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

Forrest G. Hall and Jaime Nickeson, Editors

Volume 75

BOREAS RSS-19 1994 CASI At-sensor Radiance and Reflectance Images

J. Miller and J. Freemantle

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

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BOREAS RSS-19 1994 CASI At-sensor Radiance and Reflectance Images

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BOREAS RSS-19 1994 CASI At-sensor Radiance and Reflectance Images

John R. Miller, Jim R. Freemantle

Summary

The RSS-19 team collected CASI images from the Chieftain Navaho aircraft in order to observe the seasonal change in the radiometric reflectance properties of the boreal forest landscape. CASI was deployed as a site-specific optical sensor during BOREAS field campaigns. Image data were collected with CASI on 36 days during five field campaigns between February and September 1994, primarily at flux tower sites located at study sites near Thompson, Manitoba, and Prince Albert, Saskatchewan. A variety of CASI data collection strategies were used to meet the following scientific objectives: 1) canopy bidirectional reflectance, 2) canopy biochemistry, 3) spatial variability, and 4) estimates of up and downwelling PAR and spectral albedo, as well as changes along transects across lakes and transects NSA and SSA. The images are stored as binary image files.

A subset of the 1994 CASI acquisitions have been compressed and included on the BOREAS CD-ROM set. This subset includes 3 images for the NSA-OBS site on 06-Jun-94, 08-Aug-94, and 06-Sep-94; one image for the SSA-OBS site on 24-Jul-94; and one image for the NSA-Fen site on 08-Aug-94. The CASI imagery on the BOREAS CD-ROMs have been compressed using the Gzip program. See section 8.2 for details. The rest of the 1994 BOREAS CASI archive are not contained on the BOREAS CD-ROM set. Inventory listing files are supplied on the CD-ROM to inform users of the data that were collected. See Sections 15 and 16 for information about how to acquire the data. Also see Section 11.2 for notes about anomalies found with a few of the image sizes.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS RSS-19 1994 CASI At-sensor Radiance and Reflectance Images

1.2 Data Set Introduction

The Compact Airborne Spectrographic Imager (CASI) was deployed as a site-specific optical sensor as part of the BOReal Ecosystem-Atmosphere Study (BOREAS). The overall objective of the CASI deployment was to observe the seasonal change in the radiometric reflectance properties of the boreal forest landscape. A subset of the data is available from the BOREAS Information System (BORIS).

This BORIS subset contains one spatial image per tower site per Intensive Field Campaign (IFC) per study area. All the data have been collected at approximately 1800-m above ground level (AGL). The images have been geocorrected and resampled to 2-meter square pixels using onboard Global Positioning System (GPS) data. Radiance and at-ground modeled reflectance images have been provided. This subset of CASI-processed data corresponds to the data for CASI Mission 3 described in Section 5.

1.3 Objective/Purpose

CASI was used to generate reflectance images from radiance images collected during the February to September 1994 time period. These images will be used along with Airborne Visible and Infrared Imaging Spectrometer (AVIRIS), Special Sensor Microwave/Imager (SSM/I), Landsat Thematic Mapper (TM), Geostationary Operational Environmental Satellite (GOES), Advanced Very High Resolution Radiometer (AVHRR), and Satellite Pour l'Observation de la Terre (SPOT) images to determine: (i) image-based methods to obtain surface reflectances from airborne optical imagery; (ii) the effect of temporal/spatial variability of site albedo of the boreal forest; (iii) the utility of the areal and spectral properties of beaver ponds for spatial scaling of measured trace gas emissions; (iv) the role of seasonal changes in understory components to changes in reflectance of open boreal canopies; and (v) the seasonal/temporal variation in closed canopy reflectance as a function of canopy architecture, species composition, canopy biophysical parameters of Leaf Area Index (LAI) and biomass, and phenologic development and chemistry of foliar components.

1.4 Summary of Parameters

Radiance and at-ground modeled reflectance images.

1.5 Discussion

Image data were collected with CASI on 36 days during five IFCs between February and September 1994. Data were collected primarily at flux tower sites located within the Northern Study Area (NSA) near Thompson, Manitoba and the Southern Study Area (SSA) near Prince Albert, Saskatchewan.

In order to aid BOREAS team collaborators in locating additional information pertaining to the Canadian optical remote sensing component of the BOREAS project, a BOREAS Global Hypermedia Research Information System (B/GHRIS) is under construction at York University/Centre for Research in the Earth and Space Technology (CRESTech) (Dunlop and Shepherd, 1995). It uses World Wide Web (WWW) client/server software to allow collaborators to search, browse, and retrieve distributed network-accessible documents. Radiometrically and/or spatially subsampled CASI images are provided for browsing directly at the collaborator's site. Other information describing the sensors, sensor deployment, flight lines, calibration, field campaigns, field data, calendar of events, bibliography, and more are all now available online (http://www.eol.crestech.ca/), providing up-to-date status on CASI data processing and data delivery to BORIS and collaborators.

1.6 Related Data Sets

BOREAS RSS-02 Level-1b ASAS Imagery: At-sensor Radiance in BSQ Format
BOREAS RSS-18 Level-1B AVIRIS Imagery: At-sensor Radiance in BIL Format
BOREAS RSS-19 1996 CASI At-sensor Radiance and Reflectance Images
BOREAS Level-2 MAS Imagery: Reflectance and Temperatures in BSQ Format
BOREAS Level-2 NS001 TMS Images: Reflectance and Temperatures in BSQ Format

2. Investigator(s)

2.1 Investigator(s) Name and Title

Dr. John R. Miller

2.2 Title of Investigation

Variation in Radiometric Properties of the Boreal Forest Landscape as a Function of the Ecosystem Dynamics

2.3 Contact Information

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3. Theory of Measurements

A more complete discussion of the theory behind the measurements can be found in Miller et al., 1995. A short summary is presented here.

The CASI sensor is an airborne imaging spectrometer sensor with flexible operational characteristics. It was determined that four CASI operating modes and 12 specific mission plans were needed to best meet the scientific objectives of the Remote Sensing Science (RSS)-19 group and its collaborators. The operating modes were:

(i) Full Spectral Mode (39L_288C):
39 noncontiguous cross-track pixels (looks), spacing 12 pixels, 288 spectral bands, 2.5-nm resolution

(ii) Hyperspectral Mode (101L_72C):
101 contiguous cross-track pixels, 72 spectral bands, 7.8-nm resolution

(iii) Hyperspectral Mode (404L_72C):
404 contiguous cross-track pixels, 72 spectral bands, 7.8-nm resolution

(iv) Spatial Mode: (512L_#C):
512 contiguous cross-track pixels, 3 band sets as described in the following table:

Spatial band set name:

CASI-BOREAS (FFCT15)			CASI-CIR High Resolution (CIR)			CASI-Winter (FFC-W) (FFCW7)		
Ch.	Center	HalfBndwidth	Ch.	Center	HalfBndwidth	Ch.	Center	HalfBndwidth
1	409.66	5.90						
2	443.17	5.91						
3	490.89	5.93						
4	520.14	6.82				1	485.62	36.01
5	565.44	5.95	1	565.44	5.95	2	543.23	22.82
6	619.83	5.07				3	583.26	18.43
7	665.47	5.98	2	665.47	5.98	4	635.92	15.81
8	682.51	3.30				5	666.37	15.84
9	709.47	3.30						
10	741.90	3.30						
11	750.02	6.01	3	750.02	6.01			
12	768.99	5.12						
13	799.76	5.13						
14	880.71	7.89				6	798.87	22.34
15	905.39	8.82				7	865.23	25.20

Table 1: CASI Spatial Bandsets Used during BOREAS 94, units are nm.

