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

Forrest G. Hall, Editor

Volume 83

BOREAS Level-0 C-130 Navigation Data

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BOREAS Level-0 C-130 Navigation Data

Richard Strub, Roseanne Dominguez, Jeffrey A. Newcomer

Summary

The level-0 C-130 navigation data files contain aircraft attitude and position information acquired during the digital image and photographic data collection missions over the BOREAS study areas. Various portions of the navigation data were collected at 1, 10, and 30 Hz. The level-0 C-130 navigation data collected for BOREAS in 1994 were improved over previous years in that the C-130 onboard navigation system was upgraded to output inertial navigation parameters every 1/30th of a second (i.e., 30 Hz). This upgrade was encouraged by users of the aircraft scanner data with the hope of improving the relative geometric positioning of the collected images.

Note that the level-0 C-130 navigation data are not contained on the BOREAS CD-ROM set. An inventory listing file is supplied on the CD-ROM to inform users of the data that were collected. See Section 15 for information about how to acquire actual level-0 C-130 navigation data.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS Level-0 C-130 Navigation Data

1.2 Data Set Introduction

The BOReal Ecosystem-Atmosphere Study (BOREAS) Staff Science effort covered those activities that were BOREAS community-level activities or required uniform data collection procedures across sites and time. These activities included the acquisition, processing, and archiving of aircraft navigation/attitude data to complement the digital image data.

1.3 Objective/Purpose

The level-0 C-130 navigation data collected for BOREAS in 1994 were improved over previous years in that the C-130 onboard navigation system was upgraded to output inertial navigation parameters every 1/30th of a second (i.e., 30 Hz). This upgrade was encouraged by users of the aircraft scanner data with the hope of improving the relative geometric positioning of the collected images.

1.4 Summary of Parameters

Level-0 C-130 navigation data in the BOREAS Information System (BORIS) contain the following parameters:

- American Standard Code for Information Interchange (ASCII) summary information and documentation
- ASCII software source files
- Actual navigation data files that contain aircraft attitude and position information

1.5 Discussion

Ames Research Center (ARC) processing procedures involved extracting the level-0 navigation data and an ASCII flight line summary file from the raw 0.15-inch cartridge tape. The level-0 data were then transferred to BORIS along with a C header file (C130NAV) that contains two C structures matching the cartridge format and a C program that extracts data from the cartridge format and creates values in engineering units.

BORIS staff processed the level-0 navigation data by:

- Extracting pertinent header information from the ARC product and placing it in an ASCII file on disk
- Reading selected information from the ASCII file and loading the summary data into the BORIS online data base

1.6 Related Data Sets

BOREAS Level-0 C-130 Aerial Photography
BOREAS Level-1b ASAS Imagery
BOREAS Level-1b MAS Imagery: At-sensor Radiance, Relative X and Y Coordinates
BOREAS Level-0 NS001 TMS Imagery: Digital Counts in BIL Format
BOREAS Level-0 TIMS Imagery: Digital Counts in BIL Format
BOREAS Level-1b TIMS Imagery: At-sensor Radiance in BSQ Format

2. Investigator(s)

2.1 Investigator(s) Name and Title

BOREAS Staff Science

2.2 Title of Investigation

BOREAS Staff Science Aircraft Data Acquisition Program

2.3 Contact Information

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3. Theory of Measurements

The National Aeronautics and Space Administration (NASA) Earth Resources Aircraft Program at ARC operated the C-130 aircraft to acquire data for Earth science research. Several imaging sensors, such as the Advanced Solid-State Array Spectroradiometer (ASAS), the Moderate-Resolution Imaging Spectrometer (MODIS) Airborne Simulator (MAS), the NS001 Thematic Mapper Simulator (TMS), and the Thermal Infrared Multispectral Scanner (TIMS), were flown on the C-130 for BOREAS.

Prior to BOREAS, the C-130 navigation data were collected and recorded once per second during aircraft instrument data acquisition flights. Attempts at using these 1-Hz data to perform relative corrections of the image data proved that the corrections could be made, but that higher frequency recording of the navigation parameters was required to obtain a sufficiently accurate geometric correction. Improvements of the C-130 navigation system leading up to the BOREAS acquisition flights in 1994 resulted in a navigation parameter data set recorded at 30 Hz. These 30-Hz data are being used by BORIS staff to calculate relative geometric positions of the electromagnetic sensor measurements at the pixel level. A good relative correction of the aircraft imagery into a Cartesian coordinate system will greatly improve the association of the C-130 measurements with similar measurements taken at or near Earth's surface, from other airborne sensors, and from satellite platforms.

4. Equipment

4.1 Sensor/Instrument Description

The C-130 Automated Digital Data System (CADDS) provides a means for the gathering and distribution of aircraft navigational, pertinent housekeeping, and environmental data. It incorporates data from the Delco Carousel IV A-3 Inertial Navigation System (INS), the Ashtech Z12 Global Positioning System (GPS), Honeywell APN-222 Radar Altimeter, the Rosemount 102 AH2AG Total Air Temperature (TAT) Sensor , the Precision Radiation Thermometer (PRT-5), the General Eastern 1011A two-stage thermoelectric hygrometer, and a pressure transducer.

