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

Forrest G. Hall and Jaime Nickeson, Editors

Volume 92

BOREAS Level-1B TIMS Imagery: At-sensor Radiance in BSQ Format

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National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

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BOREAS Level-1b TIMS Imagery: At-sensor Radiance in BSQ Format

Richard Strub, Jeffrey A. Newcomer, Sonia Chernobieff

Summary

The BOREAS Staff Science Aircraft 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. For BOREAS, the TIMS imagery, along with other aircraft images, was collected to provide spatially extensive information over the primary study areas. The Level-1b TIMS images cover the time periods of 16-Apr-1994 to 20-Apr-1994 and 06-Sep-1994 to 17-Sep-1994. The system calibrated images are stored in binary image format files.

Note that the Level-1b TIMS data 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 Section 15 for information about how to acquire actual Level-1b TIMS images.

Table of Contents

1. Data Set Overview

1.1 Data Set Identification

BOREAS Level-1b TIMS 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 procedures across sites and time. These activities included the acquisition, processing, and archiving of 6-band Thermal Infrared Multispectral Scanner (TIMS) image data collected on the National Aeronautics and Space Administrator's (NASA's) C-130 aircraft.

1.3 Objective/Purpose

For BOREAS, the TIMS imagery, along with the other remotely sensed images, was collected to provide spatially extensive information over the primary study areas. This information includes detailed land cover, biophysical parameter maps such as fraction of Photosynthetically Active Radiation (fPAR), Leaf Area Index (LAI), and surface thermal properties.

1.4 Summary of Parameters

The level-1b TIMS images contain JPL supplied header information and at sensor radiance values in units of milliwatts/(m^2 sr µm) for bands 1 to 6 in a band sequential (BSQ) format.

1.5 Discussion

The Jet Propulsion Laboratory (JPL) personnel obtained the original data from NASA Ames Research Center (ARC) and processed them to the at-sensor radiance product described here. The data are not corrected for look angle or atmospheric effects.

1.6 Related Data Sets

BOREAS Level-0 TIMS Imagery: Digital Counts in BIL Format
BOREAS Level-2 NS001 TMS Images: Reflectance and Temperatures in BSQ Format
BOREAS Level-1b ASAS Imagery: At-sensor Radiance in BSQ Format

2. Investigator(s)

2.1 Investigator(s) Name and Title

BOREAS Staff Science

2.2 Title of Investigation

BOREAS Staff Science Aircraft Data Acquisition Program

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3. Theory of Measurements

According to Planck's equation, all objects emit radiation, depending on their temperature and emissivity. The temperature of an object is of interest in determining the radiation balance at Earth's surface. The emissivity of an object as a function of wavelength can provide information on the object's composition. Though much of the radiation emitted from an object is absorbed by the atmosphere, a few good atmospheric windows from 3 to 5 micrometers (µm) and 8 to 14 µm exist for the remote sensing of emitted surface radiation.

The NASA Earth Resources Aircraft Program at ARC operates the C-130 aircraft to acquire data for Earth science research. The TIMS instrument used on the C-130 aircraft collects radiance measurements in six spectral bands covering the infrared spectrum from 8.2 to 12.2 µm.

Thematic considerations have dictated, within technical constraints, the choice of spectral band position and width in the TIMS sensor. These bands were chosen after many years of analysis for their value in discrimination of geologic features, and they correspond to the emissivity anomalies associated with silicate and carbonate rocks.

4. Equipment

4.1 Sensor/Instrument Description

The TIMS instrument is an optomechanical scanner designed to collect multispectral thermal imagery for geologic mapping. The TIMS is generally flown at medium altitudes and provides 3- to 20-m resolution at nadir at an altitude of 1,200 to 8,000m., respectively. The TIMS is flown aboard NASA's C-130 aircraft based at the ARC.

The six spectral channels of the TIMS sensor have the following bandpasses:

TIMS Channel	Wavelength, µm
1	8.2-8.6
2	8.6-9.0
3	9.0-9.4
4	9.4-10.2
5	10.2-11.2
6	11.2-12.2

4.1.1 Collection Environment

As part of the BOREAS Staff Science Data Collection effort, ARC personnel collected, NASA JPL personnel calibrated, and BOREAS Information System (BORIS) personnel distributed 6-band level-1b TIMS image data. The TIMS was flown on NASA's C-130 aircraft during the various BOREAS missions (see the BOREAS Experiment Plan for flight pattern details and objectives). The C-130 aircraft flew at nominal altitudes of 3000 and 5000 m during the BOREAS flights.