Note that only CASI data collected in Spatial Mode were submitted as part of the BOREAS archive. Those interested in data gathered in other CASI modes specified above and in Section 5 should contact the Principal Investigator (PI), contact 1 in Section 2.3, or see the Web page address given in Section 1.5.

4. Equipment

4.1 Sensor/Instrument Description

The CASI instrument (Itres, 1992) is composed of nine components weighing a total of 55 kg. The components of the sensor system augmented at CRESTech and as deployed at BOREAS consist of:

- Instrument Control Unit
- Keyboard Unit
- Power Supply Unit
- Sensor Head Unit
- Video Display Unit
- 60-Hz Inverter
- Downwelling Irradiance Probe
- Upwelling Irradiance Probe
- Fiber-Optic Switch Box

The Charge-Coupled Device (CCD) sensor is a P86520 series frame transfer device (EEV, Inc., Chelmsford, UK). The array is thermoelectrically cooled to reduce dark current. The imaging area of the array is 512 x 288 pixels with each element measuring 15.5 by 22 µm. The instrument can be run on 110 volts at 2.4 amps. For Direct Current (DC) operation, the inverter supplied with the system requires 28 VDC, 13 amps peak. For the optional gyro, another inverter supplies 400-Hz Alternating Current (AC).

The 512 image pixels across the 35-degree field of view (FOV) give a 1.23-meter ground resolution (cross-track) per 1-km altitude AGL. The along-track ground resolution is approximately the product of the integration time and the aircraft speed. The required integration time is directly proportional to the number of spectral bands and the number of spatial views. The spectral range of the CASI instrument used in the BOREAS project was 391 to 916 nm. The spectral resolution was 2.5-nm full width, half maximum (FWHM), with 288 pixels sampled at 1.8-nm intervals. The 2.5-nm FWHM is nominal; the bandwidth changes with wavelength (Achal, 1991). Measurements of the bandwidth of the CASI used for BOREAS have been taken at CRESTech and are being analyzed. Channel-to-wavelength registration is subject to slight deviations at large view angles because of spectral sag (Harron et al., 1992; Freemantle et al., 1991).

The CCD sensor is read out and digitized to 12 bits by a programmable electronics system that is controlled by an internal single-board computer. Data are recorded on a built-in digital recorder (Exabyte) that uses 8-mm cassette tapes as the recording medium. The frame rate is configuration-dependent up to a maximum of 85 lines/sec. The CCD can be read out to select and sum rows, to create high spatial resolution bands, or sample columns from the array, to create high spectral resolution views. The CCD sampling configuration can be easily changed by the CASI instrument operator and often several different sampling configurations are used during a data collection experiment. Additional information about the CASI sensor can be obtained from Itres instruments (http://www.itres.com/).

4.1.1 Collection Environment

Data were collected at various altitudes from 150-m AGL to 2600-m AGL. The CASI sensor can be tilted forward or aft of the aircraft. Data have been collected at a number of different sensor view angles for investigations of Bidirectional Reflectance Distribution Function (BRDF) effects. Several CCD sampling configurations were used to collect imagery. Imagery for BOREAS has been collected at the tower flux sites and auxiliary sites, and along the transect between the NSA and SSA.

4.1.2 Source/Platform

The CASI sensor was flown aboard the Chieftain Navaho aircraft operated by the Ontario Provincial Remote Sensing Office (PRSO). Data were collected at various altitudes from 150-m AGL to 2600-m AGL.

4.1.3 Mission Objectives

The complete set of mission objectives for the RSS-19 study is listed below. Note that only Mission 3 data have been submitted as part of the BOREAS archive data set. Contact the PI or see the CASI Web page for availability of other mission data.

CASI Missions:

Mission 1: Flux Tower Sites: Multiview Canopy Bi-directional Reflectance Data
CASI Operating Modes: Spatial Mode or Hyperspectral Mode
CASI Mission Flights: 57
Pixel Size: 2 x 4 m or 2 x 11 m
Swath Width: 1000 m

CASI imagery was collected over each site at 1675-m altitude AGL for at least two different azimuth angles with respect to the solar plane and at multiple sensor view angles in order to characterize the seasonal changes in the bidirectional reflectance properties of each flux-tower forest stand. Wherever possible, CASI data were collected coincident with data from the Advanced Solid-state Array Spectroradiometer (ASAS) sensor National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) onboard the C-130 aircraft, and over the Portable Apparatus for Rapid Acquisition of Bidirectional Observations of Land and Atmosphere (PARABOLA) field instrument NASA GSFC, both of which are specifically designed to measure surface bidirectional reflectance properties. For virtually all missions, CASI imagery was collected in the solar plane with sensor view angles at 45, 30, 15, 0, -15, and -30 degrees and at a 45-degree angle oblique to the solar plane with view angles at +45, 0, and -30 degrees. Note that these angles are with respect to the airplane axis, and will vary somewhat due to aircraft attitude. The operational goal established was to obtain overlapping multiview images of at least 200 m in the along track direction, centered on the site flux tower. With CASI view angle changes made manually by the sensor operator, this objective demanded synchronized tower sighting (aircrew) and sensor tilting at intervals (operator) during a pass over each flux tower to achieve three overlapping image views per pass. Thus three passes of each flux tower were required for the BRDF sampling described above. Initial comparisons between the Li and Strahler (1992) model and the CASI BRDF data for the SSA Old Jack Pine (OJP) site in the winter campaign are reported by Soffer et al. (1995), with further analysis underway.

Mission 2: Flux Tower Sites: Canopy Biochemistry
CASI Operating Mode: Full Spectral Mode
CASI Mission Flights: 37
Pixel Size: 2 x 11 m
Swath Width: 1000 m

Reflectance signatures of forest canopies at high spectral resolution in the CASI visible/near-infrared (VIS/NIR) spectral region can be related to canopy chlorophyll and nitrogen levels (e.g., Matson et al., 1994). CASI spectral mode imagery was collected for this purpose over each tower site in the solar plane on two flights: (i) nadir viewing at 1675-m AGL to obtain a spectral signature of the canopy as for a satellite sensor, and (ii) viewing in the antisolar direction at 45-degree view zenith and 1150-m AGL to minimize spectral effects of the canopy understory; the change in altitude is required to maintain constant pixel size in the two cases.

