MESSENGER

DIGITAL ELEVATION MODEL SOFTWARE INTERFACE SPECIFICATION

Version 1.6

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DOCUMENT REVIEW

This document and the archive it describes have been through PDS Peer Review and have been accepted into the PDS archive.

Kris Becker, MESSENGER DEM Working Group, has reviewed and approved this document.

Patricia Garcia, PDS Imaging Node Representative, has reviewed and approved this document.

Susan Ensor, MESSENGER Science Operations Center Lead, has reviewed and approved this document.

DOCUMENT CHANGE LOG

Date	Version	Description	Sections affected
04/01/16	1.0	Initial release.	All
04/14/16	1.2	Update MLA comparisons for USGS and add comparisons for DLR plus miscellaneous minor edits.	4.3.2, 4.3.3
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03/29/17	1.6	Removed extraneous keyword definitions from Table 9, added QUAD to the DEM and EXTRAS directories and moved the DLR DEMs to those. Added Lambert Conformal as a projection type for the DLR DEMs.	9 (Table 16), 5.2: Fig. 11, Table 11, Table 12, Table 13, 5.2.7.1

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ACRONYMS

APL	The Johns Hopkins University Applied Physics Laboratory
ASCII	American Standard Code for Information Interchange
ASU	Arizona State University
BAE	British Aerospace
CDR	Calibrated Data Record
CK	Attitude/Pointing Kernel (NAIF SPICE)
CODMAC	Committee on Data Management and Computation
CRP	Cubic Rational Polynomial
DAP	Derived Analysis Product
DEM	Digital Elevation Model
DLR	Institute of Planetary Research, German Aerospace Center, Berlin, Germany
DN	Data Number
DOY	Day of Year
EDR	Experiment Data Record
ESA	European Space Agency
FOM	Figure of Merit
FOV	Field of View
GB	Gigabyte
GDAL	Geospatial Data Abstraction Library
GeoTIFF	Geospatial Tagged Image File Format
IAU	International Astronomical Union
IEC	International Electrotechnical Commission
I/F	Intensity divided by flux, or the ratio of radiance to incident solar irradiance
ISIS	Integrated Software for Imagers and Spectrometers
ISO	International Standards Organization
JPEG	Joint Photographic Experts Group
JHU/APL	The Johns Hopkins University Applied Physics Laboratory
JPL	Jet Propulsion Laboratory
LSB	Least Significant Byte
MAD	Median Absolute Deviation
MESSENGER	MErcury, Surface, Space ENvironment, GEochemistry, and Ranging
MDIS	Mercury Dual Imaging System
MLA	Mercury Laser Altimeter
NAC	Narrow Angle Camera
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
NGATE	Next Generation Automatic Terrain Extraction (program in BAE Systems/SOCET SET)
ODL	Object Description Language
PCK	Planetary Constants Kernel (NAIF SPICE)
PDS	Planetary Data System
PSI	Planetary Science Institute
RDR	Reduced Data Record
RFO	Radio Frequency Occultation

RMS	Root Mean Square
RMSE	Root Mean Square Error
SCLK	Spacecraft Clock Kernel (NAIF SPICE)
SIS	Software Interface Specification
SOC	Science Operations Center
SOCET SET	SOftCopy Exploitation Toolkit SET (BAE Systems photogrammetry software toolkit)
SPICE	Spacecraft Planet Instrument C-matrix Events; a set of data formats for spacecraft ephemeris, attitude, and instrument pointing
SPK	Spacecraft and Planet Kernel (NAIF SPICE)
TIFF	Tagged Image File Format
TBD	To Be Determined
USGS	U.S. Geological Survey
UTC	Coordinated Universal Time
VICAR	Video Image Communication And Retrieval (JPL image processing software system)
WAC	Wide Angle Camera
XML	eXtensible Markup Language

1 Introduction

1.1 Purpose & Scope

This Software Interface Specification (SIS) describes the organization and contents of the MErcury Surface, Space, ENvironment, GEochemistry, and Ranging (MESSENGER) Digital Elevation Model (DEM) archive. The DEM products provide terrain elevation data for Mercury and are deliverable to the Planetary Data System (PDS) and via PDS are accessible to the scientific community. All data formats are based on the PDS Standards Reference [5].

This SIS is useful to those who wish to understand the format and content of the DEM products and ancillary data. The SIS applies to the DEM products including global and high-resolution regional DEMs that will be produced primarily from MESSENGER Mercury Dual Imaging System (MDIS) data acquired during the course of the MESSENGER mission. The users for whom this SIS is intended are the scientists who will analyze the data, including those associated with the MESSENGER Project and those in the general planetary science community.

1.2 Contents

This Data Product SIS describes how DEM data products generated by the MESSENGER DEM Working Group are produced, formatted, labeled, and uniquely identified. The document details standards used in generating the products. Data product structure and organization are described in sufficient detail to enable a user to read the product. The SIS also describes the ancillary data that accompany the MESSENGER DEM products as well as the contents and organization of the data volume. Finally, an example of each product label is provided.

1.3 Applicable Documents and References

The DEM Product SIS is responsive to the following MESSENGER project documents:

1. MESSENGER MErcury: Surface, Space ENvironment, GEochemistry, and Ranging: A mission to Orbit and Explore the Planet Mercury, Concept Study, March 1999.
2. MESSENGER Data Management and Archiving Plan, 7384-9019. Accessible at http://pds-imaging.jpl.nasa.gov/portal/messenger_mission.html.
3. MESSENGER Mercury Dual Imaging System (MDIS) Experiment Data Record (EDR) Software Interface Specification (SIS) (MDISEDRSIS). Available in the PDS data volume MSGRMDS_1001. Accessible at http://pds-imaging.jpl.nasa.gov/volumes/mess.html.
4. MESSENGER MDIS CDR/RDR Software Interface Specification (SIS) (MDIS_CDR_RDRSIS). Available in the PDS data volume

MSGRMDS_2001. Accessible at http://pdsimage.wr.usgs.gov.

The SIS is also consistent with the following PDS documents:

5. Planetary Data System Standards Reference, February 27, 2009, Version 3.8, JPL D-7669, Part-2.
6. Planetary Science Data Dictionary Document, JPL D-7116, Rev. F, October 20, 2008.
7. Planetary Data System Archive Preparation Guide, Version 1.1, JPL D-31224, August 29, 2006.

Additional References:

8. JPEG 2000 Image Coding System: Core Coding System, ISO/IEC 15444-1, September 15, 2004.
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10. Becker, K.J. et al., 2012, Global controlled mosaic of Mercury from MESSENGER orbital images, *Lunar Planet. Sci*., 43, abstract 2654.
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17. Perry, M. E. et al., 2015, The low degree shape of Mercury, *Geophysical Research Letters*, 42, 10.1002/2015GL065101. [PERRYETAL2015]
18. Burns, K. N., et al., Digital elevation models and derived products from LROC NAC stereo observations, *ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 1,* 2012, 483-488.

19. Gwinner, K. et al., Topography of Mars from global mapping by HRSC high-resolution digital terrain models and orthoimages: characteristics and performance, *Earth Planet. Sci. Lett*., 294, 506–519, 2010.

20. Oberst, J. et al., The morphology of Mercury's Caloris basin as seen in MESSENGER stereo topographic models, *Icarus*, 209, 230–238, 2010. [OBERSTETAL2010]

21. Preusker, F. et al., Stereo topographic models of Mercury after three MESSENGER flybys, *Planet. Space Sci*., 59, 1910–1917, 2011. [PREUSKERETAL2011]

22. Scholten, F. et al., GLD100 - The near-global lunar 100 meter raster DTM from LROC WAC stereo image data, *J. Geophys. Res*., 117, E00H17, 2012.

23. An Overview of SPICE, NASA's Ancillary Data System for Planetary Missions. (presentation), NASA Navigation and Ancillary Information Facility. December 2013. Accessible at http://naif.jpl.nasa.gov/pub/naif/toolkit_docs/Tutorials/pdf/individual_docs/04_spice_overview.pdf.

24. Becker, K. et al., 2016, First global DEM of Mercury, *Lunar Planet. Sci*., 47, abstract 2959.

25. Bradski, G.,2000, *Dr. Dobb's Journal of Software Tools*, drdobbs.com.

26. Neumann, G., 2016, Mercury shape model from laser altimetry and planetary comparisons, *Lunar Planet. Sci*., 47, abstract #2087.

27. Becker, K. et al., 2015, Criteria for automated identification of stereo image pairs, *Lunar Planet. Sci.*, 46, abstract #2703.

28. T. Tran, M.R. Rosiek, R.A. Beyer, S. Mattson, E. Howington-Kraus, M.S. Robinson, B.A. Archinal, K. Edmundson, D. Harbour, E. Anderson, and the LROC Science Team, Generating digital terrain models using LROC NAC images, *ASPRS/CaGIS*, 2010.

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30. Warmerdam, F. 2008, The Geospatial Data Abstraction Library, open source approaches in spatial data handling*, Advances in Geographic Information Science*, Vol. 2, pp. 87-104.

31. PDS Policy on Acceptable Body-Fixed Coordinate Systems, 2014. Accessible at https://pds.nasa.gov/policy/index.shtml.

32. Snyder, J.P., Map Projections – A Working Manual, U. S. Geological Survey Professional Paper 1395, 1987. [SNYDER1987]. Accessible at https://pubs.usgs.gov/pp/1395/report.pdf.

1.4 Relationship with Other Interfaces

Data products described in this SIS were produced by members of the MESSENGER DEM Working Group for use by the MESSENGER Science Team and other members of the planetary science community. Changes to this SIS may be driven by changes to products from which the DEMs are derived and the algorithms used to produce the DEMs, and may impact the tools and methods employed by the producers and end users of the DEM products. Changes in DEM data products or this SIS may also affect the design of the DEM archive volume.

The U.S. Geological Survey (USGS) global DEM [10] was created from MDIS image data [4] using the Integrated Software for Imagers and Spectrometers version 3 (ISIS) toolset [11].

The Institute of Planetary Research, German Aerospace Center (DLR) global and regional DEMs were created from MDIS image data [4] using the Video Image Communication and Retrieval (VICAR) environment (http://www-mipl.jpl.nasa.gov/external/vicar.html) with additional DLR-developed programs and tools.

The Arizona State University (ASU) regional DEMs were created from MDIS image data [4] using the British Aerospace (BAE) SOftCopy Exploitation Toolkit (SOCET) SET software suite [18], with post processing using the ISIS toolset [11] and Geospatial Data Abstraction Library (GDAL) utilities.

The MESSENGER Data Management and Archiving Plan [2] defines the overarching processes and goals for generation, validation, and delivery of products from MESSENGER to the PDS in complete, well-documented, permanent data archives in a timely fashion.

2 Instrument Overview

MDIS is a science instrument on the MESSENGER [1] spacecraft, which launched on 3 August 2004 and made six planetary flybys (one of Earth, two of Venus, and three of Mercury) before entering orbit around Mercury on 18 March 2011. The primary orbital phase lasted one Earth-year and was followed by a one-year first extended mission, completed on 17 March 2013, and an additional two-year second extended mission, completed on 28 March 2015, after which a final one-month campaign concluded with the impact of the MESSENGER spacecraft, as expected, onto the surface of Mercury on 30 April 2015. Data analysis and archiving for the second extended mission and final campaign is scheduled to complete on 31 May 2016.

The MDIS instrument [9] consists of a monochrome narrow-angle camera (NAC) and a multispectral wide-angle camera (WAC). The NAC has a 1.5-degree field-of-view (FOV), and the WAC has a 10.5-degree FOV and a 12-color filter wheel. The characteristics and names of the WAC filters are given in Table 1 [4]. Only

one camera operates at a time. The NAC and the WAC are coaligned and mounted on a cross-track pivoting platform for pointing flexibility and stowing. Onboard data compression provides capabilities for pixel binning, remapping of 12-bit data into 8 bits, and lossless or lossy compression. Data acquired from three Mercury flybys and during the primary and extended orbital periods of the mission provide the means to construct global monochrome and color image base maps. The DEM products described in this document were created primarily from NAC and/or WAC (particularly stereo) images as described in section 4.3 of this document. More information on the MDIS instrument and its orbital imaging is provided in [3,4].

Table 1. Filter numbers and their bandpasses.

Filter Number	Filter Filename Letter	Wavelength (Flight) (nm)	Width (Flight) (nm)
1	A	698.8	5.3
2	B (clear)	700	600.0
3	C	479.9	10.1
4	D	558.9	5.8
5	E	628.8	5.5
6	F	433.2	18.1
7	G	748.7	5.1
8	H	947.0	6.2
9	I	996.2	14.3
10	J	898.8	5.1
11	K	1012.6	33.3
12	L	828.4	5.2

3 Standards Used in Generating Products

3.1 PDS Standards

The MESSENGER DEM products comply with the PDS standards for file formats and labels [5]. The DEM products will be provided in PDS image (.IMG filename extension) and PDS-compliant Joint Photographic Experts Group (JPEG) 2000 (.JP2 filename extension) with detached labels (.LBL filename extension) [5, 8]. Additionally, the ancillary data (e.g., table (.TAB filename extension), text (.TXT filename extension), and eXtensible Markup Language (XML) (.XML filename extension)) files that accompany the DEM products and the archive volume structure are in conformance with PDS standards [5]. The DEM products will also comply with PDS Cartographic standards [5].

3.2 Data Storage Conventions

The MESSENGER DEM products contain binary data. These products are

provided both as standard PDS uncompressed image files (.IMG), where their format is defined in the accompanying label, and in compressed, lossless JPEG 2000 format or Tagged Image File Format (TIFF) files. Image pixel values stored in the .IMG files are given as 16-bit signed integers with least significant byte (LSB) first (little-endian) byte order or as 32-bit IEEE floating point values. JPEG 2000 files are 16-bit signed integers with most significant byte (MSB) first (big-endian) byte order. The detached PDS labels are stored as ASCII character strings conforming to the requirements defined in the PDS Standards Reference. TIFF files, when provided, are included in the EXTRAS directory.

3.3 Time Standards

All time values associated with these products are given in Coordinated Universal time (UTC).

3.4 Cartographic Standards

The projection convention adopted by the MESSENGER project is planetocentric latitudes and positive east 0 to 360 degrees domain longitudes using the planetary constants in the Planetary Constants Kernel (PCK) archived at the PDS Navigation and Ancillary Information Facility (NAIF) Node (MESSSP_1000 archive volume), which is compliant with the PDS policy on acceptable body-fixed coordinate systems [31]. These constants are being used to derive DEM products for public release. The MESSENGER global DEM products are provided in three parts including one global SIMPLE CYLINDRICAL projection and two POLAR STEREOGRAPHIC (poleward of 65 degrees latitude) projections. MESSENGER regional DEM products are provided in EQUIRECTANGULAR projection. MESSENGER quadrangle DEM products are provided in equirectangular, simple cylindrical, and lambert conformal projections depending on the product.

For products generated prior to the final MESSENGER PDS release (including sample DEM products generated for peer review only), the MESSENGER project adopted a reference radius for Mercury of 2440 km for all axes that differs from the earlier recommended IAU [16] radius of 2439.7 km. Altitudes of surface points on Mercury in units of meters were referenced to the 2440-km spherical datum. The final MDIS global and regional DEM products described in this document for public release use 2439.4 km for the Mercury reference radius.

3.4.1 Equirectangular Projections

For the equirectangular latitude map coordinate bands, the CENTER_LATITUDE of projection (Latitude of True Scale) is the equatorward boundary of each map to minimize 'distortion.' The transformation from latitude and longitude to line and sample is given by the following equations:

LINE = int(LINE_PROJECTION_OFFSET - lat*MAP_RESOLUTION)

SAMPLE = int(SAMPLE_PROJECTION_OFFSET + lon*MAP_RESOLUTION)

where:

SAMPLE = image pixel coordinate along horizontal axis (see also SAMPLE_PROJECTION_OFFSET definition below)

LINE = image pixel coordinate along veritical axis (see also LINE_PROJECTION_OFFSET definition below)

lat = latitude in degrees

lon = longitude in degrees.

Note that integral values of line and sample correspond to the center of a pixel. Lat and lon are the latitude and longitude of a given location on the surface, positive east.

MAP_RESOLUTION = the map resolution in pixels/degree, which may vary for each DEM.

LINE_PROJECTION_OFFSET = the line offset value of the map projection origin from the center of the pixel at the line and sample 1,1 (line and sample 1,1 is considered the pixel at the upper left corner of the digital array). For an EQUIRECTANGULAR map projection, origin is the equatorward edge of the DEM. The value of LINE_PROJECTION_OFFSET is positive for the DEM starting north of the equator and is negative for the DEM starting south of the equator.

SAMPLE_PROJECTION_OFFSET = the sample offset value of the map projection origin from the center of the pixel at the line and sample 1,1 (line and sample 1,1 is considered the pixel at the upper left corner of the digital array). For an EQUIRECTANGULAR map projection, the value of SAMPLE_PROJECTION_OFFSET is positive for the DEM starting to the west of the projection longitude and is negative starting to the east of the projection longitude.

3.4.2 Simple Cylindrical Projections

The simple cylindrical projection is a special case of the equirectangular projection where the center latitude is 0.

Definitions of other mapping parameters can be found in the PDS Data Dictionary.

3.4.3 Polar Stereographic Projections

For the latitude map coordinate bands projected polar stereographically, projection is centered on the north or south pole. Lines of longitude extend radially from the pole and parallels of latitude are concentric circles around the center. In the northern hemisphere, 0° longitude extends straight down from the center and 90° East longitude extends to the right. In the southern hemisphere, 0° longitude extends straight up from the center, and 90° East longitude extends

to the right. The transformation from line and sample coordinates to planetocentric latitude and longitude is given by the following equations:

```
x = (SAMPLE - LINE_PROJECTION_OFFSET - 0.5)*MAP_SCALE
y = (LINE - SAMPLE_PROJECTION_OFFSET - 0.5)*MAP_SCALE
distance = sqrt(x^2 + y^2)
lon = atan2(x,y) * 180/pi
lat = 90 - 2*atan(distance*pi/360) * 180/pi (northern hemisphere)
lat = -90 + 2*atan(distance*pi/360) * 180/pi (southern hemisphere)
```

where:

SAMPLE = image pixel coordinate along horizontal axis (see also SAMPLE_PROJECTION_OFFSET definition below)

LINE = image pixel coordinate along veritical axis (see also LINE_PROJECTION_OFFSET definition below)

x, y = map coordinates

MAP_RESOLUTION = the map resolution in pixels/degree,
MAP_SCALE = the map scale in km/pixel,

LINE_PROJECTION_OFFSET = the line offset value of the map projection origin from the center of the pixel at the line and sample 1,1 (line and sample 1,1 is considered the pixel at the upper left corner of the digital array).

SAMPLE_PROJECTION_OFFSET = the sample offset value of the map projection origin from center of the pixel at line and sample 1,1 (line and sample 1,1 is considered the pixel at the upper left corner of the digital array).

distance = distance to the point from the origin

lat = latitude in degrees

lon = longitude in degrees.

pi = the ratio of the circumference of a circle to its diameter.

The numerical values “90”, “180”, and “360” are in units of degrees.

atan, atan2, and sqrt are the standard mathematical functions.

Definitions of other mapping parameters can be found in the PDS Data Dictionary.

3.4.4 Lambert Conformal Conic Projections

A conformal, conic projection where the parallels are unequally spaced arcs of concentric circles, more closely spaced near the center of the map. Meridians are equally spaced radii of the same circles, thereby cutting parallels at right angles. Scale is true along the standard parallel(s). The pole in the same hemisphere as standard parallel(s) is a point, while the other pole is at infinity. See SNYDER1987 for a detailed description of this projection.

4 DEM Product Specification

This section describes the MESSENGER DEM IMG and JPEG 2000 products, source product list files, tables and accompanying labels. Sample PDS labels are included in section 6. Label definitions are listed in Table 16.

DEMs included in this archive include products created by USGS, DLR, and ASU. Each DEM product is described in sections that follow.

4.1 Dataset Definition and Scope

DEMs are derived products. A DEM is a gridded (raster) product that records elevation values of a given terrain in each pixel. Corresponding metadata include map projection information so pixels can be associated with latitude and longitude. Values for MESSENGER DEMs are measured relative to the planetary reference radius (i.e., elevation).

Generally, the MESSENGER DEM products described here are derived from MESSENGER MDIS image data using stereo photogrammetry (i.e., stereo pairs or sets) techniques.

The primary PDS products are DEMs provided in both PDS image (.IMG) and, optionally, JPEG 2000 (.JP2) format files.

4.2 Data Volume

The volume of DEM products is approximately 5 Gigabytes (GB).

4.3 DEM Processing

DEM production is time intensive and cannot be fully automated. It requires considerable computing resources and can take many hours of operator time. The goal is to create the most accurate elevation model possible within the resource constraints. The software and procedures for each of the MESSENGER DEM producers are also outlined here in sections 4.3.2 through 4.3.4.

Some of the DEM products may include areas in the resulting map projection grid that are interpolated. The techniques used in the interpolation of these areas are

described where applicable.

