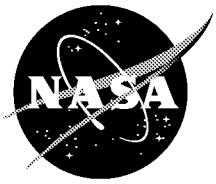
https://ntrs.nasa.gov/search.jsp?R=20010022246 2018-05-14T18:52:22+00:00Z

NASA/TM—2000–209891, Vol. 88



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

Forrest G. Hall and Jeffrey Newcomer, Editors

Volume 88

BOREAS Level-2 MAS Surface Reflectance and Temperature Images in BSQ Format

Brad Lobitz and Michael Spanner, Johnson Controls World Services,
NASA Ames Research Center, Moffett Field, California
Richard Strub, Raytheon ITSS

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

September 2000

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Brad Lobitz, Michael Spanner, Richard Strub

Summary

The BOREAS Staff Science Aircraft Data Acquisition Program focused on providing the research teams with the remotely sensed aircraft data products they needed to compare and spatially extend point results. The MAS images, along with other remotely sensed data, were collected to provide spatially extensive information over the primary study areas. This information includes biophysical parameter maps such as surface reflectance and temperature. Collection of the MAS images occurred over the study areas during the 1994 field campaigns. The level-2 MAS data cover the dates of 21-Jul-1994, 24-Jul-1994, 04-Aug-1994, and 08-Aug-1994. The data are not geographically/geometrically corrected; however, files of relative X and Y coordinates for each image pixel were derived by using the C130 navigation data in a MAS scan model. The data are provided in binary image format files.

Note that due to storage space limitations, only the level-2 MAS images collected on 21-Jul-1994 are included on the BOREAS CD-ROM series. Users interested in images from other dates should refer to the inventory listing provided on the CD-ROMs and Section 15 to determine how to obtain the data of interest. Some of the image data files on the BOREAS CD-ROMs have been compressed using the Gzip program. See Section 8.2 for details.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS Level-2 MAS Surface Reflectance and Temperature Images in BSQ Format

1.2 Data Set Introduction

The BOReal Ecosystem-Atmosphere Study (BOREAS) Staff Science effort covered those activities that were BOREAS community-level activities, or required uniform data collection procedures across sites and time. These activities included the acquisition of the relevant aircraft image data. Data from the Moderate Resolution Imaging Spectroradiometer (MODIS) Airborne Simulator (MAS) onboard the National Aeronautics and Space Administration (NASA) C130 aircraft were acquired by staff of the Medium Altitude Aircraft Branch at NASA Ames Research Center (ARC) and provided for use by BOREAS researchers. BOREAS Information System (BORIS) personnel worked with MAS personnel at NASA Goddard Space Flight Center (GSFC) in processing the MAS and related C130 navigation data to derive and archive the 12-band level-1b MAS imagery. The level-1b MAS imagery were atmospherically corrected by personnel at NASA ARC to generate the 12-band level-2 MAS imagery.

1.3 Objective/Purpose

For BOREAS, the MAS data, along with the other remotely sensed images, were collected 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). The MAS data were also to serve as test data sets for the MODIS Land Group (MODLAND) in exercising its parameter derivation algorithms.

1.4 Summary of Parameters

Level-2 MAS data in the BORIS contain the following parameters:

- descriptive information as American Standard Code for Information Interchange (ASCII) text records
- reflectance values for image bands 1 to 12
- relative X and Y pixel coordinates
- per pixel view zenith and azimuth angles

1.5 Discussion

BORIS personnel at NASA GSFC created the level-1b MAS imagery by:

- Extracting aircraft location and attitude information from BOREAS level-0 C130 navigation data.
- Combining MAS image and C130 navigation data to make a Hierarchical Data Format (HDF) file.
- Extracting image and ancillary information from the HDF file and reformatting it into a band sequential (BSQ) format 8-mm tape product for distribution, and creating a descriptive inventory of the MAS data product in the BORIS data base.

ARC personnel created the level-2 MAS imagery by:

- Obtaining the level-1b MAS imagery from BORIS.
- Obtaining radiosonde data from BORIS.
- Modeling the path transmittance and path radiative emission (thermal channels) using a Moderate Resolution Model of LOWTRAN7 (MODTRAN).
- Modeling the path water vapor column concentration and downwelling irradiance using the Second Simulation of the Satellite Signal in the Solar Spectrum (6S).
- Processing the imagery using NASA ARC's Image Atmospheric Correction (Imagecor) program.

1.6 Related Data Sets

BORIS Level-1b MAS Imagery: At-sensor Radiance in Band Sequential Format
BOREAS RSS-12 Airborne Tracking Sunphotometer Measurements
BOREAS RSS-12 Automated Ground Sunphotometer Measurements in the SSA

2. Investigator(s)

2.1 Investigator(s) Name and Title

Robert C. Wrigley (retired) Principal Investigator

Co-Investigators:
Michael A. Spanner NASA ARC
Robert E. Slye NASA ARC

2.2 Title of Investigation

BOREAS Staff Science Aircraft Data Acquisition Program

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3. Theory of Measurements

MODIS was developed as part of the Earth Observing System (EOS) to meet the scientific needs for global remote sensing of clouds, aerosols, water vapor, land, and ocean properties from space. MODIS is scheduled to be launched in 1999 on the EOS AM-1 platform (King et al., 1995). In support of MODIS remote sensing algorithm development, the MAS was developed by Daedalus Enterprises, Inc., for NASA's high-altitude ER-2 research aircraft, and is an outgrowth of the development of the Wildfire infrared imaging spectrometer. In a cooperative effort between the High Altitude Missions Branch at NASA ARC and the MODIS science team, Wildfire was converted to the MAS and upgraded over a series of several experiments, starting with the First International Satellite Cloud Climatology Project (ISCCP) Regional Experiment (FIRE II) cirrus campaign in November 1991.

The locations of the MAS spectral channels were chosen to enable a wide variety of Earth science applications. Of the 50 MAS channels, 19 have corresponding channels on MODIS. The remaining MAS channels fill in the spectral region around MODIS locations and some provide unique coverage.

One application of the MAS solar channels is the study of cloud properties at high spatial resolution. The majority of the molecular absorption in the shortwave region of the solar spectrum is due to water vapor, with some ozone absorption in the broad Chappuis band (~0.6 µm) continuum. The reflectance measurements in the 1.61-, 2.13-, and 3.74-µm windows provide useful information

on the cloud droplet size. Reflectance measurements in the visible wavelength region, in contrast, show little variation with droplet size and can thus be used to retrieve cloud optical thickness (cf. Twomey, 1989; Nakajima and King, 1990). The reflectance at 0.94 µm is attenuated by atmospheric water vapor; these measurements, in conjunction with spectrally close atmospheric window reflectances, can provide an estimate of the total precipitable water in cloud-free regions (Kaufman and Gao, 1992).

