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BOREAS TE-18, 30-m, Radiometrically Rectified Landsat TM Imagery

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BOREAS TE-18, 60-m, Radiometrically Rectified Landsat TM Imagery

Forrest G. Hall, David Knapp

Summary

The BOREAS TE-18 team used a radiometric rectification process to produce standardized DN values for a series of Landsat TM images of the BOREAS SSA and NSA in order to compare images that were collected under different atmospheric conditions. The images for each study area were referenced to an image that had very clear atmospheric qualities. The reference image for the SSA was collected on 02-Sep-1994, while the reference image for the NSA was collected on 21-Jun-1995. The 23 rectified images cover the period of 07-Jul-1985 to 18-Sep-1994 in the SSA and 22-Jun-1984 to 09-Jun-1994 in the NSA. Each of the reference scenes had coincident atmospheric optical thickness measurements made by RSS-11. The radiometric rectification process is described in more detail by Hall et al. (1991). The original Landsat TM data were received from CCRS for use in the BOREAS project.

Due to the nature of the radiometric rectification process and copyright issues, the full-resolution (30-m) images may not be publicly distributed. However, this spatially degraded 60-m resolution version of the images may be openly distributed and is available on the BOREAS CD-ROM series. After the radiometric rectification processing, the original data were degraded to a 60-m pixel size from the original 30-m pixel size by averaging the data over a 2- by 2-pixel window. The data are stored in binary image-format files.

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

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1. Data Set Overview

1.1 Data Set Identification

BOREAS TE-18, 60-m, Radiometrically Rectified Landsat TM Imagery

1.2 Data Set Introduction

The Terrestrial Ecology (TE)-18 team used a radiometric rectification process (Hall et al., 1991) to produce standardized digital number (DN) values for a series of Landsat Thematic Mapper (TM) images of the BOReal Ecosystem-Atmosphere Study (BOREAS) Southern Study Area (SSA) and Northern Study Area (NSA). The processing was performed in order to compare images that were collected under different atmospheric conditions. The images for each study area were referenced to an image that had very clear atmospheric qualities. The reference image for the SSA was collected on 02-Sep-1994, while the reference image for the NSA was collected on 21-Jun-1995. The images which were rectified range in date from 07-Jul-1985 to 18-Sep-1994 in the SSA and from 22-Jun-1984 to 09-Jun-1994 in the NSA. Each of the reference scenes had coincident atmospheric optical thickness measurements made by Remote Sensing Science (RSS)-11. The original Landsat TM data were received from the Canada Centre for Remote Sensing (CCRS) for use in the BOREAS project. The original data were degraded to a 60-m pixel size from the original 30-m pixel size by averaging the data over a 2- by 2-pixel window.

1.3 Objective/Purpose

This data product was created in order to provide scientists with a set of images that could be compared as if they were collected under the same atmospheric and illumination conditions. The radiometric rectification process was used to standardize the images for these differences so that the remaining differences in the imagery would be a result of real change in the vegetation.

1.4 Summary of Parameters

The images contain DN values that were adjusted to the following reference scenes and spatially degraded to 60-m resolution:

- SSA (WRS Path/Row 37/22-23) acquired 02-Sep-1994
- NSA (WRS Path/Row 33/21) acquired 21-Jun-1995

1.5 Discussion

TE-18 created the radiometrically rectified imagery by:

- Extracting pertinent header information from the level-3s or -3p image product.
- Performing radiometric rectification as described by Hall et al. (1991).
- Reviewing the image bands for correctness.
- Averaging 2- by 2-pixel windows to create the 60-m product.
- Writing the American Standard Code for Information Interchange (ASCII) header file and six image bands to tape.

1.6 Related Data Sets

BOREAS RSS-11 Ground Network of Sun Photometer Measurements
BOREAS TE-18, 30-m, Radiometrically Rectified Landsat TM Imagery
BOREAS Level-3s Landsat TM Imagery: Scaled At-sensor Radiance in LGSOWG Format
BOREAS Level-3b Landsat TM Imagery: At-sensor Radiance in BSQ Format
BOREAS Level-3p Landsat TM Imagery: Geocoded and Scaled At-sensor Radiance
BOREAS Level-3s SPOT Imagery: Scaled At-sensor Radiance in LGSOWG Format

2. Investigator(s)

2.1 Investigator(s) Name and Title

Dr. Forrest G. Hall
NASA GSFC

2.2 Title of Investigation

Regional-Scale Carbon Flux from Modeling and Remote Sensing

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-1) 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, Canada.

