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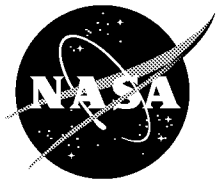

Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall, Editor

Volume 89

BOREAS Level-0 NS001 TMS Imagery: Digital Counts in BIL Format

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National Aeronautics and
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September 2000

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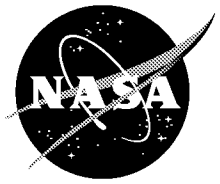

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BOREAS Level-0 NS001 TMS Imagery: Digital Counts in BIL Format

Jeffrey A. Newcomer, Roseanne Dominguez

Summary

For BOREAS, the NS001 TMS 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 fPAR and LAI. Data collections occurred over the study areas during the 1994 field campaigns.

Note that the level-0 NS001 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-0 NS001 images.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS Level-0 NS001 TMS Imagery: Digital Counts in BIL 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 eight-band NS001 Thematic Mapper Simulator (TMS) Multispectral Scanner (MSS) data collected on the National Aeronautics and Space Administration's (NASA's) C-130 aircraft. The NS001 provided spectral image data very similar to that of the Landsat Thematic Mapper (TM).

1.3 Objective/Purpose

The 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 eight-band NS001 TMS MSS data collected on NASA's C-130 aircraft.

For BOREAS, the NS001 TMS 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 fraction of Photosynthetically Active Radiation (fPAR), and Leaf Area Index (LAI).

1.4 Summary of Parameters

NS001 level-0 image data in the BOREAS Information System (BORIS) contain the following parameters:

- Original housekeeping and calibration information and image bands 1 to 8 in the Ames Research Center (ARC) Band Interleaved by Line (BIL) format.

1.5 Discussion

BORIS staff processed the NS001 TMS level-0 images by:

- Extracting pertinent header information from the level-0 image product and placing it in an American Standard Code for Information Interchange (ASCII) file on disk
- Reading the information in the disk file and loading the online data base with needed information

1.6 Related Data Sets

BOREAS Level-0 C-130 Navigation Data
BOREAS Level-0 C-130 Aerial Photography
BOREAS Level-1b ASAS Imagery
BOREAS Level-1b MAS Imagery: At-sensor Radiance, Relative X and Y Coordinates
BOREAS Level-0 TIMS Imagery: Digital Counts in BIL Format
BOREAS Level-1b TIMS 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

2.3 Contact Information

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3. Theory of Measurements

The NASA Earth Resources Aircraft Program at ARC operates the C-130 aircraft to acquire data for Earth science research. The NS001 MSS used on the C-130 aircraft collects radiance measurements in the seven Landsat-4 and -5 TM bands plus a band from 1,000 to 1,300 nm. Therefore, when reflected or emitted radiation from Earth surface features is measured from the aircraft, inferences can be made about Landsat satellite measurements.

Thematic considerations have dictated, within technical constraints, the choice of spectral band position and width in the NS001 sensor. Eight bands were selected, seven of which correspond to Landsat TM bands. These bands were chosen after many years of analysis for their value in discrimination of several Earth surface features. A blue (0.45 to 0.52 µm) band provides increased penetration of water bodies as well as supporting analyses of land use, soil, and vegetation characteristics. The lower wavelength cutoff is just below the peak transmittance of clear water, while the upper wavelength cutoff is the limit of blue chlorophyll absorption for healthy green vegetation. Wavelengths below 450 nm are substantially influenced by atmospheric scattering and absorption.

A green (0.52 to 0.60 µm) band spans the region between the blue and red chlorophyll absorption bands and therefore corresponds to the green reflectance of healthy vegetation. A red (0.63 to 0.69 µm) band includes the chlorophyll absorption band of healthy green vegetation and represents one of the most important bands for vegetation discrimination. The latter is also useful for soil and geological boundary delineations. A reflective-infrared (0.76 to 0.90 µm) band is especially responsive to the amount of vegetation biomass present in a scene. It is useful for crop identification and emphasizes soil-crop and land-water contrasts.