Users should note that differences in MESSENGER DEM products are a result of a variety of factors including varying product resolution, precision, constituent images, and processing methods used in their production.

4.3.1 Data Processing Level

DEMs are CODMAC (Committee On Data Management and Computation) Level 5 Derived Analysis Products (DAPs). CODMAC/NASA processing levels for science data sets are given in Table 2.

Table 2 NASA/CODMAC processing levels for science data sets.

NASA	CODMAC	Description
Packet data	Raw – Level 1	Telemetry data stream as received at the ground station, with science and engineering data embedded. Referred to as Packetized Data Records (**PDRs**).
Level 0	Edited raw – Level 2	Instrument science data (e.g., raw voltages, counts) at full resolution, time ordered, with duplicates and transmission errors removed. Referred to as Experiment Data Records (**EDRs**).
Level 1A	Calibrated – Level 3	NASA Level 0 data that have been located in space and may have been transformed (e.g., calibrated, rearranged) in a reversible manner and packaged with needed ancillary and auxiliary data (e.g., radiances with the calibration equations applied). Referred to as Calibrated Data Records (**CDRs**). In some cases, these also qualify as Derived Data Products (**DDPs**) or Derived Data Records (**DDRs**).
Level 1B	Resampled – Level 4	Irreversibly transformed (e.g., resampled, remapped, calibrated) values of the instrument measurements (e.g., radiances, magnetic field strength). Referred to as either Derived Data Products (**DDPs**) or Derived Analysis Products (**DAPs**), also termed Derived Data Records (**DDRs**) or Derived Analysis Records (**DARs**).
Level 1C	Derived – Level 5	NASA Level 1A or 1B data that have been resampled and mapped onto uniform space-time grids. The data are calibrated (i.e., radiometrically corrected) and may have additional corrections applied (e.g., terrain correction). Referred as Derived Analysis Products (**DAPs**) or Derived Analysis Records (**DARs**).
Level 2	Derived – Level 5	Geophysical parameters, generally derived from Level 1 data, and located in space and time commensurate with instrument location, pointing, and sampling. Referred to as Derived Analysis Products (**DAPs**) or Derived Analysis Records (**DARs**).
Level 3	Derived – Level 5	Geophysical parameters mapped onto uniform space-time grids. Referred to as Derived Analysis Products (**DAPs**) or Derived Analysis Records (**DARs**).
Ancillary	Ancillary Data – Level 6	Non-science data needed to generate calibrated or resampled data sets and consisting of such information as instrument gains and offsets, spacecraft positions, target information, and pointing information for scan platforms.

The above is based on the National Research Council CODMAC data levels.

4.3.2 USGS GLOBAL DEM Product Description

This section describes the process used by the USGS to create the USGS global Mercury DEM products contained in this archive. The ISIS software is documented in reference [11]. The photogrammetric bundle adjustment procedures used by the USGS are detailed in references [13,14].

4.3.2.1 Overview

The USGS used MESSENGER MDIS NAC and WAC-G filter (see Table 1) images in the generation of the USGS Mercury DEM. Image selection and processing were performed using the ISIS version 3 [11] software package.

The quality of mapping products (e.g., DEMs) depends greatly upon the accurate determination of image position and pointing parameters. Initial estimates for these parameters typically come from spacecraft tracking and attitude data. While the characterization of MESSENGER spacecraft position and attitude (provided by the MESSENGER navigation and mission operations teams in the form of NAIF Spacecraft and Planet Kernels (SPK) and Spacecraft Attitude/Pointing Kernels (CK), respectively) has proven to be reliable to date, an element of uncertainty in these parameters is unavoidable. This uncertainty will in turn lead to errors in registration between images utilized for DEM generation.

To minimize these errors, images are controlled photogrammetrically. The control process consists of two basic steps: image measurement followed by the least-squares bundle adjustment [13]. Overlapping images are registered to one another through the measurement of common features known as *control points*. These measurements then serve as input to the bundle adjustment which generates improved image position and pointing parameters and the triangulated ground coordinates of control points (latitude, longitude, and radius). The ISIS bundle adjustment module is called *jigsaw* [14].

A DEM is generated in a uniformly spaced map projection grid from the adjusted control points. As the control points are not uniformly spaced, not all map grid points contain a radius value. At these grid points, the radius is interpolated, described below in section 4.3.2.5, using radius values from nearby control points. In this manner, a global DEM for Mercury is obtained.

4.3.2.2 Image Selection Process

The MESSENGER MDIS cameras have collected nearly 278,000 images of Mercury's surface. The USGS DEM is created using NAC and WAC-G images (see Table 1), which constitute a subset of all the images acquired from 18 March 2011 (Mercury orbit insertion) to 1 November 2014 [24]. The MESSENGER spacecraft orbit around Mercury was highly elliptical with closest approach (periapsis) occurring over mid to high northern latitudes. Over the course of the mission, the spacecraft altitude has varied from a low of ~26 km at periapsis to ~15,000 km at apoapsis. WAC images were typically used in the northern hemisphere. In the southern hemisphere, higher-resolution NAC

observations were selected. In the equatorial region, both WAC and NAC observations were used. This strategy results in the collection of a more uniform set of images with comparable resolution.

Ultimately, 100,432 (63,536 NAC and 36,896 WAC-G) images were utilized in the creation of the control network. The resulting point cloud from the control network was used to generate the USGS DEM through interpolation. USGS selected NAC and WAC-G images with a pixel resolution between 75 and 800 meters/pixel. Additional image selection considerations included images with incidence angles < 86° and emission angles < 65°. However, exceptions had to be made in some areas where these criteria created data gaps (e.g., poles).

Images with high incidence angles, the angle between the Sun and the surface normal, produce shadows that make image registration difficult. Elevations in any shadowed areas, including the poles, are determined by interpolation.

4.3.2.3 Global Image Control

The derivation of DEMs from image data requires highly accurate co-registration of overlapping images. The overall accuracy of the DEM increases as the density of stereo observations increases. Typically, all remotely sensed image data require some adjustment to pointing attitude to improve co-registration. This process is commonly referred to as image *control*. The USGS has developed software and procedures in ISIS that create and manage a series of networks of tie points that are, in this case, distributed globally but non-uniformly. Tie points (also referred to as *control points*) consist of a set of line and sample coordinates, called *measures*, of a common feature in all images acquired of the same surface region. Each of the 100,432 images in the global control network must have at least three control points.

Successful control of a set of images requires accuracy of the control measures to the sub-pixel and control points distributed as uniformly as possible over an image. This process constitutes global image control of an image data set. The bundle adjustment provides updated pointing for each image in the network and allows generation of a radius solution at every control point in the global control network. Generation of a DEM from this process must also provide sufficient point density to increase interpolation fidelity for areas that lack control point coverage. Further details on image control software components are given at the ISIS website [11].

From 176,352 MDIS NAC and WAC-G images, 101,177 were selected that passed the resolution and angular constraints specified in 4.3.2.2. The global simple cylindrical map was partitioned into 648 10°×10° tiles and images were placed in tiles by their center image latitude/longitude coordinates. All images with greater than 3.5% common surface overlap were identified for each image. A specialized feature-based image matching application was developed using the OpenCV [25] application-programming interface (API). *findfeatures* combines

algorithms in OpenCV's 2-D Features Framework for feature-based matching of tie point measurements in overlapping image pairs with robust outlier detection. The application accepts a list of all images that overlap the reference image, which are then matched simultaneously. The output is an image-based control network of all common tie points in the overlapping regions. These individual image control networks are combined into a larger networks consisting of 14 regions globally. The least squared bundle adjustment described in 4.3.2.4 is applied to each network to ensure consistency and identify coverage issues. The 14 regional networks were combined into a southern and northern hemisphere networks and bundle adjusted once more. Finally, the north and south hemisphere control networks were combined into a global network and a final bundle adjustment was performed. The global Mercury control network created from MDIS NAC and WAC-G images contained 12,596,336 control points and 94,745,475 tie point measurements.

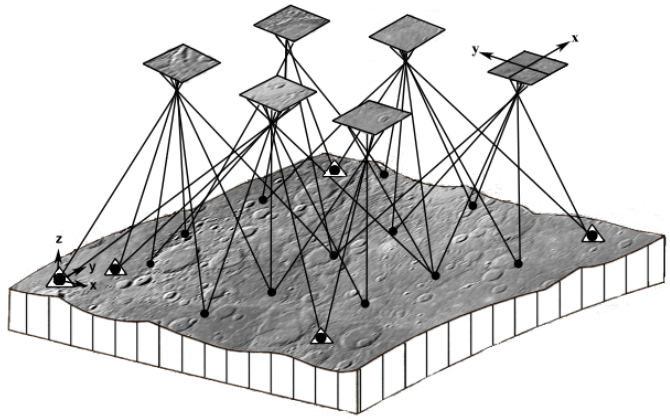

Figure 1 The Collinearity Condition.

A ground point, corresponding image measurement, and associated camera position ideally lie on a line (After [15]).

4.3.2.4 Least Squares Bundle Adjustment (ISIS module *jigsaw*)

The bundle adjustment plays a critical role in the photogrammetric control process.

The functional model, defining the relationship between image and object space coordinate systems, is known as the collinearity condition. This stipulates that, under ideal conditions, an image point measurement, corresponding ground point, and the perspective center of the camera lens lie on the same line (Figure 1).

Using the ISIS bundle adjustment module *jigsaw*, one may solve for camera pointing alone, camera position alone, or pointing and position together. Through rigorous weighting, parameters may be held fixed, allowed to adjust freely, or constrained with a priori precision information. Three-dimensional coordinates (latitude, longitude, and radius) of all ground points are also determined in the adjustment [14]. We chose to solve only for camera pointing and apply spacecraft position ephemeris provided by the MESSENGER navigation team. These points were utilized for the creation of the USGS DEM.

For the MDIS bundle adjustment, pointing angles were constrained to ±0.2 degrees. All points were constrained by ±10 km in radius. After adjustment, the average root mean squared (RMS) error in sample and line was 0.85 pixels.

4.3.2.5 DEM Product Generation

Adjusted image parameters facilitate control network/base map creation, and the resulting jigsaw radius point cloud body-fixed coordinates are used in the production of DEMs. Interpolation of radius values between points results in continuously sampled, global cartographic DEMs of the surface of Mercury. The point cloud used to interpolate the USGS DEM is provided in the archive and described in section 4.3.2.7.2.

The DEM is created using the unpublished *cnet2dem* ISIS application. This application takes the resulting control network produced by *jigsaw* and computes the radius at each map grid point. The control network was converted to a radius point cloud stored as a k-d tree structure of body-fixed x, y, and z coordinates. The k-d tree is queried to find the 11 nearest neighbor points using an L2 Euclidean distance from the pixel center of the output DEM map latitude/longitude coordinate. Points outside a 1-sigma standard deviation from the median value were deemed outliers and discarded. The median radius of the remaining points was used to represent the value at the output map pixel coordinate. A series of smoothing filters were applied to produce the final DEM. Radius values from the point cloud are translated to elevation values relative to the 2439.4 km reference radius in the DEM products.

4.3.2.6 Accuracy Assessment

The MLA team created a combined global DEM map from more than 42 million MLA data collected in the northern hemisphere and radio frequency occultation (RFO) measurements [12]. The MLA collects measurements at distances up to 1500 km with a range accuracy better than 30 m. There are 557 RFO measurement events acquired and analyzed. The RFO points in the northern hemisphere that were compared to MLA have an uncertainty of less than 200 m. The MLA/RFO global map is processed using interpolation techniques and stored in an equirectangular projection sampled at 64 pixels/degree (665 meters/pixel). This map was used as a standard baseline measure of accuracy.

The USGS created a global map using the same projection parameters as the MLA/RFO map from the point cloud. This map was also created using the *cnet2dem* application and analyzed by the MLA team using the MLR/RFO baseline.

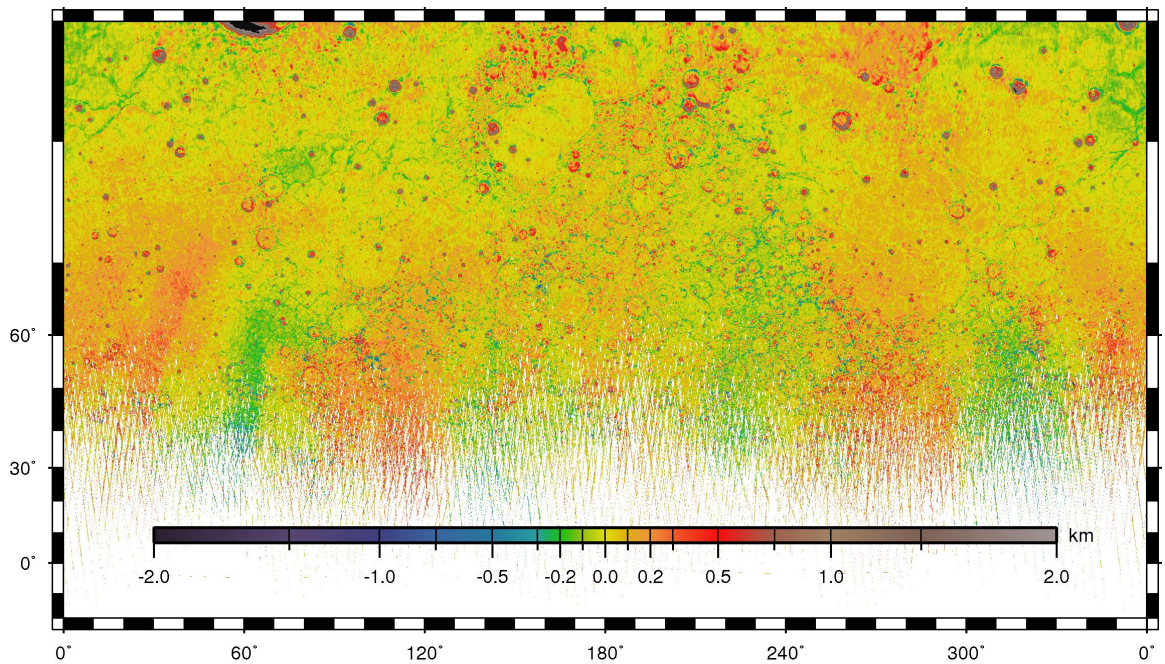

Figure 2. Differences between the USGS DEM and the MLA/RFO baseline map in the northern hemisphere.

The differences in elevation in northern hemisphere above 10°S between the USGS DEM and the MLA/RFO baseline is shown in Figure 2 above. The mean radius of the USGS DEM is ~75 meters larger, and its oblateness and elongation are ~5% smaller [26]. In the southern hemisphere, the overall residual between the MLA/RFO shape is a mean of ~145 meters. Figure 3 shows residuals in the southern hemisphere latitudes from 80°S and 11°N.

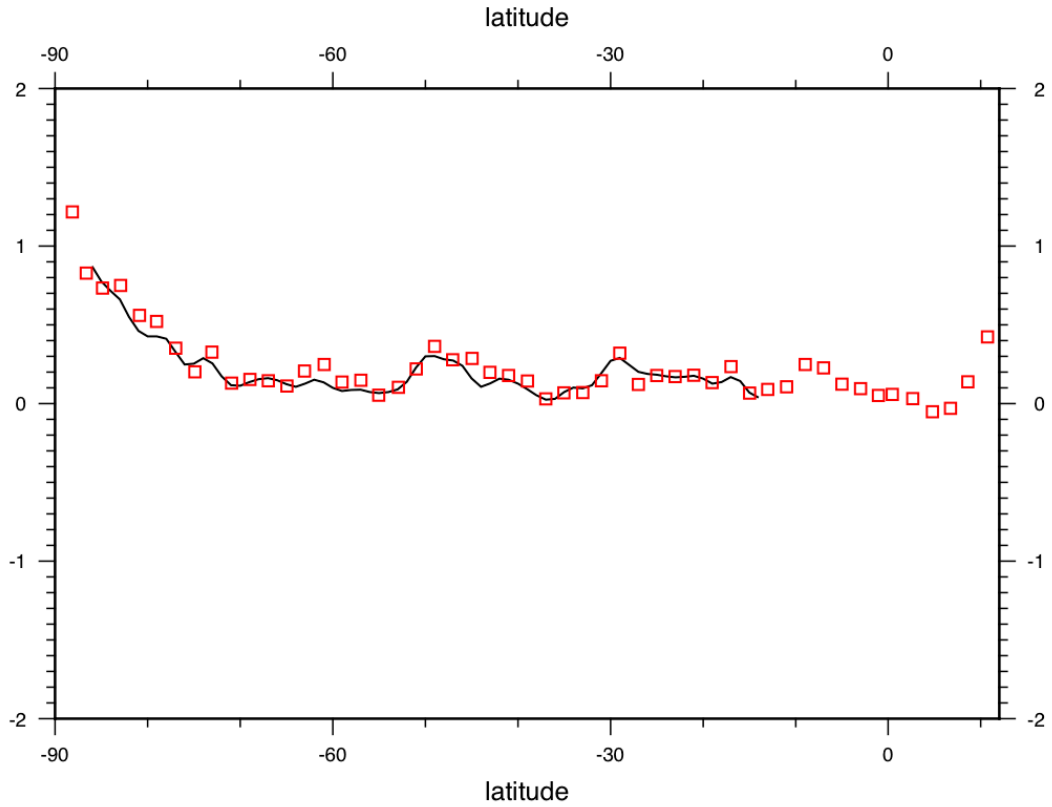

Figure 3 Plot of residuals in 2° latitude bins and filtered residual by latitude line comparing the southern hemisphere of the USGS and MLA/RF DEMs.

4.3.2.7 USGS Additional Products

The USGS DEM procedure results in several additional products that are included in the archive. These products are described below.

4.3.2.7.1 The Source Product List File

The Source Product List file is an ancillary file that contains the PDS PRODUCT_ID values of the lower-level MDIS products that were used to create the associated DEM. These are the values that would otherwise go into the SOURCE_PRODUCT_ID field in an image label. Because a DEM product may be made from a large number of other products, they are listed separately. It is a simple, unstructured text file with an attached minimal PDS label.

4.3.2.7.2 Radius Point Cloud Table

The radius point cloud is a sparse, non-uniformly distributed data set that contains the absolute radius at specific latitude/longitude locations. This dataset is derived from the USGS ISIS control process as described in [13]. The point cloud was used to derive the USGS global DEM using interpolation techniques

described above to provide radius values at uniform grid projection points. An uncertainty at each radius point is included in the table. The radius point cloud table conforms to PDS standard formatting.

4.3.3 DLR REGIONAL DEM Product Description

This section describes the stereo photogrammetric processing chain at DLR to create DEMs for Mercury. The processing pipeline described below to create MESSENGER DEMs is almost identical to DEM production pipelines used in other planetary NASA and European Space Agency (ESA) missions like Mars Express, Dawn, and Rosetta [19-22].

4.3.3.1 Overview

MESSENGER acquired hundreds of thousands of images to map Mercury's surface using the WAC for the northern hemisphere and NAC for the southern hemisphere. Over the course of nearly four years of observing Mercury from orbit, the surface of the planet was imaged completely at least twice with similar illumination conditions, but from different perspectives. Combining these images enables stereo-photogrammetric image analysis and the generation of DEMs.

Due to the enormous amount of image data, DLR decided to divide the generation of a global DEM into 15 parts called quadrangles (See Greely, R. and R.M. Batson, *Planetary Mapping*, Cambridge University Press, 1990) [GREELY&BATSON1990], of which the H03, H05, H06 ("Kuiper"), and H07 quadrangles are delivered to PDS. The general workflow is described in the following sections 4.3.3.2 – 4.3.3.6, and a detailed description of the delivered quadrangle H06 ('Kuiper' quadrangle) is given in section 4.3.3.7.

4.3.3.2 Images and Stereo Image Selection

For each DEM created, DLR selected hundreds of thousands of NAC and WAC-G images that have resolutions better than 600 m/pixel and "optimal" stereo conditions (Table 3), from which a stereo coverage map was compiled. From the map, data were selected and processed from only those areas with at least threefold stereo information.

Table 3. Characteristics of images used in DLR stereo coverage map.

Parameter	Angles
Differences in illumination	0-10°
Stereo angle	15-45°
Emission angle	0-55°
Incidence angle	5-55°
Phase angle	5-180°

Stereo-photogrammetric Methods

The stereo-photogrammetric processing for Mercury at DLR is based on a software suite that has been developed within the last decade and has been applied successfully to several planetary image data sets [19-22]. The suite comprises photogrammetric multi-image matching, bundle block adjustment and surface point triangulation, and DEM generation.