Cloud properties can also be estimated from the thermal bands. In the 3.7 µm window, both solar reflected and thermal emitted radiation are significant, though the use of the reflectance for cloud droplet size retrieval is seen to be much more sensitive than the thermal component. CO_2 absorption is important around 4.3 µm and at wavelengths greater than about 13 µm. The MAS bands in these spectral regions can indicate vertical changes of temperature. The 4.82- to 5.28-µm channels are useful for investigating both horizontal and vertical distributions of moisture. Low level moisture information is available in the split window measurements at 11.02 and 11.96 µm, and correction for moisture attenuation in the infrared windows at 3.90, 11.02, and 11.96 µm enables estimation of sea surface skin temperature (Smith et al., 1995).

The MAS infrared spectral bands enable the study of cloud properties at high spatial resolution. Products include cloud thermodynamic phase (ice vs. water, clouds vs. snow), cloud top properties, and cloud fraction. The cloud top properties (height, temperature, and effective emissivity) can be investigated using the CO_2 slicing algorithm (Wylie et al., 1994) that corrects for cloud semitransparency with the MAS infrared CO_2 bands at 11.02, 13.23, and 13.72 µm. Cloud phase can be obtained using MAS 8.60-, 11.02-, and 11.96-µm brightness temperature differencing (Strabala et al., 1994) as well as by using visible reflection function techniques (King et al., 1992) utilizing ratios of the MAS 1.61- and 0.66-µm bands.

In addition to the remote sensing of cloud radiative and microphysical properties, the MAS is of value for the remote sensing of land and water properties under channel clear-sky conditions. MAS visible and near-infrared channels have been used to estimate suspended sediment concentration in near-shore waters and to identify water types (Moeller et al., 1993; Huh et al., 1995). Land vegetation properties can also be studied.

In a cooperative effort between Dr. M. King (Code 900, NASA GSFC), BOREAS scientists, and the NASA ARC C130 missions staff, the MAS was installed into the NASA C130 aircraft for use during the 1994 summer field campaign of BOREAS.

4. Equipment

4.1 Sensor/Instrument Description

In support of MODIS remote sensing algorithm development, the MAS was developed by Daedalus Enterprises, Inc., for NASA's high-altitude ER-2 research aircraft. Over the past several years, upgrades included new detector arrays, grating modifications, an improved broadband lens for the infrared channels, new Dewars, and various electronics improvements, all of which resulted in improved in-flight radiometric performance. The overall goal was to modify the spectral coverage and gains of the MAS to emulate as many of the MODIS spectral channels as possible. With its much higher spatial resolution (50 m vs. 250-1,000 m for MODIS), MAS is able to provide unique information on the small-scale distribution of various geophysical parameters. Originally, and for the BOREAS deployment, MAS used a 12-channel, 8-bit data system that somewhat constrained the full benefit of having a 50-channel scanning spectrometer. Beginning in January 1995, a 50-channel, 16-bit digitizer was used, which greatly enhanced the capability of MAS to simulate MODIS data over a wide range of environmental conditions. The 12-data channels configured for the BOREAS Intensive Field Campaign (IFC)-2 C130 flights were:

Data Channel	MAS Spectral Channel	Center Wavelength (μm)	Spectral Feature
01	01	0.547	green peak
02	02	0.664	chlorophyll
03	04	0.745	NIR plateau
04	05	0.786	NIR plateau
05	06	0.834	NIR plateau
06	07	0.875	aerosols
07	09	0.945	water vapor
08	10	1.623	pollutants
09	20	2.142	mid-IR water
10	32	3.900	
11	45	11.002	surface temperature
12	46	12.032	surface temperature

A total of 716 Earth-viewing pixels are acquired per scan at a scan rate of 6.25 Hz. Information provided by the aircraft inertial navigation system is used to adjust the timing of the digitizer, providing up to 3.5 degrees of roll compensation, in 0.03-degree increments.

4.1.1 Collection Environment

As part of the BOREAS Staff Science data collection effort, the ARC Medium Altitude Aircraft Branch collected the 12-band MAS multispectral scanner data. The MAS was flown on NASA's C-130 aircraft during BOREAS (see the BOREAS Experiment Plan for flight pattern details and objectives). The MAS was flown at medium altitudes aboard NASA's C-130 aircraft based at NASA ARC and provided 20-meter spatial resolution at nadir at an altitude of 7,500 meters.

4.1.2 Source/Platform

For the BOREAS missions in 1994, the MAS was mounted in the NASA C130 aircraft operated by NASA ARC.

4.1.3 Source/Platform Mission Objectives

The C130 mission objectives for BOREAS were to acquire high-resolution digital imagery with a variety of sensors during optimally clear days of the BOREAS field effort in 1994.

4.1.4 Key Variables

Emitted radiation, reflected radiation, and temperature.

4.1.5 Principles of Operation

The optical system of the MAS is composed of a configuration of dichroic beam splitters, collimating mirrors, folding mirrors, diffraction gratings, filters, lenses, and detector arrays. Both the spectrometer and fore optics portions are mounted to an aluminum optical baseplate assembly, which are pinned and mated.

A full face scan mirror canted 45 degrees to the along-track direction directs light into an afocal Gregorian telescope followed by a fold mirror that directs light back through a field stop aperture. A 2.5-cm Pfund assembly paraboloid forms a collimated image of the aperture, which strikes a fold mirror that directs the incoming radiation upward into the aft optics spectrometer unit Thermal and dark visible references are viewed on the backscan rotation of the scan mirror. The thermal reference sources are two blackened copper plate temperature-controllable blackbodies. One blackbody is viewed prior to the Earth-viewing (active scan) portion of the scan, while the other is viewed following the active scan. The telescope alignment is maintained under the low-temperature environment using Invar steel and aluminum structural components.

The spectrally broadband energy transmitted and reflected by the dichroics is dispersed onto the detector arrays from blazed diffraction gratings. The bandpass of a channel is determined by the

geometry of the detector monolithic array and its location with respect to the grating.