Two of the three mid-infrared (1.00 to 1.30 µm; 1.55 to 1.75 µm) bands are sensitive to the turgidity or amount of water in plants. Such information is useful in crop drought studies and in plant vigor investigations. In addition, these are two of the few bands that can be used to discriminate between clouds, snow, and ice, which is very important in hydrologic research. The other mid-infrared band (2.08 to 2.35 µm) is important for the discrimination of geologic rock formations. It has been shown to be particularly effective in identifying zones of hydrothermal alteration in rocks. Finally, the thermal infrared (10.4 to 12.5 µm) band measures the amount of infrared radiant flux emitted from surfaces. The apparent temperature is a function of the emissivities and true or kinetic temperature of the surface. It is useful for geothermal activity location, thermal inertia mapping for geologic investigations, vegetation classification, vegetation stress analysis, and soil moisture studies.

4. Equipment

4.1 Sensor/Instrument Description

The NS001 TMS instruments are designed to simulate spectral, spatial, and radiometric characteristics of the TM sensor on the Landsat-4 and -5 spacecraft. The NS001 is generally flown at medium altitudes aboard NASA's C-130 aircraft based at ARC and provides 12.2-meter resolution at nadir at an altitude of 4,878 meters (16,000 feet). The NS001 sensor differs slightly from the Landsat TM instruments. It has seven spectral channels that are very similar to those of the TM sensor, but has an additional infrared channel, as follows:

Comparable

NS001 Channel	Wavelength, µm	Landsat TM Band
1	0.45-0.52	1
2	0.52-0.60	2
3	0.63-0.69	3
4	0.76-0.90	4
5	1.00-1.30	-
6	1.55-1.75	5
7	2.08-2.35	7
8	10.40-12.5	6

4.1.1 Collection Environment

As part of the BOREAS Staff Science data collection effort, the ARC Medium Altitude Aircraft Branch collected and processed eight-band NS001 TMS MSS data to BOREAS level-0 products. The NS001 was flown on NASA's C-130 aircraft during the BOREAS mission (see the BOREAS Experiment Plan for flight pattern details and objectives).

Maintenance and operation of the instrument are the responsibility of ARC. The C-130 Experimenter's Handbook (supplemental) produced by the Medium Altitude Aircraft Branch at ARC provides a description of the instrument, calibration procedures, and data format. Data from the level-0 tapes provided by ARC can be decoded based on the contents of the handbook.

NS001 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 under the label "demagnification factor."

4.1.2 Source/Platform

NASA's C-130 Earth Resources Aircraft.

4.1.3 Source/Platform Mission Objectives

The original purpose of the scanner was to provide low-altitude data in the Landsat TM bands for analysis prior to the launch of the satellite, and to provide calibration information from under-flights subsequent to the launch of the satellite.

4.1.4 Key Variables

Emitted radiation, reflected radiation, and temperature.

4.1.5 Principles of Operation

Design parameters of the NS001 are based on the specifications of the Landsat TM with respect to spectral band characteristics. A single spectrometer disperses the energy to cover the first six bands from 0.45 µm to 1.75 µm. An array, employing silicon, germanium, and indium antimonide detectors, is used. Band 7 is separated by a dichroic bandpass filter. Band 8, in the 10.4 µm to 12.5 µm region, is detected by a cooled mercury-cadmium-telluride detector.

Variable velocity over height (V/H) conditions are compensated by a variable speed motor that drives the scan mirror.

Each channel uses a preamplifier to provide initial video amplification. Gain and level control of video signals are adjustable from the operator's control panel. Each channel is digitized to an 8-bit resolution and is multiplexed with calibration and housekeeping data.

4.1.6 Sensor/Instrument Measurement Geometry

Instantaneous Field-of-View (IFOV)	2.5 mrad
Total Scan Angle	100 degrees
Pixels/Scan Line	699

Sensor footprint is 12.2 m by 12.2 m at nadir at 4,878 meters altitude.

4.1.7 Manufacturer of Sensor/Instrument

4.2 Calibration

The NS001 includes two full-aperture blackbodies and one integrating sphere within the scan mirror cavity. They are viewed each scan by the instrument, and the responses are embedded in the data stream. Blackbody temperatures and lamp current data are multiplexed with scanner output data. The blackbody irradiance is determined by its monitored temperature and estimated emissivity. The blackbodies are also cross-checked periodically by comparing the NS001 responses to the blackbodies and an external precision blackbody. The internal sphere is calibrated by reference to an external light source.