Maintenance and operation of the instrument are the responsibility of ARC. The C-130 Experimenter's Handbook (supplemental) produced by the Medium Altitude Missions Branch at ARC provides a description of the instrument, calibration procedures, and data format.

4.1.2 Source/Platform

NASA's C-130 Earth Resources Aircraft.

4.1.3 Source/Platform Mission Objectives

The original purpose of the TIMS scanner was to provide low-altitude data in the thermal infrared region of the electromagnetic spectrum for use in geologic mapping. For BOREAS, the TIMS was flown on the C-130 with a set of other scanners to provide full coverage of the reflected and emitted surface energy. The C-130 aircraft housed and provided appropriate power and other electronic

connections for operation of the TIMS instrument.

4.1.4 Key Variables

Emitted and reflected radiation.

4.1.5 Principles of Operation

Design parameters of the TIMS are based on the specifications of Dr. Anne B. Kahle of the NASA JPL. A rotating scan mirror scans the instrument's Instantaneous Field of View (IFOV) across track as the motion of the aircraft moves the sensor along the data collection path.

4.1.6 Sensor/Instrument Measurement Geometry

IFOV	2.5 mrad
Total Scan Angle	76.56°
Pixels/Scan Line	638

Sensor footprint is 10 x 10 m at nadir at 4,000-m altitude.

4.1.7 Manufacturer of Sensor/Instrument

The TIMS instrument was built by Daedalus Enterprises, of Ann Arbor, MI. It was further modified by the NASA Stennis Space Flight Center.

4.2 Calibration

As with the First International Satellite Land Surface Climatology Project (ISLSCP) Field Experiment (FIFE), BOREAS staff attempted to further relate remotely sensed radiances to land surface radiometers. The TIMS instrument carries two onboard blackbody sources, which fill the full aperture of the system with energy of a preset, known temperature. The two blackbody sources are viewed by the TIMS once every scan line.

The spectral bandpass of each channel was determined by the calibration laboratory at Stennis on an annual basis.

TIMS data may be intentionally overscanned, e.g., operated at some integral multiple of the desired scan rate and then subsampled in preprocessing. The subsampling factor is reported as a "demagnification factor."

4.2.1 Specifications

The wavelength ranges (in micrometers) of the bands for the TIMS are:

Band	Detector	Wavelength	Noise Equivalent Change in Temperature (NEdT)
1	HgCdTe	8.2 - 8.6	0.2°C
2	"	8.6 - 9.0	0.2°C
3	"	9.0 - 9.4	0.2°C
4	"	9.4 - 10.2	0.2°C
5	"	10.2 - 11.2	0.2°C
6	"	11.2 - 12.2	0.2°C

DESIGN DATA:

IFOV	2.5 mrads
Across-track Field-Of-View	76.56°
Nominal aperture diameter	7.5 inches
Effective aperture area	59.8 cm^2
f/number	Not available
Primary focal length	Not available

Inflight calibration	Two controllable blackbodies
V/H range	Variable, 0.025 to 0.25
Scan rate	Variable, 7.3 to 25 scans/sec.
Scan speed ability	One-third of the IFOV, scan line to scan line
Data quantization	8 bits (256 discrete levels)
Number of video samples/scan line	638
Roll compensation	+/-15°
Scan mirror	45° rotating mirror
NEdt	0.25 K

4.2.1.1 Tolerance

The TIMS channels were designed for noise-equivalent temperature differences for the channels, represented by the radiometric sensitivity (NEdT) of 0.25 K.

4.2.2 Frequency of Calibration

The TIMS was spectrally calibrated prior to each flight season at Stennis to determine the spectral response function of each channel.

4.2.3 Other Calibration Information

The TIMS instrument periodically viewed an extended-area precision blackbody source at ARC to verify linearity of response over the range of 0-50 °C.

