Earth Surface Mineral Dust Source Investigation (EMIT)

Level 1B Data Product User Guide

Initial Release

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EPDM Electronic Signatures

Snapshot of signatures from EPDM will be added upon release

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1 Introduction

1.1 Identification

This document describes information about the file structure and datasets provided in the EMIT Level 1B data product. The algorithms and data content of the Level 1B data products are described briefly in this guide, with the purpose of providing the user with sufficient information about the content and structure of the data files to enable the user to access and use the data. For a more complete description of the algorithms used, please see the L1B algorithm theoretical basis document (ATBD).

1.2 Overview

The EMIT Project will deliver space-based measurements of surface mineralogy of the Earth's arid dust source regions. These measurements are used to initialize the compositional makeup of dust sources in Earth System Models (ESMs). The dust cycle, which describe the generation, lofting, transport, and deposition of mineral dust, plays an important role in ESMs. Dust composition is presently the largest uncertainty factor in quantifying the magnitude of aerosol direct radiative forcing. By understanding the composition of mineral dust sources, EMIT aims to constrain the sign and magnitude of dust-related radiative forcing at regional and global scales. During its one-year mission on the International Space Station (ISS), EMIT will make measurements over the sunlit Earth's dust source regions that fall within ±52° latitude. EMIT will schedule up to five visits (three on average) of each arid target region and will only downlink acquisitions not dominated by cloud cover. EMIT-based maps of the relative abundance of source minerals will advance the understanding of the current and future impacts of mineral dust in the Earth system.

The EMIT instrument is a Dyson imaging spectrometer that uses contiguous spectroscopic measurements in the visible to short wave infrared region of the spectrum to resolve absorption features of dust-forming minerals. From the instrument's focal plane array, on-board avionics read out raw detector counts at 1.6 Gbps and then digitizes and stores these data to a high-speed Solid-State Data Recorder (SSDR). From there, the avionics software reads the raw, uncompressed data, packages it into frames of 32 instrument lines, screens for cloudy pixels within the frames, and performs a lossless 4:1 compression of the science data before storing the processed, compressed data back onto the SSDR. The data is later read from the SSDR, wrapped in Consultative Committee for Space Data Systems (CCSDS) packets and then formatted as Ethernet packets for transmission over the ISS network and downlinked to the EMIT Instrument Operation System (IOS). Once on the ground, the EMIT IOS delivers the raw Ethernet data to the SDS where Level 0 processing removes the Huntsville Operations and Support Center (HOSC) Ethernet headers, groups CCSDS packet streams by Application Identifier (APID), and sorts them by course and fine time.

The Level 1B data product contains calibrated spectral radiance data. In addition, the geolocation of all pixel centers is included as well as the calculation of observation geometry and illumination angles on a pixel-by-pixel basis. Each image line of the Level 1B data product is also UTC time-tagged.

All EMIT products are provided as Network Common Data Form (NetCDF) files (further information can be found at https://www.unidata.ucar.edu/software/netcdf/).

1.3 File Formats

1.3.1 1.3.1. Metadata Structure

EMIT operates from the ISS, orbiting Earth approximately 16 times in a 24-hour period. EMIT starts and stops data recording based on a surface coverage acquisition mask. The top-level metadata identifier for EMIT data is an orbit, representing a single rotation of the ISS around Earth. A period of continuous data acquisition within an orbit is called an orbit segment, where each orbit segment can cover up to thousands of kilometers down-track depending on the acquisition mask map. Each orbit segment is broken into scenes of 1280 down-track lines for convenience, though scenes may be seamlessly reassembled into orbit segments. To prevent a very small number of lines in any scene, the last scene can extend up to 2559 lines.

EMIT scenes are processed to different data levels. The bundle of data and metadata for a given scene at a given level is referred to as a granule. Each EMIT granule contains one or more NetCDF file as well as a browse PNG file. The EMITL1BRAD Radiance collections contain two NetCDF files: Radiance and Observation, and a Radiance PNG Browse file.