The radiation transmitted by the first dichroic (D1) is reflected by a mirror and diffracted by grating G1 onto a filter and lens assembly that focuses the radiation onto a silicon photovoltaic array with channel response in the wavelength range from 0.55 to 0.95 μm (channels 1-9). Part of the radiation reflected by D1 reflects off the second dichroic (D2) and is redirected by two fold mirrors, diffracted by grating G2, passed through a cold blocking filter, and focused onto an indium-antimonide (InSb) focal plane array assembly containing channels 10-25 (1.61 to 2.38 μm). From D2 the remainder of the spectrally separated energy strikes the third dichroic D3, part of which is reflected and enters port 3, where it is redirected by two fold mirrors, diffracted by grating G3, and focused onto another InSb detector array that defines band-pass characteristics for channels 26-41 (2.96 to 5.28 μm). The remainder of the energy from the scanner is transmitted through dichroic D3 into port 4, where it encounters a fold mirror, diffraction grating G4, and lens that focuses the thermal radiation onto three separate mercury-cadmium-telluride (HgCdTe) detector arrays, each with its own cold-filter to improve the signal-to-noise ratio in its respective wavelength range. Port 4 senses radiation in the wavelength range from 8.60 to 14.17 μm (channels 42-50). The InSb and HgCdTe detectors are cryogenically cooled by liquid nitrogen to 77 K in pressurized Dewars. The following table shows the spectral and radiometric characteristics of each MAS channel in the complete 50 channel system. Spectral resolution, defined as the full-width at half-maximum bandwidth of the channel, ranges from around 40 nm in the visible and infrared to about 450 nm in the thermal infrared.

MAS channel	MODIS channel	Central Wavelength (μm)	Spectral Res. (μm)	Equiv Noise*	Scene Temp (K)**	Saturation Level +	Signal-to noise ratio**
1	4	0.547	0.044	0.335		867	45.2 - 1052
2	1	0.657	0.053	0.157		1035	44.6 - 1948
3		0.704	0.042	0.178		1323.	28.7 - 1586
4	15	0.745	0.041	0.180		1412	21.5 - 1406
5		0.786	0.041	0.254		1638	12.4 - 912
6		0.827	0.042	0.237		1890	10.7 - 923
7	2	0.869	0.042	0.281		1935	8.1 - 728
8	7	0.909	0.033	0.150		314	14.9 - 1232
9	19	0.947	0.046	0.226		1600	5.5 - 720
10	6	1.609	0.052	0.039		892	4.5 - 397
11		1.663	0.052	0.029		272	5.8 - 570
12		1.723	0.050	0.026		252	5.1 - 659
13		1.775	0.049	0.026		244	2.8 - 624
14		1.825	0.046	0.025		246	1.3 - 503
15		1.879	0.045	0.029		232	1.1 - 289
16		1.932	0.045	0.014		58	1.4 - 257
17		1.979	0.048	0.019		193	1.7 - 93
18		2.030	0.048	0.022		195	2.0 - 88
19		2.080	0.047	0.012		53	3.8 - 221
20	7	2.129	0.047	0.003		55	1.0 - 1309
21		2.178	0.047	0.023		211	2.3 - 255
22		2.227	0.047	0.026		240	2.0 - 245
23		2.276	0.046	0.027		263	1.6 - 198
24		2.327	0.047	0.026		268	1.5 - 140
25		2.375	0.047	0.033		329	1.0 - 83
26		2.960	0.160	9.780	291	TBD	1.7
27		3.110	0.160	7.050	284	TBD	2.4
28		3.280	0.160	3.090	284	TBD	5.9
29		3.420	0.170	1.280	291	TBD	15.7
30		3.590	0.160	0.720	293	TBD	29.7

31	20	3.740	0.150	0.470	293	TBD	47.5	
32	21	3.900	0.170	0.370	292	TBD	62.4	
33	23	4.050	0.160	0.300	289	TBD	78.2	
34		4.210	0.160	0.810	257	TBD	23.8	
35		4.360	0.150	1.740	234	TBD	9.5	
36	25	4.520	0.160	0.280	272	TBD	83.2	
37		4.670	0.160	0.140	289	TBD	192.9	
38		4.820	0.160	0.130	286	TBD	210.2	
39		4.970	0.150	0.120	286	TBD	234.9	
40		5.120	0.160	0.140	280	TBD	199.7	g
41		5.280	0.160	0.180	275	TBD	153.7	
42	29	8.600	0.440	0.140	292	TBD	363.2	
43	30	9.790	0.620	0.120	287	TBD	465.0	
44		10.55	0.490	0.090	294	TBD	697.7	
45	31	11.02	0.540	0.100	294	TBD	654.7	
46	32	11.96	0.450	0.190	294	TBD	370.9	
47		12.88	0.460	0.460	291	TBD	161.2	
48	33	13.23	0.470	0.490	283	TBD	147.0	
49	35	13.72	0.600	1.320	256	TBD	46.7	
50	36	14.17	0.420	2.000	229	TBD	25.5	

* Noise equivalent DI ($W/m^2/mm/sr$) for channels 1-25; noise equivalent temperature difference NEDT (K) for channels 26-50. All noise measurements are based on in-flight measurements over the Gulf of Mexico on 16 January 1995.

** The thermal data (channels 26-50) are based on in-flight measurements over the Gulf of Mexico on 16 January 1995. The shortwave data (channels 1-25) are based on in-flight measurements over the Gulf of Mexico for the clear-sky scene (low signal level, where the reflectance is often less than 1%) and clouds on the north slope of Alaska on 7 June 1995 for the cloudy scene (high signal level). The range of signal-to-noise values for the shortwave channels reflects this range of scene radiance values.

\+ Units of Watts/(meter^2 * steradian * micrometer)

For a more detailed description, the reader is directed to King, M. D., W. P. Menzel, et. Al, 1995 for a more through description of the MAS system.

4.1.6 Sensor/Instrument Measurement Geometry

BOREAS IFC-2 MAS Instrument/Platform Specifications

Platform:	NASA/AMES C130
Altitude:	8000 meters (nominal)
Ground Speed:	200 knots
Pixel Spatial Resolution:	20 meters (at 8000 meters altitude)
Pixels per Scan Line:	716 (roll corrected)
Scan Rate:	6.25 scans/second
Swath width:	~14 km at 7.5 km altitude
Total Field of View:	85.92 degrees
Instantaneous Field of View:	2.5 milliradians
Roll Correction:	Plus or minus 3.5 degrees (approx)
Bits per Channel:	12
Data Rate:	246 Megabytes/hour
Visible Calibration:	Integrating sphere on the ground
Infrared Calibration:	Two onboard temperature controlled blackbodies

4.1.7 Manufacturer of Sensor/Instrument

Daedalus Enterprises, Inc.