Mission 3: Flux Tower Sites: Site Mapping
CASI Operating Mode: Spatial Mode, 15 channels
CASI Mission Flights: 48
Pixel Size: 2 x 4 m and 0.7 x 3 m
Swath Width: 1000 and 370 m

CASI imagery is expected to be the highest spatial resolution optical data available in the BOREAS data base and therefore has been of particular interest to a number of collaborators for quantifying the spatial heterogeneity of site-specific field measurements of parameters such as LAI, biomass, and canopy cover. This is of particular importance to the scaling up of boreal forest ecosystem state and

process parameters using remote sensing data. For these purposes, CASI multiband (15 channels) imagery has been collected at two altitudes (600 and 1675-m AGL) to cover the 1-km target area around each flux tower site at two spatial resolutions.

Mission 4: Flux Tower Sites: Stem Mapping
CASI Operating Mode: Spatial Mode, three channels (CIR spatial mode)
CASI Mission Flights: 28
Pixel size: 0.2 x 1 m
Swath Width: 90 m

For detailed studies a sub-meter spatial resolution is required: for canopy modeling, such detail is required to resolve individual trees and to identify shadow and sunlit canopy and sub-canopy components, as well as for community mapping of fen vegetation. This objective is beyond the CASI sensor's normal performance, but by limiting the number of spectral bands to three and flying between 150-m and 300-m AGL, this spatial resolution is approached. For the canopy modeling studies, such CASI data were collected along a specific ground transect line established by J. Chen (RSS-07) at each tower site. For the fen vegetation community studies, a few survey lines were collected for mosaicking into large high-resolution images.

Mission 5: Flux Tower Sites : PAR and Albedo
CASI Operating Mode: Hyperspectral Mode 404L_72C
CASI Mission Flights: 53
Pixel Size: 0.2 x 10 m
Swath Width: 90 m

With the CASI sensor modifications permitting collection of up and downwelling spectral irradiance data simultaneously with the normal imagery, flights at low altitude (150-m AGL) generate a measure of the spatial variability of the spectral albedo as well as the up and downwelling Photosynthetically Active Radiation (PAR). These data will also be used to measure the ratio of radiance in the GOES visible band to the total albedo for each canopy type, thereby enabling E. Smith (RSS-14) to generate seasonal albedo maps for the entire BOREAS region from GOES imagery. These same data are of interest to J. Cihlar (Terrestrial Ecology (TE)-16) and coworkers to validate models for satellite estimates of canopy absorbed PAR.

Mission 6: Lake Image Transects
CASI Operating Modes: Hyperspectral Mode 404L_72C
CASI Mission Flights: 10
Pixel Size: 2 x 11 m
Swath Width: 800 m

For IFCs 1 and 2, CASI imaging spectrometer data were collected on transects across Waskesiu and Candle Lakes at the SSA. This data collection was simultaneous with in situ water sampling and optical measurements of the above-surface and below-surface, up and downwelling spectral radiance and irradiances by R. Bukata and J. Jerome (TE-15). These combined data will be used for critical evaluation of models and algorithms to derive water constituent information such as concentrations of chlorophyll, dissolved organic content, and total suspended solids for Case 2 waters. This algorithm validation/evaluation activity is directly applicable to future satellite sensors such as the Medium Resolution Imaging Spectrometer (MERIS) and Sea-viewing Wide Field-of-view Sensor (SeaWiFS). During IFC-1, data from NASA's Airborne Ocean Color Imager (AOCI) (a prototype SeaWiFS satellite sensor) were flown simultaneously with CASI, offering the potential for evaluation of the critically important atmospheric correction algorithms for interpretation of water imagery.

Mission 7: Beaver Ponds
CASI Operating Mode: Spatial Mode, 15 channels
CASI Mission Flights: 9
Pixel Size: 0.7 x 3 m
Swath Width: 370 m

CASI multispectral imagery was collected, normally at 600-m AGL, at three NSA beaver pond sequences that were undergoing detailed field examination by N. Roulet (Trace Gas Biogeochemistry (TGB)-04). Differences and changes in dissolved organic carbon of these water bodies are expected to be manifested in spectral reflectance changes, particularly at blue wavelengths. The goal is to use CASI to determine whether there is sufficient distinction in the spatial/spectral domain to resolve beaver ponds and permit quantification of the areal extent of beaver ponds in the boreal landscape.

Mission 8: Auxiliary Sites
CASI Operating Mode: Spatial Mode, 15 channels
CASI Mission Flights: 135
Pixel Size: 2 x 4 m
Swath Width: 1000 m

CASI multispectral imagery (15 channels) was collected when possible (within aircraft and campaign time constraints), on a second priority basis, over some of the more than 65 BOREAS auxiliary sites identified to test and validate models.

Mission 9: Transects between SSA and NSA
CASI Operating Modes: Spatial Mode (15 channels) or Hyperspectral Mode
CASI Mission Flights: 5
Pixel Size: 3 x 5 m or 3 x 12 m
Swath Width: 1500 or 1160 m

CASI imagery was collected at least once in each of the Focused Field Campaign - Thaw (FFC-T), IFC-1, IFC-2, and IFC-3 campaigns at 2450-m AGL along the regional transect bridging the NSA and SSA. These data will be used to generate, where possible, transect profiles of surface parameters (and variability with 1-km-wide track swath) for comparison with similar parameters inferred from satellite imagery by collaborators.

Mission 10: Snow Course Lines
CASI Operating Mode: Spatial Mode, 7 channels
CASI Mission Flights: 37
Pixel Size: 2 x 4 m
Swath Width: 1000 m

CASI imagery was collected at 1675-m AGL along snow course lines that: (i) were ground sampled by B. Goodison (Hydrology (HYD)-04) for snow physical properties and (ii) were the subject of airborne profile sampling of gamma radiation (HYD-06) and microwave emissions (HYD-02). The optical CASI data will be used to map snow extent and snow depth in open areas.

Mission 11: Agriculture Line
CASI Operating Mode: Spatial Mode, 15 channels
CASI Mission Flights: 4
Pixel Size: 2 x 4 m
Swath Width: 1000 m

A transect was selected to characterize the agriculture to boreal forest transition at the SSA. This transect was subjected to intensive sampling by flux aircraft (Airborne Fluxes and Meteorology (AFM)-04) and was imaged with the CASI sensor in order to characterize the trends and variability of the vegetation growth along it.

Mission 12: Atmospheric Correction
CASI Operating Modes: Spatial Mode, 15 channels; 2 Hyperspectral Modes
CASI Mission Flights: 40
Pixel Size: various
Swath Width: various

A variety of multi-altitude, multi-view CASI flights were conducted, supported by surface-based and aircraft optical depth measurements, in order to evaluate methodologies being used to correct

optical airborne and satellite data from at-sensor radiance to surface reflectance. A system for acquiring downwelling radiance and total downwelling irradiance was installed alongside CASI on the aircraft to collect needed supplementary atmospheric optical data. These data were collected over (i) the RSS-19 site at the Prince Albert airport, which included canvas standard reflectance panels and an asphalt apron (for which BRDF characterization was conducted by RSS-19 personnel from Centre d'Applications et de Recherches en Teledetection (CARTEL), led by University of Sherbrooke researchers Dr. N.T. O'Neill and Dr. A. Royer); (ii) a tilled and rolled farmer's field used as an AVIRIS (NASA Jet Propulsion Laboratory (JPL)) calibration site (RSS-18); and (iii) a transect that included a new asphalt road, black spruce stands, and lakes (characterized by CARTEL researchers).