4.1.1 Collection Environment

CADDS was completed and installed in 1988. Its purpose was to gather, display, and archive selected aircraft navigational and housekeeping parameters. The data system was designed to be flexible and expandable. In 1994 integration of GPS and high-frequency aircraft parameters was introduced.

During a flight, one of the C-130 technicians operates the data system located just aft of the forward exit door in the cabin. After takeoff, the operator initializes the system, setting the time code; inserting the site name, principal investigator, date, project, and mission numbers in the computer; and initializing the tape drives. Prior to a data line run, the mission manager announces the time before a line start, generally 1 minute, and the data system operator presses a button to start the countdown. The technician will call out the time of the line start. A log sheet is kept that includes pertinent information. Line stops are handled in a similar fashion. During a line, the technician can enter

comments as directed by the mission manager. These comments are included on the 0.25-inch tape. Because of the BOREAS requirement for high-frequency input, the data provided to the BORIS archive were simply a copy of the raw 0.25-inch cartridge.

4.1.2 Source/Platform

NASA's C-130 Earth Resources Aircraft.

4.1.3 Source/Platform Mission Objectives

For BOREAS, the primary C-130 mission objective was to collect various Earth surface data in coordination with satellite overpasses for data verification and integration studies. A secondary objective was to collect data at key times when the satellites were not within range of specific sites. The C-130 was based near the BOREAS study areas, and could thus be deployed rather quickly in order to take advantage of good data collection conditions. The navigation data provide in-flight geographic location and attitude information for the onboard sensors.

4.1.4 Key Variables

The key parameters used by BORIS staff and investigators are: geographic location, time, platform attitude, altitude, atmospheric pressure, dew point, and temperature in proximity to the aircraft.

4.1.5 Principles of Operation

Dual two-degree-of-freedom gyros that feature self-generating gas bearings are used in the navigation system. These have very low drift characteristics and an excellent turn-on repeatability. The radar altimeter interfaces directly with the CPU chassis through an interface card located within the chassis. The interface sends a clock signal to the radar altimeter every 80 milliseconds to acquire the altitude input. No information is available for the geographic location beacons, GPS, or barometers. The TAT system consists of an external probe with an Aerodynamic Housing. The housing corrects for inaccurate temperature readings that would result from the expansion and compression associated with high-velocity air flow. The instrument is sensitive to a temperature range of -160 to 140 °F. It can respond at a rate of 106 °F per second with an accuracy of 0.1% of the full scale.

4.1.6 Sensor/Instrument Measurement Geometry

Source	Parameter	Precision
A/C INS #1	Latitude	0.1 minute
A/C INS #1	Longitude	0.1 minute
A/C INS #1	True Heading	0.1 degree
A/C INS #1	Drift Angle	0.1 degree
A/C INS #1	Ground Speed	1.0 nautical mile per hour
A/C INS #1	Wind Speed	1.0 nautical mile per hour
A/C INS #1	Wind Direction	1.0 degree
A/C INS #1	Distance-To-Go	0.1 nautical mile
A/C INS #1	Time-To-Go	0.1 minute
A/C INS #1	Cross Track Distance	0.1 nautical mile
A/C INS #1	Desired Track	0.1 degree
A/C INS #1	Track Angle Error	0.1 degree
A/C INS #1	Pitch	0.044 degree
A/C INS #1	Roll	0.044 degree
APN-222	Radar Altimeter	1.0 with accuracy of (5 ft + 1/2% altitude)
A/A 24-G9	True Airspeed	1.0 nautical mile per hour
TCG / GPS	Time	0.1 second
TAT	Total Air Temp	0.10 with accuracy of 2.0 °C
PRT-5	Surface Temp	0.17 with accuracy of 0.5 °C
Hygrometer	Dew Point	0.05 with accuracy of 0.1 °C
Pressure Transducer	Pressure Altitude	10 feet

GPS Z12	Time	1.0 second
GPS Z12	Latitude	0.0001 minute
GPS Z12	Longitude	0.0001 minute
GPS Z12	Altitude	0.1 meter
GPS Z12	ECEF-X Velocity	0.01 meter/sec
GPS Z12	ECEF-Y Velocity	0.01 meter/sec
GPS Z12	ECEF-Z Velocity	0.01 meter/sec

4.1.7 Manufacturer of Sensor/Instrument

CADDS is a general-purpose system composed primarily of off-the-shelf vendor-supplied boards and subassemblies. The standard systems include the Delco Carousel IV A-3 INS (installed 1989), the Ashtech Z12 GPS system (installed 1994), the Honeywell APN-222 Radar Altimeter (1988), Rosemount 102 AH2AG TAT Sensor, the General Eastern 1011A thermoelectric hygrometer system, and pressure transducers.

4.2 Calibration

See Section 4.1.6.

4.2.1 Specifications

See Section 4.1.6.

4.2.1.1 Tolerance

See Section 4.1.6.

4.2.2 Frequency of Calibration

Systems onboard the C-130 are calibrated once per year, usually just before the beginning of the flight year.

4.2.3 Other Calibration Information

None.

