which the level-3b images were derived were processed by BORIS-developed software at GSFC and CCRS. The BOREAS level-3b Landsat TM images were derived from the level-3a images by applying the sensor gain and offset information contained in the ASCII header files of the level-3a Landsat TM image products.

4.1.2 Source/Platform

Although the majority of the BOREAS Landsat TM imagery was acquired by the instrument onboard Landsat 5, some imagery was obtained with the TM sensor on the Landsat 4 platform.

4.1.3 Source/Platform Mission Objectives

The Landsat TM is designed to respond to and measure both reflected and emitted Earth surface radiation to enable the investigation, survey, inventory, and mapping of Earth's natural resources.

4.1.4 Key Variables

Reflected radiation, emitted radiation, temperature.

4.1.5 Principles of Operation

The TM is a scanning optical sensor operating in the visible and infrared wavelengths. It contains a scan mirror assembly that directly projects the reflected Earth radiation onto detectors arrayed in two focal planes. The TM achieves better image resolution, sharper color separation, and greater in-flight geometric and radiometric accuracy for seven spectral bands simultaneously than the previous generation sensor, the MultiSpectral Scanner (MSS). Data collected by the sensor are beamed back to

ground receiving stations for processing.

4.1.6 Sensor/Instrument Measurement Geometry

The TM sensor depends on the forward motion of the spacecraft for the along-track scan and uses moving mirror assembly to scan in the cross-track direction (perpendicular to the spacecraft). The instantaneous field-of-view (IFOV) for each detector from bands 1-5 and band 7 is equivalent to a 30-m square when projected to the ground at nadir; band 6 (the thermal infrared band) has an IFOV equivalent to a 120-m square at nadir.

4.1.7 Manufacturer of Sensor/Instrument

NASA GSFC
Greenbelt, MD 20771
Hughes Santa Barbara Remote Sensing (SBRS)
Goleta, CA

4.2 Calibration

The internal calibrator, a flex-pivot-mounted shutter assembly, is synchronized with the scan mirror, oscillating at the same 7-Hz frequency. During the turnaround period of the scan mirror, the shutter introduces the calibration source energy and a black direct-current restoration surface into the 100 detector fields-of-view.

The calibration signals for bands 1 through 5 and band 7 are derived from three regulated tungsten-filament lamps. The calibration source for band 6 is a blackbody with three temperature selections, commanded from the ground. The method for transmitting radiation to the moving calibration shutter allows the tungsten lamps to independently provide radiation and to contribute proportionately to the illumination of all detectors.

4.2.1 Specifications

Band	Radiometric Sensitivity [NE(dP)]*
1	0.8%
2	0.5%
3	0.5%
4	0.5%
5	1.0%
6	0.5 K [NE(dT)]
7	2.4%

Ground IFOV	30 m (Bands 1-5, 7) 120 m (Band 6)
Avg. altitude	699.6 km
Data rate	85 Mbps
Quantization levels	256
Orbit angle	8.15 degrees
Orbital nodal period	98.88 minutes
Scan width	185 km
Scan angle	14.9 degrees
Image overlap	7.6%

Note: The radiometric sensitivities are the noise-equivalent (NE) reflectance differences for the reflective channels expressed as percentages [NE(dP)] and temperature differences for the thermal-infrared bands [NE(dT)] in Kelvins.

4.2.1.1 Tolerance

The TM channels were designed for a NE differential represented by the radiometric sensitivity shown in Section 4.2.1.

4.2.2 Frequency of Calibration

The absolute radiometric calibration between bands on the TM sensor is maintained by using internal calibrators located between the telescope and the detectors that are sampled at the end of a scan.

4.2.3 Other Calibration Information

Relative within-band radiometric calibration, to reduce "striping," is provided by a scene-based procedure called histogram equalization. Because of the absolute accuracy and relative precision of this calibration scheme, it is assumed that any changes in the optics of the primary telescope or the "effective radiance" from the internal calibrator lamps are insignificant in comparison to the changes in detector sensitivity and electronic gain and bias with time and that the scene-dependent sampling is sufficiently precise for the required within-scan destriping from histogram equalization.