4.2 Calibration

Radiometric calibration of the shortwave (<2.5 mm) channels is obtained by observing laboratory standard integrating sphere sources on the ground before and after flight missions, while calibration of the infrared channels is performed in flight by viewing two onboard blackbody sources once every scan. The blackbody sources are located on either side of the scan aperture in the scanner subassembly.

Shortwave Calibration

Two radiometric sources are used for shortwave laboratory calibration during MAS development, a 76.2-cm-diameter integrating sphere maintained at NASA ARC, and a 121.9-cm-diameter integrating hemisphere maintained at NASA GSFC. Both sources are coated with $BaSO_4$ paint and internally illuminated by 12 quartz-halogen lamps. The 76.2-cm sphere is used at ARC for MAS calibrations just prior to the aircraft departure for field deployments as well as immediately following its return. This source is used to monitor long-term stability of the absolute calibration of the MAS. The 121.9-cm hemisphere has often been shipped to deployment sites and employed for MAS calibrations during the deployment. More recently, a 50.8-cm-diameter integrating hemisphere was purchased by NASA ARC to ship with the MAS on all deployments. The 50.8-cm integrating hemisphere is coated with Duraflect by Labsphere, North Sutton, NH, and is internally illuminated by 10 lamps. Recent intercomparisons in the 76.2- and 121.9-cm integrating sources suggest that this smaller, more portable, source is suitable for MAS field calibration purposes. This source is set up beneath the MAS prior to each flight to monitor day-to-day fluctuations in the MAS shortwave calibration. Calibration of the spherical integrating sources, both at ARC and during field deployments, is performed by NASA GSFC personnel using a monochromator to transfer calibration to the integrating sources at spectral intervals of 10 nm.

Thus, for each MAS shortwave channel, the radiance is related to digital count by:

$$Ib = Sb (Cb - Ob) / mb$$

where: Ib is the radiance measured in each shortwave spectral band b
Cb is the count value representing the detector response to the integrating source
Sb is the slope
Ob is the offset (digital counts when observing 'zero' radiance level)
mb is the reflectance of the 45-degree mirror (not used since 1993)

Details of the shortwave calibration and temperature correction procedure are given by Arnold et al. (1994a, b).

Longwave Calibration

The calibration of wavelengths greater than 2.96 mm is obtained from in-flight observations of two onboard blackbody sources, one operated at the ambient temperature and the other at an elevated temperature (typically 30 °C). The two blackbodies are coated with Krylon interior/exterior ultra flat black paint. The calibration slope and intercept for the thermal channels are determined from this two point measurement. The blackbody sources are viewed during every scan of the mirror. The amount of energy received by the detector is related to the digitized count value by:

$$Ib = Sb*Cb + ib$$

where: Ib is the radiance measured in each infrared spectral band b
Cb is the count value representing the detector voltage response to the scene radiance
Sb is the slope
ib is the intercept

We assume a linear response, as laboratory determinations indicate fractional nonlinearity parameters of less than 0.0001. The slope and intercept, and hence the calibration of counts to radiance, are calculated for each scan line using the count values recorded when viewing two onboard blackbody sources. Using:

w to indicate the warm blackbody,
a to indicate the ambient blackbody,
m to indicate the MAS instrument,

and taking into account blackbody emissivity e, then:

$$Sb = eb\ (Iwb - Iab\ ) / (Cwb - Cab\ )$$
$$ib = Iab + (Im - Iab\ )\ (1 - eb\ ) - Sb*Cab$$

Blackbody count values are derived as the average of 12 Fields of View (FOVs) across each blackbody surface during each scan, with the temperature of the blackbodies monitored by embedded thermistors. The emissivity of the blackbodies was obtained by viewing a well-characterized source in the laboratory, from which the emissivity was determined to be 0.94 and 0.98 for the longwave and shortwave infrared bands, respectively. For typical ocean scene temperatures, corrections for instrument radiation (IM) reflected by the MAS blackbodies are approximately 1.25 °C for the longwave and 0.25 °C for the shortwave bands, respectively.

Equivalent Planck radiances from the blackbodies are calculated for each spectral band using a spectral response weighted integral of the form:

$$Ib\ (T) = Integral[B(h, T)\ F\ (h)dh] / Integral[F(h)\ dh]$$

where: B(h, T) is the Planck function
F(h) is the spectral response for a given band
h is wavelength
T is the blackbody temperature

This can be fitted to an adjusted Planck function for the range of Earth emitted temperatures by introducing coefficients a0 and a1 such that

$$Ib\ (T) = B(hb\ ,\ a1*T + a0)$$

where hb is the central wavelength or wavenumber of band b.

4.2.1 Specifications

The wavelength range (in micrometers) of the MAS bands selected for the BOREAS IFC-2 are:

Data Channel	MAS Band	Central Wavelength	50% Bandwidth
01	01	0.547	0.043
02	02	0.664	0.055
03	04	0.745	0.040
04	05	0.786	0.040
05	06	0.834	0.042
06	07	0.875	0.041
07	09	0.945	0.043
08	10	1.623	0.057
09	20	2.142	0.047
10	32	3.900	0.150
11	45	11.002	0.448
12	46	12.032	0.447

4.2.1.1 Tolerance

Details of the shortwave calibration and temperature correction procedure are given by Arnold et al. (1994a, b).

4.2.2 Frequency of Calibration

See Section 4.2.

4.2.3 Other Calibration Information

For a more detailed calibration description, the reader is directed to King, M.D., W.P. Menzel, et al., 1995.

5. Data Acquisition Methods

As part of the BOREAS Staff Science data collection effort, NASA ARC personnel collected and provided the 12-band MAS data to BOREAS for use in science investigations. The MAS was flown on NASA's C-130 aircraft during BOREAS (see the BOREAS Experiment Plan for flight pattern details and objectives). Maintenance and operation of the instrument are the responsibility of NASA ARC.

6. Observations

6.1 Data Notes

Flight summary reports and verbal records on video tapes are available for the BOREAS MAS data.

6.2 Field Notes

None.

7. Data Description

7.1 Spatial Characteristics

Each of the 10 MAS flight lines covers a portion of the BOREAS Southern Study Area (SSA). Together, the 10 lines cover a majority of the SSA.

7.1.1 Spatial Coverage

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

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

The NAD83 corner coordinates of the Northern Study Area (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

At the nominal C130 operating altitude of 8,000 m, the MAS provided pixel resolutions of 20 m at nadir to 28 m at the scanning extremes.