4.1.4 Key Variables

The CASI sensor directly measures the following quantities; target at-sensor radiance, and downwelling and upwelling irradiance. The irradiance measurements are experimental and are undergoing intensive investigation at CRESTech. These data may not be available for the 1994 BOREAS campaign.

4.1.5 Principles of Operation

CASI is a VIS/NIR push-broom imaging spectrograph with a reflection grating and a 2-D CCD solid-state array detector. The instrument operates by looking down in a fixed direction and imaging successive lines of the scene from the platform, building a 2-D image as the platform moves forward (Anger et al., 1990). The CASI instrument has been used in a variety of applications from forest cover mapping to pollution monitoring.

4.1.6 Instrument Measurement Geometry

Data were collected at various altitudes from 160-m AGL to 2600-m AGL. The CASI sensor can be tilted forward or aft of the aircraft. Data have been collected at a number of different sensor view angles from -45 to +45 degrees for investigations of BRDF effects.

4.1.7 Manufacturer of Instrument

Itres Instruments
#155, 2635-37th Avenue N.E.
Calgary, Alberta, Canada
T1Y 5Z6
(403) 250-9944
(403) 250-9916 (fax)

4.2 Calibration

The CASI instrument has been calibrated in the Instrument Services Laboratory at CRESTech. A two-stage approach was used to determine the absolute and relative radiometric response of the instrument. An integrating sphere (Thomas et al., 1991) was used to determine the relative response of the CCD array. For an absolute radiometric calibration, a calibrated Spectralon reflectance panel (Labsphere) and a National Research Council (NRC) traceable calibrated lamp were used. Dark current data were taken to remove any instrument-related anomalies. A more detailed description of the calibration can be found in Harron et al. (1995), Babey and Soffer (1992), and Gray et al. (1997).

Rare gas lamps were used as narrow line sources to determine the spectral calibration of the instrument. A narrow bandwidth tiltable filter was used to determine the spectral bandpass of the instrument at selected wavelengths. The transmission of the window used during data collection was characterized at a range of view angles to enable correction of CASI data to at-aircraft radiance.

Radiance imagery is converted to at-ground measured reflectance using a variant of the 5S radiative transfer code, referred to as CAM5S (O'Neill et al., 1996). This procedure allows correction of the imagery at aircraft altitudes for each pixel in the scene. This is a collaborative project between the University of Sherbrooke, the Canadian Space Agency, CRESTech, and the Canadian Centre for Remote Sensing (CCRS). Further details can be found in Gray et al., 1997.

For an estimate of the absolute calibration error, we used measurements of the NASA field

calibration sphere. In June of 1994, the CASI collected imagery of the sphere. Analysis of these images shows that between 500 and 800 nm, the difference between the CASI measured value and the NASA Calibration Sphere expected value (Schafer, 1994) was less than 5%. Only one set of radiance scale factors (or calibration coefficients) was used throughout the 1994 BOREAS field season. However, the calibration exercise was repeated several times during 1994. If we assume that the calibration setup did not change, analysis of this data reveals that the CASI response characteristics did not change by more than 3% during the time of the 1994 BOREAS project. We expect that the result for BOREAS 1996 imagery would be the same as 1994.

4.2.1 Specifications

(As given by instrument manufacturer Itres)

Field of View: 35.4 degrees across-track, 0.076 degrees along-track
Spectral Range: 545-nm spectral window between about 400 and 1000 nm
Spectral Samples: 288 max at 1.9-nm intervals
Spectral Resolution: 2.2-nm FWHM @ 650 nm
Aperture: f/2.8 to f/11.0
Dynamic Range: 12 bits
Noise Floor: 1.4 DN
Signal-to-Noise Ratio: 420:1 peak
Data Throughput: 420 Kb or greater

Operating Modes:

Spatial Mode:
512 spatial pixels, 19 spectral band maximum

Spectral Mode:
288 spectral pixels, 101 adjacent looks
48 spectral pixels, 511 adjacent looks

Full Frame Mode:
288 spectral pixels, 512 spatial pixels

Environmental Operating Conditions:

Temperature: 5 to 40 °C operating, -20 to +60 °C storage
Relative Humidity: 20% to 80% non-condensing, 10% to 90% non-condensing storage
Maximum Altitude: 3048 m above sea level (unpressurized)

4.2.1.1 Tolerance

None given.

4.2.2 Frequency of Calibration

Calibration data were collected for CASI before each IFC. While only one set of calibration data has been used to calculate the radiance scale factors, the other calibration data allow tracking of any changes in the instrument response.

4.2.3 Other Calibration Information

The CASI sensor viewed the NASA GSFC large integrating sphere during IFC-1. An interagency calibration experiment was conducted at the Instrument Services Laboratory involving CRESTech, NASA GSFC, and CCRS (Harron et al., 1995), that compared the calibration radiance sources used at these institutions. See Harron et al. (1995) for details.

5. Data Acquisition Methods

The CASI sensor is an airborne imaging spectrometer sensor with flexible operational characteristics. The spectral range of the CASI instrument used in the BOREAS project was 391 to 916 nm. The CASI sensor was flown aboard the Chieftain Navaho aircraft operated by the Ontario PRSO. Data were collected at various altitudes from 150-m AGL to 2600-m AGL. The CASI sensor can be tilted forward or aft of the aircraft. Data have been collected at a number of different sensor pitch angles for investigations of BDRF effects. Several CCD sampling configurations were used to collect imagery.

The CCD sensor is read out and digitized to 12 bits by a programmable electronics system that is controlled by an internal single-board computer. Data are recorded on a built-in digital recorder (Exabyte) that uses 8-mm videocassettes as the recording medium. The frame rate is configuration-dependent up to a maximum of 85 lines/sec. The CCD can be read out to select and sum rows, to create high spatial resolution bands, or sample columns from the array, to create high spectral resolution views. The CCD sampling configuration can be easily changed by the CASI instrument operator, and often several different sampling configurations are used during a data collection experiment.

6. Observations

6.1 Data Notes

None given.

6.2 Field Notes

CASI operator comments are recorded in flight logs stored as part of the CRESTech BOREAS CASI image data base. Examination of the incident light probe (ILP) data suggests that the atmospheric conditions varied by more than 10% but not more than 20% for the images, which are part of the current BORIS submission.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

Imagery was collected at the NSA and SSA tower flux sites and auxiliary sites, and along the transect between the NSA and SSA. The imagery swath width depends on acquisition aircraft altitude but is typically between 1 and 2 km. Imagery swath length depends on duration of data acquisition. Over the tower sites, images are usually less than 10 km long. Transect images, on the other hand, can be many tens of kilometers long.

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 512 image pixels across the FOV of 35 degrees give a 1.23-meter ground resolution (cross-track) per 1-km AGL altitude. The along-track ground resolution is approximately the product of the integration time and the aircraft speed. CASI image pixels are not generally square.

7.1.4 Projection

The imagery has been geocorrected and resampled to a Universal Transverse Mercator (UTM) NAD83-grid using GPS and attitude data. This geocorrection was performed to reorient the imagery to a map grid to aid in the interpretation of the imagery. The absolute positional accuracy of the imagery should not be considered high because of the limitations of the GPS and attitude data, but the relative positional accuracy is good.