Table 1-1: EMITL1BRAD collection file list and naming convention

Collection: EMITL1BRAD
Radiance: EMIT_L1B_RAD_001_<YYYYMMDDTHHMMSS>_<OOOOOOO>_<SSS>.nc
Observation Parameters: EMIT_L1B_OBS_001_<YYYYMMDDTHHMMSS>_<OOOOOOO>_<SSS>.nc
Browse: EMIT_L1B_RAD_001_<YYYYMMDDTHHMMSS>_<OOOOOOO>_<SSS>.png

<YYYYMMDDTHHMMSS> is the UTC timestamp of the first line of the scene, e.g., 20220101T083015
<OOOOOOO> is the orbit identification number represented as <YY><DOY>NN> where YY = Year, DOY = Day of Year, NN = Incrementing number for each day (two digits)
<SSS> is the scene identification number, e.g., 007. Within an orbit, scene numbers begin at 001 and increment by 1 for each new scene.

1.3.2 L1B Data Products

The EMIT L1B Radiance collection contains at-sensor radiance and observation data in spatially raw, non-orthocorrected, format. L1B radiance have been 'flipped' in both the spectral and spatial dimensions of the focal plane array so that images appear as they would on the Earth's surface, and wavelengths start from lower to higher with increasing channel/band number. EMIT's Level 1B Radiance collection (EMITL1BRAD) contains two separate NetCDF files: radiance (EMIT_L1B_RAD) and observation (EMIT_L1B_OBS). The radiance NetCDF file contains at-sensor radiance measurements, while the observation NetCDF file contains viewing and solar geometries, timing, topographic, and other information about the observation. Both radiance and observation files contain a location group storing a geometric lookup table (GLT), an orthocorrected image that provides relative x and y reference locations from the raw scene to facilitate fast projection, as well as latitude, longitude and elevation datasets. Nodata values – primarily due to screening from the onboard cloud mask - are set to -9999.

Table 1-1: EMIT L1B Data Products Summary

Earth Science Data Type	Product Level	Data Dimensions	Spatial Resolution	Swath Width	Map Projection
Collection	*EMITL1BRAD*				
Radiance	L1	• 1242 cross-track • 1280** down-track • 285 bands	60 m*	75 km*	Non-orthocorrected, latitude and longitude tagged (WGS-84)
Observation	L1	• 1242 cross-track, • 1280** down-track • 11 bands	60 m*	75 km*	Non-orthocorrected, latitude and longitude tagged (WGS-84)

* Nominal at equator
** Scenes have at least 1280 rows. To prevent small scenes, scenes at the end of an orbit segment will have up to 2559 rows.

1.4 Product Availability

The EMIT L1B products will be available at the NASA Land Processes Distributed Active Archive Center (LP DAAC, https://lpdaac.usgs.gov/) and through NASA Earthdata (https://earthdata.nasa.gov/).

2 Description of Instrument

EMIT consists of a Dyson-type spectrometer with f-number 1.8, providing high optical photon throughput. It is based on a calcium fluoride refractive block, curved grating, slit, and a focal-plane array with 1280 cross track elements and 480 spectral elements, of which 328 are read from the FPA. EMIT measures incident illumination at the sensor, which is converted to at-sensor radiance ($\mu W\ nm^{-1}\ cm^{-2}\ sr^{-1}$) in the Level 1B product. Subsequently, surface reflectance and ultimately mineralogical and fractional cover will be estimated using this product.

The system's spectral and radiometric response properties are well characterized in advance using extensive laboratory measurements to provide a default calibration applicable as soon as EMIT begins operations on the ISS. Later, in-flight calibration and validation (Thompson et al., 2018a, 2018b) is possible as needed, and will follow standard practice established historically by instruments such as Hyperion; it will be used to validate, and if needed refine, laboratory calibrations.