The principal source used for calibrating the internal sphere for BOREAS in 1994 was a 76 cm diameter integrating sphere owned by ARC and calibrated by the Standards and Calibration Office at GSFC. The sphere contains 12 internally mounted quartz halogen lamps. Estimated uncertainty in the calibration of the sphere is +/-5%. The April 1994 calibration of the sphere was used to calibrate the internal calibration source in the NS001 in 1994.

4.2.1 Specifications

The wavelength ranges (in μm) of the bands for the NS001 are:

Band	Detector	Wavelength	Noise Equivalent (NE) (delta P) %
1	Si	0.458 - 0.519	0.5
2	Si	0.529 - 0.603	0.5
3	Si	0.633 - 0.697	0.5
4	Si	0.767 - 0.910	0.5
5	Ge	1.13 - 1.35	1.0
6	Ge	1.57 - 1.71	1.0
7	InSb	2.10 - 2.38	2.0
8	HgCdTe	10.9 - 12.3	NE(delta T) = 0.25 K

DESIGN DATA:	
IFOV	2.5 mrad
Across-track FOV	100 degrees
Nominal aperture diameter	10.16 cm
Effective aperture area	72.4 cm^2
f/number	1.85
Primary focal length	18.8 cm
Inflight calibration	Integrating sphere and two controllable blackbodies
Short wavelength array temperature	255 K
V/H range	Variable 0.025 to 0.25
Scan rate	Variable 10 to 100 scans/sec.
Scan speed stability	One-third of the IFOV, scan line to scan line
Data quantization	8 bits (256 discrete levels)
Number of video samples/scan line	699
Roll compensation	+/-15 degrees
Scan mirror	45-degree rotating mirror

4.2.1.1 Tolerance

The NS001 channels were designed for NE reflectance differences for the channels, represented by the radiometric sensitivity [NE(delta P) %; NE(delta T) K] shown in Section 4.2.1.

4.2.2 Frequency of Calibration

An integrating sphere and two controllable thermal blackbodies (BB1 and BB2) are integral to the NS001 scanner. Each is viewed once during a complete revolution of the scan mirror. The two thermal blackbodies are principally used to span the recorded thermal image, thereby providing a scaling factor for the measured data. The surface of BB2 is also used to provide the tare value (darkest object viewed per sweep) for the seven nonthermal detectors. Tare value is artificially set above zero counts (e.g., 8-10 counts) to compensate for any system drift.

For BOREAS, one of the blackbodies is used for the internal lamp offset. The average of the two blackbodies is used for the scene offset.

4.2.3 Other Calibration Information

4.2.3.1 Reflective Band Calibration

The BB2 View is used for the internal source offset; i.e., the gain is calculated in effect as:

Gain = (Ref. Lamp View - BB2 View) / Ref. Lamp Spectral Radiance

The reference lamp spectral radiance is determined by preseason calibration relative to the integrating sphere. The apparent scene spectral radiance in Watts/(m^2 sr μm) can then be calculated as:

(pixel value - (BB1 View + BB2 View) / 2) / Gain

4.2.3.2 Thermal Band Calibration

GSFC Gain (G), Offset (O), as found in the header summary file(s) are calculated as follows:

a) Calculate blackbody radiances, Lw(mW/cm^2/sr/μm) (assume emissivity=1) for BB1 and BB2 temperatures T(K) e.g.

For example:

$L_{w,bb1} = [K1 / (\exp(K2/T_{bb1})-1)]$

where: K1 = 607.05 W/cm^2/sr/μm
K2 = 1258.39 K

K1, K2 were "best fit" parameters for the temperature range of 273-323 K using the 8/87 NS001 spectral data and the Planck equation.

b) G = [(BB2 View - BB1 View) / (Lw,BB2 - Lw,BB1)]
(DN/mW/cm^2/sr/μm)

O = BB1 View - G * Lw,BB1 (DN)

Target Radiance (Lw) can then be calculated as:

(pixel value - O) / G

and at-sensor apparent temperature as:

$T = [K2 / (\ln(K1/Lw + 1)]$

5. Data Acquisition Methods

As part of the BOREAS Staff Science data collection effort, ARC Medium Altitude Aircraft Branch collected and processed 8-band NS001 TMS MSS data to BOREAS level-0 products. The NS001 was flown on NASA's C-130 aircraft during the BOREAS mission (see the BOREAS Experiment Plan for flight pattern details and objectives).