7.1.5 Grid Description

The CASI data supplied to BORIS have been geocorrected using the onboard GPS and attitude data. The imagery has been resampled to UTM coordinates with a square pixel size of 2.0 meters. This correction is only to aid in the interpretation and seasonal comparison of the imagery. The absolute positional accuracy of the imagery should not be considered high.

A study of the accuracy of the geocorrection methodology was undertaken using 1996 CASI data of the NSA Fen (Zarco, 1998). Targets, 30 cm square, were placed throughout the Fen area. The coordinates of the targets were acquired by University of Nebraska researchers R. Steinauer and D. Jelinski (TF-10) using differential GPS. A comparison of the calculated location and the measured (GPS) location of the targets showed that the absolute error was about 30 m. The average relative error, i.e., error in the distance between two points, is estimated to be about 10 m.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

Image data were collected on 36 days during five field campaigns in 1994 between 07-February and 15-September.

7.2.2 Temporal Coverage Map

The following table contains the dates of the image data provided to BORIS. The entire CASI BOREAS image archive at CRESTech is more extensive. Please contact the PI or browse CRESTech's Web site for a complete list of dates of CASI image acquisitions (http://www.eol.crestech.ca).

Site	FFC-W*	FFC-T	IFC-1	IFC-2	IFC-3
SSA-OJP	07-Feb-1994	17-Apr-1994	31-May-1994	24-Jul-1994	13-Sep-1994
SSA-YJP	08-Feb-1994	17-Apr-1994	01-Jun-1994	24-Jul-1994	13-Sep-1994
SSA-Fen	07-Feb-1994	17-Apr-1994	04-Jun-1994	24-Jul-1994	13-Sep-1994
SSA-OBS	08-Feb-1994	19-Apr-1994	27-May-1994	24-Jul-1994	13-Sep-1994
SSA-OA	09-Feb-1994	16-Apr-1994	26-May-1994	23-Jul-1994	15-Sep-1994
NSA-OJP	10-Feb-1994	20-Apr-1994	06-Jun-1994	08-Aug-1994	07-Sep-1994
NSA-YJP	11-Feb-1994	20-Apr-1994	06-Jun-1994	08-Aug-1994	06-Sep-1994
NSA-Fen	n/a	20-Apr-1994	06-Jun-1994	08-Aug-1994	07-Sep-1994
NSA-OBS	10-Feb-1994	20-Apr-1994	06-Jun-1994	08-Aug-1994	06-Sep-1994
NSA-OA @	n/a	n/a	06-Jun-1994	08-Aug-1994	06-Sep-1994

* Obstacles encountered when attempting to process the winter data set to reflectance were not overcome and thus these data exist only as at-sensor radiance.
@ The BORIS archive does not contain the NSA-OA radiance data, BORIS has reflectance only for this site, please contact CRESTech for the radiance data.

7.2.3 Temporal Resolution

CASI imagery represents the measured instantaneous irradiance and reflected target at-sensor radiance. Frequently, multiple image acquisitions over a target were obtained during one day. On some occasions, data collections were repeated on more than one day during an IFC or FFC. Please refer to the image acquisition list provided to BORIS.

7.3 Data Characteristics

7.3.1 Parameter/Variable

The image parameters are:

Scaled radiance.
Scaled reflectance.

The parameters contained in the inventory files on the CD-ROM for CASI At-sensor Radiance and Reflectance images are:

Column Name
SPATIAL_COVERAGE
DATE_OBS
START_TIME
END_TIME
PLATFORM
INSTRUMENT
NUM_BANDS
BAND_QUALITY
CLOUD_COVER
CASI_SCAN_RATE
CASI_VIEW_ANG
PIXEL_RES
LINE_RES

NW_LATITUDE
NW_LONGITUDE
NE_LATITUDE
NE_LONGITUDE
SW_LATITUDE
SW_LONGITUDE
SE_LATITUDE
SE_LONGITUDE
PLATFORM_ALTITUDE
MIN_SOLAR_ZEN_ANG
MAX_SOLAR_ZEN_ANG
MIN_SOLAR_AZ_ANG
MAX_SOLAR_AZ_ANG
CRTFCN_CODE

7.3.2 Variable Description/Definition

The CASI at-sensor radiance imagery pixel digital numbers represent scaled at-aircraft radiance values. The CASI reflectance imagery pixel digital numbers represent scaled at-ground reflectance values. The descriptions of the parameters contained in the inventory files on the CD-ROM for both types of imagery are:

Column Name	Description
SPATIAL_COVERAGE	The general term used to denote the spatial area over which the data were collected.
DATE_OBS	The date on which the data were collected.
START_TIME	The starting Greenwich Mean Time (GMT) for the data collected.
END_TIME	The ending Greenwich Mean Time (GMT) for the data collected.
PLATFORM	The object (e.g., satellite, aircraft, tower, person) that supported the instrument.
INSTRUMENT	The name of the device used to make the measurements.
NUM_BANDS	The number of spectral bands in the data.
BAND_QUALITY	The data analyst's assessment of the quality of the spectral bands in the data.
CLOUD_COVER	The data analyst's assessment of the cloud cover that exists in the data.
CASI_SCAN_RATE	The scan rate used to acquire the CASI image.
CASI_VIEW_ANG	Along-track view angle of the sensor.
PIXEL_RES	The resampled image has a nominal pixel resolution of 2 square meters.
LINE_RES	The resampled image has a nominal pixel resolution of 2 square meters.
NW_LATITUDE	The NAD83 based latitude coordinate of the northwest 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 northeast corner of the minimum bounding rectangle for the data.

NE_LONGITUDE	The NAD83 based longitude coordinate of the northeast corner of the minimum bounding rectangle for the data.
SW_LATITUDE	The NAD83 based longitude coordinate of the southwest 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 longitude coordinate of the southeast corner of the minimum bounding rectangle for the data.
SE_LONGITUDE	The NAD83 based longitude coordinate of the southeast corner of the minimum bounding rectangle for the data.
PLATFORM_ALTITUDE	The nominal altitude of the data collection 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.
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

Radiance Imagery Units are Hundredths of W/(m^2 * µm * sr). That is, divide the scaled values by 100 to get at-sensor radiance values in W/(m^2 * µm * sr). Reflectance Imagery Units are % reflectance * 500. That is divide the scaled values by 500 to get percent reflectance values. The measurement units for the parameters contained in the inventory files on the CD-ROM for both types of imagery are:

Column Name	Units
SPATIAL_COVERAGE	[none]
DATE_OBS	[DD-MON-YY]
START_TIME	[HHMM GMT]
END_TIME	[HHMM GMT]
PLATFORM	[none]
INSTRUMENT	[none]
NUM_BANDS	[counts]
BAND_QUALITY	[none]
CLOUD_COVER	[none]
CASI_SCAN_RATE	[scan lines][second^-1]
CASI_VIEW_ANG	[degrees]
PIXEL_RES	[unitless]