5. Data Acquisition Methods

As part of the BOREAS Staff Science data collection effort, BORIS distributed 6-band level-1b TIMS image data. The TIMS was flown on NASA's C-130 aircraft during the BOREAS mission (see the BOREAS Experiment Plan for flight pattern details and objectives).

Personnel at NASA ARC processed the raw data to level-0 products, which were supplied to BORIS and JPL personnel. JPL personnel in turn processed selected level-0 images to the level-1bB at-sensor radiance products described here.

6. Observations

6.1 Data Notes

The data obtained from NASA ARC processed easily into the level-1b products.

6.2 Field Notes

Flight summary reports and verbal records on videotapes are available for the BOREAS TIMS data.

7. Data Description

7.1 Spatial Characteristics

The BOREAS Level-1b TIMS images primarily cover the Southern Study Area (SSA) and the Northern Study Area (NSA). A few images were acquired for the transect area between the SSA and the NSA. The SSA and the NSA are located in the southwest and northeast portions of the overall region.

7.1.1 Spatial Coverage

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

Typical altitudes for BOREAS flights were 5,000 and 3,000 m above ground level (surface elevation of 400 m), which normally required 25 scan lines per second. These altitudes produced 12.5 m and 7.5 m pixels at nadir given the TIMS's 2.5 mrad IFOV.

7.1.4 Projection

Not applicable.

7.1.5 Grid Description

The BOREAS level-1b TIMS images are stored in their original data collection frame with increasing pixel sizes from nadir to the scanning extremes based on the scan angle.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

The data were collected during the BOREAS Focused Field Campaign-Thaw (FFC-T) and Intensive Field Campaign (IFC)-3, covering the periods of 16- to 20-Apr-1994 and 06- to 16-Sep-1994.

7.2.2 Temporal Coverage Map

IFC#	Dates
FFC-T	16-Apr-1994 -- 20-Apr-1994
IFC-3	06-Sep-1994 -- 17-Sep-1994

7.2.3 Temporal Resolution

Images were acquired on at least one day during the field campaigns.

7.3 Data Characteristics

7.3.1 Parameter/Variable

The main parameter contained in the image data files is:

At Sensor Radiance in milliwatts/(m^2 sr μm).

The descriptions of 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
PLATFORM_ALTITUDE
MIN_SOLAR_ZEN_ANG
MAX_SOLAR_ZEN_ANG
MIN_SOLAR_AZ_ANG
MAX_SOLAR_AZ_ANG
C130_MISSION_ID
C130_LINE_NUM
C130_RUN_NUM
C130_SITE
BAND_QUALITY
CLOUD_COVER
TIMS_MEAN_FRAME_STATUS
NW_LATITUDE
NW_LONGITUDE
NE_LATITUDE
NE_LONGITUDE
SW_LATITUDE
SW_LONGITUDE
SE_LATITUDE
SE_LONGITUDE
CRTFCN_CODE
```

7.3.2 Variable Description/Definition

For the image data files:

```
At-sensor radiance - The value representing the quantized DN derived by
                     the TM scanning system radiant energy incident on the
                     sensor aperture at the time of data collection in the
                     specific TIMS 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.
PLATFORM_ALTITUDE	The nominal altitude of the data collection platform above the target.
MIN_SOLAR_ZEN_ANG	The minimum angle from the surface normal (straight up) to the sun during the data collection.
MAX_SOLAR_ZEN_ANG	The maximum angle from the surface normal (straight up) to the sun during the data collection.
MIN_SOLAR_AZ_ANG	The minimum azimuthal direction of the sun during data collection expressed in clockwise increments from North.
MAX_SOLAR_AZ_ANG	The maximum azimuthal direction of the sun during data collection expressed in clockwise increments from North.
C130_MISSION_ID	The mission identifier assigned to the C130 mission in the form of YY-DDD-FF where YY is the last two digits of the fiscal year, DDD is the deployment number for "official" C130 missions and is day of year for non-"official" C130 missions (i.e., no site coverage), and FF is the flight number within the given deployment (00 is given for non-"official" C130 missions). An example would be 94-006-04.
C130_LINE_NUM	The number of the C130 line in its flights over the BOREAS area as given in the flight logs. Zero values are given for non-"official" C130 missions and for data between C130 sites or lines.
C130_RUN_NUM	The number of the C130 run in its flights over the BOREAS area as given in the flight logs. Zero value is given for non-"official" C130 missions and data between C130 sites, lines or runs.
C130_SITE	The C130 site designator as given in the flight logs. PRE is used for data taken from the airport to the first "official" C130 site, BTW is used for data taken between two "official" C130 sites, DSC is used for data taken after the last "official" C130 site, TRN is used for transect data, and YTH and YPA are used for data taken at the YTH and YPA airports (aircraft never left the ground).
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.
TIMS_MEAN_FRAME_STATUS	The mean frame status calculated from the values

	on the digital tape of TIMS data collected during the flight.
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.
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