7.1.4 Projection

The geographic orientation of each scene depends on the direction of the aircraft line of flight. Pixels and lines progress left to right, and top to bottom so pixel n, line n is in the lower right-hand corner of each scene.

The SSA flight lines were stored in their raw spatial form with pixel resolutions varying from 20 m at nadir to 28 m at the scanning extremes. The provided files of relative X and Y coordinate indicate the relative positions of the pixels from the arbitrary origin. These relative X and Y coordinates were derived from the C130 navigation data (see Section 9.3).

7.1.5 Grid Description

The provided files of relative X and Y coordinate indicate the relative positions of the pixels. These relative X and Y coordinates were derived from the C130 navigation data (see Section 9.3).

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

Currently the level-2 MAS data set contains data collected on the following dates:

- 10 flight lines collected on 21-Jul-1994 over the BOREAS SSA.
- 15 flight lines over towers collected on 21-Jul-1994 over the BOREAS SSA.
- 6 flight lines over towers collected on 24-Jul-1994 over the BOREAS SSA.
- 6 flight lines over towers collected on 04-Aug-1994 over the BOREAS NSA.
- 7 flight lines collected on 08-Aug-1994 over the BOREAS NSA.

7.2.2 Temporal Coverage Map

The following table shows the dates and times when the areas were imaged:

Site	Date	Start Time	End Time	Number of Flight Lines
SSA	21-Jul-1994	15:46:07	17:35:35	10
SSA-90A	21-Jul-1994	17:46:19	18:22:03	3
SSA-OBS	21-Jul-1994	18:46:32	19:16:16	3
SSA-OJP	21-Jul-1994	19:24:26	19:53:21	3
SSA-YJP	21-Jul-1994	20:00:06	20:26:54	3
SSA-FEN	21-Jul-1994	20:35:48	21:15:30	3
SSA-9YA	24-Jul-1994	17:09:44	17:38:34	3
	24-Jul-1994	15:58:03	16:28:30	3
NSA-YJP	04-Aug-1994	16:47:17	17:23:00	3
NSA-OBS	04-Aug-1994	16:23:44	16:18:02	3
NSA	08-Aug-1994	14:31:58	15:43:08	7

7.2.3 Temporal Resolution

The entire NSA and SSA were imaged only once in 1994. The individual tower site coverage is shown in Section 7.2.2.

7.3 Data Characteristics

7.3.1 Parameter/Variable

The main parameters contained in the image data files are:

```
Scaled Reflectance
Scaled Surface Temperature
Relative X Coordinate
Relative Y Coordinate
Scaled View Zenith
Scaled View Azimuth
```

The parameters contained in the inventory listing file on the Compact Disk - Read-Only Memory (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
MAS_SCAN_SPEED
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:

Scaled Reflectance

The ratio of derived radiant energy incident on the sensor aperture and incident radiant solar energy at the time of data collection in the specific MAS wavelength regions.

Scaled Surface Temperature

The derived surface temperature at the time of data collection in the specific MAS thermal infrared wavelength regions.

Relative X Coordinate

The X coordinate of the center of the image pixel in relation to the arbitrarily selected origin. The trend of the X coordinates of the pixels is dependent on the direction of flight of the aircraft. The X,Y coordinate system starts with the nadir pixel location of image line 1 for all flight lines positioned near the origin (0,0) and progresses based on the direction of flight. The flight direction refers to the angle of the flight path relative to magnetic north with north as 0 or 360 degrees, east as 90, south as 180, and west as 270 degrees. For example, the X coordinates for an idealized flight line in the direction of 180 degrees (south) would be increasingly positive to the left of the flight line and increasingly negative to the right of the flight line with the X coordinate for the nadir pixel being approximately 0 (zero).

Relative Y Coordinate

The Y coordinate of the center of the image pixel in relation to the arbitrarily selected origin. The trend of the Y coordinates of the pixels is dependent on the direction of flight of the aircraft. The X,Y coordinate system starts with the nadir pixel location of image line 1 for all flight lines positioned near the origin (0,0) and progresses based on the direction of flight. The flight direction refers to the angle of the flight path relative to magnetic north with north as 0 or 360 degrees, east as 90, south as 180, and west as 270 degrees. For example, the Y coordinates for an idealized flight line in the direction of 90 degrees (east) would be increasingly positive to the left of the flight line and increasingly negative to the right of the flight line with the Y coordinate for the nadir pixel being approximately 0 (zero).

Scaled View Zenith

The scaled value of the target-centered view zenith angle (complement of elevation angle). The view zenith indicates the zenith angle at which the radiant energy was traveling when detected by the sensor. The view zenith angle increases from 0 (straight up) to 90 degrees at the horizon.

Scaled View Azimuth

The scaled value of the target-centered view azimuth angle. The view azimuth angle indicates the direction in which the radiant energy was traveling when detected by the sensor. The view azimuth angle increases from 0 to 360 degrees with north as 0 or 360 degrees, east as 90, south as 180, and west as 270 degrees.

The descriptions of the parameters contained in the data files 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.
MAS_SCAN_SPEED	The rate of scan line data collection by the MAS instrument during the given flight.
NW_LATITUDE	The NAD83 based latitude coordinate of the north-west corner of the minimum bounding rectangle for the data.
NW_LONGITUDE	The NAD83 based longitude coordinate of the northwest corner of the minimum bounding rectangle for the data.
NE_LATITUDE	The NAD83 based latitude coordinate of the north east corner of the minimum bounding rectangle for the data.

NE_LONGITUDE	The NAD83 based longitude coordinate of the north east corner of the minimum bounding rectangle for the data.
SW_LATITUDE	The NAD83 based latitude coordinate of the south west corner of the minimum bounding rectangle for the data.
SW_LONGITUDE	The NAD83 based longitude coordinate of the southwest corner of the minimum bounding rectangle for the data.
SE_LATITUDE	The NAD83 based latitude coordinate of the south east corner of the minimum bounding rectangle for the data.
SE_LONGITUDE	The NAD83 based longitude coordinate of the southeast corner of the minimum bounding rectangle for the data.
CRTFCN_CODE	The BOREAS certification level of the data. Examples are CPI (Checked by PI), CGR (Certified by Group), PRE (Preliminary), and CPI-??? (CPI but questionable).