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.

The use of retrospective Landsat data presents considerable problems when it is necessary to account for the effects of sensor, atmosphere, and illumination differences over years or among acquisition dates within a year. For this reason, this data product was produced using the radiometric rectification procedure described by Hall et al. (1991). Radiometric rectification consists of two major components:

- One component identifies radiometric control sets, i.e., scene landscape elements that have the same mean reflectance between acquisition dates.
- The second component rectifies the images using a linear transformation whose coefficients force the means of the radiometric control sets to be equal.

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.

Note: Channel 6 is not included in this radiometrically rectified data set.

4.1.1 Collection Environment

The BOREAS Landsat TM level-3s and -3p images were acquired through the CCRS and used to create this radiometrically rectified product. Radiometric corrections and systematic geometric corrections are applied to produce the images in a path-oriented, systematically corrected (level-3s) or precision-corrected (level-3p) form. The images in the radiometrically rectified data product were extracted as subsets from the original BOREAS Landsat full TM scenes. The ground resolution of the images is 30 m for bands 1, 2, 3, 4, 5, and 7 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-3s and level-3p images were processed through the CCRS Geocoded Image Correction System (GICS). The Landsat satellite orbits Earth at an altitude of 705 km.

4.1.2 Source/Platform

Although the majority of the BOREAS Landsat TM imagery was acquired by the instrument onboard Landsat-5, some images were acquired from the sensor onboard the Landsat-4 satellite.

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 Landsat 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 a 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.

4.1.7 Manufacturer of Sensor/Instrument

NASA GSFC
Greenbelt, MD 20771

Santa Barbara Remote Sensing (SBRS)
75 Coromar Dr.
Goleta, CA 93117

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 field of view (FOV).

The calibration signals for bands 1-5 and 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 provide radiation independently 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%
7	2.4%

Ground IF[illegible]	30 m (Bands 1-5, 7)
Avg. alt[illegible]	[illegible].6 km
Data rate	85 Mbps
Quantiza[illegible]	256
Orbit an[illegible]	[illegible].15 degrees
Orbital [illegible]	[illegible].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)].

4.2.1.1 Tolerance

The TM channels were designed for an 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

To reduce "striping," relative within-band radiometric calibration 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.

The radiometric rectification process adjusted the DNs of the various images to the reference images of the SSA or NSA, amounting to calibration of the images to one of these two reference images. If the user wishes to compute surface reflectance for bands 3, 4, and 5 for any of these images, the following parameters should be used. These parameters were determined using aerosol optical thickness measurements at the time these reference scenes were collected. Refer to Markham et al. (1992) for more information on how to determine and use these parameters to compute surface reflectance.

NSA (Reference Image: 21-Jun-1995, Path/Row 33/21)

Band	1	2	3	4	5	7
Gain	0.6024	1.1751	0.8058	0.8145	0.1081	0.0570
Offset	-1.52	-2.84	-1.17	-1.51	-0.37	-0.15
Spherical Albedo	*	*	0.05796	0.03068	0.00621	*
Path Radiance	*	*	0.0215	0.00943	0.00117	*
Gaseous Transmission	*	*	0.93057	0.90948	0.88199	*
Scattering Transmission	*	*	0.92005	0.9536	0.98479	*

Solar Zenith Angle 38.2°

SSA (Reference Image: 02-Sep-1994, Path/Row 37/22-23)

Band	1	2	3	4	5	7
Gain	0.6024	1.1751	0.8058	0.8145	0.1081	0.0570
Offset	-1.52	-2.84	-1.17	-1.51	-0.37	-0.15
Spherical Albedo	*	*	0.0597	0.03094	0.00592	*
Path Radiance	*	*	0.02349	0.01055	0.00154	*
Gaseous Transmission	*	*	0.92918	0.92438	0.90494	*
Scattering Transmission	*	*	0.90852	0.94451	0.98023	*

Solar Zenith Angle 49.9°

Note: The atmospheric parameters were not determined as part of the TE-18 research for bands 1, 2, and 7.