4.3.3.3 Multi-image Matching

Stereoscopic measurements are based on registering the different positions of a common feature in the image planes of stereo images. The process of identifying corresponding image points (called tiepoints or conjugate points) and of accurately measuring the image coordinates of these points is commonly referred to as “image matching”. Once the position and attitude of the sensor and the geometric properties of the camera are determined through the analysis described in the next section, the image coordinates of a dense set of points (as required to generate a contiguous terrain model) can be converted to absolute coordinates including the distance from the object to the camera. Sophisticated matching techniques are required to produce a high density of corresponding points, as the goal is a contiguous model of surface topography with highest possible spatial resolution. So-called area-based image matching methods have proven to perform well for this task. Coordinates of tiepoints are sought via comparisons of gray values in small image patches (e.g., 11x11 pixels, or larger). By means of least-squares techniques, positions of the tiepoints can be established with subpixel precision using minimization techniques. Occasionally, DEMs are constructed from large numbers of overlapping images, where appropriate matching partners must be identified beforehand. At the end, the image matching is carried out individually for each “stereo model”, taking advantage of parallel computing, if available.

4.3.3.4 Triangulation and Bundle Block Adjustment Techniques

Uncertainties in camera position and pointing make complex block adjustments necessary to obtain the desired accuracy in ground coordinates of points derived from successfully matched points. The main goal of the photogrammetric bundle block adjustment is to obtain an improved model of the positions and orientations of the sensor during the image acquisition. The adjustment has to warrant that the 3-D surface point positions resulting from the joint analysis of many individual images form a geometrically consistent model of the surface. Also, every point of the model must be positioned at its correct position in the planet-fixed coordinate system. The mathematical backbone of this adjustment is the so-called collinearity equations, which define the relationship between the coordinates of points in the images via the orientation data to the corresponding surface points for one image. From multiple observations of large numbers of surface features in large numbers of images, large systems of the collinearity equations are assembled, which are simultaneously solved in several iterative steps. Sufficiently large numbers of conjugate points (or “tiepoints”) must be determined in overlapping areas of the images, as input for the adjustment. This is usually accomplished by automated techniques, such as the image matching described

above. Block adjustments can become computationally challenging when several thousands of images are involved, in which case sophisticated matrix inversion schemes are required to reduce computing time and memory allocations.

The tiepoints are the input (observations) to the block adjustment whereas the 3-D coordinates of the points on the surface (object points) and the orientation data of each image are the unknowns to be determined. The nominal position and pointing data are used as starting values to begin the iterative process. If appropriate observations are available, it is also possible to improve further unknown parameters, e.g., planet rotation models, spacecraft orbit parameters, or camera constants, by varying the relevant rotation parameters until the minimum of error totals is reached. The results of the block adjustment are improved values for the orientation data and the coordinates of the related surface points. Even without subsequent DEM processing, the improved navigation data are of great interest, as the data enable the construction of geometrically accurate image mosaics.

4.3.3.5 DEM Generation

The coordinates of matched points are used to compute 3-D object (i.e., surface) points by means of forward ray intersection. The adjusted position and pointing data are used to define the viewing rays for each image. As a result, a large number of object points represented in body-fixed coordinates as well as information on ray-intersection accuracy for each combination of corresponding rays are obtained. The accuracy estimates provide verification for image matching and the block adjustment. In the case that DEMs are constructed from multiple sets of stereo partner images, point clouds from each single stereo model are merged. This resulting point cloud will generally show variations in point density. It is therefore desirable to convert the irregular point cloud into a contiguous surface model. This is achieved either by point triangulation, which will partly preserve the pattern of the point distribution. More commonly, particularly in cases of billions of 3-D points, the points are integrated into a regular grid of height values in a map coordinate system. The 3-D points therefore are first transformed to geographic latitude/longitude/height coordinates and finally converted to line/sample coordinates in map space using some appropriate map projection (e.g., sinusoidal, stereographic, etc.). The chosen grid spacing of the raster DEM must properly relate to the spacing of the previously derived object points. If several object points are located within a DEM pixel, these are combined and represented as one average value. DEM pixels without any object point information should represent a subordinate fraction of the grid and, where present, are filled using neighborhood information. The grid values of a DEM represent height values above some chosen reference body (usually a sphere having the planet's mean radius, but in some cases an ellipsoid of revolution or a gravitational equipotential surface defined by gravity field measurements).

4.3.3.6 DEM Quality Assessment

While ground control points are widely available for the land surface of the Earth, the quality of surface models for planetary bodies like Mercury must be assessed almost entirely by analysis of internal consistency and comparisons with complementary remote sensing data. Parameters derived directly from the stereo image processing represent the most obvious quality criteria. Among these, the 3-D ray intersection error, i.e., the RMS deviation of the minimum distance between rays defining a 3-D point from an ideal intersection points, is the most powerful measure. However, simple intersections obtained from only two rays can be biased by certain conditions of projective geometry as well as certain illumination conditions. In contrast, triple and higher fold intersections have been shown to provide reliable estimates of point precision. Topographic profiles obtained from orbital laser altimetry (MLA) are reliable reference data for stereo-photogrammetric DEMs of Mercury, as the individual laser measurements typically have a height accuracy of 30 meters or better. Laser altimeter data also show a high degree of geometric consistency on a regional and global scale, which is useful, because of the occasional height offsets and model tilts of DEMs. Comparisons are particularly useful where the laser footprint on the surface and the sampling distance along the altimeter track are similar to the resolution of the stereo data. Here, laser altimeter data can be used to assess effective resolutions of the stereo DEMs. The altimeter tracks are typically merged to gridded DEMs, where areas between the tracks are filled by interpolation. When comparisons are made, care must be taken to cope with possible interpolation errors. Quality assessments can also be made if several DEMs are available for the same area.

4.3.3.7 Generation of the Quadrangle H06 DEM

The H06 Quadrangle DEM is selected as an example for discussion here. DLR selected images that have resolutions between 50 and 350 m/pixel and the "optimal" stereo conditions (Table 3) (~9,850 images in total), for which a stereo coverage map was compiled (**Error! Reference source not found.**).

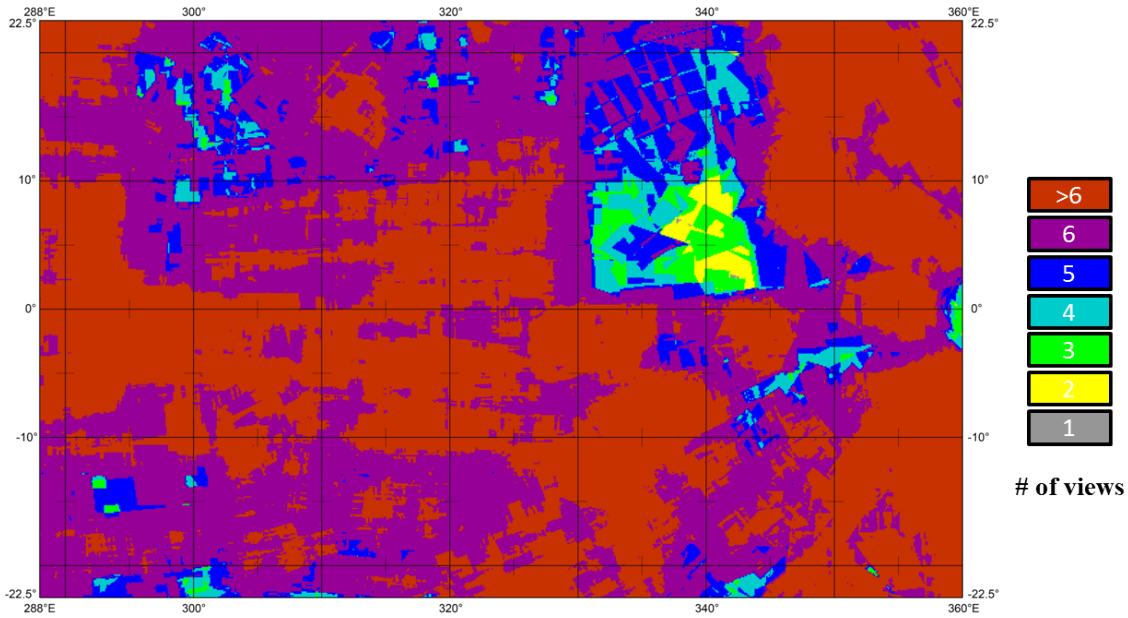

Figure 4

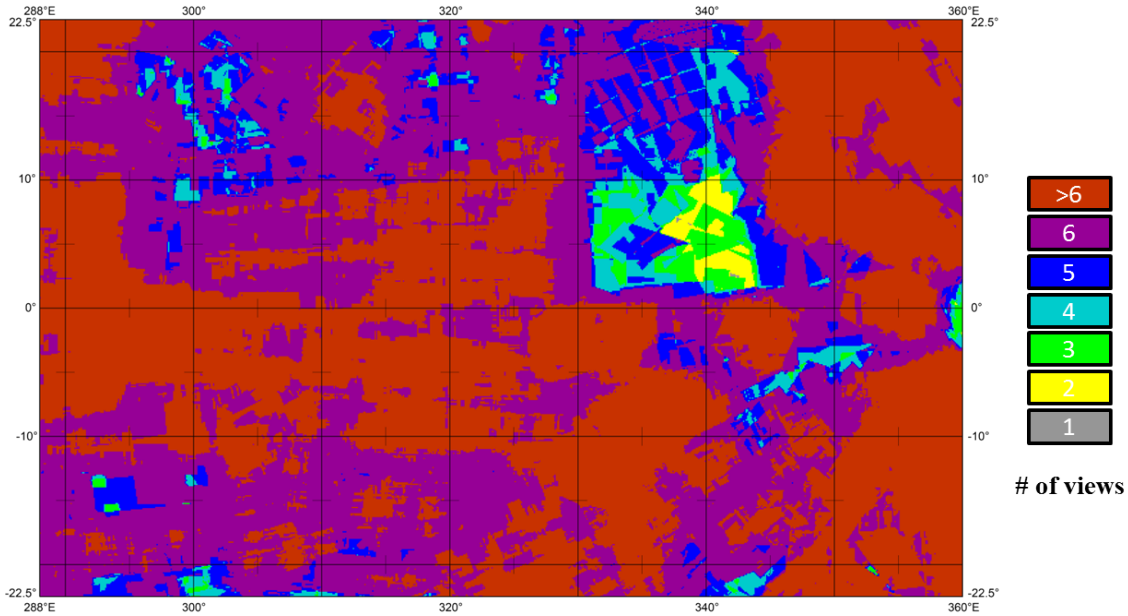

Figure 4 Equirectangular projection of stereo coverage of Quadrangle H06.

In total we found about 7,300 images, which were suitable for stereo reconstructions. The mean resolutions of those images are on average 120 m/pixel. These 7,300 images yield about 22,000 independent stereo combinations. Beginning with nominal navigation (pointing and position) data for the selected stereo images and corresponding stereo combinations, we identified ~45,000 tie points using multi-image matching (4.3.3.3). These image measurements constitute the observation following navigation data correction using a photogrammetric block adjustment (4.3.3.4). This step improved the three-dimensional (3D) point accuracy from ±850 m to ±60 m. Next, 22,000

individual matching runs were carried out to yield a 45 billion image point measurement (4.3.3.3) from which ~5.6 billion object points were computed (4.3.3.4). Only triple-overlapping images were used for the matching, and, thus, for object point calculation. The mean ray intersection error of the object points was ±60 m. Finally, we generated a DEM (Figure 5) with a lateral spacing of 222 m/pixel (~192 pixels per degree) and a vertical accuracy of about 30 m. On average, 45 object points represent one DEM grid. The H06 DEM covers 5.87 million square kilometers of Mercury's surface (about 7.8 percent of the surface). The topographic range of that area is about 9 km.

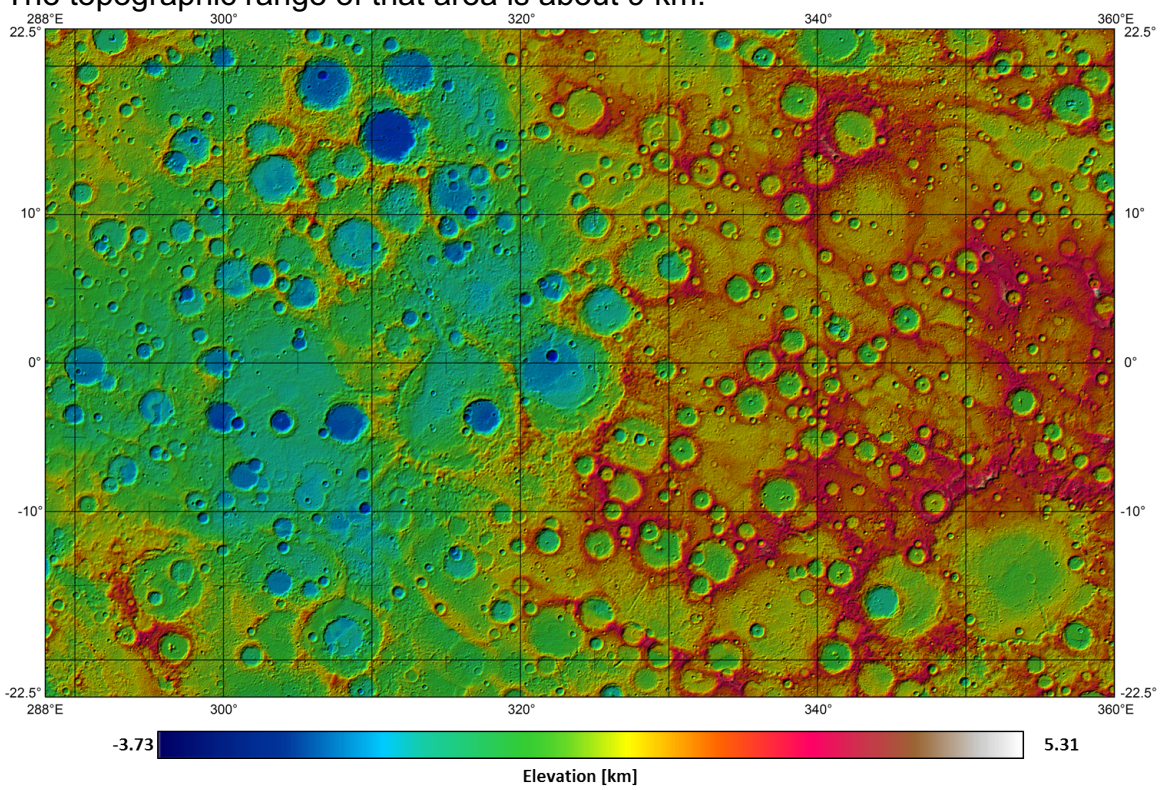

Figure 5 Hill-shaded Color-coded DEM of Quadrangle H06.

The H06 quadrangle DEM is DLR's first high-resolution regional DEM of Mercury to be delivered to the PDS.

4.3.3.8 Comparison with USGS and MLA/RFO DEMs

Figure 6 shows the shaded relief for the H06 quadrangle portion of the USGS global DEM and the DLR DEM. Arrows indicate three small craters that are present in the noticeably denser DLR DEM (192 ppd) but not in the less dense USGS DEM (64 ppd).

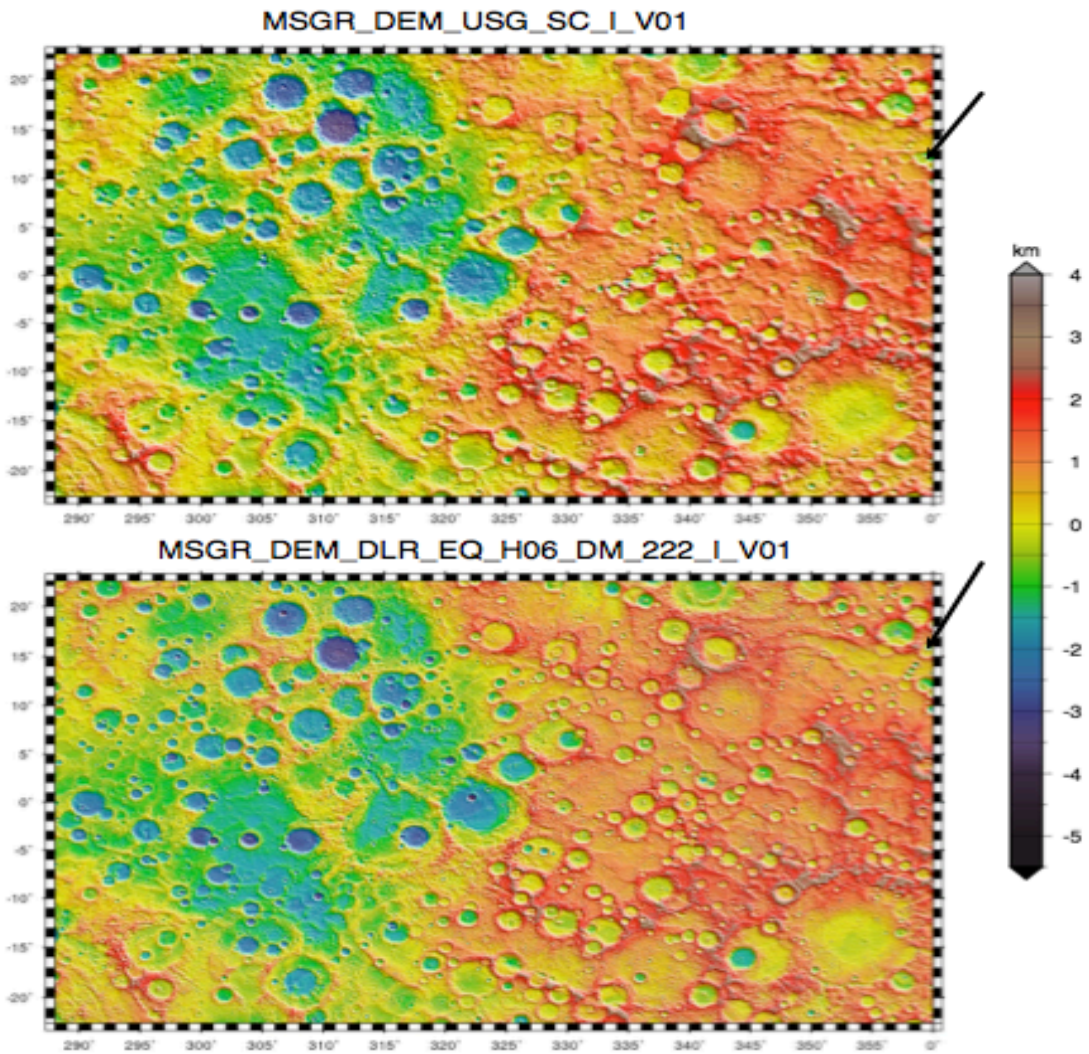

Figure 6 Shaded relief of the USGS and DLR DEMs, H06 Quadrangle

Figure 7 shows the differences between the H06 quadrangle portion of the USGS global DEM and the DLR DEM. Maximum differences between these DEMs in this region exceed +/-2 km.

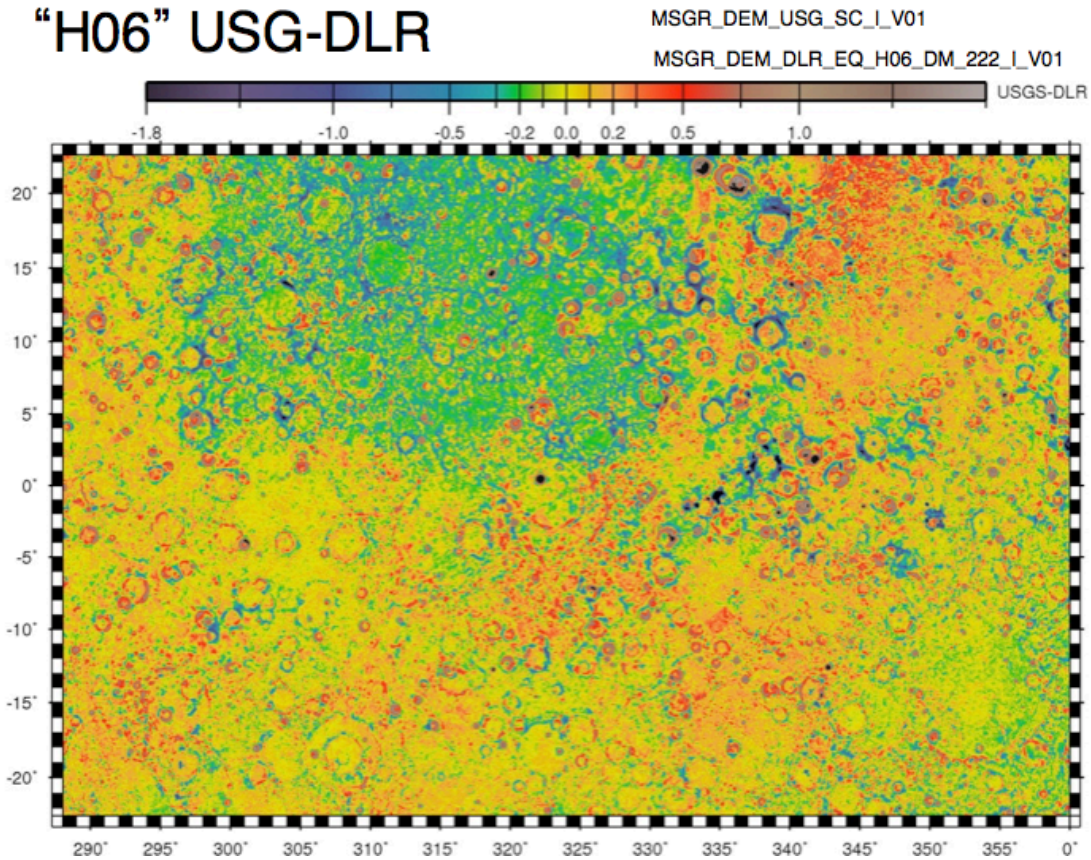

Figure 7 Differences between USGS and DLR DEMs over H06 Quadrangle

Table 4 provides summary statistics for the differences between the MLA data and the USGS and DLR DEMs in the H06 quadrangle (Figure 8 and Figure 9). The more detailed DLR data are accurate to about 100 meters and the USGS data to about 300 meters relative to the MLA data.