7.3.3 Unit of Measurement

For the image data files:

```
Scaled At-sensor radiance - Fractions of Watts/(square meter * steradian *
                            micrometer).  Look near the end of the ASCII header
                            file for scaling factors.
Relative X coordinate - meters
Relative Y coordinate - meters
Scaled View zenith - Tenths of degrees
Scaled View Azimuth - Tenths of degrees
```

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]
MAS_SCAN_SPEED	[scan lines][second^-1]

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 values stored in the listed parameters were extracted from the level-1b MAS HDF files provided to BOREAS by MAS processing personnel and processed to reflectance or surface temperature. The reflectance and surface temperature values are derived from the level-1b at-sensor radiance. The scaled at-sensor radiance and view angle values are the result of calibration and processing of the raw MAS data by MAS personnel. The relative X and Y coordinates were derived in a joint effort between BORIS and MAS personnel. The sources of the parameter values contained in the inventory listing file on the CD-ROM are:

Column Name	Data Source
SPATIAL_COVERAGE	[Determined from latitude and longitude information provided in the NASA ARC flight summary reports and navigation data files]
DATE_OBS	[Software extracted from MAS HDF files]
START_TIME	[Software extracted from MAS HDF files]
END_TIME	[Software extracted from MAS HDF files]
PLATFORM	[Data base constant]
INSTRUMENT	[Data base constant]
NUM_BANDS	[Data base constant]
PLATFORM_ALTITUDE	[Determined from information provided in the NASA ARC flight summary reports]
MIN_SOLAR_ZEN_ANG	[Calculated with software from latitude and longitude and time information]
MAX_SOLAR_ZEN_ANG	[Calculated with software from latitude and longitude and time information]
MIN_SOLAR_AZ_ANG	[Calculated with software from latitude and longitude and time information]
MAX_SOLAR_AZ_ANG	[Calculated with software from latitude and longitude and time information]
C130_MISSION_ID	[Taken from the delivered tape label and the NASA ARC Flight Summary Reports]
C130_LINE_NUM	[Taken from the delivered tape label and the NASA ARC Flight Summary Reports]
C130_RUN_NUM	[Taken from the delivered tape label and the NASA ARC Flight Summary Reports]
C130_SITE	[Taken from the delivered tape label and the NASA ARC Flight Summary Reports]
BAND_QUALITY	[Constant software parameter value]
CLOUD_COVER	[Constant software parameter value]
MAS_SCAN_SPEED	[Software extracted from MAS HDF files]
NW_LATITUDE	[Calculated with software from the C130 altitude and heading, starting and ending flight line latitude and longitude, and the static MAS 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 MAS 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 MAS 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 MAS 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 MAS 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 MAS 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 MAS 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 MAS scan angle information]
CRTFCN_CODE	[Constant data base value]

7.3.5 Data Range

The range of values for the image data files are:

Scaled At-sensor radiance

Dependent on the particular MAS band of interest due to the wavelength region covered and the scaling factor listed near the end of the ASCII header file.

Relative X coordinate

Dependent on the direction of flight with an absolute minimum of -2,147,483,648 and absolute maximum of 2,147,483,647.

Relative Y coordinate

Dependent on the direction of flight with an absolute minimum of -2,147,483,648 and absolute maximum of 2,147,483,647.

Scaled View zenith

Minimum - 0
Maximum - 900

Scaled View Azimuth

Minimum - 0
Maximum - 3599

The following table gives information about the parameter values found in the inventory file 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	21-JUL-94	08-AUG-94	None	None	None	None
START_TIME	1431	2110	None	None	None	None
END_TIME	1435	2115	None	None	None	None
PLATFORM	C130	C130	None	None	None	None
INSTRUMENT	N/A	N/A	None	None	None	None
NUM_BANDS	12	12	None	None	None	None
PLATFORM_ALTITUDE	5369	7962	None	None	None	None
MIN_SOLAR_ZEN_ANG	33.5	60.8	None	None	None	None
MAX_SOLAR_ZEN_ANG	33.5	60.8	None	None	None	None
MIN_SOLAR_AZ_ANG	104.7	228.4	None	None	None	None
MAX_SOLAR_AZ_ANG	104.7	228.4	None	None	None	None
C130_MISSION_ID	94-007-02	94-007-07	None	None	None	None
C130_LINE_NUM	1	703	None	None	None	None
C130_RUN_NUM	1	2	None	None	None	None
C130_SITE	429	432	None	None	None	None
BAND_QUALITY	N/A	N/A	None	None	None	None
CLOUD_COVER	N/A	N/A	None	None	None	None
MAS_SCAN_SPEED	6.25	6.25	None	None	None	None
NW_LATITUDE	53.67695	56.08503	None	None	None	None
NW_LONGITUDE	-106.49118	-98.28911	None	None	None	None
NE_LATITUDE	53.65457	56.07333	None	None	None	None
NE_LONGITUDE	-106.04228	-97.99831	None	None	None	None
SW_LATITUDE	53.45052	55.92475	None	None	None	None
SW_LONGITUDE	-106.50745	-98.37285	None	None	None	None
SE_LATITUDE	53.44061	55.88116	None	None	None	None
SE_LONGITUDE	-106.06016	-98.06009	None	None	None	None
CRTFCN_CODE	CPI-PRE	CPI-PRE	None	None	None	None

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

```
                    but this particular science team did not
                    measure that parameter.

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

7.4 Sample Data Record

Sample data records are not applicable to the image data itself. The following are wrapped versions of records from the inventory file 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,MAS_SCAN_SPEED,NW_LATITUDE,NW_LONGITUDE,NE_LATITUDE,
NE_LONGITUDE,SW_LATITUDE,SW_LONGITUDE,SE_LATITUDE,SE_LONGITUDE,CRTFCN_CODE
'SSA',21-JUL-94,1546,1549,'C130','MAS',12,7962.0,50.3,50.3,111.4,111.4,
'94-007-02',1,1,'430','Fair: some noise in IR channels','NOT ASSESSED',
6.25,54.09068,-104.73728,54.06974,-104.35362,53.94693,-104.7593,53.92607,
-104.37698,'CPI-PRE'
'SSA',21-JUL-94,1555,1600,'C130','MAS',12,7847.0,49.0,49.0,113.9,113.9,
'94-007-02',2,1,'430','Fair: some noise in IR channels','NOT ASSESSED',
6.25,54.11018,-104.95169,54.0795,-104.37837,53.91374,-104.98072,53.8832,
-104.41013,'CPI-PRE'
```

8. Data Organization

8.1 Data Granularity

The smallest unit of data for the level-2 MAS images is a single acquisition containing 17 sequential files.

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.

