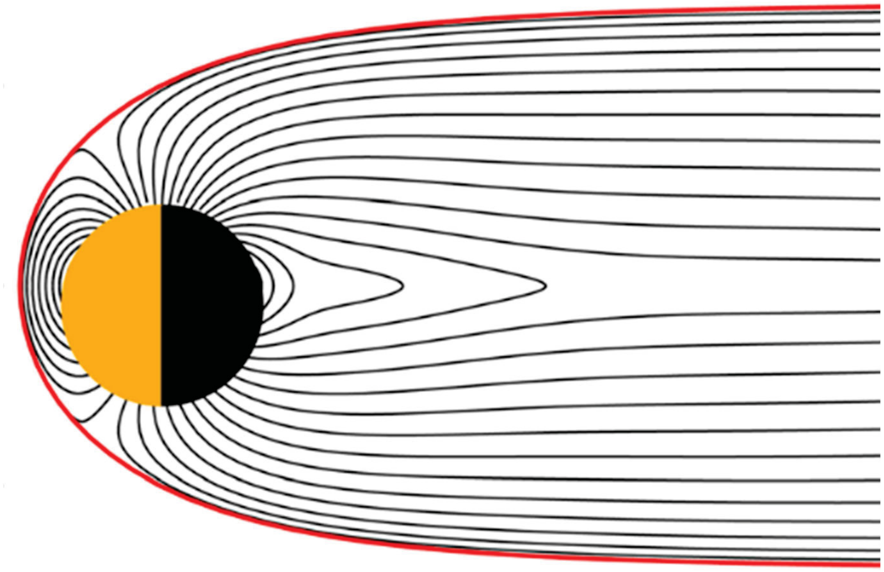
MESSENGER: Software Interface Specification for the Reduced Data Records of the Model Residuals for the Magnetometer

Version 1



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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.

Haje Korth, MESSENGER MAG Instrument Scientist and Mercury magnetic field model developer, has reviewed and approved this document.

Steve Joy, PDS PPI Node Representative, has reviewed and approved this document.

Acknowledgments

The research for and preparation of this dataset was funded by NASA's Planetary Data Archiving, Restoration, and Tools (PDART) program under grant NNX16AJ01G issued to Dr. Haje Korth (Principal Investigator) at the Johns Hopkins Applied Physics Laboratory.

Table of Contents

1. Purpose and Scope of Document

1.1 Purpose

This document provides users of the magnetic residuals (DELTA_B) data products with a detailed description of the generation, validation, and storage of the Reduced Data Record (RDR) data products. The magnetic residuals are computed as the difference between the MESSENGER Magnetometer (MAG, Figure 1) measurements and the *Korth et al*. [2017] (KT17) magnetosphere magnetic field model. The DELTA_B RDR data products have been developed within the Planetary Data Archiving, Restoration, and Tools (PDART) program and are delivered to the Planetary Data System (PDS) to support the scientific community. All data formats are based on the PDS version 4 (PDS4) standard. The residual data are those contributions to the magnetic field that are not represented by the physics in the aforementioned model are useful for the further development of empirical magnetic field models describing Mercury's magnetic field.