5. Data Acquisition Methods

During a flight, one of the C-130 technicians operates the data system located just aft of the forward exit door in the cabin. After takeoff, the operator initializes the system, setting the time code; inserting the site name, principal investigator, date, project and mission numbers in the computer; and initializing the tape drives. Prior to a data line run, the mission manager announces the time before a line start, generally 1 minute, and the data system operator presses a button to start the countdown. The technician calls out the time of the line start. A log sheet is kept that includes pertinent information. Line stops are handled in a similar fashion. During a line, the technician can enter comments as directed by the mission manager. These comments are included on the PC 0.25-inch tape. The system writes a 2,048-byte record to 0.25-inch cartridge tape each second. Because of the BOREAS requirement for high-frequency input, the data provided to the BORIS archive were simply a copy of the raw 0.25-inch cartridge tape.

6. Observations

6.1 Data Notes

None. Pertinent in-flight comments are recorded in the digital data records.

6.2 Field Notes

Flight summary reports and verbal records on videotapes are available from the C-130 flights.

7. Data Description

7.1 Spatial Characteristics

The BOREAS level-0 C-130 navigation data were collected primarily as the C-130 flew over portions of the Southern Study Area (SSA) and the Northern Study Area (NSA) during its image data acquisition missions. The SSA and the NSA are located in the southwest and northeast portions of the overall BOREAS region. Some navigation data exist in the data set that cover the BOREAS transect area between the SSA and NSA and areas outside the BOREAS region.

7.1.1 Spatial Coverage

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

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

The NAD83 corner coordinates of the NSA are:

	Latitude	Longitude
Northwest	56.249 N	98.825 W
Northeast	56.083 N	97.234 W
Southwest	55.542 N	99.045 W
Southeast	55.379 N	97.489 W

7.1.2 Spatial Coverage Map

The BOREAS level-0 C-130 navigation data were collected as the C-130 flew over portions of the SSA and NSA during its image data acquisition missions. The SSA and the NSA are located in the southwest and northeast portions of the overall BOREAS region.

7.1.3 Spatial Resolution

Spatial resolution is not strictly applicable to C-130 navigational data. The sampling rate for each portion of the navigation data can be combined with aircraft position, speed, and altitude to derive a spatial component for each data sample.

7.1.4 Projection

The BOREAS level-0 C-130 navigation data contain latitude and longitude coordinates in the parameter set. For BOREAS purposes of relative correction of aircraft data, the latitude and longitude values were not used. Although the latitude and longitude coordinates could be used to calculate coordinates for any map projection, BORIS staff did not assess their accuracy and therefore cannot make any statements about their validity.

7.1.5 Grid Description

Not applicable.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

The data were collected during BOREAS' Field Campaigns, covering the period from 16-Apr-1994 through 17-Sep-1994.

7.2.2 Temporal Coverage Map

IFC#	Dates
FFC-T	16-Apr-1994 -- 20-Apr-1994
IFC-1	23-May-1994 -- 08-Jun-1994
IFC-2	21-Jul-1994 -- 08-Aug-1994
IFC-3	08-Sep-1994 -- 17-Sep-1994

7.2.3 Temporal Resolution

Various portions of the navigation data were collected at 1, 10, and 30 Hz during the actual flights.

7.3 Data Characteristics

7.3.1 Parameter/Variable

A detailed description of the navigation data files and their content is given in Section 8.2. The parameters contained in the inventory listing file on the CD-ROM are:

Column Name
SPATIAL_COVERAGE
DATE_OBS
START_TIME
END_TIME
C130_START_LATITUDE
C130_START_LONGITUDE
C130_END_LATITUDE
C130_END_LONGITUDE
C130_MISSION_ID
C130_LINE_NUM
C130_RUN_NUM
C130_SITE
PLATFORM_TRACKING
PLATFORM_ALTITUDE

7.3.2 Variable Description/Definition

A detailed description of the navigation data files and their content is given in Section 8.2. The descriptions of the parameters contained in the inventory listing file on the CD-ROM are:

Column Name	Description
SPATIAL_COVERAGE	The general term used to denote the spatial area over which the data were collected.
DATE_OBS	The date on which the data were collected.
START_TIME	The starting Greenwich Mean Time (GMT) for the data collected.
END_TIME	The ending Greenwich Mean Time (GMT) for the data collected.

C130_START_LATITUDE	The NAD83 based latitude coordinate at the start of a C130 flight line as given in the flight summary reports.
C130_START_LONGITUDE	The NAD83 based longitude coordinate at the start of a C130 flight line as given in the flight summary reports.
C130_END_LATITUDE	The NAD83 based latitude coordinate at the end of a C130 flight line as given in the flight summary reports.
C130_END_LONGITUDE	The NAD83 based longitude coordinate at the end of a C130 flight line as given in the flight summary reports.
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).
PLATFORM_TRACKING	The azimuthal direction in which the data collection platform was traveling while collecting the data; expressed as degrees clockwise from North.
PLATFORM_ALTITUDE	The nominal altitude of the data collection platform above the target.