Table 4 Summary statistics for the differences between the MLA data and the USGS and DLR DEMs in the H06 Quadrangle

DEM/MLA H06 difference	mean (km)	s.d. (km)	mad* (km)
DLR-MLA	0.001	0.129	0.116
USGS-MLA	-0.024	0.324	0.283

* mad = median absolute deviation scaled to 1 standard deviation (s.d.)

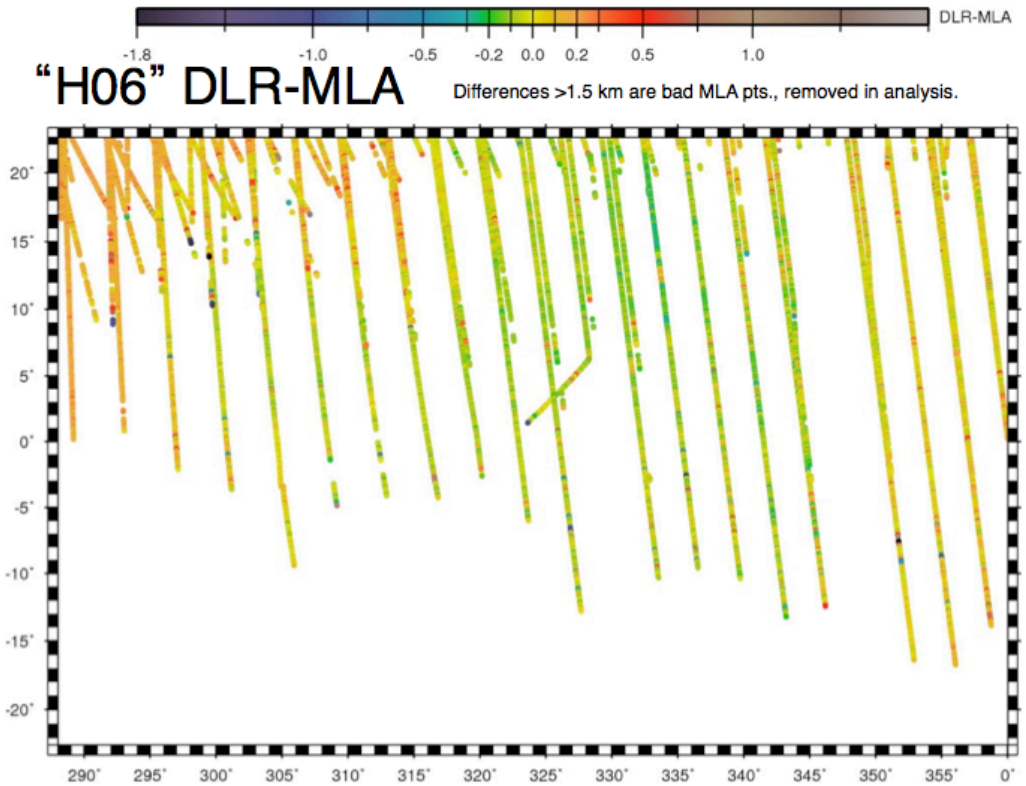

Figure 8 Differences between the DLR DEM and the MLA data in the H06 Quadrangle

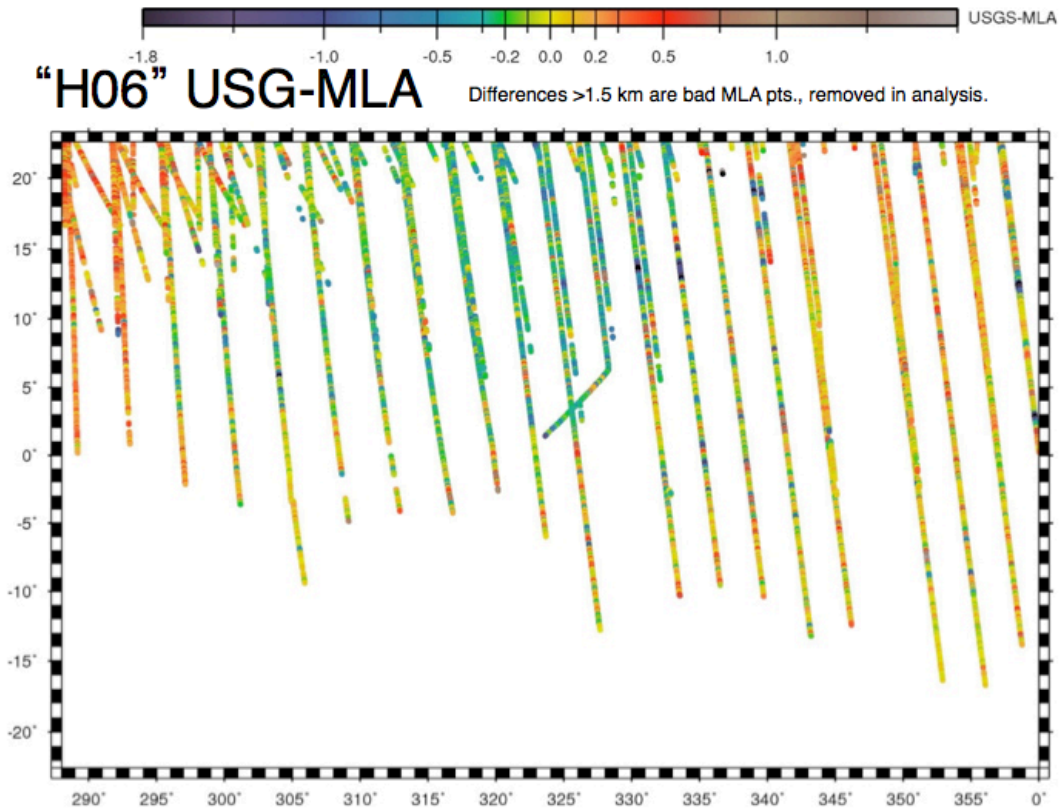

Figure 9 Differences between the USGS DEM and the MLA data in the H06 Quadrangle

4.3.4 ASU REGIONAL DEM Product Description

This section describes the stereo photogrammetric processing methodology to create regional DEM products using a combination of ISIS and SOCET SET 5.6.0 by BAE Systems, as performed by Arizona State University. Regional DEM products are created by aggregating individual DEM pairs into a single DEM product. Image selection and processing are described in the following sub-sections.

4.3.4.1 Images and Stereo Image Selection

Images for MESSENGER DEMs are selected using a two-step process. First, images with acceptable illumination conditions, such as incidence, emission, and phase angles as well as image resolution are identified according to the criteria described in [27]. Next, acceptable stereo overlap is determined by considering resolution ratios, strength of stereo (parallax/height ratio), illumination compatibility, and percentage of stereo overlap [27].

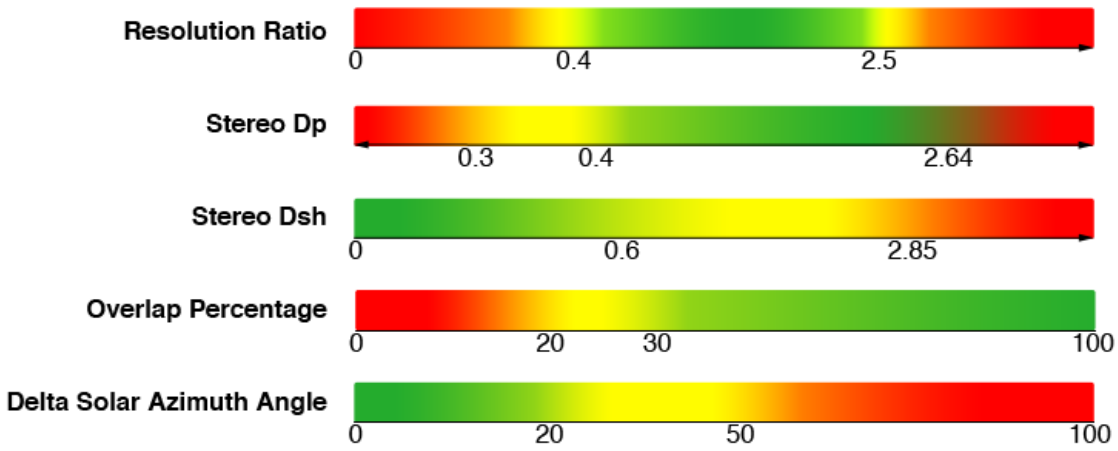

Figure 10 Stereo Image criteria used for ASU Regional DEMs.

Figure 10 indicates the stereo image criteria used for ASU regional DEMs. Red indicates values that are unacceptable, yellow indicates values that are marginally acceptable and may be used, and green indicates acceptable values that produce good stereo pairs.

Generally, NAC images are used to create ASU regional DEMs; however, WAC images will occasionally be selected for inclusion in order to bridge gaps in NAC coverage or to use for control to the MLA data.

4.3.4.2 DEM Production Methodology

Once images have been selected, they are processed using ISIS. They are ingested into ISIS, radiometrically calibrated, and initialized with the appropriate SPICE kernels. The ISIS program socetframesettings is then used to translate the SPICE information into a format ingestible by SOCET SET 5.6.0 [18]. Images are also converted into Tagged Image File Format (TIFF) files.

The 8-bit raw files and setting files generated by the socetframesettings program are then imported into BAE Systems' SOCET SET 5.6.0 software [18,28]. In SOCET SET, all overlapping images are tied together with tie points, bundle adjusted, and manually controlled to shape files of the MLA data. If the sparseness of MLA points prevents direct control, WAC images are controlled to MLA instead. The NAC images are then tightly controlled to the WAC images in order to indirectly improve their geodetic accuracy. In some cases, particularly with sites in the Southern hemisphere, there may be no MLA data available; these DEMs will have no ground control and can only be evaluated in terms of their relative (internal) precision. Once an acceptable bundle adjustment solution (with a root mean square (rms) error <= 0.5 pixels and residuals <= 1.0 pixels) is

achieved, and the images are aligned closely with the MLA data, 16-bit TIFF images are imported. Then the bundle adjustment solution information is copied over from the 8-bit images. Because the correction for the off-axis boresight causes issues with SOCET SET's interpretation of the image footprints, these 16-bit images must then be used to make new images with a cubic rational polynomial (CRP) model of the sensor. Using these new CRP images, the Next Generation Automatic Terrain Extraction (NGATE) program in SOCET SET then creates a DEM at three times the resolution of the lowest resolution image in the stereo pair. As typical NAC images have pixel scales of ~25 m to ~50 m, it is expected that these DEMs will have ground sampling distances between 80 m and 150 m. After editing out any artifacts in the DEM, the final version is used to create 16-bit orthorectified images, in which the distortion due to camera obliquity and terrain relief is removed. The final DEM, 16-bit orthorectified images (also called "orthophotos"), and figure of merit (FOM) are exported from SOCET SET, with the 32-bit DEM and 8-bit FOM exported as raw image files and orthorectified images. There are two orthorectified images for each non-mosaic feature product set (distinguished by "_O1_" and "_O2_" in their filenames and PRODUCT_IDs) and one for each mosaic product set.

These files are then imported into ISIS with the appropriate mapping parameters, including latitudes, longitudes, resolution, and projection. The DEMs are imported with elevations relative to the mean radius of Mercury (2,439.4 km). The ISIS cube of the DEM is used to create a series of sub-products, including a shaded relief map, a color-shaded relief map, and a slope map (in the EXTRAS directory) using Geospatial Data Abstraction Library (GDAL) tools [28, 30]. Legends (in the EXTRAS directory) are also produced for the continuous color-shaded relief and the discrete values used in the slope map. PDS products are made of all final products and sub-products, with the orthorectified images, DEM, and confidence products (generated from the FOM) available as .IMG files and .LBL files made for the .IMG and GeoTIFF sub-products. The GeoTIFFs are provided in the EXTRAS directory. A "README"-type text file (.TXT) with a list of source products and some quality assessment information is provided with each DEM.

NOTE: The DEM (*_DM_*.TIF) GeoTIFF products are 32-bit images. Most general-purpose image viewers are unable to properly render TIFF images of this bit depth. It is recommended that users open these files using an application that is designed to handle images with larger bit depth, such as professional GIS applications.

4.3.4.3 DEM Quality Assessment

DEMs are subject to both qualitative and quantitative analysis. Contour intervals created from the DEMs are qualitatively assessed by comparing them to the images in stereo to ensure a close match with the terrain. In addition both precision and accuracy are evaluated quantitatively. The vertical precision is reported as calculated by the SOCET SET software, in terms of relative linear precision at a 90% confidence level, meaning 90% of positional accuracies will

be equal or less than the reported value. It is expected that the vertical precision of a DEM will be less than its ground sampling distance. The horizontal precision of a DEM is equal to its ground sampling distance.

Accuracy is evaluated by calculating the offsets between the DEM and the corresponding MLA data. Channel 0 data is used for the comparison over Channel 1 data wherever possible, due to its reduced noise [29]. The mean and standard deviation of the offsets between MLA and the regional DEM are reported when available. Due to the highly elliptical orbits around Mercury, the MLA data are very sparse or non-existent in the southern hemisphere, so sometimes no or little data are available for comparison. Additionally, these regional DEMs may not be directly crossed by a MLA track; when this occurs, wide-angle images are controlled to the MLA data, and the narrow-angle images are controlled to those wide-angle images. In this case, the reported values reflect the offsets between a DEM extracted from the wide-angle images and the MLA data. Special care is taken to ensure there is no noticeable difference between the narrow-angle and wide-angle DEMs (seams between the two measure less then the precision of the narrow-angle image DEMs). If no combination of MLA tracks and wide-angle coverage can be found for controlling the narrow-angle images, the resulting DEM will have no measure of absolute accuracy, and only relative precision is reported.

There are some known artifacts in DEMs produced using SOCET SET, including some, but not all, MDIS Regional DEMs. It is highly recommended that the provided terrain shaded relief and confidence maps be examined to detect these before using the DEM. Areas that had very low contrast or were deeply shadowed with low contrast and low signal may have a “faceted” appearance. This is due to the inability of the pattern matching algorithms used for terrain extraction to correlate the images, and the use of interpolation in order to fill in the pixel. Although care is taken to ensure that shadowed areas are removed from the DEM and the contours of the low contrast areas still conform closely to the images, the terrain data in these areas should be treated with caution. In addition, DEMs may have varying levels of noise due to less than ideal lighting conditions and convergence angles. While steps have been taken to mitigate these issues, the confidence map and slope maps should be used to evaluate the noise present in the DEM. Below is a look up table containing the interpretations for the confidence map values (Table 5). The error analysis, potential present of artifacts, and the confidence map look up values are all also provided in the README file accompanying each DEM.

Table 5. ASU Regional DEM Confidence Map Lookup Table

Value	Interpretation
0	NoDATA, outside boundary (e.g. out of stereo pair overlap)
1	Shadowed
2	Saturated

3	Suspicious (edge, corner, did not correlate, etc)
4	Interpolated/ Extrapolated (e.g. from neighbor pixels)
10-14	Value range of successful correlations
15	Manually edited

5 Archive Volume Structure and Contents

This section describes the contents of the DEM Archive volume, including the file names, file contents, and file types. See Table 16 for definitions of data archive terms.

5.1 Archive Identification Parameters

The following parameters are defined for this archive volume:

VOLUME_SERIES_NAME = "MESSENGER"
VOLUME_SET_NAME = "MESSENGER DIGITAL ELEVATION MODEL"
VOLUME_SET_ID = "USA_NASA_PDS_MESSDEM_1001"
VOLUME_NAME = "MESSENGER DEM ARCHIVE"
VOLUME_ID = MESSDEM_1001

The following data set parameters are defined for the MESSENGER DEM products.

DATA_SET_NAME = “MESSENGER MERCURY MDIS LEVEL 5 DEM V1.0”
DATA_SET_ID = “MESS-H-MDIS-5-DEM-ELEVATION-V1.0”

5.2 Directory Structure

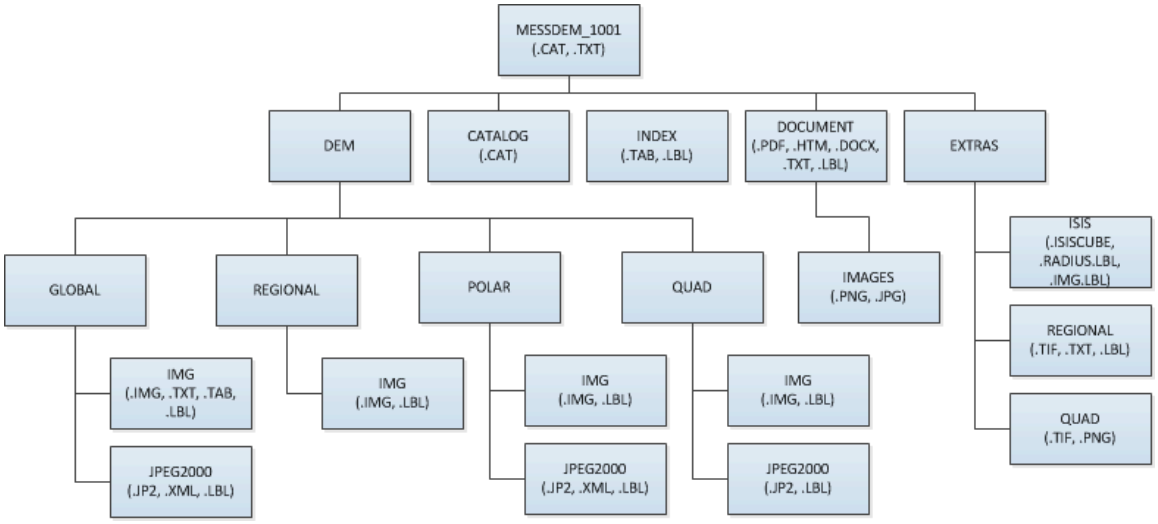

Figure 11 Directory structure of DEM archive volume.

5.2.1 Root Directory

Table 6 describes the files in the volume root directory. The catalog, DEM, index, label, document, and extras directories also reside within this directory.

Table 6. Archive volume contents.

File Name	File Contents
AAREADME.TXT	General information file. Provides users with an overview of the contents and organization of the associated volume, general instructions for its use, and contact information.
ERRATA.TXT	Text file for identifying and describing errors and/or anomalies found in the current volume, and possibly previous volumes of a set. Any known errors for the associated volume will be documented in this file.
VOLDESC.CAT	ODL file containing the VOLUME object. This gives a high-level description of the contents of the volume. Information includes: production date, producer name and institution, volume ID, etc.

5.2.2 INDEX Directory

Files in the Index Directory (Table 7) are provided to help the user locate products on the archive volume. The following files are contained in the Index Directory.

Table 7. INDEX directory contents.

File Name	File Contents
INDXINFO.TXT	A description of the contents of this directory.
INDEX.TAB	A table listing all data products in this archive volume.
INDEX.LBL	Detached PDS label for INDEX.TAB that describes INDEX.TAB.

Table 8 defines the contents of the archive volume index table. The index table contains one row for each product in the archive. Only the product labels are listed.

Table 8. INDEX.TAB file contents.

Column	Format	Description
VOLUME_ID	CHARACTER	PDS archive volume on which a data product is stored
PATH_NAME	CHARACTER	The directory path of the product within the volume.
FILE_NAME	CHARACTER	The name of the product label in the volume.
PRODUCT_ID	CHARACTER	The unique identifier of the product.
PRODUCT_CREATION_TIME	TIME	Date and time of product creation
START_TIME	TIME	UTC date and time of the earliest data collect used in the creation of the product.

Column	Format	Description
STOP_TIME	TIME	UTC date and time of the last data collect used in the creation of the product.
PRODUCT_VERSION_ID	CHARACTER	Version number of the data product.
LINES	INTEGER	Number of lines in the image.
LINE_SAMPLES	INTEGER	Number of samples per line.
BANDS	INTEGER	Number of spectral bands in the image.
MAP_PROJECTION_TYPE	CHARACTER	Map projection used.
CENTER_LATITUDE	REAL	Latitude of the image center.
CENTER_LONGITUDE	REAL	Longitude of the image center.
MAP_SCALE	REAL	Map scale in km/pixel.
MAP_RESOLUTION	REAL	Map resolution in pixels/degree.
LINE_PROJECTION_OFFSET	REAL	Line offset of map origin from the upper left of image.
SAMPLE_PROJECTION_OFFSET	REAL	Sample offset of map origin from u-left of image.
MAXIMUM_LATITUDE	REAL	Maximum latitude covered.
MINIMUM_LATITUDE	REAL	Minimum latitude covered.
WESTERNMOST_LONGITUDE	REAL	Westernmost longitude covered.
EASTERNMOST_LONGITUDE	REAL	Easternmost longitude covered.
MISSION_PHASE_NAME	CHARACTER	The phase names over which data were collected.
SPACECRAFT_CLOCK_START_COUNT	CHARACTER	MET count at start of data collection.
SPACECRAFT_CLOCK_STOP_COUNT	CHARACTER	MET count at end of data collection.