Maintenance and operation of the instrument are the responsibility of ARC. The C-130 Experimenter's Handbook (supplemental) produced by the Medium Altitude Aircraft Branch at ARC provides a description of the instrument, calibration procedures, and data format. Data from the level-0 tapes provided by ARC can be decoded based on the contents of the handbook.

NS001 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 under the label "demagnification factor."

6. Observations

6.1 Data Notes

See Section 11.

6.2 Field Notes

Flight summary reports and verbal records on videotapes are available for the BOREAS NS001 data.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The BOREAS level-0 NS001 TMS images cover portions of 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 BOREAS 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
Typical altitudes for BOREAS were around 5,000 m, producing a 12.5-m pixel at nadir given the NS001's 2.5-mrad IFOV.

7.1.4 Projection
The BOREAS level-0 NS001 images are stored in their original data collection frame with increasing pixel sizes from nadir to the scanning extremes based on the scan angle.

7.1.5 Grid Description
The BOREAS level-0 NS001 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 BOREAS' Field Campaigns, covering the period from 16-Apr-1994 through 17-Sep-1994.

7.2.2 Temporal Coverage Map

IFC#	Dates
FFC-T	16-Apr-1994 -- 20-Apr-1994
IFC-1	26-May-1994 -- 08-Jun-1994
IFC-2	21-Jul-1994 -- 08-Aug-1994
IFC-3	06-Sep-1994 -- 17-Sep-1994

7.2.3 Temporal Resolution
Images were acquired on multiple days during each of the IFCs.

7.3 Data Characteristics
A level-0 NS001 image from BORIS is contained in a single file. Each record of a level-0 NS001 data file contains 6,000 bytes. The number of records in a file varies depending on the length of the flight line. Detailed information about the contents of the data file is provided in Section 8 of this document.

7.3.1 Parameter/Variable
The main parameter contained in the image data files is:

```
Digital Number (DN).  The other parameters contained in the NS001
                      housekeeping are described in section 8.2.
```

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
NS001_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:

```
Digital Number (DN) - The quantized DN derived by the NS001 TMS scanning system
                      for the respective channel.
```

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.
NS001_MEAN_FRAME_STATUS	The mean frame status calculated from the respective values on the digital tape of NS001 data collected during the given flight. Values other than zero indicate interpolated, repeated, or zero filled lines in the image.
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: Digital Number (DN) - counts

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]
NS001_MEAN_FRAME_STATUS	[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]
CRTFCN_CODE	[none]

7.3.4 Data Source

The level-0 NS001 TMS data were collected by the NS001 instrument on the C130 aircraft. The data were processed from the aircraft tapes and supplied to BOREAS by the Medium Altitude Aircraft Branch at ARC. The source 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 Ames flight summary reports]
DATE_OBS	[Software derived from NS001 housekeeping data]
START_TIME	[Software derived from NS001 housekeeping data]
END_TIME	[Software derived from NS001 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 Ames 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 Ames Flight Summary Reports]
C130_LINE_NUM	[Taken from the delivered tape label and the NASA Ames Flight Summary Reports]
C130_RUN_NUM	[Taken from the delivered tape label and the NASA Ames Flight Summary Reports]
C130_SITE	[Taken from the delivered tape label and the NASA Ames Flight Summary Reports]
BAND_QUALITY	[Constant software parameter value]
CLOUD_COVER	[Constant software parameter value]
NS001_MEAN_FRAME_STATUS	[Software derived from NS001 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 NS001 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 NS001 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 NS001 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 NS001 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 NS001 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 NS001 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 NS001 scan angle information]
CRTFCN_CODE	[Constant data base value]

