

MODIS Airborne Simulator (MAS) Level-1 Processing System

Status and Data Availability

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Introduction

The MODIS Airborne Simulator (MAS) Level-1 processing system was designed and implemented by the MODIS Science Data Support Team at GSFC during the last half of 1991, and processed the first MAS flight data in November 1991. The purpose of the processing system is to ingest MAS Level-0 aircraft sensor, engineering and navigation data, and produce calibrated, geolocated radiances in a portable format. This document briefly describes

- the MAS instrument specifications,
- the calibration and geolocation procedures for the MAS,
- the processing system operation and output products,
- current data processing status and availability.

The calibration and geolocation methods used for the MAS were originally developed for the Multispectral Atmospheric Mapping Sensor (MAMS) at the University of Wisconsin-Madison and Marshall Space Flight Center (1).

MAS instrument description

| | |
|-----------------------------|------------------------------------------------------------------|
| Platform | NASA ER-2 aircraft |
| Ground speed | 206 meters per second (nominal) |
| Altitude | 18 kilometers (nominal) |
| Total field of view | 85.92 degrees |
| Swath width | 33.52 kilometers (at 18 kilometers altitude) |
| Instantaneous field of view | 2.5 milliradians |
| Pixel spatial resolution | 45 meters (at 18 kilometers altitude) |
| Pixels per scan line | 716 |
| Scan rate | 6.25 scan lines per second |
| Data channels | 12 |
| Bits per channel | 8 (configured to have 4 channels @ 10 bits, 7 channels @ 8 bits) |
| Data rate | 232.2 Megabytes/hour (Ames Level-0 intermediate format) |
| Spectral channels | 50 (subset of 12 selected for flight) |
| Visible calibration | Integrating sphere on the ground - none onboard |
| Infrared calibration | Two temperature controlled black bodies on board |

MAS Visible/Near-Infrared Calibration

The MAS does not have an onboard visible/near-infrared (VIS/NIR) calibration capability. An integrating sphere is used on the ground before and after flight missions to generate calibration data for the VIS/NIR channels. A linear calibration of the form

$$\text{Radiance} = \text{Slope} \times \text{Count} + \text{Intercept}$$

is used to compute VIS/NIR radiances. It is currently assumed that this calibration is not time dependent and does not change during flight. However recent instrument characterization at Ames Research Center has revealed that VIS/NIR channel sensitivity may decrease as the MAS instrument cools during ascent to cruise altitude. Efforts are underway to characterize this effect, and an updated calibration method which corrects for the sensitivity changes with temperature will be implemented. More details on the MAS VIS/NIR calibration scheme are given in Jedlovec et. al. (1).

MAS Infrared Calibration

Calibration data for the MAS infrared (IR) channels is obtained during flight from two temperature controlled blackbody sources. These blackbodies are maintained at temperatures of approximately 238 K (-35 C) and 273 K (0 C) respectively. These are viewed during every mirror scan. The calibration algorithm for these channels involves

- computing equivalent Planck radiances at the blackbody temperatures,
- computing the calibration slope and intercept by the relationships

$$\text{Slope} = \frac{\text{Radiance}(\text{BB2}) - \text{Radiance}(\text{BB1})}{\text{Count}(\text{BB2}) - \text{Count}(\text{BB1})}$$

$$\text{Intercept} = \frac{\text{Radiance}(\text{BB1}) \times \text{Count}(\text{BB2}) - \text{Radiance}(\text{BB2}) \times \text{Count}(\text{BB1})}{\text{Count}(\text{BB2}) - \text{Count}(\text{BB1})}$$

where

Radiance(BB1), Radiance(BB2) are the equivalent Planck radiances for the cool (238 K) and warm (273 K) blackbodies respectively,

Count(BB1), Count(BB2) are the digital instrument counts for the cool (238 K) and warm (273 K) blackbodies respectively,

- computing the equivalent sensor radiance for each pixel by the relationship

$$\text{Radiance} = \text{Slope} \times \text{Count} + \text{Intercept}.$$

This procedure is performed for every IR channel on every scanline. No averaging of MAS blackbody data is done. More details on the MAS IR calibration scheme are given in Jedlovec et. al. (1).