5.2.3 CATALOG Directory

The files in the Catalog Directory (Table 9) provide a top-level understanding of the mission, spacecraft, instruments, and data set. The files in this directory become part of the PDS Catalog to provide background information for the user searching for data. Their format and contents are further specified in the PDS Standards Reference [5]. The following files are found in the Catalog Directory.

Table 9. CATALOG directory contents.

File Name	File Contents
CATINFO.TXT	Identifies and describes the function of each file in the catalog directory.
MDIS_DEM_DS.CAT	Data set description.
MDIS_NAC_INST.CAT	Describes the MDIS Narrow Angle Camera (NAC), data from which the DEM products are created.
MDIS_WAC_INST.CAT	Describes the MDIS Wide Angle Camera (WAC), data from which the some of the DEM products are partly created.
INSTHOST.CAT	Description of the MESSENGER spacecraft for the PDS catalog.
DEM_EQU_MAP.CAT	Data set map projection information for equatorial region

DEM_POLAR_MAP.CAT	Data set map projection information for polar region
MISSION.CAT	Description of the MESSENGER mission for the PDS catalog.
PERSON.CAT	List of personnel associated with the MESSENGER PDS delivery who may be contacted for information about the data volume.
REF.CAT	Catalog objects' citation list for the PDS catalog.

5.2.4 DOCUMENT Directory

The Document Directory (Table 10) contains documentation to help the user understand and use the archive data. The following files are contained in the Document Directory.

Table 10. DOCUMENT directory contents.

File Name	File Contents
DOCINFO.TXT	Identifies and describes the function of each file in the document directory.
MSGR_DEM_SIS.PDF	Software Interface Specification for the DEM data products as an Adobe PDF document.
MSGR_DEM_SIS.HTM	Software Interface Specification for the DEM data products as an HTML document.
MSGR_DEM_SIS.LBL	PDS label for DEM_SIS.PDF and DEM_SIS.HTM.
IMAGES/	Subdirectory containing image files to be included with the HTML.
JP2INFO.TXT	Describes JPEG2000 image encoding and format.

5.2.5 DEM Directory

The DEM Directory (Table 11) contains the data products for this archive volume. It contains subdirectories for global and regional products.

Table 11. DEM directory structure.

File Name	File Contents
GLOBAL/IMG/ GLOBAL/JPEG2000/	Subdirectories containing the global DEM products and labels.
REGIONAL/IMG/	Subdirectory containing the regional DEM products and labels. These are centered on selected planetary surface features.
POLAR/IMG/ POLAR/JPEG2000	Subdirectories containing the polar region products and labels.
QUAD/IMG QUAD/JPEG2000	Subdirectories containing quadrangle-based products and labels.

5.2.5.1 DEM/GLOBAL, REGIONAL and POLAR Directories

The GLOBAL, REGIONAL, POLAR, and QUAD Directories (Table 12) reside within the DEM directory and each contain separate subdirectories for the regular image (.IMG) and JPEG 2000 versions (.JP2) of the global DEM products and their associated labels.

Table 12. GLOBAL, REGIONAL , POLAR, and QUAD directory contents.

File Name	File Contents
IMG/	Subdirectory containing the PDS image formatted products and labels.
IMG/*.IMG	The PDS image format versions of the DEM data products.
IMG/*.LBL	The detached labels for the image format DEM data products.
IMG/*.TXT	Source product list file. A simple text file with an attached label that lists the SOURCE_PRODUCT_IDs of the lower-level products that were used to create the DEM product.
IMG/*.TAB	Point cloud ancillary. A PDS table file with detached label associated with USGS products.
POINTCLOUDTAB.FMT	Describes the format of the USGS point cloud file.
JPEG2000/	Subdirectory containing the USGS and DLR JPEG 2000 formatted products and labels.
JPEG2000/*.JP2	The JPEG 2000 format versions of the DEM data products.
JPEG2000/*.LBL	The detached labels for the JPEG 2000 format DEM data products.
JPEG2000/*_AUX.XML	The auxiliary files with XML metadata useful for displaying USGS JPEG2000 images with GDAL tools.

5.2.6 EXTRAS Directory

The EXTRAS directory contains files that are not part of the formal archive volume, but might still be useful to some users, and are therefore included. It contains ISIS, REGIONAL, and QUAD subdirectories with files of various types and formats. These are described in the included EXTRINFO.TXT file.

Table 13 EXTRAS directory structure

File Name	File Contents
ISIS/	Subdirectory containing the ISIS data files supporting the USGS equatorial and polar DEMs.
REGIONAL/	Subdirectory containing TIF image files and .TXT product notes supporting the ASU regional DEMs.
QUAD/	Subdirectory containing TIF and .PNG image files supporting the DLR quadrangle DEMs.

5.2.7 File Type, Naming and Storage

MESSENGER DEMs are produced in a gridded or plain raster format. The DEMs themselves are stored in PDS standard image (.IMG) and JPEG 2000 (.JP2) formats with detached PDS labels. See Table 16 for label keyword definitions. Image file pixels are 32-bit floating point values. JPEG 2000 file pixel values are scaled unsigned integers values.

5.2.7.1 Product Naming Conventions

The naming conventions detailed below apply to the DEM and associated ancillary products. The file names developed for this PDS archive are restricted to a maximum 36-character base name and 3 character extension name with a period separating the file and extension names. Also known as the “36.3” format, this is compliant with the ISO 9660 Level 2 specification (maximum of 40 characters), which is required by PDS. Below is the detailed naming convention for this dataset.

<u>Global and Polar DEM PRODUCT_ID Naming convention:</u>

```
MSGR_DEM_iii_pp_c_Vnn.ext
MSGR_DEM_iii_pp_c_Vnn_AUX.XML
where
iii = producer institution
      USG = U.S. Geological Survey
pp = projection
      SC = Simple Cylindrical
      NP = North Polar Stereographic
      SP = South Polar Stereographic
      00 = Not Applicable for the product
c = product code
      I = image format file
      J = JPEG 2000 file
```

```
      S = source product list file
      C = point cloud file
nn = 2 digit version number
ext = file extension indicating file type
      IMG = image file
      TAB = text table file
      TXT = free format text file
      JP2 = JPEG 2000 file
      XML = USGS auxiliary (AUX) file with XML metadata useful for
            displaying JPEG2000 images with GDAL tools
            NOTE: It may be necessary to rename these files to
            *.aux.xml when used with Geospacial Data Abstraction
            Library (GDAL)-based tools.
      LBL = PDS label file
```

Source Product List Naming convention:

The source product list naming convention follows that of the DEM products and its file extension will always be .TXT. Source Product list files will have attached minimal labels.

MSGR_DEM_iii_pp_S_Vnn.TXT for global products

Point Cloud File naming convention:

The point cloud file naming convention follows that of the DEM products and its file extension will always be .TAB. Point cloud files will have detached labels.

MSGR_DEM_iii_pp_C_Vnn.TAB for USGS global products

Quadrangle DEM PRODUCT_ID Naming convention:

```
The DLR DEM follows the following naming convention:
MSGR_DEM_iii_pp_Haa_mm_sss_c_Vnn.ext
where
iii = producer institution
      DLR = German Aerospace Center
pp  = projection
      EQ = equirectangular
      LC = lambert conformal
      SC = simple cylindrical
      00 = not applicable
aa  = the IAU-defined quadrangle number on planet Mercury
      00-11
      (See Greely, R. and R.M. Batson, Planetary Mapping, Cambridge
       University Press, 1990)
mm  = product type
      DM = primary 16-bit DEM product
sss = map scale in m/pixel truncated to the nearest integer, “000” if
      not applicable
c  = product code
      I = image format file
      J = JPEG 2000 file
```

```
      T = GeoTIFF format
      P = PNG file (if available for EXTRAS directory)
nn = 2 digit version number
ext = file extension indicating file type
      IMG = image file
      JP2 = JPEG 2000 file
      TIF = GeoTIFF file
      PNG = PNG file
LBL = PDS label file
```

Regional DEM PRODUCT_ID Naming convention:

```
The ASU DEMs follow the following naming convention:
MSGR_DEM_iii_pp_aaaaabb_mm_sss_c_Vnn.ext
where
iii = producer institution
      ASU = Arizona State University
pp  = projection
      EQ = equirectangular
      00 = not applicable
aaaaa = designation of the site name that the DEM covers
bb    = designation of the stereo pair
      <nn> = a uniquely numbered integer stereo pair for the site
      MS = mosaic of the site containing all the stereo pairs
mm  = product type
      DM = primary 32-bit DEM product
      CF = confidence map
      CL = legend associated with the color-shaded relief map
      CS = color-shaded relief map
      O1 = 16-bit orthorectified image, image 1
      O2 = 16-bit orthorectified image, image 2
            NOTE: The "O" in the above are capital letter Oh, not zero.
      SL = slope map legend
      SM = slope map
      TS = terrain shaded relief map
      RM = readme file
ss  = map scale in m/pixel truncated to the nearest integer, "00" if
      not applicable
c  = product code
      I = image format file
      T = GeoTIFF file
      S = source product list file
nn = 2 digit version number

ext = file extension indicating file type
      IMG = image file
      TAB = text table file
      TXT = free format text file
      TIF = GeoTIFF file
      XML = Optional auxiliary file with XML metadata useful for
            displaying JPEG2000 images with GDAL tools
      LBL = PDS label file
```

NOTES:

1. There are two instances of the ASU orthorectified image (_O1_, _O2_) products in the archive. Their filenames are distinguished only by the image numbers (e.g., O1, O2). Every individual feature name (e.g.

KERTS01) represents a single stereo pair. Because each stereo pair is made up of two images, there are two different orthorectified images, each of which is generated at a higher and a lower pixel scale. There is only one DEM per stereo pair, and all the other products are generated based on that one DEM, so there is only one instance of each of the other name types (DM, CL, CF, CS, SL, etc). The orthorectified images associated with mosaics (e.g., KERTSMS) are themselves mosaics built up from all the individual orthorectified images and there is only one such product associated with each mosaic.

2. The ASU CL, CS, SL, SM, TS, and RM product types as well as GeoTIFF and .TXT files are located in the EXTRAS/REGIONAL directory of the archive volume.

5.2.7.1.1 Sample File Names

Table 14 provides examples demonstrating the naming convention for global and regional DEM products created from MESSENGER observations. The global product in this example is a MESSENGER DEM referenced from the Mercury geoid in simple cylindrical projection and produced by the USGS. PDS image and JPEG 2000 versions are provided with an accompanying source product list and point cloud files. The regional products in this example are of the Catullus site in equirectangular coordinates, and produced by ASU.

Table 14. Sample file names.

MSGR_DEM_USG_SC_I_V01.IMG	Global USGS DEM in PDS image format
MSGR_DEM_USG_SC_J_V01.JP2	Global USGS DEM in JPEG 2000 format
MSGR_DEM_USG_SC_S_V01.TXT	SOURCE_PRODUCT_IDs list file for global USGS DEM.
MSGR_DEM_USG_SC_C_V01.TAB	Global USGS DEM point cloud file
MSGR_DEM_ASU_EQ_SANDR13_DM_90_I_V01.IMG	Regional ASU DEM image in PDS image format covering the SANDR crater region at a scale of 90 m/pixel.
MSGR_DEM_ASU_EQ_SANDR13_CF_90_I_V01.IMG	Regional ASU DEM confidence map in PDS image format covering the SANDR crater region at a scale of 90 m/pixel.
MSGR_DEM_ASU_EQ_SANDR13_O2_30_I_V01.IMG	Regional ASU orthorectified image #2 in PDS image format covering the SANDR crater region at a scale of 30 m/pixel.
MSGR_DEM_ASU_EQ_SANDR13_CL_90_T_V01.TIF	Regional ASU DEM legend in TIFF format for the associated color-shaded relief map. Included in the EXTRAS directory.
MSGR_DEM_ASU_EQ_SANDRMS_CS_150_T_V01.TIF	Regional ASU DEM color-shaded relief map in TIFF format

	covering the SANDR crater region at a scale of 150 m/pixel. Included in the EXTRAS directory.
MSGR_DEM_ASU_EQ_SANDR13_SL_90_T_V01.TIF	Regional ASU DEM legend for the associated slope map product. Included in the EXTRAS directory.
MSGR_DEM_ASU_EQ_SANDR13_SM_90_T_V01.TIF	Regional ASU DEM slope map in TIFF format covering the SANDR crater region at a scale of 90 m/pixel. Included in the EXTRAS directory.
MSGR_DEM_ASU_EQ_SANDR13_TS_90_T_V01.TIF	Regional ASU DEM terrain shaded relief map in PDS image format covering the SANDR crater region at a scale of 90 m/pixel. Included in the EXTRAS directory.
MSGR_DEM_ASU_EQ_SANDR13_DM_90_T_V01.TIF	Regional ASU DEM image in TIFF format covering the SANDR crater region at a scale of 90 m/pixel. Included in the EXTRAS directory.
MSGR_DEM_DLR_SC_H06_DM_222_I_V02.IMG	Regional DLR DEM covering the H06 “Kuiper” quadrangle at a scale of 222 m/pixel

6 Label Descriptions

Below are template PDS detached labels for MESSENGER global and regional DEM products and ancillary files. The example global product files are in simple cylindrical projection and the example regional product files are in equirectangular projection. Template labels are also provided for the DEM source product image list and point cloud files.

6.1 Sample DEM Product Labels

6.1.1 USGS Global DEM (IMG) PDS Label

```
PDS_VERSION_ID = PDS3

/*   File Format   */

RECORD_TYPE        = FIXED_LENGTH
RECORD_BYTES       = 46080
FILE_RECORDS       = 11520
INTERCHANGE_FORMAT = BINARY

/*    Pointers    */

^IMAGE             = "MSGR_DEM_USG_SC_I_V01.IMG"

/*    Image and parameter description     */

DATA_SET_ID                     = "MESS-H-MDIS-5-DEM-ELEVATION-V1.0"
PRODUCT_ID                      = "MSGR_DEM_USG_SC_I_V01"
```

```
PRODUCT_VERSION_ID              = "1"
PRODUCER_FULL_NAME              = "KRIS J. BECKER"
PRODUCER_ID                     = USGS
PRODUCER_INSTITUTION_NAME       = "U.S. GEOLOGICAL SURVEY"
PRODUCT_TYPE                    = DEM
MISSION_NAME                    = MESSENGER
SPACECRAFT_NAME                 = MESSENGER
INSTRUMENT_HOST_NAME            = MESSENGER
INSTRUMENT_NAME                 = ("MERCURY DUAL IMAGING SYSTEM NARROW ANGLE
                                  CAMERA", "MERCURY DUAL IMAGING SYSTEM WIDE
                                  ANGLE CAMERA")
INSTRUMENT_ID                   = ("MDIS NAC","MDIS WAC")
TARGET_NAME                     = MERCURY
MISSION_PHASE_NAME              = {"MERCURY ORBIT","MERCURY ORBIT YEAR 2",
                                 "MERCURY ORBIT YEAR 3","MERCURY ORBIT YEAR 4"}
START_TIME                      = 2011-03-18T00:00:00
STOP_TIME                       = 2014-11-01T00:00:00
SPACECRAFT_CLOCK_START_COUNT    = "N/A"
SPACECRAFT_CLOCK_STOP_COUNT     = "N/A"
SOFTWARE_NAME                   = ISIS
SOFTWARE_VERSION_ID             = "3.4.11"
PRODUCT_CREATION_TIME           = 2016-02-08T12:00:00
DESCRIPTION                    = "Mercury MESSENGER MDIS Digital Elevation
Model (DEM). With OFFSET and SCALING_FACTOR applied, DN scaled units are
Meters (relative to 2439.4 kilometer datum). Equirectangular (Simple
Cylindrical) projection, global product."

OBJECT = IMAGE
  LINES                       = 11520
  LINE_SAMPLES                = 23040
  BANDS                       = 1
  UNIT                        = METER
  MINIMUM                     = -5382.0
  MAXIMUM                     = 4978.5
  OFFSET                      = 0.0
  SCALING_FACTOR              = 0.5
  SAMPLE_BITS                 = 16
  SAMPLE_BIT_MASK             = 2#1111111111111111#
  SAMPLE_TYPE                 = LSB_INTEGER
  MISSING_CONSTANT            = -32768
  BAND_STORAGE_TYPE           = BAND_SEQUENTIAL
END_OBJECT = IMAGE

OBJECT = IMAGE_MAP_PROJECTION
  ^DATA_SET_MAP_PROJECTION     = "DEM_EQU_MAP.CAT"
  MAP_PROJECTION_TYPE          = "SIMPLE CYLINDRICAL"
  COORDINATE_SYSTEM_TYPE       = "BODY-FIXED ROTATING"
  A_AXIS_RADIUS                = 2439.4 <km>
  B_AXIS_RADIUS                = 2439.4 <km>
  C_AXIS_RADIUS                = 2439.4 <km>
  COORDINATE_SYSTEM_NAME       = PLANETOCENTRIC
  POSITIVE_LONGITUDE_DIRECTION = EAST
  CENTER_LATITUDE              = 0.0 <deg>
  CENTER_LONGITUDE             = 180.0 <deg>
  LINE_FIRST_PIXEL             = 1
  LINE_LAST_PIXEL              = 11520
  SAMPLE_FIRST_PIXEL           = 1
  SAMPLE_LAST_PIXEL            = 23040
  MAP_PROJECTION_ROTATION      = 0.0 <deg>
  MAP_RESOLUTION               = 64.0 <pix/deg>
  MAP_SCALE                    = 0.66524315270546 <km/pixel>
  MAXIMUM_LATITUDE             = 90.0 <deg>
  MINIMUM_LATITUDE             = -90.0 <deg>
  EASTERNMOST_LONGITUDE        = 360.0 <deg>
  WESTERNMOST_LONGITUDE        = 0.0 <deg>
  LINE_PROJECTION_OFFSET       = 5759.5 <pixel>
  SAMPLE_PROJECTION_OFFSET     = 11519.5 <pixel>
END_OBJECT = IMAGE_MAP_PROJECTION
END
```