7.3.5 Data Range

The maximum range of DNs in each level-0 NS001 image band is limited from 0 (zero) to 255 so that the values can be stored in a single 8-bit (1-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	6	2343	None	None	None	None
END_TIME	6	2237	None	None	None	None
PLATFORM	C130	C130	None	None	None	None
INSTRUMENT	N/A	N/A	None	None	None	None
NUM_BANDS	8	8	None	None	None	None
PLATFORM_ALTITUDE	106	8025	None	None	None	None
MIN_SOLAR_ZEN_ANG	32.3	64.8	None	None	None	None
MAX_SOLAR_ZEN_ANG	33.3	71.3	None	None	None	None
MIN_SOLAR_AZ_ANG	92.9	274.3	None	None	None	None
MAX_SOLAR_AZ_ANG	94.1	283.1	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	3	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
NS001_MEAN_FRAME_STATUS	0	40	-99	None	None	None
NW_LATITUDE	53.02807	56.3363	None	None	None	None
NW_LONGITUDE	-106.53493	-97.90026	None	None	None	None
NE_LATITUDE	53.02709	56.09363	None	None	None	None
NE_LONGITUDE	-106.23253	-97.65146	None	None	None	None
SW_LATITUDE	53.00191	56.0027	None	None	None	None
SW_LONGITUDE	-106.61522	-97.96021	None	None	None	None

```
SE_LATITUDE          53.00094       55.9992        None    None    None    None
SE_LONGITUDE         -106.24214     -97.76988      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 that 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 a 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-0 NS001 images is not available here. The following are wrapped versions of the first few records from the level-0 NS001 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,NS001_MEAN_FRAME_STATUS,NW_LATITUDE,NW_LONGITUDE,
NE_LATITUDE,NE_LONGITUDE,SW_LATITUDE,SW_LONGITUDE,SE_LATITUDE,SE_LONGITUDE,
CRTFCN_CODE
'SSA-9OA',16-APR-94,1606,1606,'C130','NS001',8,4754.0,56.1,56.3,123.5,123.8,
'94-004-09',301,1,'429','NOT ASSESSED','NOT ASSESSED',0.0,53.68983,-106.33041,
53.67367,-105.94092,53.53624,-106.34776,53.52015,-105.9597,'PRE'
'SSA-9OA',16-APR-94,1606,1610,'C130','NS001',8,4754.0,55.8,56.1,123.8,124.6,
'94-004-09',301,1,'429','NOT ASSESSED','NOT ASSESSED',0.0,53.68983,-106.33041,
53.673 46,-105.93592,53.53646,-106.34773,53.52015,-105.9547,'PRE'
```

8. Data Organization

8.1 Data Granularity

The smallest unit of data for level-0 NS001 images is a single image. Although the image inventory is contained on the BOREAS CD-ROM set, the actual level-0 NS001 images are not. See Section 15 for information about how to obtain the data.

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.

A level-0 NS001 image from BORIS is contained in a single file. Each record of a level-0 NS001 data file contains 6,000 bytes. The number of records in a file varies depending on the length of the flight line. Each physical record of 6,000 bytes contains eight logical records of 750 bytes. These sets of eight logical records contain the consecutive eight bands of NS001 data for a given image line in BIL format. Each logical record contains 50 bytes of housekeeping information, 699 bytes of image data, and 1 filler byte. The fields containing 16- or 32-bit (2- or 4-byte) values are stored as 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. The specific logical record structure is:

Bytes	Description
1-50	Channel Scanline Housekeeping Information
1 - 2	Data Frame Status 0 Good frame 10 Interpolated data 20 Repeated data 30 Zero-fill for data
3 - 4	Radiance Per Count Calibration Values Visible channel (1-7) flight calibration values in units of tens (not tenths) of nanowatts per square centimeter per micron per steradian per count. Thermal channel is not used.
5 - 8	Scanline Count (32-bit integer)
9 - 10	BB1 Thermistor Count
11 - 12	BB2 Thermistor Count
13 - 14	BB1 Thermal Reference Temperature in units of hundredths of degrees C
15 - 16	BB2 Thermal Reference Temperature in units of hundredths of degrees C
17 - 18	Scan Speed in units of hundredths of scans per second
19 - 20	GMT Hours
21 - 22	GMT Minutes
23 - 24	GMT Seconds in units of tenths of seconds
25 - 26	Demagnification Value (X 100)
27 - 28	Total Air Temperature (TAT) in units of tenths of °C TAT algorithm is TAT(°C)=0.483(16-bit value)-70.4
29 - 30	Gain Value (X 1000) Visible channel (1-7) gain value is defined as 1000 times (REF LAMP RAD COUNT minus BB1 RAD COUNT) divided by (the laboratory value of reference lamp less tare). Thermal channel (8) is not used.
31 - 32	Channel Number
33 - 36	Time (GMT)expressed as a 7-digit number HHMMSST
37 - 38	BB1 Radiance Count
39 - 40	BB2 Radiance Count
41 - 42	Reference Lamp Voltage Count
43 - 44	Reference Lamp Current Count
45 - 46	Reference Lamp State (16 bits 00000000ab000000)

```
                a=1 means reference lamp selected as visible high-level
                    calibration source
                b=0 means lamp has degraded below predetermined
                    level of 12.8V
                b=1 means lamp has not degraded below predetermined level
             (i.e., a value of 192 (= 128 + 64) indicates a good lamp state
47 - 48     Reference Lamp Radiance Count
49 - 50     Precision Radiation Thermometer (PRT-5) in units of
             tenths of °C (-40.0 to +70.0 °fC)
             (memo 21-Feb-1985)

51 - 749  Digitized Video Pixel Information (see note below)
51        Digitized Video Pixel #699; Image Pixel #1
52        Digitized Video Pixel #698; Image Pixel #2
53        Digitized Video Pixel #697; Image Pixel #3
54        Digitized Video Pixel #696; Image Pixel #4
...
749       Digitized Video Pixel #1; Image Pixel #699
750       Filler Byte
```

NOTE: Based on the scanning direction of the NS001 instrument (right to left or clockwise) and how it is mounted in the C-130 aircraft, the first ground area imaged is to the far left of the aircraft's direction of travel. This pixel in a given scan line is labeled as Video Pixel #1, and the last ground area imaged (to the far right of the aircraft's direction of travel) is labeled as Video Pixel #699. This set of video pixels is reversed in order when they are written to the level-0 tape file records so that the pixels are in the correct spatial position when read by the user.

9. Data Manipulations

9.1 Formulae

9.1.1 Derivation Techniques and Algorithms

None.

9.2 Data Processing Sequence

9.2.1 Processing Steps

BORIS staff processed the level-0 NS001 imagery by:

- Extracting pertinent header and calibration information from the level-0 image product and writing it to a disk file
- Reading the information in the disk file and loading the online data base with needed information

9.2.2 Processing Changes

None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

None.

9.3.2 Calculated Variables

None.

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

The NS001 data are calibrated in-flight by reference to the NS001 internal integrating sphere source. Apparent instabilities in this source or its monitoring circuitry, which are not fully understood, are the principal limiting factors in the absolute calibration of NS001 data. Uncertainties caused solely by this behavior reached 25% in 1987, though more typically they are expected to be less than 15%. Other identified error sources at the 1-2% level for typical signals include dark current drift along the scan line, hysteresis-like sensitivity changes along the scan line, random noise, scan-speed-induced errors, and nonlinearity of radiance with wavelength.

Channel 7 (2.08-2.35 µm) shows a number of peculiarities that are hysteresis-like, including a change in the apparent dark current drift along scan with scene brightness and a drop in sensitivity in scanning across a bright target of an estimated 8% over the total 100-degree scan angle. Polarization sensitivity of the NS001 was such that for typical atmospheric conditions, errors in channel 1 (0.45-0.52 µm) radiances would be up to +/-10% and vary with scan angle; this progressively decreases with increasing wavelength (Markham and Ahmad, 1992).

10.2 Quality Assessment

10.2.1 Data Validation by Source

Spectral errors could arise from image-wide signal-to-noise ratio, saturation, cross-talk, spikes, and response normalization caused by a change in gain.

10.2.2 Confidence Level/Accuracy Judgment

System optical focus is continually monitored by close observation of the apparent sharpness and resolution of objects appearing in scenes after data processing. Although this is somewhat subjective, the approach has proved to be a viable alternative compared to the classical resolution measurement method.

The latter method 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.