For the image data files: At-sensor radiance - milliwatts/(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]
PLATFORM_ALTITUDE	[meters]
MIN_SOLAR_ZEN_ANG	[degrees]
MAX_SOLAR_ZEN_ANG	[degrees]
MIN_SOLAR_AZ_ANG	[degrees]
MAX_SOLAR_AZ_ANG	[degrees]
C130_MISSION_ID	[none]
C130_LINE_NUM	[none]
C130_RUN_NUM	[none]
C130_SITE	[none]

BAND_QUALITY	[none]
CLOUD_COVER	[none]
TIMS_MEAN_FRAME_STATUS	[none]
NW_LATITUDE	[degrees]
NW_LONGITUDE	[degrees]
NE_LATITUDE	[degrees]
NE_LONGITUDE	[degrees]
SW_LATITUDE	[degrees]
SW_LONGITUDE	[degrees]
SE_LATITUDE	[degrees]
SE_LONGITUDE	[degrees]
CRTFCN_CODE	[none]

7.3.4 Data Source

The level-1b TIMS data were derived by JPL personnel from the original level-0 data. The sources of the parameter values contained in the inventory listing file on the CD-ROM are:

Column Name	Data Source
SPATIAL_COVERAGE	[Determined from latitude and longitude information provided in the NASA ARC flight summary reports]
DATE_OBS	[Software derived from TIMS housekeeping data]
START_TIME	[Software derived from TIMS housekeeping data]
END_TIME	[Software derived from TIMS housekeeping data]
PLATFORM	[Data base constant]
INSTRUMENT	[Data base constant]
NUM_BANDS	[Data base constant]
PLATFORM_ALTITUDE	[Determined from latitude and longitude information provided in the NASA ARC flight summary reports]
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]
C130_MISSION_ID	[Taken from the delivered tape label and the NASA ARC Flight Summary Reports]
C130_LINE_NUM	[Taken from the delivered tape label and the NASA ARC Flight Summary Reports]
C130_RUN_NUM	[Taken from the delivered tape label and the NASA ARC Flight Summary Reports]
C130_SITE	[Taken from the delivered tape label and the NASA ARC Flight Summary Reports]
BAND_QUALITY	[Constant software parameter value]
CLOUD_COVER	[Constant software parameter value]
NS001_MEAN_FRAME_STATUS	[Software derived from TIMS housekeeping data]
NW_LATITUDE	[Calculated with software from the C130 altitude and heading, starting and ending flight line latitude and longitude, and the static NS001 scan

	angle information]
NW_LONGITUDE	[Calculated with software from the C130 altitude and heading, starting and ending flight line latitude and longitude, and the static TIMS scan angle information]
NE_LATITUDE	[Calculated with software from the C130 altitude and heading, starting and ending flight line latitude and longitude, and the static TIMS scan angle information]
NE_LONGITUDE	[Calculated with software from the C130 altitude and heading, starting and ending flight line latitude and longitude, and the static TIMS scan angle information]
SW_LATITUDE	[Calculated with software from the C130 altitude and heading, starting and ending flight line latitude and longitude, and the static TIMS scan angle information]
SW_LONGITUDE	[Calculated with software from the C130 altitude and heading, starting and ending flight line latitude and longitude, and the static TIMS scan angle information]
SE_LATITUDE	[Calculated with software from the C130 altitude and heading, starting and ending flight line latitude and longitude, and the static TIMS scan angle information]
SE_LONGITUDE	[Calculated with software from the C130 altitude and heading, starting and ending flight line latitude and longitude, and the static TIMS scan angle information]
CRTFCN_CODE	[Constant data base value]