For a given band, the at-sensor radiance of a pixel can be computed with the following equation:

At-sensor radiance = DN * Gain + Offset

5. Data Acquisition Methods

The BOREAS Landsat TM level-3s and -3p images that were used to create this product 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). The images in this data set are subsets of the full images covering the NSA or SSA. The ground resolution was degraded to 60 m from the original 30-m resolution. The pixel values of the images can range from 0 to 255. This allows each pixel to be stored in a single-byte field.

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 Landsat TM images generally cover the SSA and the NSA, which are located in the southwest and northeast portions of the BOREAS region (Sellers and Hall, 1994). Each image in this data set covers a slightly different area, but each covers all or part of the NSA or SSA.

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

The spatial resolution of each pixel was degraded to 60 m from the original 30 m resolution of Landsat TM. Each 60-m pixel in these images represents an average of a 2- by 2-pixel window of the original 30-meter pixels.

7.1.4 Projection

The Landsat TM images are in a Universal Transverse Mercator (UTM) projection based on the NAD83. However, these images are not precisely registered in this projection. Any comparison of these images will require coregistration by the user. The level-3a georeferenced Landsat TM data can be used to create georeferenced images from these radiometrically rectified data.

7.1.5 Grid Description

The grid spacing for each pixel in the Landsat TM images is 60 m in the UTM projection.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

This data set contains 23 images collected from 22-Jun-1984 to 18-Sep-1994.

7.2.2 Temporal Coverage Map

The following two lists provide dates for all the radiometrically rectified TM images that are available from BOREAS.

Date	Study Area
07-Jul-1985	SSA
11-Aug-1986	SSA
30-Aug-1987	SSA
04-Sep-1989	SSA
06-Aug-1990	SSA
05-May-1991	SSA
06-Jun-1991	SSA
24-Jul-1991	SSA
09-Aug-1991	SSA
10-Sep-1991	SSA
07-Jun-1[illegible]	[illegible]
23-Jun-1[illegible]	[illegible]
25-Jul-1[illegible]	[illegible]
18-Sep-1[illegible]	[illegible]

Date	[illegible] Area
22-Jun-1[illegible]	[illegible]
19-Aug-1[illegible]	[illegible]
15-Aug-19[illegible]	[illegible]
01-Jun-19[illegible]	NSA
08-Jun-1988	NSA
20-Aug-1988	NSA
05-Sep-1988	NSA
25-Jul-1990	NSA
09-Jun-1994	NSA

7.2.3 Temporal Resolution

The strategy for the radiometrically rectified images was to obtain the best temporal sequence of images over 10 years and to get good coverage of the growing season in one particular year. The tables in Section 7.2.2 reflect this strategy.

7.3 Data Characteristics

7.3.1 Parameter/Variable

Scaled DN.

7.3.2 Variable Description/Definition

The images contain scaled DNs stored in single-byte values that are adjusted to match the radiometric and atmospheric characteristics of the reference images of the SSA and NSA.

7.3.3 Unit of Measurement

The DNs are unitless but represent at-sensor radiance in Watts/(m^2 * ster * μm) after applying gain and offset values; see Section 4.2.3. For a given band, the at-sensor radiance of a pixel can be computed with the following equation:

```
At-sensor radiance = DN * Gain + Offset
```

7.3.4 Data Source

The data contained in this data set come from various portions of the Landsat satellite system, the TM instrument, and the ground processing components. The imagery products from CCRS were used to create the radiometrically rectified images.

7.3.5 Data Range

The maximum range of the DN values in each radiometrically rectified Landsat TM image band is limited from 0 (zero) to 255 so that the values can be stored in a single 8-bit (byte) field.

7.4 Sample Data Record

Not applicable.

8. Data Organization

8.1 Data Granularity

The smallest unit of data that can be ordered from this radiometrically rectified data is a single image.