6.1.2 USGS Global DEM (JPEG 2000) PDS Label

```
PDS_VERSION_ID = PDS3

/*    Image and parameter description     */

DATA_SET_ID                    = "MESS-H-MDIS-5-DEM-ELEVATION-V1.0"
PRODUCT_ID                     = "MSGR_DEM_USG_SC_J_V01"
PRODUCT_VERSION_ID             = "1"
PRODUCER_FULL_NAME             = "KRIS J. BECKER"
PRODUCER_ID                    = USGS
PRODUCER_INSTITUTION_NAME      = "U.S. GEOLOGICAL SURVEY"
PRODUCT_TYPE                   = DEM
MISSION_NAME                   = MESSENGER
SPACECRAFT_NAME                = MESSENGER
INSTRUMENT_HOST_NAME           = MESSENGER
INSTRUMENT_NAME                = ("MERCURY DUAL IMAGING SYSTEM NARROW ANGLE
                                 CAMERA", "MERCURY DUAL IMAGING SYSTEM WIDE
                                 ANGLE CAMERA")
INSTRUMENT_ID                  = ("MDIS NAC","MDIS WAC")
TARGET_NAME                    = MERCURY
MISSION_PHASE_NAME             = {"MERCURY ORBIT","MERCURY ORBIT YEAR 2",
                                "MERCURY ORBIT YEAR 3","MERCURY ORBIT YEAR 4"}
START_TIME                     = 2011-03-18T00:00:00
STOP_TIME                      = 2014-11-01T00:00:00
SPACECRAFT_CLOCK_START_COUNT   = "N/A"
SPACECRAFT_CLOCK_STOP_COUNT    = "N/A"
PRODUCT_CREATION_TIME          = 2016-02-08T12:00:00
SOFTWARE_NAME                  = "Geospatial Data Abstraction Library (GDAL)"
SOFTWARE_VERSION_ID            = "1.10.1"
RATIONALE_DESC                 = "The JPEG2000 image associated with this
label is provided as a supplement to the 16-bit primary data product
(MSGR_DEM_USG_SC_I_V01.IMG)"
NOTE                           = "PDS label for 16-bit (signed) JPEG2000
image."

/* The JPEG2000 image data file associated with this label. */
OBJECT = COMPRESSED_FILE
    FILE_NAME                  = "MSGR_DEM_USG_SC_J_V01.JP2"
/* NOTE: JPEG2000 DN scaled units are Meters (relative to 2439.4 kilometer  */
/* datum) Also see original image DN units and scaling factor below in      */
/* UNCOMPRESSED_FILE group                                                  */
    RECORD_TYPE                = UNDEFINED
    ENCODING_TYPE              = "JP2"
    FILE_RECORDS               = 11520
    INTERCHANGE_FORMAT         = BINARY
    /* The name of the original source file. */
    UNCOMPRESSED_FILE_NAME     = "MSGR_DEM_USG_SC_I_V01.IMG"
    /* The amount of original image data. */
    REQUIRED_STORAGE_BYTES     = "530841600"
    SAMPLE_TYPE                = MSB_INTEGER
    SAMPLE_BITS                = 16
    ^DESCRIPTION               = "JP2INFO.TXT"
END_OBJECT = COMPRESSED_FILE

/* The source image data definition. */
/* Note: The values of the FILE_NAME and ^IMAGE fields in the               */
/* UNCOMPRESSED_FILE object contain the name of a hypothetical file that    */
/* could be created by decompressing the JP2 product, but that does not     */
/* actually exist in the archive volume. These fields are here to comply    */
/* with PDS 3 standards.                                                    */
OBJECT = UNCOMPRESSED_FILE
    FILE_NAME    = "MSGR_DEM_USG_SC_J_V01.IMG"
    RECORD_TYPE  = FIXED_LENGTH
    RECORD_BYTES = 46080
    FILE_RECORDS = 11520
    ^IMAGE       = "MSGR_DEM_USG_SC_J_V01.IMG"
      OBJECT = IMAGE
        LINES                      = 11520
        LINE_SAMPLES               = 23040
        BANDS                      = 1
        BAND_STORAGE_TYPE          = BAND_SEQUENTIAL
        /* NOTE: DN scaled units are Meters (surface elevation at each    */
```

```
        /* pixel). With SCALING_FACTOR = 0.5, and OFFSET = 0              */
        UNIT                        = METER
        MINIMUM                     = -5382.0
        MAXIMUM                     = 4978.5
        OFFSET                      = 0.0
        SCALING_FACTOR              = 0.5
        SAMPLE_BITS                 = 16
        SAMPLE_BIT_MASK             = 2#1111111111111111#
        SAMPLE_TYPE                 = LSB_INTEGER
        MISSING_CONSTANT            = -32768
      END_OBJECT = IMAGE
END_OBJECT = UNCOMPRESSED_FILE

OBJECT                     = AUX_FILE
  FILE_NAME                = "MSGR_DEM_USG_SC_J_V01_AUX.XML"
  RECORD_TYPE              = STREAM
  FILE_RECORDS             = UNK
  DESCRIPTION              = "This is an auxiliary file accompanying
     the JPEG2000 file. It contains metadata in XML format that
     is useful for displaying the image using a GDAL supported tool."
END_OBJECT                 = AUX_FILE

OBJECT = IMAGE_MAP_PROJECTION
  ^DATA_SET_MAP_PROJECTION     = "DEM_EQU_MAP.CAT"
  MAP_PROJECTION_TYPE          = "SIMPLE CYLINDRICAL"
  COORDINATE_SYSTEM_TYPE       = "BODY-FIXED ROTATING"
  A_AXIS_RADIUS                = 2439.4 <km>
  B_AXIS_RADIUS                = 2439.4 <km>
  C_AXIS_RADIUS                = 2439.4 <km>
  COORDINATE_SYSTEM_NAME       = PLANETOCENTRIC
  POSITIVE_LONGITUDE_DIRECTION = EAST
  CENTER_LATITUDE              = 0.0 <deg>
  CENTER_LONGITUDE             = 180.0 <deg>
  LINE_FIRST_PIXEL             = 1
  LINE_LAST_PIXEL              = 11520
  SAMPLE_FIRST_PIXEL           = 1
  SAMPLE_LAST_PIXEL            = 23040
  MAP_PROJECTION_ROTATION      = 0.0 <deg>
  MAP_RESOLUTION               = 64.0 <pix/deg>
  MAP_SCALE                    = 0.66524315270546 <km/pixel>
  MAXIMUM_LATITUDE             = 90.0 <deg>
  MINIMUM_LATITUDE             = -90.0 <deg>
  EASTERNMOST_LONGITUDE        = 360.0 <deg>
  WESTERNMOST_LONGITUDE        = 0.0 <deg>
  LINE_PROJECTION_OFFSET       = 5759.5 <pixel>
  SAMPLE_PROJECTION_OFFSET     = 11519.5 <pixel>
END_OBJECT = IMAGE_MAP_PROJECTION
END
```

6.1.3 USGS Global DEM (Source Product List) PDS Label

```
PDS_VERSION_ID                 = PDS3
PRODUCT_VERSION_ID             = "1"
RECORD_TYPE                    = FIXED_LENGTH
RECORD_BYTES                   = 27
FILE_RECORDS                   = 100432
^TABLE                         = "MSGR_DEM_USG_SC_S_V01.TXT"

/* Identification Data Elements */
DATA_SET_ID                    = "MESS-H-MDIS-5-DEM-ELEVATION-V1.0"
PRODUCER_FULL_NAME             = "KRIS J. BECKER"
PRODUCER_ID                    = USGS
PRODUCER_INSTITUTION_NAME      = "U.S. GEOLOGICAL SURVEY"
PRODUCT_TYPE                   = DEM
MISSION_NAME                   = MESSENGER
SPACECRAFT_NAME                = MESSENGER
INSTRUMENT_HOST_NAME           = MESSENGER
INSTRUMENT_NAME                = ("MERCURY DUAL IMAGING SYSTEM NARROW ANGLE
                                 CAMERA", "MERCURY DUAL IMAGING SYSTEM WIDE
                                 ANGLE CAMERA")
```

```
INSTRUMENT_ID                   = ("MDIS NAC","MDIS WAC")
TARGET_NAME                     = MERCURY
MISSION_PHASE_NAME              = {"MERCURY ORBIT","MERCURY ORBIT YEAR 2",
                                  "MERCURY ORBIT YEAR 3","MERCURY ORBIT YEAR 4"}
PRODUCT_ID                      = "MSGR_DEM_USG_SC_S_V01"
PRODUCT_CREATION_TIME           = 2016-02-11T09:08:00
START_TIME                      = 2011-03-18T00:00:00
STOP_TIME                       = 2014-11-01T00:00:00
SPACECRAFT_CLOCK_START_COUNT    = "N/A"
SPACECRAFT_CLOCK_STOP_COUNT     = "N/A"
DESCRIPTION                     =  "The DEM source product list file. This file
contains the PDS PRODUCT_ID values of the lower-level MDIS products that were
used to create the associated DEM."

OBJECT = TABLE
 COLUMNS                        = 1
 INTERCHANGE_FORMAT             = ASCII
 ROW_BYTES                      = 27
 ROWS                           = 100432
 DESCRIPTION                    = "The DEM source product list file. This file
contains the PDS PRODUCT_ID values of the lower-level MDIS products that were
used to create the associated DEM."

  OBJECT = COLUMN
    NAME                        = SOURCE_ID
    COLUMN_NUMBER               = 1
    DATA_TYPE                   = CHARACTER
    START_BYTE                  = 1
    BYTES                       = 26
    FORMAT                      = "A26"
    DESCRIPTION                 = "The source PRODUCT_ID (including year
      and day identification of the lower-level MDIS products used to
      created the associated DEM."
  END_OBJECT = COLUMN

END_OBJECT = TABLE
END
```

6.1.4 USGS Global DEM (Point Cloud File) PDS Label

```
PDS_VERSION_ID                = "PDS3"

/*** FILE FORMAT ***/
FILE_RECORDS                  = 12596336
RECORD_TYPE                   = FIXED_LENGTH
RECORD_BYTES                  = 274

/*** GENERAL DATA DESCRIPTION PARAMETERS ***/
PRODUCT_ID                    = "MSGR_DEM_USG_SC_C_V01"
PRODUCT_VERSION_ID            = "1.0"
PRODUCT_CREATION_TIME         = 2014-12-02T19:23:00
PRODUCT_TYPE                  = "DEM"
STANDARD_DATA_PRODUCT_ID      = "JIGSAW_BUNDLE.OUT"
SOFTWARE_NAME                 = "JIGSAW"
SOFTWARE_VERSION_ID           = "2014-02-13"
SOURCE_PRODUCT_ID             = "MSGR_DEM_USG_SC_C_V01.TAB"
POSITIVE_LONGITUDE_DIRECTION = EAST
INSTRUMENT_HOST_NAME          = MESSENGER
INSTRUMENT_NAME               = "MERCURY DUAL IMAGING SYSTEM"
INSTRUMENT_ID                 = "MDIS"
DATA_SET_ID                   = "MESS-H-MDIS-5-DEM-ELEVATION-V1.0"

COORDINATE_SYSTEM_NAME        = PLANETOCENTRIC
COORDINATE_SYSTEM_TYPE        = "BODY-FIXED ROTATING"
TARGET_NAME                   = MERCURY
MISSION_PHASE_NAME            = {"MERCURY ORBIT","MERCURY ORBIT YEAR 2",
                                  "MERCURY ORBIT YEAR 3","MERCURY ORBIT YEAR 4"}
PRODUCER_ID                   = USGS
PRODUCER_FULL_NAME            = "KRIS J. BECKER"
PRODUCER_INSTITUTION_NAME     = "U.S. GEOLOGICAL SURVEY"
START_TIME                    = 2011-03-18T00:00:00
```

```
STOP_TIME                    = 2014-11-01T00:00:00
SPACECRAFT_CLOCK_START_COUNT = "N/A"
SPACECRAFT_CLOCK_STOP_COUNT  = "N/A"

^TABLE = "MSGR_DEM_USG_SC_C_V01.TAB"
OBJECT                       = TABLE
 COLUMNS                       = 17
 INTERCHANGE_FORMAT            = ASCII
 ROW_BYTES                     = 274
 ROWS                          = 12596336
 DESCRIPTION                   = "This table contains the jigsaw bundle.out
    data file. It contains the set of body fixed X,Y,Z coordinates."
 ^STRUCTURE                    = "POINTCLOUDTAB.FMT"
END_OBJECT                    = TABLE
END
```

6.1.4.1 Point Cloud Table Format Description

```
OBJECT = COLUMN
  COLUMN_NUMBER = 1
  NAME          = POINT_ID
  DATA_TYPE     = CHARACTER
  UNIT          = NONE
  START_BYTE    = 2
  BYTES         = 32
  DESCRIPTION   = "Unique point identifier for each jigsaw control point."
END_OBJECT = COLUMN

OBJECT = COLUMN
  COLUMN_NUMBER = 2
  NAME          = STATUS
  DATA_TYPE     = CHARACTER
  UNIT          = NONE
  START_BYTE    = 37
  BYTES         = 12
  DESCRIPTION   = "Status of point.  It can be FREE, FIXED or CONSTRAINED."
END_OBJECT = COLUMN

OBJECT = COLUMN
  COLUMN_NUMBER = 3
  NAME          = ACCEPTED_MEASURES
  DATA_TYPE     = ASCII_INTEGER
  UNIT          = NONE
  START_BYTE    = 51
  BYTES         = 4
  DESCRIPTION   = "Number of accepted (non-rejected) measures for the control
                   point. This is actually the number of images that contain
                   the control point (also referred to as the point depth)."
END_OBJECT = COLUMN

OBJECT = COLUMN
  COLUMN_NUMBER = 4
  NAME          = REJECTED_MEASURES
  DATA_TYPE     = ASCII_INTEGER
  UNIT          = NONE
  START_BYTE    = 56
  BYTES         = 4
  DESCRIPTION   = "Number of measures rejected by jigsaw during the bundle
                   adjustment (if outlier rejection is active)"
END_OBJECT = COLUMN

OBJECT = COLUMN
  COLUMN_NUMBER = 5
  NAME          = RESIDUAL_RMS
  DATA_TYPE     = ASCII_REAL
```

```
  UNIT          = PIXELS
  START_BYTE    = 61
  BYTES         = 8
  DESCRIPTION   = "Root mean square error of residuals for a point.
                   Indicates the statistical measure of variation in the
                   difference of each measure within a control point."
END_OBJECT = COLUMN

OBJECT = COLUMN
  COLUMN_NUMBER = 6
  NAME          = ADJUSTED_LATITUDE
  DATA_TYPE     = ASCII_REAL
  UNIT          = DEGREES
  START_BYTE    = 70
  BYTES         = 16
  DESCRIPTION   = "Latitude coordinate of the control point. This is the
                   adjusted location of the control point after jigsaw bundle
                   adjustment."
END_OBJECT = COLUMN

OBJECT = COLUMN
  COLUMN_NUMBER = 7
  NAME          = ADJUSTED_LONGITUDE
  DATA_TYPE     = ASCII_REAL
  UNIT          = DEGREES
  START_BYTE    = 87
  BYTES         = 16
  DESCRIPTION   = "Longitude coordinate of control point. This is the
                   adjusted location of the control point after jigsaw bundle
                   adjustment."
END_OBJECT = COLUMN

OBJECT = COLUMN
  COLUMN_NUMBER = 8
  NAME          = ADJUSTED_RADIUS
  DATA_TYPE     = ASCII_REAL
  UNIT          = KILOMETERS
  START_BYTE    = 104
  BYTES         = 16
  DESCRIPTION   = "Radius of control point. This is the adjusted radius of
                   the control point after jigsaw bundle adjustment."
END_OBJECT = COLUMN

OBJECT = COLUMN
  COLUMN_NUMBER = 9
  NAME          = SIGMA_LATITUDE
  DATA_TYPE     = ASCII_REAL
  UNIT          = METERS
  START_BYTE    = 121
  BYTES         = 16
  DESCRIPTION   = "Adjusted uncertainty of Latitude coordinate of the control
                   point after jigsaw bundle adjustment."
END_OBJECT = COLUMN

OBJECT = COLUMN
  COLUMN_NUMBER = 10
  NAME          = SIGMA_LONGITUDE
  DATA_TYPE     = ASCII_REAL
  UNIT          = METERS
  START_BYTE    = 138
  BYTES         = 16
  DESCRIPTION   = "Adjusted uncertainty of Longitude coordinate of the
                   control point after jigsaw bundle adjustment."
END_OBJECT = COLUMN
```

```
OBJECT = COLUMN
  COLUMN_NUMBER = 11
  NAME          = SIGMA_RADIUS
  DATA_TYPE     = ASCII_REAL
  UNIT          = METERS
  START_BYTE    = 155
  BYTES         = 16
  DESCRIPTION   = "Adjusted uncertainty of Radius coordinate of the control
                   point after jigsaw bundle adjustment."
END_OBJECT = COLUMN

OBJECT = COLUMN
  COLUMN_NUMBER = 12
  NAME          = DELTA_LATITUDE
  DATA_TYPE     = ASCII_REAL
  UNIT          = METERS
  START_BYTE    = 172
  BYTES         = 16
  DESCRIPTION   = "Latitude adjustment. The number of meters the latitude
                   coordinate has been adjusted by the jigsaw bundle
                   adjustment."
END_OBJECT = COLUMN

OBJECT = COLUMN
  COLUMN_NUMBER = 13
  NAME          = DELTA_LONGITUDE
  DATA_TYPE     = ASCII_REAL
  UNIT          = METERS
  START_BYTE    = 189
  BYTES         = 16
  DESCRIPTION   = "Longitude adjustment. The number of meters the longitude
                   coordinate has been adjusted by the jigsaw bundle
                   adjustment."
END_OBJECT = COLUMN

OBJECT = COLUMN
  COLUMN_NUMBER = 14
  NAME          = DELTA_RADIUS
  DATA_TYPE     = ASCII_REAL
  UNIT          = METERS
  START_BYTE    = 206
  BYTES         = 16
  DESCRIPTION   = "Radius adjustment. The number of meters the radius has
                   been adjusted by the jigsaw bundle adjustment."
END_OBJECT = COLUMN

OBJECT = COLUMN
  COLUMN_NUMBER = 15
  NAME          = X
  DATA_TYPE     = ASCII_REAL
  UNIT          = KILOMETERS
  START_BYTE    = 223
  BYTES         = 16
  DESCRIPTION   = "Body-fixed X coordinate of the vector from the center of
                   the target body to the surface coordinate location."
END_OBJECT = COLUMN

OBJECT = COLUMN
  COLUMN_NUMBER = 16
  NAME          = Y
  DATA_TYPE     = ASCII_REAL
  UNIT          = KILOMETERS
  START_BYTE    = 240
  BYTES         = 16
  DESCRIPTION   = "Body-fixed Y coordinate of the vector from the center of
```

```
                    the target body to the surface coordinate location."
END_OBJECT = COLUMN

OBJECT = COLUMN
  COLUMN_NUMBER = 17
  NAME          = Z
  DATA_TYPE     = ASCII_REAL
  UNIT          = KILOMETERS
  START_BYTE    = 257
  BYTES         = 16
  DESCRIPTION   = "Body-fixed Z coordinate of the vector from the center of
                    the target body to the surface coordinate location."
END_OBJECT = COLUMN
END
```

6.1.5 USGS Polar DEM (IMG) PDS Label

```
PDS_VERSION_ID = PDS3

/*   File Format   */

RECORD_TYPE        = FIXED_LENGTH
RECORD_BYTES       = 9250
FILE_RECORDS       = 4625
INTERCHANGE_FORMAT = BINARY

/*    Pointers    */

^IMAGE             = "MSGR_DEM_USG_NP_I_V01.IMG"

/*    Image and parameter description     */

DATA_SET_ID                    = "MESS-H-MDIS-5-DEM-ELEVATION-V1.0"
PRODUCT_ID                     = "MSGR_DEM_USG_NP_I_V01"
PRODUCER_FULL_NAME             = "KRIS J. BECKER"
PRODUCER_ID                    = USGS
PRODUCER_INSTITUTION_NAME      = "U.S. GEOLOGICAL SURVEY"
PRODUCT_VERSION_ID             = "1"
PRODUCT_TYPE                   = DEM
MISSION_NAME                   = MESSENGER
SPACECRAFT_NAME                = MESSENGER
INSTRUMENT_HOST_NAME           = MESSENGER
INSTRUMENT_NAME                = ("MERCURY DUAL IMAGING SYSTEM NARROW ANGLE
                                 CAMERA", "MERCURY DUAL IMAGING SYSTEM WIDE
                                 ANGLE CAMERA")
INSTRUMENT_ID                  = ("MDIS NAC","MDIS WAC")
TARGET_NAME                    = MERCURY
MISSION_PHASE_NAME             = {"MERCURY ORBIT","MERCURY ORBIT YEAR 2",
                                 "MERCURY ORBIT YEAR 3","MERCURY ORBIT YEAR 4"}
START_TIME                     = 2011-03-18T00:00:00
STOP_TIME                      = 2014-11-01T00:00:00
SPACECRAFT_CLOCK_START_COUNT   = "N/A"
SPACECRAFT_CLOCK_STOP_COUNT    = "N/A"
SOFTWARE_NAME                  = ISIS
SOFTWARE_VERSION_ID            = "3.4.11"
PRODUCT_CREATION_TIME          = 2016-02-08T12:00:00
NOTE                           = "Mercury MESSENGER MDIS Digital Elevation
Model (DEM). With OFFSET and SCALING_FACTOR applied, DN scaled units are
Meters (relative to 2439.4 kilometer datum). Polar Stereographic projection,
north polar region."

OBJECT = IMAGE
  LINES                      = 4625
  LINE_SAMPLES               = 4625
  BANDS                      = 1
  BAND_STORAGE_TYPE          = BAND_SEQUENTIAL
  UNIT                       = METER
  MINIMUM                    = -4177.5
  MAXIMUM                    = 2934.0
  OFFSET                     = 0.0
  SCALING_FACTOR             = 0.5
```

```
  SAMPLE_BITS                = 16
  SAMPLE_BIT_MASK            = 2#1111111111111111#
  SAMPLE_TYPE                = LSB_INTEGER
  MISSING_CONSTANT           = -32768
END_OBJECT = IMAGE

OBJECT = IMAGE_MAP_PROJECTION
  ^DATA_SET_MAP_PROJECTION     = "DEM_POLAR_MAP.CAT"
  MAP_PROJECTION_TYPE          = "POLAR STEREOGRAPHIC"
  COORDINATE_SYSTEM_TYPE       = "BODY-FIXED ROTATING"
  COORDINATE_SYSTEM_NAME       = PLANETOCENTRIC
  A_AXIS_RADIUS                = 2439.4 <km>
  B_AXIS_RADIUS                = 2439.4 <km>
  C_AXIS_RADIUS                = 2439.4 <km>
  POSITIVE_LONGITUDE_DIRECTION = EAST
  CENTER_LATITUDE              = 90.0 <deg>
  CENTER_LONGITUDE             = 0.0 <deg>
  LINE_FIRST_PIXEL             = 1
  LINE_LAST_PIXEL              = 4625
  SAMPLE_FIRST_PIXEL           = 1
  SAMPLE_LAST_PIXEL            = 4625
  MAP_PROJECTION_ROTATION      = 0.0 <deg>
  MAP_RESOLUTION               = 64.0 <pix/deg>
  MAP_SCALE                    = 0.66524315270546 <km/pixel>
  MAXIMUM_LATITUDE             = 90.0 <deg>
  MINIMUM_LATITUDE             = 55.0 <deg>
  EASTERNMOST_LONGITUDE        = 360.0 <deg>
  WESTERNMOST_LONGITUDE        = 0.0 <deg>
  LINE_PROJECTION_OFFSET       = 2312.5 <pixel>
  SAMPLE_PROJECTION_OFFSET     = 2312.5 <pixel>
END_OBJECT = IMAGE_MAP_PROJECTION
END
```