2.1 Instrument Specifications

Table 2-1: Instrument Specifications

Property	Quantity	Comments
Spectral range	381-2493 nm	
Number of bands	285	
Detector elements	1280 cross-track 480 spectral elements	
Data Dimensions	1242 cross-track 1280** down-track	
Cross-track FOV	11°	
Swath Width	75* km	
IFOV (cross-track x along-track)	155 x 71 µrad	
Ground Sampling Distance (GSD)	60m	Nominal @ equator
Spectral Resolution	~7.5 nm	
Radiometric accuracy	Pending Peer Review	
SNR	Pending Peer Review	

* Nominal at equator
** Images have at least 1280 rows. To prevent small scenes, scenes at the end of an orbit segment will have up to 2559 rows.

3 File Structure

3.1 Dimensions and Global Attributes

The NetCDF files contain metadata information describing the dimensions of the datasets (down-track, cross-track, bands, ortho_y, and ortho_x), where down-track and cross-track describe the dimensions of the non-orthocorrected datasets, and ortho_y and ortho_x describe the dimensions of the orthocorrected (EPSG:4326 projected) GLT bands.

Each NetCDF file contains a list of global attributes describing mission relevant information.

3.2 Radiance

The L1B Radiance provides at-sensor measured radiance in raw, spatial format (non-orthocorrected). The following table describes the file's structure and content.

Table 3-1: L1B Radiance File Structure and Content

Field Name	Type	Units	Comments
Group	***Root***		
Radiance	float32 Multiband array (1280x1242x285)	$\mu W\ nm^{-1}\ cm^{-2}\ sr^{-1}$	
Group	***location***		
GLT-X	int32	Index	
GLT-Y	int32	Index	
Lat	float64	Decimal Degree	
Lon	float64	Decimal Degree	
Elevation	float64	Meters	
Group	***/instrument_band_parameters***		
Wavelength	float32	nm	Wavelength grid
FWHM	float32	nm	Full width at half maximum

3.3 Observation

The L1B Observation NetCDF file provides scene and instrument observation conditions. The following table describes the file's structure and content. **Note that the observation variable dataset is provided as a multiband array on the root group level without individual band labels.** The labels are provided in the instrument band parameters group.

Table 3-2: L1B Observation File Content and Structure

Field Name	**Type**	**Units**	**Comments**
Group	*/*		
Observation	float32		3D array with band parameters specified
Group	***/location***		
GLT-X	int32	Index	
GLT-Y	int32	Index	
Lat	float64	Decimal Degree	
Lon	float64	Decimal Degree	
Elevation	float64	Meters	
Group	***/sensor_band_parameters***		
observation_bands	str Array	Labels	Array of strings indicating the name of each observation band

The contents of each observation band are shown in the table below.

Table 3-3: Observation Bands

Band Name	**Units**	**Comments**
Path length	meters	distance between sensor and ground
To-sensor Zenith	Degree	0 to 90 degrees from zenith
To-sensor Azimuth	Degree	0 to 360 degrees clockwise from N
To-sun zenith	Degree	0 to 90 degrees from zenith
To-sun azimuth	Degree	0 to 360 degrees clockwise from N
Phase angle	Degree	degrees between to-sensor and to-sun vectors in principal plane

Slope	Angle	local surface slope as derived from DEM in degrees
Aspect	Angle	local surface aspect 0 to 360 degrees clockwise from N
cosine i	unitless	apparent local illumination factor based on DEM slope and aspect and to sun vector, 0 to 1
UTC Time	Fractional Hours	Fractional hours since UTC midnight
Earth-sun distance (AU)	Astronomical Units	Distance between the earth and the sun.