Each TM reflective band and the internal calibrator lamps were calibrated prior to launch using lamps in integrating spheres that were in turn calibrated against lamps traceable to calibrated National Bureau of Standards lamps. The absolute radiometric calibration constants in the "short-term" and "long-term" parameter files used for ground processing were modified after launch if there was an inconsistency within or between bands, a change in the inherent dynamic range of the sensors, or a desire to make quantized and calibrated values from one sensor match those from another.

5. Data Acquisition Methods

The BOREAS Landsat TM level-3s and -3p images were acquired through the CCRS. Radiometric corrections and systematic or precision geometric corrections are applied to produce the images in a path-oriented form. A full TM image contains 6,920 pixels in each of 5,728 lines (see Section 11.2). Before any geometric corrections, the ground resolution is 30 m for bands 1-5 and 7 and 120 m for band 6 at nadir. The pixel values of the images can range from 0 to 255. This allows each pixel to be stored in a single-byte field. The level-3a images from which the level-3b images were derived were processed by BORIS-developed software at GSFC and CCRS. The BOREAS level-3b Landsat TM images were derived from the level-3a images by applying the sensor gain and offset information contained in the ASCII header files of the level-3a Landsat TM image products.

6. Observations

6.1 Data Notes

None.

6.2 Field Notes

Not applicable.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The BOREAS level-3b Landsat TM images cover the Southern Study Area (SSA) and the Northern Study Area (NSA). The SSA and the NSA are located in the southwest and northeast portions of the overall region.

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

	Latitude	Longitude
Northwest	54.321 N	106.228 W
Northeast	54.225 N	104.237 W
Southwest	53.515 N	106.321 W
Southeast	53.420 N	104.368 W

The NAD83 corner coordinates of the NSA are:

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

7.1.2 Spatial Coverage Map

Not available.

7.1.3 Spatial Resolution

Before any geometric corrections, the spatial resolution at nadir is 30 m for bands 1-5 and 7 and 120 m for band 6. These values increase with scan angle away from the nadir path. The level-3s and -3p Landsat TM images have had geometric corrections applied so that the spatial resolution for all pixels is 30 m in all bands. The level-3s images have a high level of internal spatial integrity, but the actual geographic coordinates contained on the tape can be offset from their actual positions by as much as 20 km. The level-3p images have a high level of internal spatial integrity and have had ground control added to improve the accuracy of the geographic coordinates provided on the tape. In processing the level-3s and -3p images to level-3a and -3b products, BORIS has provided equations for calculating the latitude, longitude of any image pixel but has not performed any further geometric corrections or spatial resampling of the image data. The image pixels retain their 30 meter spatial resolution with some leveling of the geographic accuracy of the pixel positions.

7.1.4 Projection

The level-3a Landsat TM images are in a Universal Transverse Mercator (UTM) projection based on NAD83. Detailed projection parameter information for the individual images is contained in the ASCII header file. Ground control point locations and least squares equations to calculate the latitude and longitude of any pixel in the image were included in the ASCII header file by BORIS personnel (see Sections 9.2.1 and 9.2.2).

7.1.5 Grid Description

The pixel/grid spacing for each pixel in the level-3a Landsat TM images is 30 m in the UTM projection.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

Imagery acquired before the BOREAS field campaigns were conducted is included in the BOREAS archive with imagery collected during the project. Historical Landsat data have been acquired by CCRS routinely since the launch of Landsat 1 and are kept in the CCRS archive.

Since the mid-1980s, CCRS has been acquiring and archiving all Landsat data over Canada during the growing season; however, during the winter, only requested data were obtained. For BOREAS,

this policy was modified to obtain data throughout the year over the BOREAS region. The acquired data are archived by CCRS and can be interrogated to ascertain which scenes were archived and their characteristics. The entire set of BOREAS Landsat TM acquisitions cover 22-Jun-1984 to 09-Jul-1996.

7.2.2 Temporal Coverage Map

The following two lists provide dates for all the level-3b Landsat TM images that are available from BOREAS.