LINE_RES	[unitless]
NW_LATITUDE	[degrees]
NW_LONGITUDE	[degrees]
NE_LATITUDE	[degrees]
NE_LONGITUDE	[degrees]
SW_LATITUDE	[degrees]
SW_LONGITUDE	[degrees]
SE_LATITUDE	[degrees]
SE_LONGITUDE	[degrees]
PLATFORM_ALTITUDE	[meters]
MIN_SOLAR_ZEN_ANG	[degrees]
MAX_SOLAR_ZEN_ANG	[degrees]
MIN_SOLAR_AZ_ANG	[degrees]
MAX_SOLAR_AZ_ANG	[degrees]
CRTFCN_CODE	[none]

7.3.4 Data Source

The sources of the CASI image data were the CASI sensor and the Center for Research in Earth and Space Technology (CRESTECH). The sources of the parameter values contained in the inventory files on the CD-ROM for both types of imagery are:

Column Name	Data Source
SPATIAL_COVERAGE	[Assigned by BORIS]
DATE_OBS	[CASI header file]
START_TIME	[CASI header file]
END_TIME	[CASI header file]
PLATFORM	[CASI header file]
INSTRUMENT	[CASI header file]
NUM_BANDS	[CASI header file]
BAND_QUALITY	[CASI header file]
CLOUD_COVER	[CASI header file]
CASI_SCAN_RATE	[CASI header file]
CASI_VIEW_ANG	[CASI header file]
PIXEL_RES	[CASI header file]
LINE_RES	[CASI header file]
NW_LATITUDE	[CASI header file]
NW_LONGITUDE	[CASI header file]
NE_LATITUDE	[CASI header file]
NE_LONGITUDE	[CASI header file]
SW_LATITUDE	[CASI header file]
SW_LONGITUDE	[CASI header file]
SE_LATITUDE	[CASI header file]
SE_LONGITUDE	[CASI header file]
PLATFORM_ALTITUDE	[CASI header file]
MIN_SOLAR_ZEN_ANG	[CASI header file]
MAX_SOLAR_ZEN_ANG	[CASI header file]
MIN_SOLAR_AZ_ANG	[CASI header file]
MAX_SOLAR_AZ_ANG	[CASI header file]
CRTFCN_CODE	[Assigned by BORIS]

7.3.5 Data Range

The digital numbers in the image files will range from 0 - 65,536. The following table gives information about the parameter values found in the data files on the CD-ROM.

CASI At-sensor Radiance Images:

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	07-FEB-94	15-SEP-94	None	None	None	None
START_TIME	1404	2143	None	None	None	None
END_TIME	1405	2145	None	None	None	None
PLATFORM	NAVAHO CHIEFTAIN	NAVAHO CHIEFTAIN	None	None	None	None
INSTRUMENT	N/A	N/A	None	None	None	None
NUM_BANDS	7	15	None	None	None	None
BAND_QUALITY	N/A	N/A	None	None	None	None
CLOUD_COVER	N/A	N/A	None	None	None	None
CASI_SCAN_RATE	19.27	33.29	None	None	None	None
CASI_VIEW_ANG	-5	0	None	None	None	None
PIXEL_RES	1.71	2.17	None	None	None	None
LINE_RES	1.7	3.83	None	None	None	None
NW_LATITUDE	53.63843	55.95204	None	None	None	None
NW_LONGITUDE	-106.23791	-98.28328	None	None	None	None
NE_LATITUDE	53.63594	55.94605	None	None	None	None
NE_LONGITUDE	-106.17867	-98.21297	None	None	None	None
SW_LATITUDE	53.57209	55.91876	None	None	None	None
SW_LONGITUDE	-106.24834	-98.30351	None	None	None	None
SE_LATITUDE	53.56735	55.91097	None	None	None	None
SE_LONGITUDE	-106.18801	-98.21984	None	None	None	None
PLATFORM_ALTITUDE	1689.7	2403.5	None	None	None	None
MIN_SOLAR_ZEN_ANG	33.3	77.9	None	None	None	None
MAX_SOLAR_ZEN_ANG	33.3	77.9	None	None	None	None
MIN_SOLAR_AZ_ANG	98.5	230	None	None	None	None
MAX_SOLAR_AZ_ANG	98.5	230	None	None	None	None
CRTFCN_CODE	CPI	CPI	None	None	None	None

CASI Reflectance Images:

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	15-SEP-94	None	None	None	None
START_TIME	1404	2118	None	None	None	None
END_TIME	1407	2121	None	None	None	None
PLATFORM	NAVAHO CHIEFTAIN	NAVAHO CHIEFTAIN	None	None	None	None
INSTRUMENT	N/A	N/A	None	None	None	None
NUM_BANDS	15	15	None	None	None	None
BAND_QUALITY	N/A	N/A	None	None	None	None
CLOUD_COVER	N/A	N/A	None	None	None	None
CASI_SCAN_RATE	19.27	19.27	None	None	None	None
CASI_VIEW_ANG	0	0	None	None	None	None

PIXEL_RES	0	2.11	None	None	None	None
LINE_RES	0	3.68	None	None	None	None
NW_LATITUDE	53.63646	55.94297	None	None	None	None
NW_LONGITUDE	-98.32127	-98.29217	None	None	None	None
NE_LATITUDE	53.63004	55.93541	None	None	None	None
NE_LONGITUDE	-98.26272	-98.23005	None	None	None	None
SW_LATITUDE	53.58731	55.92376	None	None	None	None
SW_LONGITUDE	-98.34373	-98.31119	None	None	None	None
SE_LATITUDE	53.57732	55.91852	None	None	None	None
SE_LONGITUDE	-98.2818	-98.25267	None	None	None	None
PLATFORM_ALTITUDE	135.7	2437.3	None	None	None	None
MIN_SOLAR_ZEN_ANG	72.4	97.1	None	None	None	None
MAX_SOLAR_ZEN_ANG	72.4	97.1	None	None	None	None
MIN_SOLAR_AZ_ANG	119.5	216.5	None	None	None	None
MAX_SOLAR_AZ_ANG	119.5	216.5	None	None	None	None
CRTFCN_CODE	CPI	CPI	None	None	None	None

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

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

7.4 Sample Data Record

The following are data record from a sample data file on the CD-ROM:

```
SPATIAL_COVERAGE,DATE_OBS,START_TIME,END_TIME,PLATFORM,INSTRUMENT,NUM_BANDS,
BAND_QUALITY,CLOUD_COVER,CASI_SCAN_RATE,CASI_VIEW_ANG,PIXEL_RES,LINE_RES,
NW_LATITUDE,NW_LONGITUDE,NE_LATITUDE,NE_LONGITUDE,SW_LATITUDE,SW_LONGITUDE,
SE_LATITUDE,SE_LONGITUDE,PLATFORM_ALTITUDE,MIN_SOLAR_ZEN_ANG,MAX_SOLAR_ZEN_ANG,
MIN_SOLAR_AZ_ANG,MAX_SOLAR_AZ_ANG,CRTFCN_CODE
'SSA-9OA',16-APR-94,1602,1603,'NAVAHO CHIEFTAIN','CASI',15,'NOT ASSESSED',
'NOT ASSESSED',19.27,0.0,0.0,0.0,53.63646,-98.31321,53.63004,-98.25458,
53.61682,-98.31931,53.61039,-98.26071,2211.3,82.1,82.1,142.5,142.5,'CPI'
'SSA-FEN',17-APR-94,1724,1725,'NAVAHO CHIEFTAIN','CASI',15,'NOT ASSESSED',
'NOT A SSESSED',19.27,0.0,0.0,0.0,53.81175,-98.31979,53.80323,-98.2417,53.77206,
-98.332 15,53.76355,-98.25414,2162.2,76.3,76.3,161.0,161.0,'CPI'
```

8. Data Organization

8.1 Data Granularity

The smallest unit of data tracked by BORIS is a set of 1994 at-sensor radiance or reflectance data collected at a given site on a given day.