* All geometry products in the observation dataset are calculated using SRTM as a surface

3.4 Shared Products

3.4.1 Geometry Lookup Table (GLT)

EMIT's radiance and observation data are provided in non-orthocorrected spatially raw format (termed 'instrument'). To conveniently project the instrument data onto a gridded geographical map, we provide a geometry lookup table (GLT) is provided. The GLT dataset is an orthocorrected product with a fixed pixel size projected into a North-up WGS-84 system that contains the information about which original pixel occupies which output pixel in the final product. The GLT file contains two parameters – instrument cross-track (e.g. column, sample, or x) index, and instrument down-track (e.g. row, line, or y) index. These two numbers provide the one-based relative reference from the upper left corner of the instrument-space dataset. The GLT uses one-based indexing, and 0 is the nodata value.

Table 3-4: GLT File Structure and Content

Field Name	Type	Units	Comments
GLT cross-track lookup	int32	Index	Cross-track is the column, or x direction
GLT down-track lookup	int32	Index	Down-track is the row, or y direction

3.4.2 Location

EMIT data product files contain location information in the orientation they were collected (without orthocorrection) in order to preserve the maximum information content. However, for user convenience, products are 'flipped' from the orientation in which they were acquired from the focal plane array in order to match the spatial and spectral orientation of the ground (this means an image rotation and translation would be sufficient to approximate the true ground location, though a a more sophisticated process is used and outlined in the Level 1B ATBD). The following location data are provided: latitude, longitude, elevation. The latitude and longitude coordinates are given in EPSG:4326 (coordinates on the WGS-84 ellipsoid). The longitude values are Easting (values increasing Eastward from Greenwich). The elevation dataset is sourced from the Shuttle Radar Topography Mission (SRTM v3, void filled with ASTER v2), and is resampled to EMIT's spatial resolution.

Table 3-5: Location File Structure and Content

Field Name	Type	Units	Comments
Latitude	float64	Degree	Degrees increasing Eastward from Greenwich
Longitude	float64	Degree	Degrees increasing North from the equator
Elevation	float64	Meters	Estimated ground elevation at pixel center

4 References

Appendix A: Acronyms

Term	Definition
ADC	Analog to Digital Converter
APID	Application Identifier
ASCII	American Standard Code for Information Interchange
BIL	Band Interleaved by Line
CCSDS	Consultative Committee for Space Data Systems
DAAC	Distributed Active Archive Center
DCID	Data Collection Identifier
DN	Digital Number
EMIT	Earth Mineral dust source InvesTigation
ENVI	Environment for Visualizing Images
ESDIS	Earth Science Data and Information System
ESM	Earth System Model
FPA	Focal Plane Array
FPGA	Field Programmable Gate Array
FPIE	Focal Plane Interface Electronics
FPIE-A	Focal Plane Interface Electronics - Analog
FSW	Flight Software
Gbps	Gigabits per second
GLT	Geometry Lookup Table
HOSC	Huntsville Operations and Support Center
ICD	Interface Control Document
IOS	Instrument Operations System
ISS	International Space Station
JPL	Jet Propulsion Laboratory
kHz	Kilohertz
L0	Level 0 (compressed, raw packets)
L1A	Level 1A (reconstructed, uncompressed data reassembled into scenes)
L1B	Level 1B (calibrated radiances with geolocation parameters)
L2A	Level 2A (atmospherically-corrected surface reflectance)
L2B	Level 2B (mineral feature depth maps)
L3	Level 3 (gridded global map of mineral composition and abundances)
L4	Level 4 (model runs of GISS ModelE2 and NCAR CESM)
LP DAAC	Land Processes Distributed Active Archive Center
LSB	Least Significant Bit
MSB	Most Significant Bit
NASA	National Aeronautics and Space Administration
NetCDF	Network Common Data Format
PGE	Product Generation Executable
PLRA	Program Level Requirements Appendix
ROIC	Readout Integrated Circuit
SDS	Science Data System
SIS	Software Interface Specification

SSDR	Solid State Data Recorder
UTC	Universal Time Coordinated