Date	Study Area
11-Jul-1984	SSA
12-Aug-1984	SSA
07-Jul-1985	SSA
11-Aug-1986	SSA
18-Aug-1986	SSA
30-Aug-1987	SSA
20-Jun-1988	SSA
06-Jul-1988	SSA
23-Aug-1988	SSA
02-Jul-1989	SSA
04-Sep-1989	SSA
06-Aug-1990	SSA
06-Aug-1990	SSA
29-Aug-1990	SSA
05-May-1991	SSA
06-Jun-1991	SSA
24-Jul-1991	SSA
09-Aug-1991	SSA
10-Sep-1991	SSA
15-Jun-1992	SSA
18-Jan-1993	SSA
29-Jul-1993	SSA
06-Feb-1994	SSA
20-Apr-1994	SSA
07-Jun-1994	SSA
29-Mar-1995	SSA
03-Jul-1995	SSA
21-Sep-1995	SSA
27-Jan-1996	SSA
02-May-1996	SSA
30-Jul-1996	SSA

Date	Study Area
22-Jun-1984	NSA
19-Aug-1985	NSA
15-Aug-1986	NSA
01-Jun-1988	NSA
20-Aug-1988	NSA
05-Sep-1988	NSA
07-Aug-1989	NSA
25-Jul-1990	NSA
28-Jul-1991	NSA
06-Aug-1992	NSA
02-Aug-1993	NSA
10-Feb-1994	NSA
09-Jun-1994	NSA
13-Feb-1995	NSA
09-Apr-1995	NSA
11-May-1995	NSA
21-Jun-1995	NSA
22-May-1996	NSA
09-Jul-1996	NSA

7.2.3 Temporal Resolution

The Landsat TM satellite revisit frequency is 16 days for each path/row; however, in the BOREAS region the overlap between adjacent scene paths is about 50%.

7.3 Data Characteristics

7.3.1 Parameter/Variable

The main parameter contained in the image data files is at-sensor radiance. The parameters contained in the inventory listing file on the CD-ROM are:

Column Name
SPATIAL_COVERAGE
DATE_OBS
START_TIME
END_TIME
PLATFORM
INSTRUMENT
NUM_BANDS
BAND_QUALITY
CLOUD_COVER
PATH_NUM
ROW_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

For the image data files:

At-sensor radiance - The value representing the radiant energy incident on the sensor aperture at the time of data collection in the specific TM wavelength regions.

The descriptions of the parameters contained in the inventory listing file on the CD-ROM are:

Column Name	Description
SPATIAL_COVERAGE	The general term used to denote the spatial area over which the data were collected.
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 units for the at-sensor radiance values are hundredths of Watts/(m^2 * sr * µm) (i.e., Watts/(m^2 * sr * µm) multiplied by 100). Divide the 16-bit values by 100 to get radiance values of Watts/(m^2 * sr * µm). The measurement units for the parameters contained in the inventory listing file 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]
PATH_NUM	[unitless]
ROW_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 data contained in the level-3b Landsat TM data files came from applying the gain and offset values supplied in the level-3s and level-3p images to the image data file values. The information in the ASCII header file came from various portions of the Landsat satellite, the TM instrument, and the ground processing components. The sources of the parameter values contained in the inventory listing file on the CD-ROM are:

Column Name	Data Source
SPATIAL_COVERAGE	[Determined by BORIS software from latitude and longitude information contained on the level-3s data files.]
DATE_OBS	[Determined by BORIS software from data and time information contained on the level-3s data files.]
START_TIME	[Determined by BORIS software from data and time information contained on the level-3s data files.]
END_TIME	[Determined by BORIS software from data and time information contained on the level-3s data

	files.]
PLATFORM	[Determined by BORIS software from platform information contained on the level-3s data files.]
INSTRUMENT	[Constant software value]
NUM_BANDS	[Determined by BORIS software from processing of the data files.]
BAND_QUALITY	[Assessed by BORIS personnel from viewing the image.]
CLOUD_COVER	[Assessed by BORIS personnel from viewing the image.]
PATH_NUM	[Determined by BORIS software from location information contained on the level-3s data files.]
ROW_NUM	[Determined by BORIS software from location information contained on the level-3s data files.]
NW_LATITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
NW_LONGITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
NE_LATITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
NE_LONGITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
SW_LATITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
SW_LONGITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
SE_LATITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
SE_LONGITUDE	[Determined by BORIS software from location information contained on the level-3s data files.]
PLATFORM_ALTITUDE	[Determined by BORIS software from platform information contained on the level-3s data files.]
MIN_SOLAR_ZEN_ANG	[Calculated with software from latitude and longitude and time information]
MAX_SOLAR_ZEN_ANG	[Calculated with software from latitude and longitude and time information]
MIN_SOLAR_AZ_ANG	[Calculated with software from latitude and longitude and time information]
MAX_SOLAR_AZ_ANG	[Calculated with software from latitude and longitude and time information]
CRTFCN_CODE	[Assigned by BORIS based on processing.]