MAS Geolocation

Geolocation data for the MAS is recorded continuously during flight by the ER-2 Inertial Navigation System (INS). The important parameters are time, latitude, longitude, heading and altitude. The INS updates these values every 5 seconds.

The geolocation algorithm is only applied to portions of a flight where the aircraft flew a straight and level line. Straight line flight tracks are identified by manual inspection of the change in aircraft heading with time. Linear regressions for aircraft latitude, longitude, heading and altitude versus time are computed for the straight line flight tracks.

To geolocate a given MAS straight line flight track, the MAS start time and scanline number at the beginning of the flight track are determined. These are used as a reference for the rest of the flight track, since MAS times are truncated to whole seconds. The scanline number and scan rate are used to determine the time elapsed to subsequent scanlines in the flight track. Once the time for a given scanline is computed, the linear regression relationships are used to compute aircraft latitude, longitude, heading and altitude at that time. Latitudes and longitudes are then computed for every 10th pixel on that scanline (pixels 1, 10, 20, 30,, 690, 700, 710, 716). Solar zenith and azimuth angles, and aircraft scan and azimuth angles are also computed for every 10th pixel. Every scanline in a straight line flight track is geolocated in this way. Scanlines which are not included in straight line flight tracks have no geolocation data computed. However it should be noted that the INS data is still available during these sections. More details on the MAS geolocation scheme are given in Jedlovec et. al. (1).

MAS Level-1 Data Processing System

The MAS Level-1 Data Processing System was designed at GSFC on DEC VAX/VMS and Silicon Graphics Iris systems in FORTRAN77, and currently runs on either system. The present processing configuration uses a VAX system as a MAS Level-0 data staging area, and a Silicon Graphics Iris as a processing platform.

The current sequence of processing steps is:

- (1) Read MAS Level-0 tapes onto VAX,
- (2) Check Level-0 data for anomalies or problems,
- (3) Determine flight track time limits from INS data,
- (4) Compute navigation regressions from time limit data,
- (5) Compute calibration data,
- (6) Create calibrated, geolocated data set for each flight line,
- (6) Move Level-1 data to FTP site,
- (7) Writing Level-1 data summary for FTP site.

The data is currently distributed by File Transfer Protocol (FTP) over Internet. A facility for distributing data on Exabyte 8mm tapes will exist in the near future.

MAS Level-1B data format

During the design of the MAS Level-1 processing system, it was decided that many of the problems associated with dataset portability and usability could be solved by creating the MAS Level-1B datasets in a standard, portable format. After some investigation, the Network Common Data Form (NetCDF) interface (2) was selected as the means for reading and writing the MAS Level-1B data files. NetCDF was developed by the Unidata Program Center at the University Corporation for Atmospheric Research (UCAR). The purpose of NetCDF is to allow the user to create, access, and share scientific data in a form that is self-describing and network-transparent. "Self-describing" means that a file includes information defining the data it contains. "Network-transparent" means that a file is represented in a form that can be accessed by computers with different ways of storing integers, characters, and floating-point numbers.

NetCDF data files are accessed through C or FORTRAN interfaces which are provided by UCAR. The interfaces have been successfully tested by UCAR on the following platforms:

- Sun 3, SPARCstation (SunOS)
- DEC VAX (VMS, Ultrix)
- DECstation (Ultrix)
- IBM RISC System 6000 (AIX)
- Cray YMP (UNICOS)
- IBM PS/2 (MSDOS, OS/2)

The NetCDF interface library source code is available from UCAR by anonymous FTP. Instructions on how to obtain the software are appended to this document (Appendix 1).

MAS Level-1B data contents

The product generated by the MAS Level-1 processing system is defined to be calibrated, geolocated radiances. When designing the MAS Level-1B dataset, a prime concern was that all Level-0 engineering and ancillary input data be maintained in the output data set.

Each individual Level-1B dataset contains calibrated, geolocated radiances for all MAS channels for one straight line flight track, or flight line. Each Level-1B flight line is contained within one NetCDF file. A description of a Level-1B flight line file is appended to this document (Appendix 2).