7.3.5 Data Range

The maximum range of DNs in each level-1b TIMS image band is limited from -16,384 to 16,383 so that the values can be stored in a two-byte field. 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	16-APR-94	17-SEP-94	None	None	None	None
START_TIME	2	959	None	None	None	None
END_TIME	5	959	None	None	None	None
PLATFORM	C130	C130	None	None	None	None
INSTRUMENT	N/A	N/A	None	None	None	None
NUM_BANDS	6	6	None	None	None	None
PLATFORM_ALTITUDE	4640	7265.5	None	None	None	None
MIN_SOLAR_ZEN_ANG	73.8	121.4	None	None	None	None
MAX_SOLAR_ZEN_ANG	74	121.7	None	None	None	None
MIN_SOLAR_AZ_ANG	.3	358.3	None	None	None	None
MAX_SOLAR_AZ_ANG	.7	358.8	None	None	None	None
C130_MISSION_ID	94-004-09	94-009-09	None	None	None	None
C130_LINE_NUM	1	703	None	None	None	None

C130_RUN_NUM	1	2	None	None	None	None
C130_SITE	429	433	None	None	None	None
BAND_QUALITY	N/A	N/A	None	None	None	None
CLOUD_COVER	N/A	N/A	None	None	None	None
TIMS_MEAN_FRAME_ STATUS			None	None	None	Blank
NW_LATITUDE	53.65307	56.17763	None	None	None	None
NW_LONGITUDE	-106.54837	-97.96291	None	None	None	None
NE_LATITUDE	53.6305	56.12803	None	None	None	None
NE_LONGITUDE	-106.09913	-97.77578	None	None	None	None
SW_LATITUDE	53.45336	55.89295	None	None	None	None
SW_LONGITUDE	-106.63445	-98.02344	None	None	None	None
SE_LATITUDE	53.37184	55.84932	None	None	None	None
SE_LONGITUDE	-106.13012	-97.83714	None	None	None	None
CRTFCN_CODE	PRE	PRE	None	None	None	None

```
Minimum Data Value -- The minimum value found in the column.
Maximum Data Value -- The maximum value found in the column.
Missng Data Value  -- The value that indicates missing data. This is used to
                      indicate that an attempt was made to determine the
                      parameter value, but the attempt was unsuccessful.
Unrel Data Value   -- The value that indicates unreliable data.  This is used
                      to indicate an attempt was made to determine the
                      parameter value, but the value was deemed to be
                      unreliable by the analysis personnel.
Below Detect Limit -- The value that indicates parameter values below the
                      instruments detection limits.  This is used to
                      indicate that an attempt was made to determine the
                      parameter value, but the analysis personnel determined
                      that the parameter value was below the detection
                      limit of the instrumentation.
Data Not Cllctd    -- This value indicates that no attempt was made to
                      determine the parameter value.  This usually
                      indicates that BORIS combined several similar but
                      not identical data sets into the same data base table
                      but this particular science team did not
                      measure that parameter.

Blank -- Indicates that blank spaces are used to denote that type of value.
N/A   -- Indicates that the value is not applicable to the respective column.
None  -- Indicates that no values of that sort were found in the column.
```

7.4 Sample Data Record

A sample data record for the level-1b TIMS images is not available here. The following are wrapped versions of the first few records from the level-1b TIMS inventory table on the CD-ROM.

```
SPATIAL_COVERAGE,DATE_OBS,START_TIME,END_TIME,PLATFORM,INSTRUMENT,NUM_BANDS,
PLATFORM_ALTITUDE,MIN_SOLAR_ZEN_ANG,MAX_SOLAR_ZEN_ANG,MIN_SOLAR_AZ_ANG,
MAX_SOLAR_AZ_ANG,C130_MISSION_ID,C130_LINE_NUM,C130_RUN_NUM,C130_SITE,
BAND_QUALITY,CLOUD_COVER,TIMS_MEAN_FRAME_STATUS,NW_LATITUDE,NW_LONGITUDE,
NE_LATITUDE,NE_LONGITUDE,SW_LATITUDE,SW_LONGITUDE,SE_LATITUDE,SE_LONGITUDE,
CRTFCN_CODE
```

```
'SSA',16-APR-94,606,610,'C130','TIMS',6,4753.1,115.2,115.4,343.9,344.4,
'94-004-09',301,1,'429','NOT ASSESSED','NOT ASSESSED',,53.71754,-106.37024,
53.6996,-105.93603,53.52663,-106.39161,53.50878,-105.95939,'PRE'
'SSA',16-APR-94,615,618,'C130','TIMS',6,4771.0,115.5,115.7,346.2,346.8,
'94-004-09',303,1,'429','NOT ASSESSED','NOT ASSESSED',,53.65307,-106.48068,
53.6305,-105.92932,53.62535,-106.48372,53.60279,-105.93272,'PRE'
```