7.3.5 Data Range

The range of at-sensor radiance values is dependent on the initial digital number (DN) range in the level-3a images. A value of zero is used to fill spatial areas in the images where no spectral data were acquired (see Section 9.1). The overall minimum and maximum at-sensor radiance values for each band in units of Watts/(square meter * steradian * micrometer) are:

Band	Minimum (DN = 0)	Maximum (DN = 255)
1	-1.52	152.10
2	-2.84	296.81
3	-1.17	204.30
4	-1.51	206.19
5	-0.37	27.19
6	1.24	15.60
7	-0.15	14.37

The following table gives information about the parameter values found in the inventory table on the CD-ROM.

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SPATIAL_COVERAGE	N/A	N/A	None	None	None	None
DATE_OBS	22-JUN-84	09-JUL-96	None	None	None	None
START_TIME	1638	1735	None	None	None	None
END_TIME	1638	1735	None	None	None	None
PLATFORM	LANDSAT-5	LANDSAT-5	None	None	None	None
INSTRUMENT	THEMATIC MAPPER	THEMATIC MAPPER	None	None	None	None
NUM_BANDS	7	7	None	None	None	None
BAND_QUALITY	N/A	N/A	None	None	None	None
CLOUD_COVER	N/A	N/A	None	None	None	None
PATH_NUM	33	38	None	None	None	None
ROW_NUM	21	23	None	None	None	None
NW_LATITUDE	54.0591	57.1963	None	None	None	None
NW_LONGITUDE	-107.89	-97.8737	None	None	None	None
NE_LATITUDE	53.61007	56.43718	None	None	None	None
NE_LONGITUDE	-104.75394	-94.81617	None	None	None	None
SW_LATITUDE	52.55109	55.7164	None	None	None	None
SW_LONGITUDE	-108.4801	-99.2081	None	None	None	None
SE_LATITUDE	52.11603	54.96871	None	None	None	None
SE_LONGITUDE	-105.44857	-95.84373	None	None	None	None
PLATFORM_ALTITUDE	705300	705300	None	None	None	None
MIN_SOLAR_ZEN_ANG	35.2	77.9	None	None	None	None
MAX_SOLAR_ZEN_ANG	35.2	77.9	None	None	None	None
MIN_SOLAR_AZ_ANG	132.5	154.6	None	None	None	None
MAX_SOLAR_AZ_ANG	132.5	154.6	None	None	None	None
CRTFCN_CODE	CPI	CPI	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 Landsat TM images is not available here. The following are wrapped versions of the first few records from the level-3b Landsat TM inventory table on the CD-ROM:

```
SPATIAL_COVERAGE,DATE_OBS,START_TIME,END_TIME,PLATFORM,INSTRUMENT,NUM_BANDS,
BAND_QUALITY,CLOUD_COVER,PATH_NUM,ROW_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
'NSA',22-JUN-84,1701,1701,'LANDSAT-5','THEMATIC MAPPER',7,'GOOD','50%',33,21,
56.8912,-99.1682,56.40572,-95.89303,55.39045,-99.80904,54.92147,-96.65237,
705300.0,36.5,36.5,142.8,142.8,'CPI'
'SSA',11-JUL-84,1732,1732,'LANDSAT-5','THEMATIC MAPPER',7,'GOOD',
'20% CLOUD COVER',38,22,55.1409,-107.731,54.67553,-104.59718,53.63487,
-108.31922,53.18647,-105.29384,705300.0,37.0,37.0,140.0,140.0,'CPI'
```

8. Data Organization

8.1 Data Granularity

The smallest orderable unit of data for the level-3b Landsat TM images is a specific image.

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 within single apostrophe marks. There are no spaces between the fields.

A level-3b Landsat TM image produced by the BORIS contains a set of eight files (i.e., an ASCII header file followed by seven band sequential format image data files). Specific information about these files is as follows:

FILE 1 (90 byte ASCII text records)

- Description of level-3b product files
- Original image header information (tape values are decoded based on the conventions outlined in the User's Guide for Landsat Thematic Mapper Computer-Compatible Tapes document, 1985; EOSAT).
- Level-3b image coordinates (using the first scan in file as line 1) and subset derived information (see Section 9).
- Georeferencing information summary (min and max latitude/longitude)
- Coordinates (image subset (pixel,line) and (longitude,latitude)) of the control points used to improve georeferencing.