7.3.3 Unit of Measurement

A detailed description of the navigation data files and their content is given in Section 8.2. 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]
C130_START_LATITUDE	[degrees]
C130_START_LONGITUDE	[degrees]
C130_END_LATITUDE	[degrees]
C130_END_LONGITUDE	[degrees]
C130_MISSION_ID	[none]
C130_LINE_NUM	[none]
C130_RUN_NUM	[none]
C130_SITE	[none]
PLATFORM_TRACKING	[degrees]
PLATFORM_ALTITUDE	[meters]

7.3.4 Data Source

A detailed description of the navigation data files and their content is given in Section 8.2. The source of the parameter values contained in the inventory listing file on the CD-ROM are:

Column Name	Data Source
SPATIAL_COVERAGE	[Determined from latitude and longitude information in the data]
DATE_OBS	[Software derived from the data]
START_TIME	[Software derived from the data]
END_TIME	[Software derived from the data]
C130_START_LATITUDE	[Software derived from the data]
C130_START_LONGITUDE	[Software derived from the data]
C130_END_LATITUDE	[Software derived from the data]
C130_END_LONGITUDE	[Software derived from the data]
C130_MISSION_ID	[Software derived from the data]
C130_LINE_NUM	[Software derived from the data]
C130_RUN_NUM	[Software derived from the data]
C130_SITE	[Software derived from the data]
PLATFORM_TRACKING	[Software derived from the data]
PLATFORM_ALTITUDE	[Software derived from the data]

7.3.5 Data Range

The range of values for the parameters in the actual navigation data files was not tabulated. The following table gives information about the parameter values found in the inventory table on the CD-ROM.

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SPATIAL_COVERAGE	N/A	N/A	None	None	None	None
DATE_OBS	16-APR-94	17-SEP-94	None	None	None	None
START_TIME	1422	2217	None	None	None	None

END_TIME	1426	2244	None	None	None	None
C130_START_LATITUDE	37.91	56.12667	None	None	None	None
C130_START_LONGITUDE	-121.59667	-97.84	None	None	None	None
C130_END_LATITUDE	37.895	56.05167	None	None	None	None
C130_END_LONGITUDE	-121.62167	-97.84	None	None	None	None
C130_MISSION_ID	94-004-09	94-009-09	None	None	None	None
C130_LINE_NUM	1	703	None	None	None	None
C130_RUN_NUM	1	3	None	None	None	None
C130_SITE	429	999	999	None	None	None
PLATFORM_TRACKING	1	359	None	None	None	Blank
PLATFORM_ALTITUDE	91	8025	None	None	None	Blank

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

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

7.4 Sample Data Record

A sample data record for the level-0 C130 navigation data is not available here. The following are wrapped versions of the first few records from the level-0 C130 navigation data inventory:

```
SPATIAL_COVERAGE,DATE_OBS,START_TIME,END_TIME,C130_START_LATITUDE,
C130_START_LONGITUDE,C130_END_LATITUDE,C130_END_LONGITUDE,C130_MISSION_ID,
C130_LINE_NUM,C130_RUN_NUM,C130_SITE,PLATFORM_TRACKING,PLATFORM_ALTITUDE
'SSA-9OA',16-APR-94,1606,1610,53.53,-105.965,53.68167,-106.32,'94-004-09',301,1,
'429',306.0,4754.0
'SSA-9OA',16-APR-94,1615,1618,53.62833,-106.465,53.63333,-106.075,'94-004-09',
303,1,'429',80.0,4754.0
'SSA-9OA',16-APR-94,1625,1629,53.62833,-105.8867,53.63,-106.3583,'94-004-09',
303 ,2,'429',278.5,4754.0
```

8. Data Organization

8.1 Data Granularity

The smallest unit of level-0 C-130 navigation data is all the C-130 navigation information collected during the C-130 flights over the BOREAS areas in 1994. All of the data along with summary, documentation, and software files are contained on a single tape for distribution.

8.2 Data Format(s)

The C-130 level-0 tape contains 39 files that are mapped out as follows:

FILE NO.	INTENDED FILE NAME	DESCRIPTION
1	NAV.HED	ASCII HEADER FILE
2	NAV.INV	ASCII INVENTORY OF TAPE FILES
3	C130NAV.H	INCLUDE FILE FOR TEST.C
4	C130NAV_COMPUTE.H	INCLUDE FILE FOR C130NAV.COMPUTE.C
5	TEST.H	INCLUDE FILE FOR TEST.C AND C130NAV_GETDAT.C
6	TEST.C	ORIGINAL (ARC) VERSION OF C130_GETNAV.C
7	TEST_PRINT.C	TEST.PRINT.C SOURCE CODE
8	C130NAV_EXTRACT.C	C130NAV.EXTRACT.C SOURCE CODE
9	C130_GETNAV.C	GSFC MODIFIED TEST.C: MAIN PROGRAM
10	MAKEFILE	UNIX COMMAND FILE
11	README	NASA/ARC INFORMATION
12	TEST.LISTING	EXAMPLE OUTPUT
13-39	F1.DAT...F27.DAT	BINARY C130 NAVIGATION DATA FILES

File 1 (102-byte ASCII text records):
- Description/title of each BORIS C-130 navigation data product file on tape.

File 2 (102-byte ASCII text records):
- Contents of the navigation data tape files.
- Listing of all dates, missions, flights, lines, and runs contained in each of the 27 binary navigation data files (files 16 to 42) on tape.