8. Data Organization

8.1 Data Granularity

The smallest unit of data for level-1b TIMS images is a single 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 with single apostrophe marks. There are no spaces between the fields.

Each level-1b TIMS scene is stored in 6 files, one per spectral band. Each band in a scene is contained in a file of 1276 byte records, the first two of which are ASCII header information. The following records each contain one image line of 698 2-byte pixels. These 16-bit data are high-order byte first. For computer systems using low-order byte first ordering, the bytes in these fields need to be swapped before they can be interpreted properly.

9. Data Manipulations

9.1 Formulae

9.1.1 Derivation Techniques and Algorithms

First, a header label is created for the file that includes the number of scan lines, number of samples, number of bands (default: six), and file organization (default: BSQ). The TIMSCAL program is used next to convert the raw data to instrument perceived radiance data. This file is then separated into six files constituting the six TIMS bands for further manipulation.

Additional calibration programs used by the JPL science team are FIT, XFORM, and C130RECT (see Section 9.2.1 for detailed description of these programs).

9.2 Data Processing Sequence

9.2.1 Processing Steps

TIMSCAL produces an output of instrument perceived radiance data. The output is a data set of all six bands stored in 2-byte integers. The units output for radiance images are: milliwatts/(m^2 sr µm). The units output for temperature images are in hundredths of degrees Centigrade. Output is in 2-byte signed integer format. Next, the data are separated into the six TIMS bands for processing by the investigator, or further processing of the data to output a hardcopy quality image.

FIT is a VICAR applications program that performs automatic linear stretches on 2-byte images anywhere in the 2-byte range (-32768 to +32767). FIT computes a grey-level frequency table (histogram) of the input image. The histogram has 65536 bins, hence spans the entire halfword range from -32768 to +32767. The program determines linear stretch constants IMIN and IMAX such that:

- IMIN is the largest I that satisfies the equation: A(-32768,I) <= PL * A(-32768,32767)
- IMAX is the smallest I that satisfies the equation: A(I,32767) <= PH * A(-32768,32767)

The linear stretch that is applied to the image is defined as:

```
          HV - LV
Y =   -----------  (X - IMIN) + LV
      IMAX - IMIN
```

where X and Y are the input and output DN values respectively for each pixel.

XFORM will perform a linear transformation on the input data. The transformation is specified by a matrix input as a parameter.

Each corresponding pixel from the input data sets is represented by a vector x[T] = (x1,x2,...xm)[T], where [T] denotes Transpose.

A gain and offset are then applied to each component before it is written to the output data set.

Auto-scale mode is the default condition and was used in the processing of this data. In auto-scale mode, the gains and offsets for each band are calculated by fitting the output histogram to user-specified parameters.

C130RECT removes scan-angle distortion in images acquired by scanners that sample at equal angular increments. Tilt can be corrected and the aspect ratio of the image can be adjusted. C130RECT is essentially divided into three parts. The first of these handles simple initialization and computes (using basic trigonometry) values for the variables which are dependent on the image tilt and scan width. The second part of the program fills a resampling address array which, for each input pixel position, gives a real-valued index into the input buffer from which values may be interpolated; this array mapping may be dumped to the screen by specifying the DEBUG option. The third part of the program reads in each line of the image, and using the resampling address array and C routine resamp, corrects each line for distortion according to the tilt and scan width specified, finally outputting each line to the output image.

BORIS staff processed the level-1b TIMS images by:

- Extracting the American Standard Code for Information Interchange (ASCII) header record from the level-1b image product and placing it on disk.
- Reading the information in the disk file and loading the online data base with needed information.