8.2 Data Format

8.2.1 Uncompressed Data Files

The Compact Disk-Read-Only Memory (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 CASI image product consists of the following two files:

```
File 1:  Header file containing American Standard Code for Information
         Interchange (ASCII) characters (80 bytes per record)
File 2:  Binary image data file in Band Interleaved by Line (BIL) format
```

The pixel values in the image data files are stored in 2-bytes (high-order byte first). The image size and number of bands varies depending on the CASI CCD sampling configuration. The ASCII header file describes the number of pixels, bands and lines. Note that extra bytes were found at the end of the at-sensor radiance image files. This was either an artifact of the image processing package used to write the image files or it may have been due to problems noted in section 11.2. In either case we have not found that it affects the reading or importing of the data.

The following set of lines shows the type of information contained in a sample header file.

```
                *** BOREAS CASI IMAGE HEADER ***
                ---------------------------------

Comment                              : BOREAS - NSA, FEN
BOREAS Site Identifier               : FEN
Image Identifier                     : Tape: 197 File: 14
```

DATE AND MISSION INFORMATION

Date (DD-MM-YYYY) (GMT)	: 07-09-1994
Start Time (GMT) (HH:MM:SS)	: 21:18:42.000000
Stop Time (GMT) (HH:MM:SS)	: 21:21:10.000000
Study Area	: BOREAS - NSA
Altitude (m) (ASL)	: 1754.30
Heading (deg CW from North)	: 49.3353
Ground speed (m/s)	: 61.8243
Site Name	: FEN
Frame Rate (1/s)	: 19.27
Platform	: C-GCJX Navaho
Image Mode	: Imaging
Start Latitude, Longitude	: 55.9362, -98.3755
Stop Latitude, Longitude	: 55.8827, -98.4863

CALIBRATION INFORMATION

Is data calibrated ?	: yes
Calibration file	: e223f40.rad
Calibration Date (DD-MM-YYYY)	: 01-11-1996
Calibration Scale Factor	: 50000
Calibration Units	: Reflectance
Along track look angle (deg)	: 0
Across track look swath (deg)	: 35.4
Center pixel size across track (m)	: 1.82
Center pixel size along track (m)	: 3.20
Wavelengths (nm)	: 409.70 443.17 490.90 520.10 565.40 619.80
Wavelengths (nm) (continued)	: 665.50 682.51 709.47 742.0 750.00 769.00
Wavelengths (nm) (continued)	: 799.80 880.70 905.40
Fstop	: 4.0
Bandset	: ffct15
Lens Identifier	: Not Specified

IMAGE SIZE AND FORMAT INFORMATION

Number of lines original image	: 2660
Number of pixels original image	: 512
Num lines (Geocorrected image)	: 1760
Num pixels (Geocorrected image)	: 672
Num of lines offset original	: 68
Num of lines from original	: 2008
Number of bands	: 15
Data type	: 2 byte, big endian, integer
Interleave mode	: BIL
Bands Present	: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Tape Record Size	:
Image Record Size	:
Number of Header Records	: 0
Number of Bytes / Header Record	: 0

8.2.2 Compressed CD-ROM Files

On the BOREAS CD-ROMs, the inventory files are stored as ASCII text files, as are the image header files (.hdr). However, the image data files have been compressed with the Gzip compression program (file name *.gz). These data have been compressed using gzip version 1.2.4 and the high compression (-9) option (Copyright (C) 1992-1993 Jean-loup Gailly). Gzip (GNU zip) 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 websites (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

Radiance can be derived from the formula: Rad=DN/100
Reflectance can be derived from the formula: Ref(%) = (DN/500)

9.2 Data Processing Sequence

9.2.1 Processing Steps

Radiance Imagery:

- Instrument operator's flight logs entered into imagery data base.
- Raw CASI data dumped from Exabyte tape to disc.
- Graphic Interchange Format (GIF) quicklook imagery derived from raw data to allow imagery browsing.
- GPS data extracted from CASI raw imagery. Imagery data base updated with
- GPS values for image acquisition time, altitude, heading, and speed.
- CASI raw data calibrated, using radiance scale factors, to radiance.
- Output file is in PCIDSK format.
- Attitude data (Gyro) extracted from file.
- Image geocorrected using GPS and attitude data. Resampled to desired grid size.
- PCIDSK format rewritten to BIL binary format for BORIS submission.
- ASCII header file created, one per imagery file.

Reflectance Imagery:

- Instrument operator's flight logs entered into imagery data base.
- Raw CASI data dumped from Exabyte tape to disc.
- GIF quicklook imagery derived from raw data to allow imagery browsing.
- GPS data extracted from CASI raw imagery. Imagery data base updated with GPS values for image acquisition time, altitude, heading, and speed.
- CASI raw data calibrated, using radiance scale factors, to radiance.
- Output file is in PCIDSK format.
- Atmospheric correction control file created using sunphotometer data and sensor geometry information.
- Radiance image (from step 5) corrected to at-ground modeled reflectance using CAM5S.
- Attitude data (Gyro) extracted from file.
- Image geocorrected using GPS and attitude data. Resampled to desired grid size.
- PCIDSK format rewritten to BIL binary format for BORIS submission.
- ASCII header file created, one per imagery file

9.2.2 Processing Changes
None.

9.3 Calculations
None given.

9.3.1 Special Corrections/Adjustments
None given.

9.3.2 Calculated Variables
None given.

9.4 Graphs and Plots
None.

10. Errors

10.1 Sources of Error
The absolute positional accuracy of the imagery should not be considered high because of limitations of the GPS and attitude data.

10.2 Quality Assessment
All images submitted to BORIS have been checked to ensure that:
- All channels are saved.
- No obvious sensor anomalies exist.
- The target has been acquired.

10.2.1 Data Validation by Source
None given.

10.2.2 Confidence Level/Accuracy Judgment
None given.

10.2.3 Measurement Error for Parameters
None given.

10.2.4 Additional Quality Assessments
None given.

10.2.5 Data Verification by Data Center
BORIS personnel reviewed a random sample of the images by reading them online and displaying the images on a terminal screen. No particularly anomalous items were noted in the visual review, however ORNL discovered the image size discrepancy noted in section 11.2.

11. Notes

11.1 Limitations of the Data
The imagery has been geocorrected and resampled to aid in the interpretation of the imagery. The absolute positional accuracy of the imagery should not be considered high because of limitations of the GPS and attitude data.