8.2 Data Format(s)

8.2.1 Uncompressed Data Files

Each image in this data set consists of seven files, one ASCII header file and six binary image files.

FILE 1 (80 byte ASCII text records)

- Header file indicating acquisition date and time, Path/Row, Pixels per line, and Number of lines.

FILES 2 - 7 (A band-sequential (BSQ) set of files containing image bands 1 to 5 and 7, respectively.)

- Each pixel value is in units of digital counts (see Section 11.2).
- 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.

The characteristics for each image are:

Date	Number Of Pixels	Number Of Lines	Study Area
30-Aug-1987	2048	1536	SSA
18-Sep-1994	2048	1536	SSA
04-Sep-1989	2048	1536	SSA
11-Aug-1986	2048	1536	SSA
06-Aug-1990	2048	1536	SSA
07-Jun-1994	1024	1536	SSA
25-Jul-1994	1024	1536	SSA
23-Jun-1994	1024	1536	SSA
07-Jul-1985	2048	1536	SSA
09-Aug-1991	2048	1536	SSA
24-Jul-1991	2048	1536	SSA
06-Jun-1991	2048	1536	SSA
10-Sep-1991	2048	1536	SSA
05-May-1991	2048	1536	SSA
15-Aug-1986	2048	1280	NSA
19-Aug-1985	1334	1280	NSA
20-Aug-1988	2048	1280	NSA
05-Sep-1988	2048	1280	NSA
25-Jul-1990	2048	1280	NSA
22-Jun-1984	2048	1280	NSA
08-Jun-1988	1334	1280	NSA
09-Jun-1994	1334	1280	NSA
01-Jun-1988	2048	1280	NSA

8.2.2 Compressed CD-ROM Files

On the BOREAS CD-ROMs, file 1 listed above is stored as ASCII text; however, files 2-7 have been compressed with the GNU zip (Gzip) compression program (file name *.gz), version 1.2.4, using the high compression (-9) option (Copyright (C) 1992-1993 Jean-loup Gailly). Gzip uses the Lempel-Ziv algorithm (Welch, 1994) used in the zip and PKZIP programs. The compressed files may be uncompressed using gzip (-d option) or gunzip. Gzip is available from many Web sites (for example, ftp site prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

9. Data Manipulations

9.1 Formulae

9.1.1 Derivation Techniques and Algorithms

Not applicable.

9.2 Data Processing Sequence

9.2.1 Processing Steps

TE-18 created the radiometrically rectified Landsat TM images by:

- Selecting scenes for the period of interest (mid-1980's to mid-1990's).
- Selecting a clear reference scene for the NSA and SSA.
- For each scene to be rectified, selecting a radiometric control set from the nonvegetated extremes of the Kauth-Thomas (KT) greenness-brightness distribution function. This is done by identifying pixels with both low greenness and low or high brightness extremes.
- Calculating radiometric transformation from the subject image to the reference image. This linear function can be determined by finding the mean of the dark targets and the mean of the bright targets.
- For each band of the subject image, running the image through radiometric transformation, producing a radiometrically rectified image.
- Averaging the 30-meter imagery over a 2- by 2-pixel window to produce 60-m pixels.
- Writing the files to tape.
- Copying the ASCII and compressing the binary files for release on CD-ROM.

The selection of a radiometric control set is designed to identify the brightest and darkest scene reflectors whose reflectance can be expected to remain within very narrow ranges over time. This set of landscape elements or pixels does not necessarily occupy the same scene coordinates over time, as do geometric control points for spatial image rectification. Instead, the radiometric control sets are selected to occupy equivalent positions in the radiometric distribution of each image; namely, the "nonvegetated" extremes of the two-dimensional distribution function in the KT greenness-brightness plane. The basis for this approach is as follows. We know that if a scene has nonvegetated landscape elements, then they will be represented by pixels that are the "least" green of the KT greenness-brightness histogram for that scene. Such pixels are usually water bodies, bare rock outcrops, roads, or bare fields. Of the image features available for rectification, water and bare rock will have the least variation in reflectance with time. Please refer to Hall et al. (1991) for detailed information about the radiometric rectification process.

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

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.