Files 3 - 9 (102-byte ASCII text records):
- NASA ARC-supplied software for unpacking the binary navigation data files.

Each file represents one C source code module or C source include file. Each file should be named as follows after being copied from tape to disk:

FILE NO.	CREATED/INTENDED FILE NAME	DESCRIPTION	BYTES PER RECORD
3	c130nav.h	Include file for test.c	102
4	c130nav_compute.h	Include file for c130nav.compute.c	102
5	test.h	Include file for test.c and c130nav_getdat.c	102
6	test.c	Original (ARC) version of c130_getnav.c	102
7	test_print.c	test.print.c source Code vvvvv	102
8	c130nav_extract.c	c130nav.extract.c source Code	102
9	c130_getnav.c	GSFC Modified test.c: main program	102
10	Makefile	UNIX command file	80
11	README	NASA/ARC information	80
12	test.listing	Example output	132

File 10 (102-byte ASCII text records):
Sun/UNIX MAKEFILE: This file should be renamed Makefile on a Sun workstation or an equivalent computer platform. Note that problems have been experienced attempting to use the Makefile pulled from the BORIS tape because of the padding of the fixed length records in the file. Some editing or other manipulation of the file may be necessary in order to use it successfully on a Sun system. The software enclosed on the original ARC tape delivered to GSFC was compiled and run successfully on a Sun workstation under the UNIX(r) System V Release 4.0 operating system. One attempt to compile this source failed on a Silicon Graphics IRIX (SGI) workstation under the IRIX System V.4 operating system because the operating system could not locate system include files. No further attempt was made to port this software to the SGI, and no attempt was made to build the software under the VAX/VMS domain.

File 11 (102-byte ASCII text records):
The original file name was README. This file contains software notes written by NASA ARC staff dated 27-Jun-1994.

File 12 (132-byte ASCII text records):
An example output file produced by the above software. This output was used at NASA GSFC as a guide to selectively extract values such as time, roll, and pitch, needed to process MAS image data collected from the C-130 aircraft.

Files 13-39 (2,048-byte binary and ASCII, combined, records):
27 files of C-130 navigation data containing multiple flight lines per file.

C-130 navigation data are recorded as a 2,048-byte record once per second. The data format as described by the NASA ARC software is raw, binary, data in bytes 1-1024 and ASCII data in bytes 1025-2048. Further details of the data definitions, data type, and C structures used to manipulate the data are found in the C include file C130NAV.h (Tape file 3) listed above. A description of the fields contained on each data record follows:

Binary C-130 Navigation Data Record Format:

```
Description                     Units           Byte #'s
-----------                    ------          ---------
Record counter                                   1 -   2
Time code (BCD, dddhhmmsst)                      3 -   7
    ddd = Julian Day
     hh = hour of the day (0..23)
     mm = minutes (0..59)
     ss = seconds (0..59)
      t = tenths of seconds (0..9) MSB
Event flag                                       8
Bits 12345678:
      1:  0 --> INS1    1 --> INS2
      2:  0 --> VCR off 1 --> VCR on
      3:  reserved
      4:  0 --> AR1700 off
          1 --> AR1700 on
      5:  reserved
      6:  0 --> Keyboard
          1 --> Thumbwheel
    7&8: 00 --> line never occurred
         01 --> line start
         10 --> line stop
```

11 --> line abort		
Status flag --> bits 12345678		9
Record counter		1 - 2
Distance to go	meters	10 - 15
Time to go	seconds	16 - 21
Cross track distance	meters	22 - 27
Desired track	-	28 - 33
Track Angle Error	-	34 - 39
Drift angle	degrees	40 - 45
Align St	-	46 - 51
Latitude	degrees	52 - 57
Longitude	degrees	58 - 63
Ground speed	m/sec	64 - 69
Track angle	degrees	70 - 75
True heading	degrees	76 - 81
Wind speed	m/sec	82 - 87
Wind angle (direction)	degrees	88 - 93
Vertical profile distance	meters	94 - 99
Vertical speed	m/sec	100 - 105
A/D parameters, sampled 10 times per record		
8 parameters each as follows:		106 - 265
PRT-5 data	°C	
PRT-5 range	°C	
TAT	°C	
Hygrometer (dew point)	°C	
Software use only	-	
Pressure altitude	meters	
Reserved	-	
Reserved	-	
S/D parameters sampled 30 times per record		
5 parameters each as follows:		266 - 565
Pitch1	degrees	
Roll1	degrees	
Pitch2	degrees	
Roll2	degrees	
tHead	degrees	
Thumbwheel month number	(ASCII)	566 - 567
Thumbwheel day (of month)	(ASCII)	568 - 569
Thumbwheel year (e.g., 94)	(ASCII)	570 - 571
Thumbwheel site number	(ASCII)	572 - 575
Thumbwheel Julian day	(ASCII)	576 - 578
Thumbwheel mission number	(ASCII)	579 - 581
Thumbwheel glight number	(ASCII)	582 - 584
Thumbwheel A... G... L...	(ASCII)	585 - 587
Thumbwheel project number	(ASCII)	588 - 592
Thumbwheel line number	(ASCII)	593 - 595
Thumbwheel run number	(ASCII)	596 - 597
Keyboard line number	(ASCII)	598 - 600
Keyboard run number	(ASCII)	601 - 602
Keyboard site number	(ASCII)	603 - 605
Keyboard mission number	(ASCII)	606 - 608
Keyboard project number	(ASCII)	609 - 613
Keyboard flight number	(ASCII)	614 - 616