11.2 Known Problems with the Data

- Four data files have fewer bytes than required by the number of rows and columns ("lines" and "pixels") listed in the header files. These are:
  - SSA-FEN radiance image from 13-Sep-1994, 18:01 GMTHeader lists 1603 rows, 1072 columns.Correct values are 1063 rows, 1072 columns.
  - NSA-OJP radiance image from 10-Feb-1994, 20:32 GMTHeader lists 611 rows, 621 columns.Correct values are 606 rows, 610 columns.
  - NSA-YJP radiance image from 11-Feb-1994, 20:27 GMTHeader lists 808 rows, 649 columns.Correct values are 546 rows, 558 columns.
  - NSA-OJP reflectance image from 07-Sep-1994, 20:59 GMT Header lists 2965 rows, 2693 columns. Correct values are UNKNOWN. The pattern of non-zero bytes in the binary data combined with the file size suggest 2694 rows and 2693 columns, but using values close to these proved unsuccessful.

- NSA-OA reflectance image from 06-Jun-1994, 18:52 GMT, lists the reflectance scaling factor as 100. The data values suggest that the header value should be corrected to 50000 in agreement with that of other reflectance images.

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 given.

12. Application of the Data Set

The CASI images can be used for detailed spectral analysis of the various boreal vegetation types and for characterizing the BOREAS site for modeling purposes.

13. Future Modifications and Plans

None given.

14. Software

14.1 Software Description

Software exists at CRESTech to manipulate and analyze the CASI data in the PCIDSK format. Software has been developed at CRESTech to calibrate the CASI imagery from its native tape format to calibrated radiance and then to modeled at-ground reflectance. Additional software modules can generate a "red edge" image from the reflectance. Other image map products are being developed. While the software works on the PCIDSK file format, the PCI EASI/PACE product is not required.

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

14.2 Software Access

For information about available software, please contact the individuals named in Section 2.

Gzip is available from many WWW-sites across the net (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 RSS-19 1994 CASI 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

CASI image data are available on 8-mm tape media.

16.2 Film Products

None.

16.3 Other Products

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

Color GIF images of the BORIS subset are available and additional imagery can be viewed on the CRESTech World Wide Web (WWW) site (http://www.eol.crestech.ca/).

The following ancillary data may be of interest:

- GPS data.
- Gyro data.
- Upwelling and downwelling light probe data, which may become available.

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17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

AC	- Alternating Current
AFM	- Airborne Fluxes and Meteorology
AGL	- Above Ground Level
AOCI	- Airborne Ocean Color Imager
ASAS	- Advanced Solid-state Array Spectroradiometer
ASCII	- American Standard Code for Information Interchange
AVHRR	- Advanced Very High Resolution Radiometer
AVIRIS	- Airborne Visible and Infrared Imaging Spectroradiometer
B/GHRIS	- BOREAS Global Hypermedia Research Information System
BIL	- Band Interleaved by Line
BOREAS	- BOReal Ecosystem-Atmosphere Study
BORIS	- BOREAS Information System
BRDF	- Bidirectional Reflectance Distribution Function
BSQ	- Band Sequential
CARTEL	- Centre d'Applications et de Recherches en Teledetection
CASI	- Compact Airborne Spectrographic Imager
CCD	- Charge-Coupled Device
CCRS	- Canada Centre for Remote Sensing
CD-ROM	- Compact Disk-Read-Only Memory
CRESTech	- Centre for Research in Earth and Space Technology
DC	- Direct Current
EOL	- Earth Observations Laboratory
EOS	- Earth Observing System
EOSDIS	- EOS Data and Information System
FFC-T	- Focused Field Campaign - Thaw
FFC-W	- Focused Field Campaign - Winter
FOV	- Field of View
FWHM	- Full Width, Half Maximum
GIF	- Graphic Interchange Format
GIS	- Geographic Information System
GMT	- Greenwich Mean Time
GOES	- Geostationary Operational Environmental Satellite
GPS	- Global Positioning System
GSFC	- Goddard Space Flight Center
HYD	- Hydrology
IFC	- Intensive Field Campaign

ILP - Incident Light Probe
ISTS - Institute for Space and Terrestrial Science
JPL - Jet Propulsion Laboratory
LAI - Leaf Area Index
MAS - MODIS Airborne Simulator
MERIS - Medium Resolution Imaging Spectrometer
MODIS - Moderate Resolution Imaging Spectrometer
NAD83 - North American Datum of 1983
NASA - National Aeronautics and Space Administration
NRC - National Research Council
NSERC - Natural Sciences and Engineering Research Council
NSA - Northern Study Area
OA - Old Aspen
OBS - Old Black Spruce
OJP - Old Jack Pine
ORNL - Oak Ridge National Laboratory
PANP - Prince Albert National Park
PAR - Photosynthetically Active Radiation
PARABOLA - Portable Apparatus for Rapid Acquisition of Bidirectional Observations of Land and Atmosphere
PI - Principal Investigator
PRSO - Provincial Remote Sensing Office
RSS - Remote Sensing Science
SeaWiFS - Sea-viewing Wide Field-of-View Sensor
SPOT - Satellite Pur l'Observation de la Terre
SSA - Southern Study Area
SSM/I - Special Sensor Microwave/Imager
TE - Terrestrial Ecology
TF - Tower Flux
TGB - Trace Gas Biogeochemistry
TM - Thematic Mapper
TMS - Thematic Mapper Simulator
URL - Uniform Resource Locator
UTM - Universal Transverse Mercator
VIS/NIR - Visible/Near-Infrared
WWW - World Wide Web
YJP - Young Jack Pine

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13. ABSTRACT *(Maximum 200 words)*

The RSS-19 team collected CASI images from the Chieftain Navaho aircraft in order to observe the seasonal change in the radiometric reflectance properties of the boreal forest landscape. CASI was deployed as a site-specific optical sensor during BOREAS field campaigns. Image data were collected with CASI on 36 days during five field campaigns between February and September 1994, primarily at flux tower sites located at study sites near Thompson, Manitoba, and Prince Albert, Saskatchewan. A variety of CASI data collection strategies were used to meet the following scientific objectives: 1) canopy bidirectional reflectance, 2) canopy biochemistry, 3) spatial variability, and 4) estimates of up and downwelling PAR and spectral albedo, as well as changes along transects across lakes and transects NSA and SSA. The images are stored as binary image files.

A subset of the 1994 CASI acquisitions have been compressed and included on the BOREAS CD-ROM set. This subset includes 3 images for the NSA-OBS site on 06-Jun-94, 08-Aug-94, and 06-Sep-94; one image for the SSA-OBS site on 24-Jul-94; and one image for the NSA-Fen site on 08-Aug-94. The CASI imagery on the BOREAS CD-ROMs have been compressed using the Gzip program. See section 8.2 for details. The rest of the 1994 BOREAS CASI archive are not contained on the BOREAS CD-ROM set. Inventory listing files are supplied on the CD-ROM to inform users of the data that were collected. See Sections 15 and 16 for information about how to acquire the data. Also see Section 11.2 for notes about anomalies found with a few of the image sizes.

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