MAS Level-1B data availability

The MAS Level-1B data is currently distributed at GSFC by anonymous FTP via Internet. Details on how this may be done are appended to this document (Appendix 3). Since many of

the typical MAS flight line files are tens of megabytes in size, FTP transfers to remote sites can be slow. For this reason, a facility to distribute MAS data on Exabyte 8mm tapes is under development. Plans are also underway to develop an on-line catalog system for the MAS data.

MAS data processing status

The current inventory of MAS Level-0 data at GSFC includes 1 test flight, 1 ferry flight, 11 science flights (FIRE) and 3 calibration runs (FIRE). The next major MAS mission will be the ASTEX deployment in June 1992. The following table lists the MAS data processed so far at GSFC, as of 9 April 1992.

| <u>Flight Date</u> | <u>Area covered during flight</u> | <u>Level-0 data received</u> | <u>Processing completed</u> | <u>INS offset fixed</u> |
|--------------------|-----------------------------------|------------------------------|---------------------------------|-------------------------|
| 10/31/91 | Ames test flight CA/NV | yes | 3/3 tracks | yes |
| 11/12/91 | Ferry flight CA to TX | yes (subset) | 1/1 tracks | no |
| 11/14/91 | Coffeyville KS | yes | 16/16 tracks | no |
| 11/18/91 | Coffeyville KS | yes | 14/14 tracks | yes |
| 11/21/91 | Coffeyville KS | yes | | |
| 11/22/91 | Coffeyville KS | yes | | |
| 11/24/91 | Gulf coast TX/LA | yes | | |
| 11/25/91 | Coffeyville KS | yes | | |
| 11/26/91 | Coffeyville KS | yes | | |
| 12/03/91 | Gulf coast TX/LA | yes | | |
| 12/04/91 | Gulf coast TX/LA | yes | | |
| 12/05/91 | Coffeyville KS | yes | 29/29 tracks | no |
| 12/07/91 | Coffeyville KS | yes | | |
| 11/16/91 | Ground visible calibration | yes | 10481 scanlines (no navigation) | |
| 11/20/91 | Ground visible calibration | yes | 6078 scanlines (no navigation) | |
| 11/23/91 | Ground visible calibration | yes | 10281 scanlines (no navigation) | |

Appendices 4, 5 and 6 show some of the summary data generated for the MAS FIRE flight on 18 November 1991.

References

- (1) Improved Capabilities of the Multispectral Atmospheric Mapping Sensor (MAMS), January 1989, G.J. Jedlovec et. al., NASA TM 100352, Marshall Space Flight Center.
- (2) NetCDF Users Guide, An Interface for Data Access, Version 2.0, October 1991, Unidata Program Center, University Corporation for Atmospheric Research.

Appendix 1

Instructions for obtaining the netCDF library source code and documentation

The following sequence of commands and command output demonstrates how to retrieve the netCDF library source code and documentation from UCAR via anonymous FTP. The computer system used was a Silicon Graphics Iris with the Irix 3.3.2 operating system.

```
% ftp unidata.ucar.edu
Connected to unidata.ucar.edu.
220 groucho FTP server (SunOS 4.1) ready.
Name (unidata.ucar.edu:gumley): anonymous
331 Guest login ok, send ident as password.
Password:
230 Guest login ok, access restrictions apply.
ftp> cd pub
250 CWD command successful.
ftp> binary
200 Type set to I.
ftp> get netcdf-2.02.tar.Z
local: netcdf-2.02.tar.Z remote: netcdf-2.02.tar.Z
200 PORT command successful.
150 Binary data connection for netcdf-2.02.tar.Z (128.183.252.9,1288) (830751
bytes).
226 Binary Transfer complete.
830751 bytes received in 100.72 seconds (8.05 Kbytes/s)
ftp> quit
221 Goodbye.
% uncompress netcdf-2.02.tar.Z
% tar xvof netcdf-2.02.tar
```

This netCDF version (2.02) was downloaded on 11 March 1992.
Installation questions or problems should be addressed to Russ Rew at UCAR
(russ@unidata.ucar.edu).

Appendix 2

Structure of a MAS Level-1B NetCDF flight track file

The following information summarizes the variables in a MAS flight track file. All MAS flight track files have this same format.

dimensions:

This section defines the dimensions of the variables contained in the data set.