6.1.6 DLR Regional DEM (IMG) PDS Label

```
PDS_VERSION_ID                 = PDS3

/* FILE DATA ELEMENTS */

RECORD_TYPE                    = FIXED_LENGTH
RECORD_BYTES                   = 27650
FILE_RECORDS                   = 8643
INTERCHANGE_FORMAT             = BINARY

/* POINTERS TO DATA OBJECTS */

^IMAGE                         = "MSGR_DEM_DLR_SC_H06_DM_222_I_V02.IMG"

/*    Image and parameter description     */

DATA_SET_ID                    = "MESS-H-MDIS-5-DEM-ELEVATION-V1.0"
PRODUCT_ID                     = "MSGR_DEM_DLR_SC_H06_DM_222_I_V02"
ORIGINAL_PRODUCT_ID            = "MERCURY-H06.SPG.192PPD.2015_12.001.01P"
PRODUCT_VERSION_ID             = "2"
PRODUCT_TYPE                   = DEM
PRODUCER_ID                    = DLR
PRODUCER_INSTITUTION_NAME      = "GERMAN AEROSPACE CENTER (DLR)"
PRODUCER_FULL_NAME             = "FRANK PREUSKER"
MISSION_NAME                   = MESSENGER
SPACECRAFT_NAME                = MESSENGER
INSTRUMENT_HOST_NAME           = MESSENGER
INSTRUMENT_NAME                = {"MERCURY DUAL IMAGING SYSTEM NARROW ANGLE
                                 CAMERA","MERCURY DUAL IMAGING SYSTEM WIDE
                                 ANGLE CAMERA"}
INSTRUMENT_ID                  = {"MDIS-NAC","MDIS-WAC"}
MISSION_PHASE_NAME             = {"MERCURY ORBIT","MERCURY ORBIT YEAR 2",
                                "MERCURY ORBIT YEAR 3","MERCURY ORBIT YEAR 4"}
TARGET_NAME                    = MERCURY
START_TIME                     = "N/A"
STOP_TIME                      = "N/A"
SPACECRAFT_CLOCK_START_COUNT   = "N/A"
```

```
SPACECRAFT_CLOCK_STOP_COUNT    = "N/A"
SOFTWARE_NAME                  = "N/A"
SOFTWARE_VERSION_ID            = "N/A"
PRODUCT_CREATION_TIME          = 2016-02-08T18:14:00

DESCRIPTION                    = "Mercury MESSENGER MDIS Digital Elevation
Model (DEM), simple cylindrical projection, quadrangle product."

NOTE                           = "DTM: Height [m] equals DN. Vertical
reference: Height above sphere/ellipsoid (as defined by map axis)."

/* DATA OBJECT DEFINITIONS */

OBJECT                           = IMAGE
  INTERCHANGE_FORMAT             = BINARY
  LINES                          = 8641
  LINE_SAMPLES                   = 13825
  OFFSET                         = 0.0
  SCALING_FACTOR                 = 1.0
  SAMPLE_TYPE                    = LSB_INTEGER
  SAMPLE_BITS                    = 16
  BANDS                          = 1
  BAND_STORAGE_TYPE              = BAND_SEQUENTIAL
  MINIMUM                        = -3733
  MAXIMUM                        = 5310
  UNIT                           = METER
  MISSING_CONSTANT               = -32768
END_OBJECT                       = IMAGE

/* MAP OBJECT DEFINITIONS */

OBJECT                           = IMAGE_MAP_PROJECTION
  ^DATA_SET_MAP_PROJECTION       = "DEM_EQU_MAP.CAT"
  MAP_PROJECTION_TYPE            = "SIMPLE CYLINDRICAL"
  COORDINATE_SYSTEM_TYPE         = "BODY-FIXED ROTATING"
  COORDINATE_SYSTEM_NAME         = PLANETOCENTRIC
  A_AXIS_RADIUS                  = 2439.4 <km>
  B_AXIS_RADIUS                  = 2439.4 <km>
  C_AXIS_RADIUS                  = 2439.4 <km>
  CENTER_LATITUDE                = 0.0 <deg>
  CENTER_LONGITUDE               = 324.0 <deg>
  EASTERNMOST_LONGITUDE          = 0.0 <deg>
  WESTERNMOST_LONGITUDE          = -72.0 <deg>
  LINE_FIRST_PIXEL               = 1
  LINE_LAST_PIXEL                = 8641
  SAMPLE_FIRST_PIXEL             = 1
  SAMPLE_LAST_PIXEL              = 13825
  LINE_PROJECTION_OFFSET         = 4320.0
  MAP_PROJECTION_ROTATION        = 0.0 <deg>
  MAP_RESOLUTION                 = 192.0 <pix/deg>
  MAP_SCALE                      = 0.22174771757 <km/pixel>
  MAXIMUM_LATITUDE               = 22.5 <deg>
  MINIMUM_LATITUDE               = -22.5 <deg>
  POSITIVE_LONGITUDE_DIRECTION   = EAST
  SAMPLE_PROJECTION_OFFSET       = 6912.0
END_OBJECT                       = IMAGE_MAP_PROJECTION

END
```

6.1.7 DLR Regional DEM (JPEG 2000) PDS Label

```
PDS_VERSION_ID                 = PDS3

/*    Image and parameter description     */

DATA_SET_ID                    = "MESS-H-MDIS-5-DEM-ELEVATION-V1.0"
PRODUCT_ID                     = "MSGR_DEM_DLR_SC_H06_DM_222_J_V02"
ORIGINAL_PRODUCT_ID            = "MERCURY-H06.192PPD.EQUIDISTANT.V01.00"
PRODUCT_VERSION_ID             = "2"
PRODUCT_TYPE                   = DEM
PRODUCER_ID                    = DLR
PRODUCER_INSTITUTION_NAME      = "GERMAN AEROSPACE CENTER (DLR)"
```

```
PRODUCER_FULL_NAME              = "FRANK PREUSKER"
MISSION_NAME                    = MESSENGER
SPACECRAFT_NAME                 = MESSENGER
INSTRUMENT_HOST_NAME            = MESSENGER
INSTRUMENT_NAME                 = {"MERCURY DUAL IMAGING SYSTEM NARROW ANGLE
                                  CAMERA","MERCURY DUAL IMAGING SYSTEM WIDE
                                  ANGLE CAMERA"}
INSTRUMENT_ID                   = {"MDIS-NAC","MDIS-WAC"}
MISSION_PHASE_NAME              = {"MERCURY ORBIT","MERCURY ORBIT YEAR 2",
                                 "MERCURY ORBIT YEAR 3","MERCURY ORBIT YEAR 4"}
TARGET_NAME                     = MERCURY
START_TIME                      = "N/A"
STOP_TIME                       = "N/A"
SPACECRAFT_CLOCK_START_COUNT    = "N/A"
SPACECRAFT_CLOCK_STOP_COUNT     = "N/A"
SOFTWARE_NAME                   = "N/A"
SOFTWARE_VERSION_ID             = "N/A"
PRODUCT_CREATION_TIME           = 2017-03-03T00:00:00
RATIONALE_DESC                  = "The JPEG2000 image associated with this
label is provided as a supplement to the 16-bit primary data product
(MSGR_DEM_DLR_SC_H06_DM_222_I_V02.IMG)"
NOTE                            = "PDS label for 16-bit (signed) JPEG2000
image."

/* The JPEG2000 image data file associated with this label. */
OBJECT = COMPRESSED_FILE
    FILE_NAME                   = "MSGR_DEM_DLR_SC_H06_DM_222_J_V02.JP2"
/* NOTE: JPEG2000 DN units are Meters (relative to 2439.4 kilometer datum) */
/* Also see original image DN units below in UNCOMPRESSED_FILE group    */
    RECORD_TYPE                 = UNDEFINED
    ENCODING_TYPE               = "JP2"
    FILE_RECORDS                = 8641
    INTERCHANGE_FORMAT          = BINARY

    /* The name of the original source file. */
    UNCOMPRESSED_FILE_NAME      = "MSGR_DEM_DLR_SC_H06_DM_222_I_V02.IMG"
    /* The amount of original image data. */
    REQUIRED_STORAGE_BYTES      = "34288423"
    ^DESCRIPTION                = "JP2INFO.TXT"
    SAMPLE_TYPE                 = MSB_INTEGER
    SAMPLE_BITS                 = 16
END_OBJECT = COMPRESSED_FILE

/* The source image data definition. */
/* Note: The values of the FILE_NAME and ^IMAGE fields in the               */
/* UNCOMPRESSED_FILE object contain the name of a hypothetical file that    */
/* could be created by decompressing the JP2 product, but that does not     */
/* actually exist in the archive volume. These fields are here to comply    */
/* with PDS 3 standards.                                                    */
OBJECT = UNCOMPRESSED_FILE
    FILE_NAME    = "MSGR_DEM_DLR_SC_H06_DM_222_J_V02.IMG"
    RECORD_TYPE  = FIXED_LENGTH
    RECORD_BYTES = 27650
    FILE_RECORDS = 8643
    ^IMAGE       = "MSGR_DEM_DLR_SC_H06_DM_222_J_V02.IMG"
    OBJECT = IMAGE
        LINES                     = 8641
        LINE_SAMPLES              = 13825
        BANDS                     = 1
        BAND_STORAGE_TYPE         = BAND_SEQUENTIAL
        /* NOTE: DN units are Meters (surface elevation at each pixel) */
        /* With SCALING_FACTOR = 1, and OFFSET = 0                     */
        OFFSET                    = 0.0
        SCALING_FACTOR            = 1.0
        SAMPLE_BITS               = 16
        SAMPLE_BIT_MASK           = 2#1111111111111111#
        SAMPLE_TYPE               = MSB_INTEGER
        MISSING_CONSTANT          = -32768
        MINIMUM                   = -3733
        MAXIMUM                   = 5310
        UNIT                      = METER
    END_OBJECT = IMAGE
END_OBJECT = UNCOMPRESSED_FILE
```

```
OBJECT                            = IMAGE_MAP_PROJECTION
  ^DATA_SET_MAP_PROJECTION        = "DEM_EQU_MAP.CAT"
  MAP_PROJECTION_TYPE             = "SIMPLE CYLINDRICAL"
  COORDINATE_SYSTEM_TYPE          = "BODY-FIXED ROTATING"
  COORDINATE_SYSTEM_NAME          = PLANETOCENTRIC
  A_AXIS_RADIUS                   = 2439.4 <km>
  B_AXIS_RADIUS                   = 2439.4 <km>
  C_AXIS_RADIUS                   = 2439.4 <km>
  CENTER_LATITUDE                 = 0.0 <deg>
  CENTER_LONGITUDE                = 324.0 <deg>
  EASTERNMOST_LONGITUDE           = 0.0 <deg>
  WESTERNMOST_LONGITUDE           = -72.0 <deg>
  LINE_FIRST_PIXEL                = 1
  LINE_LAST_PIXEL                 = 8641
  SAMPLE_FIRST_PIXEL              = 1
  SAMPLE_LAST_PIXEL                = 13825
  LINE_PROJECTION_OFFSET          = 4320.0
  MAP_PROJECTION_ROTATION         = 0.0 <deg>
  MAP_RESOLUTION                  = 192.0 <pix/deg>
  MAP_SCALE                       = 0.22174771757 <km/pixel>
  MAXIMUM_LATITUDE                = 22.5 <deg>
  MINIMUM_LATITUDE                = -22.5 <deg>
  POSITIVE_LONGITUDE_DIRECTION    = EAST
  SAMPLE_PROJECTION_OFFSET        = 6912.0
END_OBJECT                        = IMAGE_MAP_PROJECTION

END
```

6.1.8 ASU Regional DEM (IMG) PDS Label

```
PDS_VERSION_ID            = PDS3

/* The source image data definition. */
RECORD_TYPE   = FIXED_LENGTH
RECORD_BYTES  = 1568
FILE_RECORDS  = 407
^IMAGE        = "MSGR_DEM_ASU_EQ_CATLS01_DM_85_I_V01.IMG"

/* Identification Information  */
DATA_SET_ID               = "MESS-H-MDIS-5-DEM-ELEVATION-V1.0"
DATA_SET_NAME             = "MESSENGER MERCURY MDIS LEVEL 5 DEM V1.0"
PRODUCER_INSTITUTION_NAME = "ARIZONA STATE UNIVERSITY"
PRODUCER_ID               = "ASU"
PRODUCER_FULL_NAME        = "MARK ROBINSON, PH.D"
PRODUCT_ID                = "MSGR_DEM_ASU_EQ_CATLS01_DM_85_I_V01"
PRODUCT_VERSION_ID        = "1"
PRODUCT_TYPE              = DEM
INSTRUMENT_HOST_NAME      = MESSENGER
INSTRUMENT_NAME           = "MERCURY DUAL IMAGING SYSTEM NARROW ANGLE CAMERA"
INSTRUMENT_ID             = "MDIS-NAC"
TARGET_NAME               = MERCURY
RATIONALE_DESC            = "Created to examine local topographic features of
                            Mercury"
SOFTWARE_NAME             = {"ISIS","SOCET SET"}

/* Time Parameters */
START_TIME                   = "N/A"
STOP_TIME                    = "N/A"
SPACECRAFT_CLOCK_START_COUNT = "N/A"
SPACECRAFT_CLOCK_STOP_COUNT  = "N/A"
PRODUCT_CREATION_TIME        = 2016-03-26T00:52:01

/* NOTE:                                                                  */
/* This raster image is composed of a set of pixels that represent finite  */
/* areas, and not discrete points.  The center of the upper left pixel is  */
/* defined as line and sample (1.0,1.0). The                               */
/* [LINE,SAMPLE]_PROJECTION_OFFSET elements are the pixel offset from line */
/* and sample (1.0,1.0) to the map projection origin (defined by the       */
/* CENTER_LATITUDE and CENTER_LONGITUDE elements).  These offset values    */
/* are positive when the map projection origin is to the right or below    */
```

```
/* the center of the upper left pixel. This definition was adopted in      */
/* November 2011 by the LROC team.                                          */

OBJECT = IMAGE_MAP_PROJECTION
    ^DATA_SET_MAP_PROJECTION = "DEM_EQU_MAP.CAT"
    MAP_PROJECTION_TYPE          = EQUIRECTANGULAR
    A_AXIS_RADIUS                = 2439.4 <km>
    B_AXIS_RADIUS                = 2439.4 <km>
    C_AXIS_RADIUS                = 2439.4 <km>
    COORDINATE_SYSTEM_NAME       = PLANETOCENTRIC
    COORDINATE_SYSTEM_TYPE       = "BODY-FIXED ROTATING"
    POSITIVE_LONGITUDE_DIRECTION = EAST
    /* NOTE:  CENTER_LATITUDE and CENTER_LONGITUDE describe the location   */
    /* of the center of projection, which is not necessarily equal to the  */
    /* location of the center point of the image.                          */
    CENTER_LATITUDE              = 21.884519 <deg>
    CENTER_LONGITUDE             = 180.0 <deg>
    LINE_FIRST_PIXEL             = 1
    LINE_LAST_PIXEL              = 404
    SAMPLE_FIRST_PIXEL           = 1
    SAMPLE_LAST_PIXEL            = 392
    MAP_PROJECTION_ROTATION      = 0.0 <deg>
    MAP_RESOLUTION               = 500.951 <pix/deg>
    MAP_SCALE                    = 0.08500000000051 <km/pixel>
    MAXIMUM_LATITUDE             = 22.28862656 <deg>
    MINIMUM_LATITUDE             = 21.48215976 <deg>
    EASTERNMOST_LONGITUDE        = 292.97093173 <deg>
    WESTERNMOST_LONGITUDE        = 292.12764997 <deg>
    LINE_PROJECTION_OFFSET       = 11165.0 <pixel>
    SAMPLE_PROJECTION_OFFSET     = -52123.1 <pixel>
END_OBJECT = IMAGE_MAP_PROJECTION

OBJECT = IMAGE
    DESCRIPTION                = "MDIS digital terrain models of high-priority
                                 targets"

    LINES                      = 404
    LINE_SAMPLES               = 392
    SAMPLE_TYPE                = PC_REAL
    SAMPLE_BITS                = 32
    SAMPLE_BIT_MASK            = 2#11111111111111111111111111111111#
    MISSING_CONSTANT           = -3.40282265508890445E+38
    MINIMUM                    = -2.6863979492 <km>
    MAXIMUM                    = .11963431549 <km>

    BAND_STORAGE_TYPE          = BAND_SEQUENTIAL
    BANDS                      = 1

END_OBJECT = IMAGE
END
```

6.1.9 ASU Regional Confidence Map (IMG) PDS Label

```
PDS_VERSION_ID            = PDS3

/* The source image data definition. */
RECORD_TYPE   = FIXED_LENGTH
RECORD_BYTES  = 392
FILE_RECORDS  = 415
^IMAGE        = "MSGR_DEM_ASU_EQ_CATLS01_CF_85_I_V01.IMG"

/* Identification Information  */
DATA_SET_ID               = "MESS-H-MDIS-5-DEM-ELEVATION-V1.0"
DATA_SET_NAME             = "MESSENGER MERCURY MDIS LEVEL 5 DEM V1.0"
PRODUCER_INSTITUTION_NAME = "ARIZONA STATE UNIVERSITY"
PRODUCER_ID               = "ASU"
PRODUCER_FULL_NAME        = "MARK ROBINSON, PH.D"
PRODUCT_ID                = "MSGR_DEM_ASU_EQ_CATLS01_CF_85_I_V01"
PRODUCT_VERSION_ID        = "1"
PRODUCT_TYPE              = DEM
```

```
INSTRUMENT_HOST_NAME      = MESSENGER
INSTRUMENT_NAME           = "MERCURY DUAL IMAGING SYSTEM NARROW ANGLE CAMERA"
INSTRUMENT_ID             = "MDIS-NAC"
TARGET_NAME               = MERCURY
RATIONALE_DESC            = "Created to examine local topographic features of
                            Mercury"
SOFTWARE_NAME             = {"ISIS","SOCET SET"}

/* Time Parameters */
START_TIME                   = "N/A"
STOP_TIME                    = "N/A"
SPACECRAFT_CLOCK_START_COUNT = "N/A"
SPACECRAFT_CLOCK_STOP_COUNT  = "N/A"
PRODUCT_CREATION_TIME        = 2016-03-26T00:52:02

/* NOTE:                                                                  */
/* This raster image is composed of a set of pixels that represent finite  */
/* areas, and not discrete points.  The center of the upper left pixel is  */
/* defined as line and sample (1.0,1.0). The                               */
/* [LINE,SAMPLE]_PROJECTION_OFFSET elements are the pixel offset from line */
/* and sample (1.0,1.0) to the map projection origin (defined by the       */
/* CENTER_LATITUDE and CENTER_LONGITUDE elements).  These offset values    */
/* are positive when the map projection origin is to the right or below    */
/* the center of the upper left pixel. This definition was adopted in      */
/* November 2011 by the LROC team.                                         */

OBJECT = IMAGE_MAP_PROJECTION
    ^DATA_SET_MAP_PROJECTION     = "DEM_EQU_MAP.CAT"
    MAP_PROJECTION_TYPE          = EQUIRECTANGULAR
    A_AXIS_RADIUS                = 2439.4 <km>
    B_AXIS_RADIUS                = 2439.4 <km>
    C_AXIS_RADIUS                = 2439.4 <km>
    COORDINATE_SYSTEM_NAME       = PLANETOCENTRIC
    COORDINATE_SYSTEM_TYPE       = "BODY-FIXED ROTATING"
    POSITIVE_LONGITUDE_DIRECTION = EAST
    /* NOTE:  CENTER_LATITUDE and CENTER_LONGITUDE describe the location   */
    /* of the center of projection, which is not necessarily equal to the  */
    /* location of the center point of the image.                          */
    CENTER_LATITUDE              = 21.884519 <deg>
    CENTER_LONGITUDE             = 180.0 <deg>
    LINE_FIRST_PIXEL             = 1
    LINE_LAST_PIXEL              = 404
    SAMPLE_FIRST_PIXEL           = 1
    SAMPLE_LAST_PIXEL            = 392
    MAP_PROJECTION_ROTATION      = 0.0 <deg>
    MAP_RESOLUTION               = 500.951 <pix/deg>
    MAP_SCALE                    = 0.08500000000051 <km/pixel>
    MAXIMUM_LATITUDE             = 22.28862656 <deg>
    MINIMUM_LATITUDE             = 21.48215976 <deg>
    EASTERNMOST_LONGITUDE        = 292.97093173 <deg>
    WESTERNMOST_LONGITUDE        = 292.12764997 <deg>
    LINE_PROJECTION_OFFSET       = 11165.0 <pixel>
    SAMPLE_PROJECTION_OFFSET     = -52123.1 <pixel>
END_OBJECT = IMAGE_MAP_PROJECTION

OBJECT = IMAGE
    DESCRIPTION                = "MDIS digital terrain models of high-priority
                                 targets"

    LINES                      = 404
    LINE_SAMPLES               = 392
    SAMPLE_TYPE                = MSB_UNSIGNED_INTEGER
    SAMPLE_BITS                = 8
    SAMPLE_BIT_MASK            = 2#11111111#
    MISSING_CONSTANT           = 0

    BAND_STORAGE_TYPE          = BAND_SEQUENTIAL
    BANDS                      = 1

END_OBJECT = IMAGE
END
```