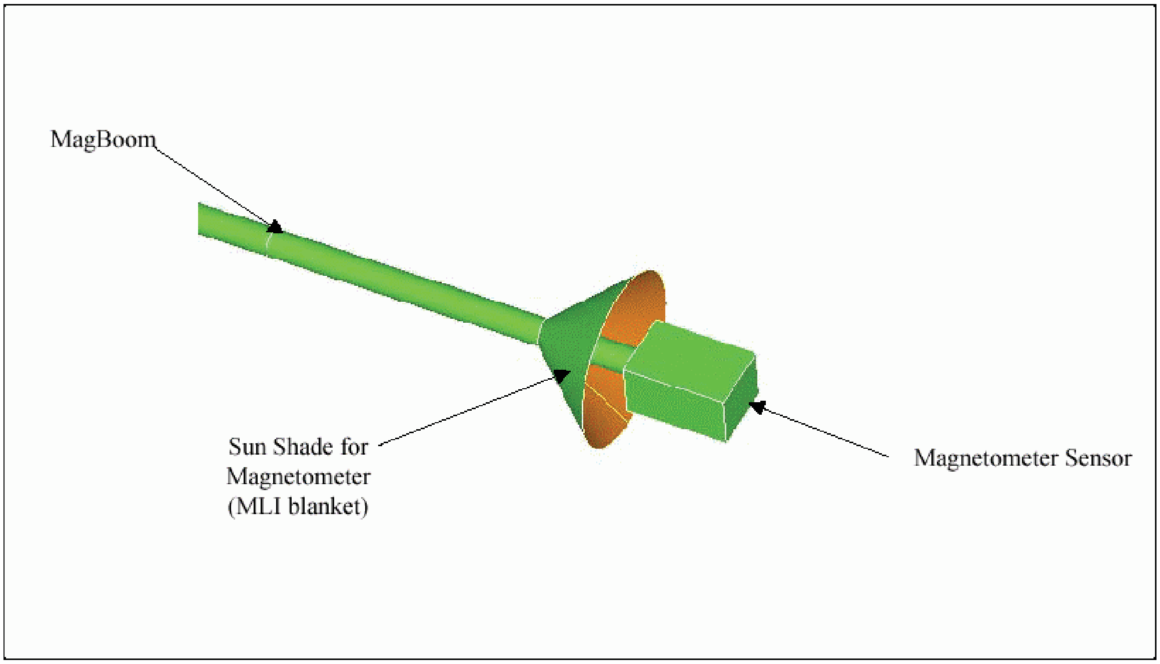

Figure 1: MAG Instrument.

1.2 Scope

This Software Interface Specification (SIS) is useful to those who wish to understand the format and content of KT17 DELTA_B RDR data products. The SIS applies to data products produced following the conclusion of the MESSENGER mission and the subsequent development of the empirical magnetic field model for Mercury's magnetospheric magnetic field, which includes the internal dynamo field and external contributions from magnetospheric current systems. The data products were derived from MAG RDR data products, which are based on MAG Experiment Data Records (EDRs) and Calibrated Data Records (CDRs). The description of MAG EDRs, CDRs, and RDRs is outside the scope of this SIS. Please refer to SIS documents for these products archived at the PDS.

In addition, this SIS describes the DELTA_B RDR documentation collection. The documentation collection provides information required to understand and use the DELTA_B RDR data products for scientific analysis. Sufficient information to allow investigators to generate DELTA_B RDR-level data from the MAG RDR products is provided, including a description of the empirical magnetospheric magnetic field model and algorithm required for the production of the DELTA_B RDR data products. The software executables are not PDS archival products and are specifically excluded from this data archive.

The DELTA_B RDR data products were derived from MAG RDR data and the KT17 empirical magnetic field model. These products contain 1-second time-averaged magnetic field data, which have been converted to physical units, transformed into physical coordinate systems, and tagged with averaged time stamps and spacecraft location. The products also contain the value of the internal and external magnetic field models evaluated at this spacecraft location, and the magnetic field residuals computed as the difference between the observed and modeled field. The products further include the heliocentric distance of Mercury and the Mercury magnetic activity, which are input parameters to the KT17 model. The algorithms applied to MAG RDR data to generate DELTA_B RDRs are described below.

2. Applicable Documents

The following documents are relevant to the DELTA_B RDR SIS:

- MESSENGER Mercury: Surface, Space Environment, Geochemistry, Ranging; A mission to Orbit and Explore the Planet Mercury, Concept Study, March 1999. Document ID number FG632/ 99-0479.
- Planetary Data System Standards Reference, October 2, 2020, Version 1.15.0, JPL D-7669, Part-2.
- The PDS4 Data Provider's Handbook, October 2, 2020, Version 1.15.0.
- MESSENGER: Software Interface Specification for Experiment Data Records of the Magnetometer, The Johns Hopkins University Applied Physics Laboratory, September 25, 2006.
- MESSENGER: Software Interface Specification for Calibrated Data Records of the Magnetometer, The Johns Hopkins University Applied Physics Laboratory, January 9, 2012.
- MESSENGER: Software Interface Specification for Reduced Data Records of the Magnetometer, The Johns Hopkins University Applied Physics Laboratory, January 16, 2016.
- B. J. Anderson et al., The Magnetometer Instrument on MESSENGER, Space Sci. Rev., 131, 417-350, doi:10.1007/s11214-007-9246-7, 2007.
- Anderson, B. J., C. L. Johnson, and H. Korth (2013), A magnetic disturbance index for Mercury's magnetic field derived from MESSENGER Magnetometer data, Geochem. Geophys. Geosyst., 14, 3875–3886, doi: 10.1002/ggge.20242.