Time = UNLIMITED ; // (2601 currently)

This dimension is the 'length' dimension of the data set. It is extendable in the sense that extra data can be added at the end of the data set. Physically this dimension corresponds to elapsed time, however it also corresponds to the incrementing of the scan line counter.

NumberOfChannels = 12 ;

This is the number of channels on the MAS.

NumberOfPixels = 716 ;

This is the number of pixels across a MAS scan.

HeaderLength = 1840 ;

This is the length of the ASCII data set header. This is composed of blocks of 80 characters, which contain no carriage return, line feed or similar record separators. Currently the header contains one line of descriptive text that is entered by the person who processed the data, followed by 22 lines which describe the MAS instrument configuration as used in processing. This text is self-documenting.

AnchorIndexSize = 73 ;

This is the number of geolocation anchor points per scan line. Each MAS scan line has geolocation data for every 10th pixel (to save space). The geolocation data is defined for pixel numbers 1, 10, 20, 30, 40,.....680, 690, 700, 710 and 716 which makes a total of 73 geolocation anchor points.

It should be noted that pixels 1 to 358 are on the starboard (right) side of the aircraft, while pixels 359 to 716 are on the port (left) side of the aircraft.

variables:

This section defines the type and size of the variables in the output data set.

The type definitions are from the C language, however the equivalent FORTRAN types are

char = CHARACTER,

short = INTEGER*2,

long = INTEGER*4,

float = REAL*4.

char DataSetHeader(HeaderLength) ;
 ASCII header text.
 This indicates which spectral bands were selected, which channels had 8 or 10 bit data, which channels were calibrated using the MAS blackbodies (IR channels), and slopes/intercepts for the visible/near-IR channels.

short AnchorPtIndex(AnchorIndexSize) ;
 Pixel numbers for which geolocation information is defined.

short DataFrameStatus(Time) ;
 (Level-0 MAS engineering data)
 Zero indicates good data.

long ScanLineCounter(Time) ;
 (Level-0 MAS engineering data)
 Scan line count, increments by 1 for every scan line.

long ThumbWheelSwitches(Time) ;
 (Level-0 MAS engineering data)
 Data system thumbwheel switch settings.

short ScanRate(Time) ;
 (Level-0 MAS engineering data)
 Scan rate in scans per second (x 10, nearest integer).

long GMTTime(Time) ;
 (Level-0 MAS engineering data)
 Greenwich Mean Time (HHMMSS).

short S-BendIndicator(Time) ;
 (Level-0 MAS engineering data)
 S-bend indicator : 0=no S-bend, 1=S-bend.

short AircraftRollCount(Time) ;
 (Level-0 MAS engineering data)
 Aircraft roll count (signed integer, positive is right),
 0.03 degrees per count.

long Year&DayOfYear(Time) ;
 Year, month, day (YYYYMMDD).

short BlkBdy1Temperature(Time, NumberOfChannels) ;
 (Level-0 MAS engineering data)
 Black Body 1 (cold) thermal reference temperature
 (degrees C x 100)

short BlkBdy2Temperature(Time, NumberOfChannels) ;
 (Level-0 MAS engineering data)
 Black Body 2 (hot) thermal reference temperature
 (degrees C x 100)

short AmplifierGain(Time, NumberOfChannels) ;
 (Level-0 MAS engineering data)

Instrument Gain (x 1000)

short BlkBdy1Counts(Time, NumberOfChannels) ;

(Level-0 MAS engineering data)

Black Body 1 (cold) radiance count

short BlkBdy2Counts(Time, NumberOfChannels) ;

(Level-0 MAS engineering data)

Black Body 2 (hot) radiance count

float CalibrationSlope(Time, NumberOfChannels) ;

Count to radiance calibration slope.

Radiance = (count*slope + intercept)/gain (visible/near-IR channels),

Radiance = count*slope + intercept (IR channels).

Radiance units are:

milliWatts per square centimeter per steradian per micron

for visible/near-IR channels (calibrated by integrating sphere),

milliWatts per square centimeter per steradian per wavenumber

for IR channels (calibrated using MAS blackbodies).

float CalibrationIntercept(Time, NumberOfChannels) ;

Count to radiance calibration intercept.