Comment	(ASCII)	617 - 696
Record counter for RS232	(BCD)	697 - 700
NS001 scan line counter	(BCD)	701 - 704
Frame counter	(Unspecified)	705 - 709
Filler	(Unspecified)	710
Time code	(Unspecified)	711 - 717
Time code event	(Unspecified)	718 - 724
Time code period	(Unspecified)	725 - 726
N/S velocity	(Unspecified)	727 - 732
E/W velocity	(Unspecified)	733 - 738
filler	-	739 - 1024
Record counter	(Unspecified)	1025 - 1029
VCR status	(Unspecified)	1030 - 1036
AR1700 status	(Unspecified)	1037 - 1043
Line status	(Unspecified)	1044 - 1050
Time (DDDHHMMSSt)	(ASCII)	1051 - 1060
Filler	set to lower-case "x"	1061 - 1070
Distance to go	meters	1071 - 1081
Filler	set to lower-case "x"	1082 - 1085
Time to go	seconds	1086 - 1094
Filler	set to lower-case "x"	1095 - 1098
Cross-track distance	degrees	1099 - 1108
Filler	set to lower-case "x"	1109 - 1111
Desired track	-	1112 - 1120
Filler	set to lower-case "x"	1121 - 1124
Track angle error	-	1125 - 1134
Filler	set to lower-case "x"	1135 - 1138
Drift angle	degrees	1139 - 1147
Filler	set to lower-case "x"	1148 - 1151
Reserved for align	-	1152 - 1160
Filler	set to lower-case "x"	1161 - 1164
Latitude	degrees	1165 - 1175
Filler	set to lower-case "x"	1176 - 1179
Longitude	degrees	1180 - 1191
Filler	set to lower-case "x"	1192 - 1195
Ground speed	m/sec	1196 - 1203
Filler	set to lower-case "x"	1204 - 1207
Reserved for track angle	degrees	1208 - 1216
Filler	set to lower-case "x"	1217 - 1220
True heading	degrees	1221 - 1229
Filler	set to lower-case "x"	1230 - 1233
Wind speed	m/sec	1234 - 1241
Filler	set to lower-case "x"	1242 - 1245
Wind angle direction	degrees	1246 - 1253
Filler	set to lower-case "x"	1257
Reserved for vert pro distance	meters	1258 - 1266
Filler	set to lower-case "x"	1267 - 1270
Vertical speed	m/sec	1271 - 1280
Filler	set to lower-case "x"	1281 - 1284
PRT-5	°C	1285 - 1290
Dew point	°C	1291 - 1296
TAT	°C	1297 - 1302
RESERVED	-	1303 - 1346
Pitch	degrees	1347 - 1350

Roll	degrees	1351 - 1354
True heading	degrees	1355 - 1358
Filler (set to lower case "x")	-	1359 - 1362
Radar Altitude	meters	1363 - 1367
Filler (set to lower case "x")	-	1368 - 1420
Month number	(ASCII)	1421 - 1422
Day (of the month)	(ASCII)	1423 - 1424
Year (last 2 digits)	(ASCII)	1425 - 1426
Thumbwheel site number	(ASCII)	1427 - 1430
Thumbwheel Julian day	(ASCII)	1431 - 1433
Thumbwheel mission number	(ASCII)	1434 - 1436
Thumbwheel flight number	(ASCII)	1437 - 1439
Thumbwheel A... G... L...	(ASCII)	1440 - 1442
Thumbwheel project number	(ASCII)	1443 - 1447
Thumbwheel line number	(ASCII)	1448 - 1450
Thumbwheel run number	(ASCII)	1451 - 1452
Keyboard line number	(ASCII)	1453 - 1455
Keyboard run number	(ASCII)	1456 - 1457
Keyboard site number	(ASCII)	1458 - 1460
Keyboard mission number	(ASCII)	1461 - 1463
Keyboard project number	(ASCII)	1464 - 1468
Keyboard flight number	(ASCII)	1469 - 1471
Filler	set to lower-case "x"	1472
Comment	(ASCII)	1473 - 1552
Record counter for RS232		1553 - 1560
Site name	(ASCII)	1561 - 1581
Filler	set to lower-case "x"	1582
NS001 scan line count	(BCD)	1583 - 1588
Filler	set to lower-case "x"	1589 - 1598
GPS data	(ASCII)	1599 - 1730
Filler	set to lower-case "x"	1731 - 1768
Event time code	(Unspecified)	1769 - 1786
Photo frame count #1	(Unspecified)	1787 - 1797
Filler	set to lower-case "x"	1798
Photo frame count #2	(ASCII)	1799 - 1809
Filler	set to lower case "x"	1810 - 2048

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.

9. Data Manipulations

9.1 Formulae

9.1.1 Derivation Techniques and Algorithms

None.