8.2.1 Uncompressed Data Files

One level-2 MAS image product consists of 17 files in the following order:

- File 1: An ASCII header file containing information relating to the mission, location, acquisition time, sensor parameters, aircraft location and attitude, and radiometric calibration parameters.
- Files 2 - 10: Bands 1 to 9 stored as 16-bit (2-byte) (low-order byte first) binary scaled reflectance values. Scaling factors are provided at the end of the end of the ASCII header file.
- File 11 - 13: Bands 10 to 12 stored as 16-bit (2-byte) (low-order byte first) binary scaled temperature values (degrees Celsius). The scaling factor is provided at the end of the end of the ASCII header file.
- File 14: Relative X coordinates stored as 32-bit binary values in tenths of meters (low-order byte first).
- File 15: Relative Y coordinates stored as 32-bit binary values in tenths of meters (low-order byte first).
- File 16: Scaled view azimuth values stored as 16-bit binary values in tenths of degrees (low-order byte first).

- File 17: Scaled view zenith values stored as 16-bit binary values in tenths of degrees (low-order byte first).

The geographic orientation of each scene depends on the direction of the aircraft line of flight. Pixels and lines progress left to right, and top to bottom so pixel n, line n is in the lower right-hand corner of each scene.

All scene files contain a variable number of fixed-length records. The ASCII header files contain records that are 80 bytes in length. All binary files associated together for a given flight contain the same number of records. The number of binary records in a flight varies depending on the length of that flight line. Each binary data record in all flights represents 716 image pixels. Therefore, the image and view angle file records contain 716*2 = 1432 bytes and the relative X and Y coordinate files contain 716*4 = 2864 bytes.

8.2.2 Compressed CD-ROM Files

On the BOREAS CD-ROMs, the ASCII header file (file 1) for each image is stored as ASCII text; however, files 2 to 17 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 Web sites (for example, ftp site prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

9. Data Manipulations

9.1 Formulae

The atmospheric correction algorithm, Imagecor, applied to the MAS level-1b data is fully documented in Wrigley et al. (1992), which has been since been modified to include water vapor, and to remove path thermal emission for thermal channels. Imagecor was developed by Robert Wrigley and Robert Slye for the atmospheric correction of data from the First International Satellite Land Surface Climatology Project (ISLSCP) Field Experiment (FIFE) and uses a simple atmospheric model with a modified single-scattering approximation, which permits full image scenes to be processed relatively quickly.

9.1.1 Derivation Techniques and Algorithms

Derivation of the relative X and Y coordinates starts with determining the relative positions of the nadir pixel in each image line. The nadir pixel coordinates are defined to proceed relative to an arbitrary starting X,Y location. Nadir X,Y coordinates are derived as a function of the following parameters:

- Instantaneous velocities X, Y, and Z from the C130 navigation data.
- Tracking (actual direction aircraft is pointing) values derived as a function of true heading and drift. To arrive upon nadir pixel tracking, the 1-Hz drift values and 30-Hz true heading values are interpolated to nadir pixel values. Nadir pixel drift is added to the nadir true heading values to obtain nadir pixel tracking values. Note that drift may be a positive or negative value.

The calculations used to derive relative X and Y coordinates of the nadir pixels are:

```
X0       = First (earlier) nadir X location
X1       = Succeeding nadir X location
Y0       = First (earlier) nadir Y location
Y1       = Succeeding nadir Y location
DTime    = Time1 - Time0
           [Delta time stamps between succeeding nadir pixels]
```

```
TH0, TH1 = True Heading at succeeding nadir pixels
Dr0, Dr1 = Drift values at succeeding nadir pixels
Tr0, Tr1 = Tracking at succeeding nadir pixels
VX,VY,VZ = Global Positioning System (GPS) velocities in an X, Y and Z GPS
           reference system
Sp0, Sp1 = Ground Speed
           [square root ((VX*VX) + (VY*VY) + (VZ*VZ))]
V0x      = SP0 * cos(TH0 + Dr0)
           [X Velocity at Time0]
V1x      = SP1 * cos(TH1 + Dr1)
           [X Velocity at Time1]
V0y      = SP1 * sin(TH0 + Dr0)
           [Y Velocity at Time0]
V1y      = SP1 * sin(TH1 + Dr1)
           [Y Velocity at Time1]
AVEV01X  = (V0x + V1x) / 2.0
           [Average X velocity between Time0 and Time1]
AVEV01Y  = (V0y + V1y) / 2.0
           [Average Y velocity between Time0 and Time1]
X        = X0 + (AVE01X * DTime)
           [Succeeding nadir X coordinate]
Y        = Y0 + (AVE01Y * Dtime)
           [Succeeding nadir Y coordinate]
```

The atmospheric correction algorithm, Imagecor, applied to the MAS level-1b data is fully documented in Wrigley et al. (1992). Changes implemented since then were the inclusion of water vapor corrections and the ability to process thermal data. Water vapor corrections are based on modeled water vapor transmittance output by 6S combined with water vapor transmittance derived from 940nm channel sunphotometer data. This transmittance and the spectral response function of the sunphotometer channel was used to determine the equivalent water vapor column content. Imagecor then uses this content to estimate the transmittance across the scene.

The thermal channels were corrected by using MODTRAN to model path emission and transmittance at twelve equally spaced angles across the scene and interpolating the path emission between these points.

9.2 Data Processing Sequence

9.2.1 Processing Steps

BORIS staff creates level-1B MAS image products from HDF files. The input HDF file is created by combining MAS image data with aircraft navigation data in an iterative procedure as follows: BORIS staff extracts start and end flight line times from the level-0 C130 aircraft navigation data associated with the flight. BORIS staff uses the start and end times for the flight line to extract the relevant aircraft navigation data to determine nadir pixel times. BORIS staff processes/linearly interpolates the extracted navigation parameters such as roll, pitch, heading, drift, and acceleration for the nadir pixel time. The nadir location parameters (roll, pitch, radar altitude, X and Y grid coordinates) are plotted to perform visual review of the data for anomalous values. Nadir pixel navigation parameter values are then combined with MAS spectral data by MAS processing staff to create an HDF image product consisting of MAS spectral data and ancillary information for each flight line run. All HDF files are written to 8-mm tape and logged in the BORIS data base. Each MAS HDF file is converted to the BORIS BSQ 8-mm tape product. The 17 files, as described above, for each unique flight, are written to tape, in BORIS level-1B BSQ format, for distribution. The BORIS-format MAS tapes are then logged into the BORIS data base.