The rectification transforms will be inexact to the extent that there is noise in the determination of the radiometric control points. Other sources of error can include biases introduced by radiometric control points with reflectance that is not constant from image to image or nonlinearity of the radiance values between images.

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 geometry 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 in the original imagery is difficult. The uncertainties in prelaunch and postlaunch updates of the absolute TM calibration constants are nominally specified to be less than 10%. A root mean square 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.

Since the radiometric rectification process derives atmospheric characteristics from another image, it will most likely produce errors that are larger than exist within an image for which the atmospheric optical thickness was measured directly.

10.2.3 Measurement Error for Parameters

Not available.

10.2.4 Additional Quality Assessments

In the original Landsat TM data, 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 BOREAS Information System (BORIS) processing. The images have a minimum of cloud cover over the study areas.

10.2.5 Data Verification by Data Center

BORIS staff 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

Some images had clouds and other atmospheric features that made it difficult to identify targets for radiometric rectification. In cases where the atmosphere is not homogenous across the image, the radiometric rectification may not adequately account for atmospheric variation between images.

11.2 Known Problems with the Data

See Section 11.1.

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

The radiometrically rectified Landsat TM images are useful for anyone interested in high spatial resolution imagery over the entire NSA or SSA.

13. Future Modifications and Plans

None.

14. Software

14.1 Software Description

BORIS staff developed software and command procedures to average the 30-m pixels in a 2- by 2-pixel window to degrade the imagery to 60 m. Gzip uses the Lempel-Ziv algorithm (Welch, 1994) used in the zip and PKZIP commands.

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. 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 60-m radiometrically rectified Landsat TM imagers 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

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

These data can be made available on 8-mm, Digital Archive Tape (DAT) media.

16.2 Film Products

None.

16.3 Other Products

These data are available on the BOREAS CD-ROM series.

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17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

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ASCII    - American Standard Code for Information Interchange
BOREAS   - BOReal Ecosystem-Atmosphere Study
BORIS    - BOREAS Information System
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
FOV      - Field of View
FPAR     - Fraction of Photosynthetically Active Radiation
GICS     - Geocoded Image Correction System
GIS      - Geographic Information System
GPS      - Global Positioning System
GSFC     - Goddard Space Flight Center
IFOV     - Instantaneous Field-of-View
KT       - Kauth-Thomas
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
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NTS	- National Topographic System
ORNL	- Oak Ridge National Laboratory
PANP	- Prince Albert National Park
RSS	- Remote Sensing Science
SBRC	- Santa Barbara Research Center
SBRS	- Santa Barbara Remote Sensing
SSA	- Southern Study Area
TE	- Terrestrial Ecology
TM	- Thematic Mapper
URL	- Uniform Resource Locator
UTM	- Universal Transverse Mercator
WWW	- World Wide Web

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Hall, F.G., "Regional-Scale Carbon Flux from Modeling and Remote Sensing." 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.

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13. ABSTRACT *(Maximum 200 words)*

The BOREAS TE-18 team used a radiometric rectification process to produce standardized DN values for a series of Landsat TM images of the BOREAS SSA and NSA in order to compare images that were collected under different atmospheric conditions. The images for each study area were referenced to an image that had very clear atmospheric qualities. The reference image for the SSA was collected on 02-Sep-1994, while the reference image for the NSA was collected on 21-Jun-1995. The 23 rectified images cover the period of 07-Jul-1985 to 18-Sep-1994 in the SSA and 22-Jun-1984 to 09-Jun-1994 in the NSA. Each of the reference scenes had coincident atmospheric optical thickness measurements made by RSS-11. The radiometric rectification process is described in more detail by Hall et al. (1991). The original Landsat TM data were received from CCRS for use in the BOREAS project. Due to the nature of the radiometric rectification process and copyright issues, the full-resolution (30-m) images may not be publicly distributed. However, this spatially degraded 60-m resolution version of the images may be openly distributed and is available on the BOREAS CD-ROM series. After the radiometric rectification processing, the original data were degraded to a 60-m pixel size from the original 30-m pixel size by averaging the data over a 2- by 2-pixel window. The data are stored in binary image-format files.

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