9.2.2 Processing Changes

None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

The TIMS data are not geometrically corrected. The data contain both panoramic distortion, as a function of the 76.56-degree total FOV, and other spatial perturbations induced by a moving aircraft.

9.3.2 Calculated Variables

None given.

9.4 Graphs and Plots

None given.

10. Errors

10.1 Sources of Error

See Section 9.3.1. Other sources of error include possible nonunity emissivity of the onboard blackbodies and inexact knowledge of the exact blackbody temperatures in flight conditions. In 1989, a honeycomb scheme container was used for the blackbodies, which made the above errors much smaller.

10.2 Quality Assessment

10.2.1 Data Validation by Source

Spectral errors could arise because of image-wide signal-to-noise ratio, saturation, cross-talk, spikes, response normalization caused by a change in gain. JPL personnel did not perform any error validation.

10.2.2 Confidence Level/Accuracy Judgment

The system's optical focus is continually monitored by close observation of the apparent sharpness and resolution of objects appearing in scenes after data processing. Although this approach is somewhat subjective, it has proven to be a viable alternative compared to the classical resolution measurement method, which requires removing the scanner system from the C-130 airplane with subsequent setup. This is not a practical option during the flying/deployment portion of the year. However, any observed focus degradation would be corrected by focus adjustment.

There was no reason to believe that the data were faulty; therefore, the confidence level was high for these data.

10.2.3 Measurement Error for Parameters

The NEdT for the channels is typically 0.2 °C or less, depending on aircraft flight regime, with variations caused by vibration.

10.2.4 Additional Quality Assessments

The TIMS has periodically viewed a precision extended-area blackbody calibration source to verify linearity over the 0-50 °C range.

The hardcopy images are visually reviewed for any obvious distortions that may be eliminated by the JPL programs. None were noticed and the data were not manipulated further.

10.2.5 Data Verification by Data Center

BORIS personnel reviewed the values extracted from the tape files and loaded into the data base and visually reviewed a random set of the images on a display screen. No anomalous items were discovered in the review.

11. Notes

11.1 Limitations of the Data

None given.

11.2 Known Problems with the Data

None given.

11.3 Usage Guidance

Because of variable conditions found in different flight regimes on the C-130 aircraft, the onboard blackbody temperatures reported in the housekeeping data may be artificially high, which will result in apparently elevated ground temperatures. This is caused by cold air blasting on the front surface of these reference sources. An airdam (air fence) was installed to shelter the sensor from the wind, thereby minimize the effects of the wind blast.

The TIMS data are not geometrically corrected. The data contain both panoramic distortions, as a function of the 76-degree total FOV, as well as other spatial perturbations induced by a moving aircraft.

11.4 Other Relevant Information

None given.

12. Application of the Data Set

The TIMS data can be used to analyze the thermal properties of various surface targets. The data provide a six-channel spectral emissivity curve, which is used as a diagnostic tool to identify various minerals and man-made surfaces.

13. Future Modifications and Plans

None.

14. Software

14.1 Software Description

BORIS staff developed software and command procedures for:

- Extracting header and calibration information from level-1b TIMS images on tape and writing it to ASCII files on disk.
- Reading the ASCII disk file and logging the level-1b TIMS image products into the Oracle data base tables.

14.2 Software Access

The software is written in C and is operational on VAX 6410 and MicroVAX 3100 systems at Goddard Space Flight Center (GSFC). The primary dependencies in the software are the Oracle data base utility routines.

15. Data Access

The TIMS 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

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

15.4 Data Center Status/Plans

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

16. Output Products and Availability

16.1 Tape Products

The BOREAS level-1b TIMS data can be made available on 1600- or 6250-Bytes Per Inch (BPI) 9-track, 8-mm, or Digital Archive Tape (DAT) media.

16.2 Film Products

Color aerial photographs and video records were made during data collection. The video record includes aircraft crew cabin intercom conversations and an audible tone that was initiated each time the sensor was triggered. The BOREAS data base contains an inventory of available BOREAS aircraft flight documentation, such as flight logs, videotapes, and photographs.

16.3 Other Products

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

17. References

17.1 Platform/Sensor/Instrument/Data Processing Documentation

There is a Daedalus Operator's Manual for TIMS, but it is proprietary and may not be reproduced without their permission. Contact Daedalus Enterprises, Ann Arbor, MI, for details.