10.2.3 Measurement Error for Parameters

The NE spectral radiance for the channels ranges from 0.08 to 2.77 microwatts per square cm. Uncertainties caused by the behavior of the internal integrating sphere reached 25% in 1987, though more typically they are expected to be less than 15%.

10.2.4 Additional Quality Assessments

None.

10.2.5 Data Verification by Data Center

None, other than reviewing the values extracted from the tape files and loaded in the data base.

11. Notes

11.1 Limitations of the Data

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

- Certain values in the header information, such as MEAN FRAME STATUS, MEAN and STDV GSFC, and AMES GAIN and OFFSETS, especially for bands 7 and 8, were outside the valid range for these parameters. Such values, when found, were entered into the BORIS data base as the number -99.0 or -999.0, depending on the data base field width. The problem appears to occur at random.

11.2 Known Problems with the Data

None.

11.3 Usage Guidance

The NS001 data are not geometrically corrected. The data contain both panoramic distortion, as a function of the 100-degree total FOV, as well as other spatial perturbations induced by a moving aircraft.

11.4 Other Relevant Information

Two in-flight adjustments are made that affect the radiometric calibration of the reflective channels. The primary adjustment is to the postamplifier gain of each channel. This is adjusted with a channel-specific potentiometer before and between data acquisitions to optimize the spread of the data across the range of the A/D converter (8 bits). The gain settings are continuously variable and are not directly recorded in the data; they are inferred from changes in the instrument response to the integrating sphere. The second adjustment is for scan speed, which is adjusted between 10 and 85 scans per second to maintain contiguous scan lines, or some multiple of contiguous lines if contiguity is not maintainable at the altitude required for data collection. Typical altitudes for BOREAS in 1994 were 5,000 m, which produced 12.5-m pixels at nadir given the NS001's 2.5-mrad IFOV.

Although the image inventory is contained on the BOREAS CD-ROM set, the actual level-0 NS001 images are not. See Section 15 for information about how to acquire the actual level-0 NS001 images.

12. Application of the Data Set

These data can be used to supplement the Landsat TM coverage of the BOREAS areas during 1994 for high-resolution mapping of the ground surface.

13. Future Modifications and Plans

None. The NS001 instrument was decommissioned in October 1995.

14. Software

14.1 Software Description

BORIS staff developed software and command procedures for:

- Extracting header information from level-0 NS001 TMS images on tape and writing it to ASCII files on disk
- Reading the ASCII disk file and logging the level-0 NS001 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 GSFC. The primary dependencies in the software are the tape I/O library and the Oracle data base utility routines.

15. Data Access

The level-0 NS001 TMS 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-0 NS001 TMS data can be made available on 8-mm, Digital Archive Tape (DAT), or 9-track tapes at 1600 or 6250 Bytes Per Inch (BPI).

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-0 NS001 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

```
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
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
FFC-T    - Focused Field Campaign - Thaw
FIFE     - First ISLSCP Field Experiment
FOV      - Field-of-View
fPAR     - fraction of Photosynthetically Active Radiation
GICS     - Geocoded Image Correction System
GIS      - Geographic Information System
GMT      - Greenwich Mean Time
GSFC     - Goddard Space Flight Center
IFC      - Intensive Field Campaign
```

```
IFOV    - Instantaneous Field-of-View
ISLSCP  - International Satellite Land Surface Climatology Project
LAI     - Leaf Area Index
MAS     - MODIS Airborne Simulator
MODIS   - Moderate-Resolution Imaging Spectrometer
MSS     - Multispectral Scanner
NAD83   - North American Datum of 1983
NASA    - National Aeronautics and Space Administration
NE      - Noise Equivalent
NSA     - Northern Study Area
ORNL    - Oak Ridge National Laboratory
PANP    - Prince Albert National Park
PRT     - Precision Radiation Thermometer
SSA     - Southern Study Area
TAT     - Total Air Temperature
TIMS    - Thermal Infrared Multispectral Scanner
TM      - Thematic Mapper
TMS     - Thematic Mapper Simulator
URL     - Uniform Resource Locator
```

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For BOREAS, the NS001 TMS 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 fPAR and LAI. Data collections occurred over the study areas during the 1994 field campaigns

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