9.2 Data Processing Sequence

9.2.1 Processing Steps

ARC received the raw 0.25-inch cartridge tape from the C-130 technicians. The data files were read and loaded to disk. Distribution to the BORIS archive consisted of the raw data files along with C structures to read and process the data. BORIS staff further processed the level-0 C-130 navigation data by:

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

9.2.2 Processing Changes

ARC applied no special or additional processing to the C-130 navigation data from BOREAS.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

ARC made no special adjustments or offsets to the data.

9.3.2 Calculated Variables

ARC made no special adjustments or offsets to the data.

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

Not all high-frequency samples (30 for synchro-digital (S/D) and 10 for analog-digital (A/D)) change between consecutive records. One explanation is the navigation system sampled the same value (at exactly a 1-second interval) for consecutive records. This can happen in relatively stable, level flight. Another explanation is that the navigation system failed to record all high-frequency samples (30 for S/D or 10 for A/D). Tests show the second explanation to be true most of the time, and samples were skipped at random during the 1-second interval.

The field for the average true heading to a tenth of a degree contains four digits. The first digit prints as a sign (+/-), thus overwriting the hundreds digit of average true heading.

No algorithm has been found to convert time reported by GPS to universal time.

10.2 Quality Assessment

10.2.1 Data Validation by Source

Data distribution to NASA ARC occurs at the conclusion of the deployment. Data tapes are presented in total for documentation and archive. Data evaluation consists primarily of identifying component failure (i.e. radar altitude, GPS values, pressure measurements.).

10.2.2 Confidence Level/Accuracy Judgment

The quality of the data is judged to be good.

10.2.3 Measurement Error for Parameters

See Sections 4.1.6 and 8.2.

10.2.4 Additional Quality Assessments

Quality Assessment performed by BORIS staff:

- BORIS staff built and ran the software provided by NASA ARC on a Sun workstation. This software listed values for all parameters on selected 1-per-second C-130 navigation file records. A subset of this information was redirected to ASCII files and printed.
- A copy of the ARC software was modified to produce ASCII listings of selected 1-, 10-, and 30-Hz data, including pressure and radar altitude, pitch, roll, drift, and time stamps for entire flight lines. These listings were transferred to a Macintosh and plotted with the Microsoft Excel program. Certain problems found in the data as revealed by these plots are described in Section 11.1.

10.2.5 Data Verification by Data Center

None given.

11. Notes

11.1 Limitations of the Data

See Section 11.2.

11.2 Known Problems with the Data

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

- BORIS staff found that the second and third data files (tape files 17 and 18), f1.dat and f2.dat, are duplicates.
- BORIS staff created time series plots and found significant noise in the 10- and 30-Hz data. It was discovered that the 30-Hz data intermittently provided fewer than 30 samples per record, although it was not clear from where the values were missing or if the sampling rate was different for each 1-second interval.
- Several spurious/outlier values were present, particularly in the first three recorded 30-Hz values per record. These seemed to be left over from the last fully sampled (30-Hz) record in the data set.
- The C-130 navigation data records have been assumed to be 1 second apart, and uncorrected, steadily increasing time stamps for each record do exist in the file. Plots of ARC "Corrected" times, however, show redundant or unequally spaced time stamps from record to record. Plots of "Corrected" times, for example, showed that record n started at 30.9 seconds, record n+1 at 31.8 seconds, and record n+2 at 32.9 seconds. This may be an issue for those attempting to interpolate times for 10- and 30-Hz data.
- During actual data acquisition, the comment field buffer was not cleared from flight line to flight line; as a result, data collection field notes appear in subsequent flight lines until a new comment or field note was entered. Therefore, some field notes refer to flight-line-run combinations other than the flight line represented by the record containing the comment.
- It was discovered that Site 433, Line 1 shown on the ARC hardcopy color map in the C-130 Mission Summary Report for Mission 94-006-07 is actually composed of three flight lines (Lines 3, 4, and 5). The navigation data also reflect this set of three lines to be Site 433, Line 1.
- For its use in relative correction of aircraft images, BORIS staff interpolated and smoothed the data to achieve a consistent temporal resolution of the needed variables, but only after selectively deleting known outlying values. Discussions with ARC staff indicated that hardware and software upgrades were being made to prevent or reduce these problems in future C-130 flights. Users of this data set, however, should quality check the C-130 navigation parameter values further before use.

11.3 Usage Guidance

All of the files on the BORIS C-130 navigation data tape should be copied to disk. The ASCII header file should be read, and output files should be named according to this document. The software files were compiled and linked without incident on a Sun workstation by BORIS staff using the UNIX make command. An attempt to build the software under the SGI and VAX/VMS operating systems was unsuccessful; the C language compilers were unable to locate certain system ".h" include files. No further attempt was made to port the Sun software and Makefile to either SGI/IRIX or VAX/VMS platforms. It is likely that the ".dat" files will have to be byte-swapped in order for ARC software to read these data on SGI and VAX/VMS platforms.

Several flight lines are contained in each of the ".dat" files. The inventory file, which is the second file on the tape, shows which flight mission data are contained in each ".dat" file. Within this listing, certain line, flight, date, and other information are missing, blank, filled, or filled with a lower-case 'x' because of the automated fashion in which the inventory listing was compiled at GSFC. Blank or dummy flight, line, and run numbers exist because this is what was contained on the ARC data tape for these designators.