The flight lines were then sent to NASA ARC for atmospheric correction processing. This processing was as follows: Upload the data tape and export the image data to files with native byte

order. Download the 21-Jul-1994 radiosonde data from BORIS. Model the path transmittance and path radiative emission for the thermal channels using a MODTRAN. Model the path water vapor column concentration and downwelling irradiance using the 6S for visible and near- and mid-infrared channels. Process the image data to reflectance or surface temperature using Imagecor. Generate a header file for each of the MAS flight lines. For each flight line, write to tape each header file and level-2 image data. Send the level-2 data tape to BORIS.

When the level-2 images are returned, BORIS personnel: Extract and verify information from the data products for logging into the relational data base inventory. Compress the data for distribution on CD-ROM.

9.2.2 Processing Changes

None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

See Section 9.1.1.

9.3.2 Calculated Variables

See Section 9.1.1.

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

Errors could arise in the acquired imagery due to location accuracy, distortion of lengths, anisomorphism, instrument's local coherence, and multispectral registration. Other errors could arise from inherent radiometric imperfections of the sensors. Whatever the processing level, the geometric quality of the image depends on the accuracy of the viewing geometry. Spectral errors could arise due to image-wide signal-to-noise ratio, saturation, cross-talk, spikes, and response normalization due to change in gain.

In addition to these errors, the level-2 errors are dependent on the accuracy of the aerosol optical depth measurements used in the atmospheric correction processing. Errors due to using a single-scattering approximation should be minimal because the BOREAS optical depths were low (met the single-scattering requirement).

10.2 Quality Assessment

10.2.1 Data Validation by Source

MAS level-2 pixel data agreed well with Remote Sensing Science (RSS)-03 helicopter acquired Barnes Modular Multispectral Radiometer (MMR, BOREAS PI: Charles Walthall) data for the BOREAS primary study sites. With similar geometric and site condition inputs, both 6S and MODTRAN modeled reflectances also were in close agreement to the Imagecor results.

10.2.2 Confidence Level/Accuracy Judgment

One set of calibration coefficients was used throughout the BOREAS project rather than recalculated for each flight. Errors are usually +/- 5% when recalculated for each flight.

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 staff reviewed the data with software and visual examination of the images at various stages of the processing to ensure that the data appeared as expected.

11. Notes

11.1 Limitations of the Data

None.

11.2 Known Problems with the Data

None.

11.3 Usage Guidance

Before uncompressing the Gzip files on CD-ROM, be sure that you have enough disk space to hold the uncompressed data files. Then use the appropriate decompression program provided on the CD-ROM for your specific system.

11.4 Other Relevant Information

None.

12. Application of the Data Set

These data would be useful for creating a reflectance mosaic of the study sites and in investigating the bidirectional reflectance properties at the tower flux sites.

13. Future Modifications and Plans

None.

14. Software

14.1 Software Description

BORIS personnel developed software and command procedures to:

- Unpack and subset the level-0 C130 navigation data.
- Perform linear interpolation of the level-0 C130 navigation parameters.
- Convert the HDF data files received from MAS personnel to the BORIS BSQ 8-mm tape product.
- Write the 17 files for each unique flight to tape for distribution.
- Extract header information from level-1b BSQ images on tape.
- Log the BSQ format MAS tapes into the BORIS data base.

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

The details of the software used by MAS personnel to derive the HDF level-1b products is currently unknown.

The atmospheric correction software, Imagecor, was written in the C language and is operation on Sun Microsystems Solaris systems and has few hardware dependencies.

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

14.2 Software Access

All of the described BORIS software is available upon request. BORIS staff would appreciate knowing of any problems discovered with the software, but cannot promise to fix them.

Gzip is available from many Web sites across the Internet (for example, ftp site prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

15. Data Access

The level-2 MAS surface reflectance and temperature 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-2 MAS 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, video tapes, and photographs.

16.3 Other Products

Note that due to storage space limitations, only the level-2 MAS images collected on 21-Jul-1994 are included on the BOREAS CD-ROM series. Users interested in images from other dates should refer to the inventory listing provided on the CD-ROMs and Section 15 to determine how to obtain the data of interest.

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17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

6S - Second Simulation of the Satellite Signal in the Solar Spectrum
ARC - Ames Research Center
ASCII - American Standard Code for Information Interchange
BOREAS - BOReal Ecosystem-Atmosphere Study
BORIS - BOREAS Information System
BPI - Bytes Per Inch
BSQ - Band Sequential
CCT - Computer Compatible Tape
CD-ROM - Compact Disk-Read-Only Memory
DAAC - Distributed Active Archive Center
DAT - Digital Archive Tape
EOS - Earth Observing System
EOSDIS - EOS Data and Information System
FIFE - First ISLSCP Field Experiment
FIRE II - First ISCCP Regional Experiment
FOV - Field of View
FPAR - Fraction of Photosynthetically Active Radiation
GIS - Geographic Information System
GPS - Global Positioning System
GSFC - Goddard Space Flight Center
HDF - Hierarchical Data Format
IFC - Intensive Field Campaign
IFOV - Instantaneous Field of View
ISCCP - International Satellite Cloud Climatology Project
ISLSCP - International Satellite Land Surface Climatology Project
LAI - Leaf Area Index
LOWTRAN - Low Resolution Atmospheric Transmission Code
MAS - MODIS Airborne Simulator
MMR - Modular Multispectral Radiometer
MODIS - MODerate Imaging Spectroradiometer
MODLAND - MODIS Land Group
MODTRAN - MODerate Resolution Atmospheric Transmission Code
NAD83 - North American Datum of 1983
NASA - National Aeronautics and Space Administration
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
RSS - Remote Sensing Science
SSA - Southern Study Area
URL - Uniform Resource Locator
UTM - Universal Transverse Mercator
YA - Young Aspen
YJP - Young Jack Pine

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13. ABSTRACT *(Maximum 200 words)*

The BOREAS Staff Science Aircraft Data Acquisition Program focused on providing the research teams with the remotely sensed aircraft data products they needed to compare and spatially extend point results. The MAS images, along with other remotely sensed data, were collected to provide spatially extensive information over the primary study areas. This information includes biophysical parameter maps such as surface reflectance and temperature. Collection of the MAS images occurred over the study areas during the 1994 field campaigns. The level-2 MAS data cover the dates of 21-Jul-1994, 24-Jul-1994, 04-Aug-1994, and 08-Aug-1994. The data are not geographically/geometrically corrected; however, files of relative X and Y coordinates for each image pixel were derived by using the C130 navigation data in a MAS scan model. The data are provided in binary image format files.

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