6.1.10 ASU Regional Orthorectified Image (IMG) PDS Label

```
PDS_VERSION_ID            = PDS3

/* The source image data definition. */
RECORD_TYPE   = FIXED_LENGTH
RECORD_BYTES  = 2468
FILE_RECORDS  = 1274
^IMAGE        = "MSGR_DEM_ASU_EQ_CATLS01_OR_27_I_V01.IMG"

/* Identification Information  */
DATA_SET_ID               = "MESS-H-MDIS-5-DEM-ELEVATION-V1.0"
DATA_SET_NAME             = "MESSENGER MERCURY MDIS LEVEL 5 DEM V1.0"
PRODUCER_INSTITUTION_NAME = "ARIZONA STATE UNIVERSITY"
PRODUCER_ID               = "ASU"
PRODUCER_FULL_NAME        = "MARK ROBINSON, PH.D"
PRODUCT_ID                = "MSGR_DEM_ASU_EQ_CATLS01_OR_27_I_V01"
PRODUCT_VERSION_ID        = "1"
PRODUCT_TYPE              = DEM
INSTRUMENT_HOST_NAME      = MESSENGER
INSTRUMENT_NAME           = "MERCURY DUAL IMAGING SYSTEM NARROW ANGLE CAMERA"
INSTRUMENT_ID             = "MDIS-NAC"
TARGET_NAME               = MERCURY
RATIONALE_DESC            = "Created to examine local topographic features of
                            Mercury"
SOFTWARE_NAME             = {"ISIS","SOCET SET"}

/* Time Parameters */
START_TIME                   = "N/A"
STOP_TIME                    = "N/A"
SPACECRAFT_CLOCK_START_COUNT = "N/A"
SPACECRAFT_CLOCK_STOP_COUNT  = "N/A"
PRODUCT_CREATION_TIME        = 2016-03-26T00:52:07

/* NOTE:                                                                  */
/* This raster image is composed of a set of pixels that represent finite  */
/* areas, and not discrete points.  The center of the upper left pixel is  */
/* defined as line and sample (1.0,1.0). The                              */
/* [LINE,SAMPLE]_PROJECTION_OFFSET elements are the pixel offset from line */
/* and sample (1.0,1.0) to the map projection origin (defined by the      */
/* CENTER_LATITUDE and CENTER_LONGITUDE elements).  These offset values    */
/* are positive when the map projection origin is to the right or below    */
/* the center of the upper left pixel. This definition was adopted in      */
/* November 2011 by the LROC team.                                        */

OBJECT = IMAGE_MAP_PROJECTION
    ^DATA_SET_MAP_PROJECTION     = "DEM_EQU_MAP.CAT"
    MAP_PROJECTION_TYPE          = EQUIRECTANGULAR
    A_AXIS_RADIUS                = 2439.4 <km>
    B_AXIS_RADIUS                = 2439.4 <km>
    C_AXIS_RADIUS                = 2439.4 <km>
    COORDINATE_SYSTEM_NAME       = PLANETOCENTRIC
    COORDINATE_SYSTEM_TYPE       = "BODY-FIXED ROTATING"
    POSITIVE_LONGITUDE_DIRECTION = EAST
    /* NOTE:  CENTER_LATITUDE and CENTER_LONGITUDE describe the location   */
    /* of the center of projection, which is not necessarily equal to the  */
    /* location of the center point of the image.                          */
    CENTER_LATITUDE              = 21.884519 <deg>
    CENTER_LONGITUDE             = 180.0 <deg>
    LINE_FIRST_PIXEL             = 1
    LINE_LAST_PIXEL              = 1272
    SAMPLE_FIRST_PIXEL           = 1
    SAMPLE_LAST_PIXEL            = 1234
    MAP_PROJECTION_ROTATION      = 0.0 <deg>
    MAP_RESOLUTION               = 1577.067 <pix/deg>
    MAP_SCALE                    = 0.026999999999953003 <km/pixel>
    MAXIMUM_LATITUDE             = 22.28862656 <deg>
    MINIMUM_LATITUDE             = 21.48206582 <deg>
    EASTERNMOST_LONGITUDE        = 292.97088111 <deg>
    WESTERNMOST_LONGITUDE        = 292.12764997 <deg>
    LINE_PROJECTION_OFFSET       = 35150.1 <pixel>
    SAMPLE_PROJECTION_OFFSET     = -164090.2 <pixel>
END_OBJECT = IMAGE_MAP_PROJECTION
```

```
OBJECT = IMAGE
    DESCRIPTION                 = "MDIS digital terrain models of high-priority
                                  targets"

    LINES                       = 1272
    LINE_SAMPLES                = 1234
    SAMPLE_TYPE                 = LSB_UNSIGNED_INTEGER
    SAMPLE_BITS                 = 16
    SAMPLE_BIT_MASK             = 2#111111111111111#
    MISSING_CONSTANT            = 0

    BAND_STORAGE_TYPE           = BAND_SEQUENTIAL
    BANDS                       = 1

END_OBJECT = IMAGE
END
```

6.2 Product Validation

Before PDS release, all DEM products and labels will be validated by the producers with support from the MESSENGER DEM Working Group and the MESSENGER Science Operations Center (SOC) personnel who assemble the archive for delivery.

6.3 Release Plan

DEM products will be delivered to PDS for release to the public according to the delivery schedule in the MESSENGER Data Management and Archiving Plan [2].

7 Appendix - Data Archive Terms

Table 15. Data archive terms.

Archive	An archive consists of one or more data sets along with all the documentation and ancillary information needed to understand and use the data. An archive is a logical construct independent of the medium on which it is stored.
Archive volume, archive volume set	A volume is a unit of medium on which data products are stored; for example, one DVD. An archive volume is a volume containing all or part of an archive; that is, data products plus documentation and ancillary files. When an archive spans multiple volumes, they are called an archive volume set. Usually the documentation and some ancillary files are repeated on each volume of the set, so that a single volume can be used alone.
Calibrated Data Records (CDRs)	Image data calibrated to radiance, or processed further to I/F or I/F corrected to solar illumination angle = 30 degrees, e = 0 degrees (NAC or WAC). CODMAC level 4.
Data Product	A labeled grouping of data resulting from a scientific observation, usually stored in one file. A product label identifies, describes, and defines the structure of the data. An example of a data product is a planetary image, a spectrum table, or a time series table.
Data Set	An accumulation of data products. A data set together with supporting documentation and ancillary files is an archive.
Experiment Data Records (EDRs)	Non-map-projected raw data (NAC or WAC). CODMAC level 2.

8 Appendix - SPICE Kernel Files Used in MESSENGER Data Products

The following SPICE kernel files will be used for initial image

geolocation/registration and to compute any geometric quantities found in the PDS labels. Kernel files will be generated throughout the mission with a file-naming convention specified by the MESSENGER project and archived at the PDS NAIF Node in the MESSSP_1000 archive volume.

***.bsp:**
MESSENGER spacecraft ephemeris file. Also known as the Planetary Spacecraft Ephemeris Kernel (SPK) file.

*.**bc:**
MESSENGER orientation files. These include the spacecraft attitude C-Kernel (CK) files and the MDIS instrument pivot and MDIS instrument attitude history CK files.

***.tf**:

MESSENGER reference frame file. Also known as the Frames Kernel. Contains the MESSENGER spacecraft, science instrument, and communications antennae frame definitions.

***.ti**:

MESSENGER instrument kernels (I-kernel). Contain references to mounting alignment, temperature-dependent focal lengths (MDIS), operation modes, and timing as well as internal and field of view geometry.

***.tsc:**
MESSENGER spacecraft clock coefficients file. Also known as the Spacecraft Clock Kernel (SCLK) file.

***.tpc:**
Planetary constants file. Also known as the Planetary Constants Kernel (PcK) file.

***.tls:**
NAIF leapseconds kernel file. Used in conjunction with the SCLK kernel to convert between Universal Time Coordinated (UTC) and MESSENGER Mission Elapsed Time (MET). Also called the Leap Seconds Kernel (LSK) file.

9 Appendix – PDS Label Keyword Definitions

The definitions of PDS label keywords used in DEM product labels are given below. Not all product labels will contain all of these keywords.

Table 16. PDS label keyword definitions.

Definitions of keywords used in the MESSENGER DEM IMG and JP2000 Labels	
Keyword	Definition

PDS_VERSION_ID	The version number of the PDS standard that is valid when the data product is created. PDS3 is used for MESSENGER Products.
RECORD_TYPE	Designated record type of the file.
RECORD_BYTES	Number of bytes per record.
FILE_RECORDS	Number of records per file.
INTERCHANGE_FORMAT	Indicates if the product ` binary or text data.
^IMAGE_HEADER	(Optional) The location of the image header object within the product file.
^IMAGE	The location of the image object within a file. If the image is the only object in the file, this is just the file name of the image (.IMG) file.
IMAGE_HEADER	Optional object within label
HEADER_TYPE	Indicates the type of header data structure.
IMAGE	Object within label
LINES	Number of image lines (rows) in the image object.
LINE_SAMPLES	Number of samples (columns) per image line. This dimension is the fasted varying dimension of the image array.
BANDS	Number of spectral bands used to create the image.
OFFSET	The value that must be added to the scaled pixel value. See SCALING_FACTOR.
SCALING_FACTOR	The scaling_factor and offset elements provides the constant values by which the stored pixel values are converted to standardized units. Note: The pixel values in the DEM are not scaled.
NOTE	(Optional) Miscellaneous note on the product.
SAMPLE_BITS	Number of bits per sample or pixel.
SAMPLE_BIT_MASK	The sample_bit_mask element identifies the active bits in each sample. Note: In the PDS, the domain of sample_bit_mask is dependent upon the currently described value in the sample_bits element and only applies to integer values.
SAMPLE_TYPE	Data type of the samples in the product (PC_REAL, LSB_INTEGER, MSB_INTEGER, MSB_UNSIGNED_INTEGER, LSB_UNSIGNED_INTEGER.
MISSING_CONSTANT	(Optional) The missing_constant element supplies the numeric value used to signify that no elevation data is contained in the pixel.
CORE_NULL	(Optional) Missing data indicator.
CORE_LOW_REPR_SATURATION	(Optional) Indicates low-end data type saturation.
CORE_HIGH_REPR_SATURATION	(Optional) Indicates high-end data type saturation.
CORE_LOW_INSTR_SATURATION	(Optional) Indicates pixel saturation at low end.
CORE_HIGH_INSTR_SATURATION	(Optional) Indicates pixel saturation at high end.
UNIT	Indicates the units of the sample items.
Identification Information	**Group within label**
DATA_SET_ID	MESS-H-MDIS-5-DEM_ELEVATION-V1.0 The data_set_id element is a unique alphanumeric identifier for a data set or a data product. The data_set_id value for a given data set or product is constructed according to flight project naming conventions. In most cases the data_set_id is an abbreviation of the data_set_name.
PRODUCER_INSTITUTION_NAME	USGS/ASTROGEOLOGY (U.S. Geological Survey (USGS) Astrogeology branch); Institute of Planetary Research, German Aerospace Center (DLR); Arizona State University (ASU) The producer_institution_name element identifies university, research center, NASA center or other institution associated with the production of a data set. This would generally be an institution associated with the element producer_full_name.
PRODUCER_ID	USGS DLR ASU The producer_id element provides a short name or acronym for the producer or producing team/group of a dataset
PRODUCER_FULL_NAME	The producer_full_name element provides the full_name of the individual mainly responsible for the production of a data set.

PRODUCT_ID	The product_id data element represents a permanent, unique identifier assigned to a data product by its producer. Note: In the PDS, the value assigned to product_id must be unique within its data set. Additional note: The product_id can describe the lowest-level data object that has a PDS label.
PRODUCT_VERSION_ID	The product_version_id element identifies the version of an individual product within a data set. Note: This is not the same as the data set version that is an element of the data_set_id value.
INSTRUMENT_HOST_NAME	MESSENGER The instrument_host_name element provides the full name of the host on which an instrument is based. This host can be either a spacecraft or an earth base.
INSTRUMENT_ID	MDIS-NAC and/or MDIS-WAC. The instrument_id element provides an abbreviated name or acronym that identifies an instrument.
TARGET_NAME	MERCURY The target_name element identifies a target. The target may be a planet, satellite, ring, region, feature, asteroid or comet.
SPACECRAFT_NAME	The name of the spacecraft. Always MESSENGER.
START_TIME	The start time of data collection for the product.
STOP_TIME	The end time of data collection for the product.
SPACECRAFT_CLOCK_START_COUNT	The spacecraft MET clock count at start of data collection, including the clock partition.
SPACECRAFT_CLOCK_STOP_COUNT	The spacecraft MET clock count at end of data collection, including the clock partition.
PRODUCT_CREATION_TIME	The time at which this version of the product was created (not the time of data collection).
SOFTWARE_NAME	Name of the software used to create the product.
SOFTWARE_VERSION_ID	Version of the software used in product creation.
DESCRIPTION	Textual description of the product.
RATIONALE_DESC	(Optional) Describes the rationale for performing a particular observation.
IMAGE_MAP_PROJECTION	**Object within label**
^DATA_SET_MAP_PROJECTION	The data_set_map_projection object is one of two distinct objects that define the map projection used in creating the digital images in a PDS data set. The name of other associated object that completes the definition is called IMAGE_MAP_PROJECTION. The map projection information resides in these two objects, essentially to reduce data redundancy and at the same time allow the inclusion of elements needed to process the data at the image level. Static information applicable to the complete data set resides in the DATA_SET_MAP_PROJECTION object, while dynamic information that is applicable to the individual images reside in the IMAGE_MAP_PROJECTION object. The DATA_SET_MAP_PROJECTION object is to be included in an Archive Quality Data Product Label, and used to load the map projection catalog data into a PDS Catalog.
MAP_PROJECTION_TYPE	EQUIRECTANGLAR, POLAR STEROGRAPHIC The map_projection_type element identifies the type of projection characteristic of a given map.

A_AXIS_RADIUS	nnnn.nn <km> The a_axis_radius element provides the value of the semimajor axis of the ellipsoid that defines the approximate shape of a target body. 'A' is usually in the equatorial plane. NOTE: The EQUIRECTANGULAR projection is based on the formula for a sphere. To eliminate confusion in the IMAGE_MAP_PROJECTION object we have set all three radii, A_AXIS_RADIUS, B_AXIS_RADIUS, and C_AXIS_RADIUS to the same number. The value recorded in the three radii is the local radius at the center latitude on Mercury, that is, 2,439.4 kilometers. Using the local radius of the ellipsoid implies that the MAP_SCALE and MAP_RESOLUTION are true at the center latitude.
B_AXIS_RADIUS	nnnn.nn <km> The b_axis_radius element provides the value of the intermediate axis of the ellipsoid that defines the approximate shape of a target body. 'B' is usually in the equatorial plane.
C_AXIS_RADIUS	nnnn.nn <km> The c_axis_radius element provides the value of the semiminor axis of the ellipsoid that defines the approximate shape of a target body. 'C' is normal to the plane defined by 'A' and 'B'.
COORDINATE_SYSTEM_NAME	The coordinate_system_name element provides the full name of the coordinate system to which the state vectors are referenced. PDS has currently defined body-fixed rotating coordinate systems.
POSITIVE_LONGITUDE_DIRECTION	The positive_longitude_direction element identifies the direction of longitude (e.g. EAST, WEST) for a planet. The IAU definition for direction of positive longitude is adopted. Typically, for planets with prograde rotations, positive longitude direction is to the WEST. For planets with retrograde rotations, positive longitude direction is to the EAST. However, the MESSENGER project has adopted the positive EAST longitude system for cartographic products.
CENTER_LATITUDE	The center_latitude element provides a reference latitude of the map projection. The map_scale (or map_resolution) is typically defined at the center_latitude and center_longitude of the map projection.
CENTER_LONGITUDE	The center_longitude element provides a reference longitude for certain map projections. For example, in an Orthographic projection, the center_longitude along with the center_latitude defines the point or tangency between the sphere of the planet and the plane of the projection. The map_scale (or map_resolution) is typically defined at the center_latitude and center_longitude. In unprojected images, center_longitude represents the longitude at the center of the image frame.
LINE_FIRST_PIXEL	The line_first_pixel element provides the line (row) index for the first pixel that was physically recorded at the beginning of the image array. Note: In the PDS, for a fuller explanation on the use of this data element in the Image Map Projection Object, please refer to the PDS Standards Reference.
LINE_LAST_PIXEL	The line_last_pixel element provides the line (rows) index for the last pixel that was physically recorded at the end of the image array. Note: In the PDS, for a fuller explanation on the use of this data element in the Image Map Projection Object, please refer to the PDS Standards Reference.
SAMPLE_FIRST_PIXEL	The sample_first_pixel element provides the sample (column) index for the first pixel that was physically recorded at the beginning of the image array. Note: In the PDS, for a fuller explanation on the use of this data element in the Image Map Projection Object, please refer to the PDS Standards Reference.
SAMPLE_LAST_PIXEL	The line_last_pixel element provides the sample (column) index for the last pixel that was physically recorded at the end of the image array. Note: In the PDS, for a fuller explanation on the use of this data element in the Image Map Projection Object, please refer to the PDS Standards Reference.

MAP_PROJECTION_ROTATION	The map_projection_rotation element provides the clockwise rotation, in degrees, of the line and sample coordinates with respect to the map projection origin (line_projection_offset, line_projection_offset) This parameter is used to indicate where 'up' is in the projection. For example, in a polar stereographic projection does the zero meridian go center to bottom, center to top, center to left, or center to right? The polar projection is defined such that the prime meridian goes center to bottom. However, by rotating the map projection, the prime meridian can go in any direction. Note: 180 degrees is at the top of the North Pole and 0 degrees is at the top of the South Pole. For example, if 0 degrees is at the top of the North Pole than the map_projection_rotation would be 180 degrees.
MAP_RESOLUTION	The map_resolution element identifies the scale of a given map. Please refer to the definition for map_scale for a more complete definition. Note: For MESSENGER DEM products the map_resolution is expressed in pixels/degree.
MAP_SCALE	The map_scale element identifies the scale of a given map in km/pixel at the center latitude and longitude of the projection.
MAXIMUM_LATITUDE	The maximum_latitude element specifies the northernmost latitude of a spatial area, such as a map, mosaic, bin, feature, or region.
MINIMUM_LATITUDE	The minimum_latitude element specifies the southernmost latitude of a spatial area, such as a map, mosaic, bin, feature, or region.
LINE_PROJECTION_OFFSET	The line_projection_offset element provides the line offset value of the map projection origin position from the center of the pixel at line and sample 1,1 (the pixel at line and sample 1,1 is considered the upper left corner of the digital array) Note: that the positive direction is to the right and down.
SAMPLE_PROJECTION_OFFSET	The sample_projection_offset element provides the sample offset value of the map projection origin position from the center of the pixel at line and sample 1,1 (the pixel at line and sample 1,1 is considered the upper left corner of the digital array). Note: that the positive direction is to the right and down.
EASTERNMOST_LONGITUDE	The following definitions describe easternmost longitude for the body-fixed, rotating coordinate systems: For planetocentric coordinates and for planetographic coordinates in which longitude increases toward the east, the easternmost (rightmost) longitude of a spatial area (e.g., a map, mosaic, bin, feature or region) is the maximum numerical value of longitude unless it crosses the prime meridian.
WESTERNMOST_LONGITUDE	The following definitions describe westernmost longitude for the body-fixed, rotating coordinate systems: For planetocentric coordinates and for planetographic coordinates in which longitude increases toward the east, the westernmost (leftmost) longitude of a spatial area (e.g., a map, mosaic, bin, feature or region) is the minimum numerical value of longitude unless it crosses the prime meridian.
COMPRESSED_FILE	**Object within label**
ENCODING_TYPE	Type of compression used (e.g., JPEG 2000).
UNCOMPRESSED_FILE_NAME	The name of the original source file.
REQUIRED_STORAGE_BYTES	The uncompressed file size.
UNCOMPRESSED_FILE	**Object within label (JPEG2000 labels only)**
NAME	(Optional) Name of the object within the file.
TABLE	**Object within label**
COLUMNS	Number of columns in table.
ROW_BYTES	Length of a table row in bytes.
ROWS	Number of rows in the table.
^STRUCTURE	Reference to an external format file that is included in the label.