11.4 Other Relevant Information

Not applicable.

12. Application of the Data Set

To date, BORIS staff, in conjunction with MAS data processing personnel, have used the C-130 navigation data to calculate relative coordinates for flight lines of MAS data pixels scanned from the C-130 aircraft over the BOREAS SSA and NSA. The C-130 navigation data provided aircraft position and attitude at 1, 10, and 30 Hz. These parameters were used to derive relative Cartesian X and Y grid coordinates for each MODIS flight line image pixel using software that models the MAS sensor scanning system. The theory and working algorithms that were implemented to achieve this are described in detail in the BORIS documentation provided for the BORIS MAS Level 1-B data set. This algorithm could provide the basis for deriving relative position coordinates for other sensors that were in operation during this or other C-130 flights.

13. Future Modifications and Plans

No modification is planned for the C-130 navigation data currently logged in the BORIS data base. The BOREAS experience, however, has led to hardware modifications at NASA ARC in an effort to improve the completeness and integrity of acquired C-130 navigation data.

14. Software

14.1 Software Description

The NASA ARC navigation data unpacking software is written in C and compiles and runs under the SunOS Version 5.0+ operating system. The BORIS software is written in C and is operational under the VAX/VMS Version 5.0+, OpenVMS Versions 5.5-2, and SGI System V.4+ operating systems at GSFC. The primary dependencies in the VMS software are the tape I/O library and Oracle data base utility routines on the VAX computers.

NASA ARC provided the BORIS archive with the raw 2,048-byte data. To facilitate accessing and understanding, NASA ARC also provided a supplemental software distribution containing a C structure that gives a name to each parameter (c130nav.h) and then provides code that transfers the 2,048-byte record into the structure (c130nav_extract.c). The user can access these parameters by name from the C130VALUES structure. BORIS staff developed software and command procedures

for:

- Writing the ASCII summary information, ARC data extraction software, and binary navigation files to tape
- Creating an ASCII inventory of the binary data file contents and logging this information as well as the software and summary information on tape into the BORIS Oracle data base tables

14.2 Software Access

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

15. Data Access

The level-0 C-130 navigation data are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services
Oak Ridge National Laboratory
P.O. Box 2008 MS-6407
Oak Ridge, TN 37831-6407
Phone: (423) 241-3952
Fax: (423) 574-4665
E-mail: ornldaac@ornl.gov or ornl@eos.nasa.gov

15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics http://www-eosdis.ornl.gov/.

15.3 Procedures for Obtaining Data

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

15.4 Data Center Status/Plans

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

16. Output Products and Availability

16.1 Tape Products

The BOREAS level-0 C-130 navigation 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 sensors were triggered. The BOREAS data base contains an inventory of available BOREAS aircraft flight documentation, such as flight logs, videotapes, and photographs.

16.3 Other Products

None.

17. References

17.1 Platform/Sensor/Instrument/Data Processing Documentation

Airborne Instrumentation Research Project - Flight Summary Reports for Flight No. 94-004-09 to 94-009-09 4/16 - 9/17, 1994. NASA Ames Research Center. Airborne Missions and Applications Division. Moffett Field, California. 94035.

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

17.2 Journal Articles and Study Reports

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

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

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

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

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

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

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

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

```
A/D     - Analog-Digital
ARC     - Ames Research Center
ASAS    - Advanced Solid-State Array Spectroradiometer
ASCII   - American Standard Coding for Information Interchange
BOREAS  - BOReal Ecosystem-Atmosphere Study
BORIS   - BOREAS Information System
BPI     - Bytes Per Inch
CADDS   - C-130 Automated Digital Data System
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
FFC-T   - Focused Field Campaign - Thaw
GIS     - Geographic Information System
GPS     - Global Positioning System
GSFC    - Goddard Space Flight Center
IFC     - Intensive Field Campaign
INS     - Inertial Navigation System
MAS     - MODS Airborne Simulator
MODIS   - Moderate-Resolution Imaging Spectrometer
NAD 83  - North American Datum of 1983
NASA    - National Aeronautics and Space Administration
NSA     - Northern Study Area
ORNL    - Oak Ridge National Laboratory
PANP    - Prince Albert National Park
PRT-5   - Precision Radiation Thermometer
SCSI    - Small Computer Serial Interface
S/D     - synchro-digital
SGI     - Silicon Graphics IRIX
SSA     - Southern Study Area
TAS     - True Air Speed
TAT     - Total Air Temperature
TIMS    - Thermal Infrared Multispectral Scanner
TMS     - Thematic Mapper Simulator
URL     - Uniform Resource Locator
```

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13. ABSTRACT *(Maximum 200 words)*

The level-0 C-130 navigation data files contain aircraft attitude and position information acquired during the digital image and photographic data collection missions over the BOREAS study areas. Various portions of the navigation data were collected at 1, 10, and 30 Hz. The level-0 C-130 navigation data collected for BOREAS in 1994 were improved over previous years in that the C-130 onboard navigation system was upgraded to output inertial navigation parameters every 1/30th of a second (i.e., 30 Hz). This upgrade was encouraged by users of the aircraft scanner data with the hope of improving the relative geometric positioning of the collected images.

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