FILES 2 - 8

- A band sequential set of files containing image bands 1 to 7, respectively.
- Each of the 5728 records in each files contains 13840 bytes.
- Each of the 13840 byte records contains 6920 16-bit/two-byte pixel values stored as low order byte first. (See Section 11.2)
- Each pixel value is in units of hundredths of Watts/(m^2 * sr * µm) (i.e., Watts/(m^2 * sr * µm) multiplied by 100).
- Each 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 left to right and top to bottom so that pixel n, line n is in the lower right-hand corner.

9. Data Manipulations

9.1 Formulae

9.1.1 Derivation Techniques and Algorithms

The procedure used to calculate the Landsat TM at-sensor radiance values was developed at GSFC as part of the BOREAS Staff Science effort. The level-3b image bands were calculated from BOREAS level-3a Landsat TM images using the band-respective gain and offset values contained in each level-3a image ASCII header file.

9.2 Data Processing Sequence

9.2.1 Processing Steps

BORIS staff creates the level-3b Landsat TM images by :

- Inventorying the level-3a image by date and time in the online data base.
- Extracting pertinent header information from the level-3a image product and placing it in the level-3b ASCII header file.
- Calculating at-sensor radiance values for each band and scaling them to 16-bit (2-byte) integer values on disk.
- Applying level-3a geometric transformation coefficients to calculate improved latitude, longitude coordinates from pixel, line values.
- Writing the files of information to tape.
- Inventorying the level-3b products in the data base.

Some cloud cover and image quality assessment information was generated when BORIS staff created the level-3a products. This information was entered into the BORIS data base but is not included with the images on tape. To obtain this information, see the inventory file included on the CD-ROMs or see Section 15.1.

The ground control points for the SSA were selected from 1:50,000-scale National Topographic System (NTS) maps. Different maps will tend to have different levels of accuracy; however, all of the control points that were used for each image have an error of no more than 1.5 pixels (45 meters).

The ground control points for the NSA were selected using 13 ground control points located in the field with a global positioning system (GPS). Most of these points are road intersections within the study area that are easily identifiable on the imagery. Because they are of such high precision, 13 points are sufficient to produce an acceptable transformation equation. These GPS coordinates were determined and used in the NSA due to unexplainable discrepancies that resulted when points digitized from the 1:50,000-scale NTS maps over the western portion of the NSA were used.

The NSA images from Path/Row 34/21 did not cover the entire study area and only a portion of the 13 GPS points fell within these images. For such cases, another image of the NSA that had been georeferenced using GPS points was used to perform an image-to-image registration. This made it possible to select enough ground control points to produce a good transformation equation.

9.2.2 Processing Changes

After processing several Landsat TM images to level-3a products, an error was discovered in the software that caused the level-3a images to contain 6,930 pixels in each image line versus the correct 6,920 pixels per image line. This error also caused some of the first level-3b images to contain 6,930 pixels per line. After the software problem was discovered, the number of pixels in the subsequently processed images was set at 6,920. However, the images processed prior to the software change still contain 6,930 pixels per line. The extra 10 pixels are located at the end of each line and contain values of zero.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

None.

9.3.2 Calculated Variables

At-sensor Radiance = Scaled value * Gain + Offset

where: Scaled Value = Scaled at-sensor radiance value from the level-3a image [counts]
Gain = the value from the level-3a ASCII header file [Watts/(m^2 * sr * µm * DN)]
Offset = the value from the level-3a ASCII header file [Watts/(m^2 * sr * µm)]

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

Errors could arise in the acquired imagery from location inaccuracy, distortion of lengths, anisomorphism, the instrument's local coherence, and multispectral registrability. Other errors could arise from inherent radiometric imperfections of the sensors.

10.2 Quality Assessment

10.2.1 Data Validation by Source

Whatever the processing level, the geometric quality of the image depends on the accuracy of the viewing geometry and the ground control points as required to adjust the viewing model. Spectral errors could arise from image-wide signal-to-noise ratio, saturation, cross-talk, spikes, and response normalization caused by change in gain.