NASA. 1990. C-130 Earth Resources Aircraft Experimenter's Handbook. National Aeronautics and Space Administration, Ames Research Center. Moffett Field, CA.

Airborne Instrumentation Research Project. 1994. Flight Summary Reports for Flight No. 94-004-09 to 94-009-09 or April 16, 1994 to September 19, 1994. NASA Ames Research Center, Airborne Missions and Applications Division, Moffett Field, CA 94035.

17.2 Journal Articles and Study Reports

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

Sellers, P. and F. Hall. 1994. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1994-3.0, NASA BOREAS Report (EXPLAN 94).

Sellers, P. and F. Hall. 1996. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1996-2.0, NASA BOREAS Report (EXPLAN 96).

Sellers, P., F. Hall, and K.F. Huemmrich. 1996. Boreal Ecosystem-Atmosphere Study: 1994 Operations. NASA BOREAS Report (OPS DOC 94).

Sellers, P., F. Hall, and K.F. Huemmrich. 1997. Boreal Ecosystem-Atmosphere Study: 1996 Operations. NASA BOREAS Report (OPS DOC 96).

Sellers, P., F. Hall, H. Margolis, B. Kelly, D. Baldocchi, G. den Hartog, J. Cihlar, M.G. Ryan, B. Goodison, P. Crill, K.J. Ranson, D. Lettenmaier, and D.E. Wickland. 1995. The boreal ecosystem-atmosphere study (BOREAS): an overview and early results from the 1994 field year. Bulletin of the American Meteorological Society. 76(9):1549-1577.

Sellers, P.J., F.G. Hall, R.D. Kelly, A. Black, D. Baldocchi, J. Berry, M. Ryan, K.J. Ranson, P.M. Crill, D.P. Lettenmaier, H. Margolis, J. Cihlar, J. Newcomer, D. Fitzjarrald, P.G. Jarvis, S.T. Gower, D. Halliwell, D. Williams, B. Goodison, D.E. Wickland, and F.E. Guertin. 1997. BOREAS in 1997: Experiment Overview, Scientific Results and Future Directions. Journal of Geophysical Research 102(D24): 28,731-28,770.

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

```
ARC     - Ames Research Center
ASAS    - Advanced Solid-state Array Spectroradiometer
ASCII   - American Standard Code for Information Interchange
BIL     - Band Interleaved by Line
BOREAS  - BOReal Ecosystem-Atmosphere Study
BORIS   - BOREAS Information System
BPI     - Bytes Per Inch
BSQ     - Band Sequential
CCRS    - Canada 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
FFC-T   - Focused Field Campaign - Thaw
FIFE    - First ISLSCP Field Experiment
FOV     - Field-Of-View
fPAR    - fraction of Photosynthetically Active Radiation
GIS     - Geographic Information System
GMT     - Greenwich Mean Time
GSFC    - Goddard Space Flight Center
HgCdTe  - mercury-cadmium-tellurium
HTML    - HyperText Markup Language
I/O     - Input/Output
IFC     - Intensive Field Campaign
IFOV    - Instantaneous Field-of-View
ISLSCP  - International Satellite Land Surface Climatology Project
JPL     - Jet Propulsion Laboratory
LAI     - Leaf Area Index
NAD83   - North American Datum 1983
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NASA    - National Aeronautics and Space Administration
NEdt    - Noise-Equivalent Change in Temperature
NSA     - Northern Study Area
ORNL    - Oak Ridge National Laboratory
PANP    - Prince Albert National Park
SSA     - Southern Study Area
TIMS    - Thermal Infrared Multispectral Scanner
TM      - Thematic Mapper
TMS     - Thematic Mapper Simulator
URL     - Uniform Resource Locator
```

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

BOREAS Staff Science, "BOREAS Staff Science Aircraft 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.

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13. ABSTRACT *(Maximum 200 words)*

The BOREAS Staff Science Aircraft 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. For BOREAS, the TIMS imagery, along with other aircraft images, was collected to provide spatially extensive information over the primary study areas. The Level-1b TIMS images cover the time periods of 16-Apr-1994 to 20-Apr-1994 and 06-Sep-1994 to 17-Sep-1994. The system calibrated images are stored in binary image format files.

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