Units are the same as the calibration slope.

float PixelLatitude(Time, AnchorIndexSize) ;

Latitudes for pixels at geolocation anchor points.

Latitude ranges from -90 degrees at the South Pole to

+90 degrees at the North Pole.

float PixelLongitude(Time, AnchorIndexSize) ;

Longitudes for pixels at geolocation anchor points.

Longitude is zero at the Greenwich Meridian, and ranges

from -180 degrees (West) to +180 degrees (East).

float SensorZenithAngle(Time, AnchorIndexSize) ;

MAS sensor zenith angle for pixels at geolocation anchor points.

Defined as the zenith angle (degrees) of a vector from

the sensor to the pixel (nadir sensor zenith angle = 0).

float SensorAzimuthAngle(Time, AnchorIndexSize) ;

MAS sensor azimuth angle for pixels at geolocation anchor points.

Defined as the azimuth angle (degrees) clockwise from

North of a vector from the pixel to the sensor.

float SolarZenithAngle(Time, AnchorIndexSize) ;

Solar zenith angle for pixels at geolocation anchor points.

Defined as the zenith angle (degrees) of a vector from

the pixel to the Sun.

float SolarAzimuthAngle(Time, AnchorIndexSize) ;

Solar azimuth angle for pixels at geolocation anchor points.

Defined as the azimuth angle (degrees) clockwise from

North of a vector from the pixel to the Sun.

float AircraftLatitude(Time) ;
Aircraft subpoint latitude (degrees, derived from INS data).

float AircraftLongitude(Time) ;
Aircraft subpoint longitude (degrees, derived from INS data).

float AircraftHeading(Time) ;
Aircraft heading (degrees, derived from INS data).

float AircraftAltitude(Time) ;
Aircraft altitude (meters, derived from INS data).

float AircraftPitch(Time) ;
Aircraft pitch angle (degrees, derived from INS data).

short CalibratedData(Time, NumberOfChannels, NumberOfPixels) ;
Calibrated MAS radiances for all channels and all pixels
(x 100, nearest integer).
Radiance units are:
milliWatts per square centimeter per steradian per micron
for visible/near-IR channels (calibrated by integrating sphere),
milliWatts per square meter per steradian per wavenumber
for IR channels (calibrated using MAS blackbodies).

Appendix 3

Accessing the MAS anonymous FTP site

An anonymous FTP account has been set up to enable users of MAS data to become familiar with the structure of MAS Level-1B datasets, and to provide a limited distribution mechanism for MAS Level-1B data. Questions should be directed to:

Liam E. Gumley (RDC 301-982-3748 gumley@ltp.gsfc.nasa.gov), or
Thomas E. Goff (RDC 301-982-3704 teg@ltp.gsfc.nasa.gov).

Connecting to the anonymous FTP site

The files in the account have been set up specifically for Silicon Graphics Iris users. It is therefore advisable to use your own Iris as a base for retrieving files. However, you can still retrieve data using any computer with FTP. To connect to the host, type

```
ftp ltpiris2.gsfc.nasa.gov
```

(or if that doesn't work)

```
ftp 128.183.252.9
```

For a username, enter

```
anonymous
```

and for a password, enter your Internet ID, e.g.

```
hoges@barbie.gsfc.nasa.gov
```

You should then change to the MAS directory by typing

```
cd pub/MAS
```

Getting files from the anonymous FTP area

Files in the area are either ASCII or BINARY. In order to transfer them correctly to your own machine, you must tell your FTP program what type of file you are going to fetch. For example, to get the BINARY file shrimp.dat, you would type

```
binary  
get shrimp.dat
```

Similarly, to get the ASCII file downunder.doc, you would type

```
ascii  
get downunder.doc
```

Please ensure you use the correct transfer mode to avoid possible file corruption. Note that MAS Level-1B data files (with .cdf extension) are always in BINARY form.

Directories and files in the anonymous FTP area

The first file you will see is 00readme.doc - you are now reading it.

There are several directories present.