10.2.2 Confidence Level/Accuracy Judgment

Assessment of accuracy of the absolute radiometric constants is difficult. The uncertainties in prelaunch and postlaunch updates of the absolute calibration constants are nominally specified to be less than 10%. A root mean square (rms) summing of known errors in the prelaunch calibration suggests that this may be a reasonable estimate of overall uncertainty in the prelaunch calibration.

There are also known, but as yet uncorrected, effects associated with temperature-dependence of the TM internal calibrator that may be contributing to apparent discontinuous changes at launch and to the continuous changes of gain while in orbit. Additional uncertainties for exoatmospheric reflectances are probably less than 2% in the visible/near-infrared and less than 5% in the shortwave infrared portion of the spectrum as judged by the current differences in estimates of the solar irradiance.

10.2.3 Measurement Error for Parameters

The rms errors for the latitude and longitude least-squares equations are listed in the ASCII header file of each image. The rms error for the selected points was approximately 1.5 pixels (i.e., 45 meters) in the X and Y directions. Therefore, the overall RMS error for each scene should be below this threshold.

10.2.4 Additional Quality Assessments

The ability to reproduce coincident TM and ground measurements made for five dates at White Sands, NM, to about 5% for bands 1-4 suggests a potential for monitoring sensor change for the system with time. The images were screened for cloud cover before BORIS processing. Each level-3b image has a minimum of cloud cover over the study areas.

10.2.5 Data Verification by Data Center

BORIS checked the image files by visually inspecting them on a display screen and reading the ASCII header files for correctness.

11. Notes

11.1 Limitations of the Data

None.

11.2 Known Problems with the Data

To date, the following discrepancies/problems have been noted in the data:

- Due to a software error in the level-3a processing, several level-3b Landsat TM images created contain 6,930 pixels rather than the correct 6,920 pixels. The last 10 pixel values may or may not contain spurious values but should be ignored.
- Some header files refer to Level-1 rather than Level-3 or to L1B rather than L3B since they were created by software prior to BORIS finalization of data categories.
- The 15-Aug-1986 scene for Path/Row 33/21 has an error in its list of ground control points. Control point number 612 is listed, but the pixel and line information actually corresponds to point number 613. Therefore, latitude/longitude coordinates for point 613 should be used from the list below.
- Level-3B images for the BOREAS NSA (Path/Row 33/21, 34/21) have ground control points in the ASCII header file numbered 601 through 629. The updated coordinates for these points should be:

Point Number	Longitude	Latitude
601	98.82064W	55.88655N
602	98.82180W	55.88114N
603	98.78512W	55.88217N
604	97.91873W	55.81210N
605	97.85946W	55.78508N
606	97.83772W	55.77294N
607	97.83192W	55.76364N
608	97.90285W	55.69227N
609	97.89372W	55.70106N
610	97.86028W	55.73037N
611	97.85835W	55.72543N
612	98.09482W	55.51495N
613	98.05691W	55.53442N
620	98.92360W	55.70465N
621	98.85014W	55.80254N
622	98.42479W	55.91969N
623	98.08685W	55.86547N
624	98.37678W	55.68005N
625	98.45378W	55.84137N
626	98.54973W	55.70142N
627	98.35490W	55.72299N
628	98.36780W	56.13641N
629	98.36713W	56.01236N

11.3 Usage Guidance

None.

11.4 Other Relevant Information

None.

12. Application of the Data Set

The level-3b Landsat TM images are useful for anyone interested in high spatial resolution imagery over the entire NSA or SSA. They may also be useful for testing various atmospheric correction algorithms.

13. Future Modifications and Plans

None.

14. Software

14.1 Software Description

BORIS staff developed software and command procedures for:

- Processing level-3a Landsat TM images on tape to level-3b products on disk.
- Writing the level-3b Landsat TM products from disk to tape.
- Extracting header information from level-3b Landsat TM images on tape.
- Copying level-3b Landsat TM images from tape to disk.
- Logging level-3b Landsat TM image products into the Oracle data base tables.
- Converting between the geographic systems of (latitude, longitude), UTM (northing, easting), and BOREAS (x,y) grid locations.

The software mentioned under items 1 to 5 is written in the C language and is operational on VAX 6410 and MicroVAX 3100 systems at GSFC. The primary dependencies in the software are the tape I/O library and the Oracle data base utility routines.