Directory util contains source code, executable programs, and netCDF libraries for use on the Iris. The files in this directory are

| Size | Name | Description |
|--------|----------------|-----------------------------------------------|
| 58172 | fdump | (BIN) file dump program (Iris only) |
| 18737 | fdump.c | (ASC) file dump C source code |
| 94376 | libnetcdf.a | (BIN) netCDF v2.02 library (Iris only) |
| 424176 | masdump | (BIN) MAS file dump program (Iris only) |
| 9251 | masdump.f | (ASC) MAS file dump FORTRAN source code |
| 151388 | ncdump | (BIN) netCDF file dump program (Iris only) |
| 1532 | netcdf.doc | (ASC) how to get netCDF source via FTP |
| 10162 | netcdf.h | (ASC) netCDF v2.02 C header file |
| 5050 | netcdf.inc | (ASC) netCDF v2.02 FORTRAN include file |
| 132444 | netcdf2pci | (BIN) netCDF to PCI program (Iris only) |
| 5922 | netcdf2pci10.c | (ASC) netCDF to PCI C source code |
| 134156 | subset | (BIN) netCDF image subset program (Iris only) |
| 11659 | subset31.c | (ASC) netCDF image subset C source |

Several other directories will be present, each of which contains MAS Level-1B flight lines. The syntax of the directory names will be something like

12nov91

which represents the day, month and year of the flight in question. Each directory will contain files from just one flight. Each file will have a name like

12nov91-01.cdf

where the '-01' represents the flight line number. These files are typically large (many megabytes) and are BINARY in form. They may take a significant period of time to transfer with FTP. Included in each of these directories will also be a file named something like

12nov91.doc

which is an ASCII text file containing a brief summary of the flight. Also, a file named something like

12nov91.ins

will be present, which is a BINARY file containing the ER-2 Inertial

Navigation System (INS) data for the flight. These files have 150 bytes per line, and are ASCII text (but use BINARY transfer for FTP).

Appendix 4MAS Flight Summary

Date : 18-NOV-1991
 Takeoff : 1920Z
 Landing : 0120Z
 Airfield : Ellington AFB, Houston TX
 Aircraft : ER-2 709
 Destination : Coffeyville KS
 Purpose : FIRE deployment (cirrus cloud study)
 Scanlines : 68973
 Channels : 12 (2 - 8 @ 8 bits, 9 - 12 @ 10 bits, 1 was bit bucket)
 IFOV : 2.5 milliradians
 MAS clock : Internal
 INS clock : Internal
 Clock offset: INS - MAS = 65.06 seconds CORRECTED

Total of 14 straight line flight tracks

| Number | Start Time | End Time | (Times in decimal hours) |
|--------|---------------|-------------|--------------------------|
| 01 | 20.551 | 20.586 | |
| 02 | 20.614 | 20.860 | |
| 03 | 20.942 | 21.018 | |
| 04 | 21.028 | 21.112 | |
| 05 | 21.168 | 21.340 | |
| 06 | 21.404 | 21.582 | |
| 07 | 21.639 | 21.806 | |
| 08 | 21.860 | 22.043 | |
| 09 | 22.061 | 22.236 | |
| 10 | 22.275 | 22.475 | |
| 11 | 22.522 | 22.650 | |
| 12 | 22.704 | 22.892 | |
| 13 | 22.954 | 23.124 | |
| 14 | 23.185 | 23.351 | |

Appendix 5MAS Level-1B flight line summary

| | |
|-------------------------------|-------------------------|
| Date | 18-NOV-1991 |
| Start time | 221639.00 hours |
| End time | 222818.00 hours |
| Nominal heading | 62 degrees |
| Nominal altitude | 19903 meters |
| Number of scan lines | 4351 |
| Start, end scan line numbers | 68691 73046 |
| Nominal BB1, BB2 temperatures | -37.43 C, -0.72 C |
| First valid navigated record | 1 |
| Nadir start lat, lon | 35.964, -96.697 degrees |
| Top left lat, lon | 35.819, -96.597 degrees |
| Top left solar zen, azm | 79.865, 237.111 degrees |
| Last valid navigated record | 4351 |
| Nadir end lat, lon | 36.585, -95.243 degrees |
| Bottom right lat, lon | 36.737, -95.333 degrees |
| Bottom right solar zen, azm | 83.214, 239.730 degrees |

Appendix 6

ER-2 flight track for MAS 18 November 1991 FIRE mission