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

14.2 Software Access

All of the described software 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 Landsat TM images are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

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

15.2 Data Center Identification

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

15.3 Procedures for Obtaining Data

Although the BOREAS level-3b Landsat TM images are being held in a public archive, copyright restrictions limit the distribution and use of the data. The BOREAS CD-ROM series is publicly available and contains some of the level-3a Landsat TM images. However, other Landsat TM image products in the collection are available only to official BOREAS project personnel. Please contact the ORNL DAAC User Services office to get the most recent information.

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 Landsat TM data can be made available on 8-mm, Digital Archive Tape (DAT), or 9-track tapes at 1600 or 6250 Bytes Per Inch (BPI).

Although the BOREAS level-3b Landsat TM images are being held in a public archive, copyright restrictions limit the distribution and use of the data. The BOREAS CD-ROM series is publicly available and contains some of the level-3a Landsat TM images. However, other Landsat TM image products in the collection are available only to official BOREAS project personnel. Please contact the ORNL DAAC User Services office (see Section 15.1) to get the most recent information.

16.2 Film Products

None.

16.3 Other Products

Although the image inventory is contained on the BOREAS CD-ROM set, the actual level-3b Landsat TM images are not. See Section 15 for information about how to obtain the data.

17. References

17.1 Platform/Sensor/Instrument/Data Processing Documentation

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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.

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17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

ASCII	- American Standard Code for Information Interchange
BOREAS	- BOReal Ecosystem-Atmosphere Study
BORIS	- BOREAS Information System
BPI	- Bytes Per Inch
BSQ	- Band Sequential
CCRS	- Canada Centre for Remote Sensing
CCT	- Computer-Compatible Tape
CD-ROM	- Compact Disk-Read-Only Memory
DAAC	- Distributed Active Archive Center
DAT	- Digital Archive Tape
DN	- Digital Number
EOS	- Earth Observing System
EOSDIS	- EOS Data and Information System
ERTS	- Earth Resources Technology Satellite
FOLD	- Federally Owned Landsat Database
FOV	- Field of View
FPAR	- Fraction of Photosynthetically Active Radiation
GICS	- Geocoded Image Correction System
GIS	- Geographic Information System
GMT	- Greenwich Mean Time
GPS	- Global Positioning System
GSFC	- Goddard Space Flight Center
IFOV	- Instantaneous Field-of-View

```
I/O      - Input/Output
LAI      - Leaf Area Index
LGSOWG   - Landsat Ground Station Operations Working Group
LTWG     - LGSOWG Technical Working Group
MSS      - Multispectral Scanner
NAD27    - North American Datum of 1927
NAD83    - North American Datum of 1983
NASA     - National Aeronautics and Space Administration
NE       - Noise Equivalent
NSA      - Northern Study Area
NTS      - National Topographic System
ORNL     - Oak Ridge National Laboratory
PANP     - Prince Albert National Park
rms      - root-mean-square
RSI      - Radarsat International
SBRC     - Santa Barbara Research Center
SSA      - Southern Study Area
TIPS     - Thematic Mapper Image Processing System
TM       - Thematic Mapper
URL      - Uniform Resource Locator
UTM      - Universal Transverse Mercator
WWW      - World Wide Web
```

20. Document Information

20.1 Document Revision Dates

Written: 04-Jan-1995
Last Updated: 29-Nov-1999

20.2 Document Review Dates

BORIS Review: 02-Mar-1998
Science Review: 06-Mar-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 Landsat TM level-3b images resulted from a joint development and processing effort between BOReal Ecosystem-Atmosphere Study (BOREAS) staff at the Canada Centre for Remote Sensing (CCRS) and the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC). The original level-3s and -3p data were acquired by CCRS and processed by Radarsat International (RSI) under an agreement with CCRS. 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:

BOREAS Staff Science, "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

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For BOREAS, the level-3b Landsat TM data, along with the other remotely sensed images, were collected in order to provide spatially extensive information over the primary study areas. This information includes radiant energy, detailed land cover, and biophysical parameter maps such as FPAR and LAI. Although very similar in content to the level-3a Landsat TM products, the level-3b images were created to provide users with a directly usable at-sensor radiance image. Geographically, the level-3b images cover the BOREAS NSA and SSA. Temporally, the images cover the period of 22-Jun-1984 to 09-Jul-1996. The images are available in binary, image format files.

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