- Johnson, C. L., M. E. Purucker, H. Korth, B. J. Anderson, R. M. Winslow, M. M. H. Al Asad, J. A. Slavin, I. I. Alexeev, R. J. Phillips, M. T. Zuber, and S. C. Solomon (2012), MESSENGER observations of Mercury's magnetic field structure, J. Geophys. Res., 117, E00L14, doi: 10.1029/2012JE004217.
- Korth, H., N. A. Tsyganenko, C. L. Johnson, L. C. Philpott, B. J. Anderson, M. M. Al Asad, S. C. Solomon, and R. L. McNutt Jr. (2015), Modular model for Mercury’s magnetospheric magnetic field confined within the average observed magnetopause, J. Geophys. Res. Space Physics, 120, 4503–4518, doi:10.1002/ 2015JA02102.
- Korth, H., C. L. Johnson, L. Philpott, N. A. Tsyganenko, and B. J. Anderson (2017), A dynamic model of Mercury’s magnetospheric magnetic field. Geophysical Research Letters, 44, 10,147–10,154, doi:10.1002/ 2017GL074699.
- Winslow, R. M., B. J. Anderson, C. L. Johnson, J. A. Slavin, H. Korth, M. E. Purucker, D. N. Baker, and S. C. Solomon (2013), Mercury's magnetopause and bow shock from MESSENGER Magnetometer observations, J. Geophys. Res. Space Physics, 118(5), 2213−2227, doi:10.1002/jgra.50237.

3. Relationships with Other Interfaces

The DELTA_B RDR data products were transferred to the PDS Planetary Plasma Interactions (PPI) Node. The data within the RDR files are stored in PDS table character classes.

4. Roles and Responsibilities

The authors of this document are responsible for the development of the empirical magnetic field model for Mercury’s magnetosphere and for processing and transmitting the DELTA_B RDR data products to the PDS for long-term archiving.

5. Data Product Characteristics and Environment

5.1 Overview

The KT17 empirical magnetic field model mathematically describes the global configuration of Mercury’s magnetospheric magnetic field, and it has been fit using the MESSENGER MAG observations. The model residuals (the difference between the measured and modeled magnetic fields) indicate potential deficiencies in the model and are useful for future model improvement and other scientific investigations. The model used for production of this archive is an offset dipole and the external contributions from magnetopause and magnetotail currents as described by *Korth et al.*, [2017]. The model identifier, KT17, is based from the initials of its primary developers, Haje Korth and Nikolai Tsyganenko, and the two-digit publication year.

5.2 Data Product Overview

The DELTA_B RDR data products are comprised of the time averaged magnetic field observations from the MAG RDRs, the modeled (internal and external) magnetic field vectors evaluated at the spacecraft location, and the difference of the observed and modeled magnetometer vectors (residuals or DELTA_B) in the Mercury solar orbital (MSO) and

Mercury body fixed (MBF) coordinate systems. The DELTA_B RDR products also contain the heliocentric distance of Mercury and the magnetospheric magnetic activity [*Anderson et al.,* 2013], which are input parameters to the KT17 model. The magnetospheric activity index describes the magnetospheric disturbance level, which is comparable to geomagnetic activity at Earth, as a number between 0 (quiet) and 100 (highly disturbed). The index is derived from MAG CDR data products. The MSO and MBF coordinate systems were chosen based on their usefulness to scientific analyses. The data products contain only data acquired within the model magnetosphere. For each MAG RDR in MSO and MBF coordinates, one DELTA_B RDR file was produced, with the exception of days in which the spacecraft never enters the magnetosphere. For magnetosphere passes for which an activity index was not available, an average value of 50 was used. Each DELTA_B RDR data product consists of two files – a data file with ASCII table fixed format and a detached PDS4 label, which describes the content of the data file. The PDS4 labels are ASCII text files written in the eXtensible Markup Language (XML). Each label file defines the start and end time of the observation, product creation time, the structure of the ASCII table, and the columns within the table. The label file also contains the release notes for the data file. One set of these two files contains the observations collected on a given UTC day in a given coordinate system. A detailed description of the DELTA_B RDR data products is given in the proceeding section 6.

5.2.1 Science DELTA_B RDR Products

The DELTA_B RDRs contain data records comprised of four different magnetic field vectors: (1) the calibrated three-axis magnetic field samples from the magnetometer averaged over one second copied from the MAG RDRs; (2 and 3) the modeled offset dipole (internal) and the KT17 external magnetic fields evaluated at the MESSENGER ephemeris; and (4) the total modeled field residuals.

The residual vector field data are available in the following geophysical coordinate systems:

1. Mercury solar orbital (MSO) coordinates, defined as +X pointing from Mercury center toward the Sun, +Z pointing northward perpendicular to Mercury's orbital plane, and +Y completing the right handed system. Venus-centered Venus solar orbital (VSO) coordinates are similarly defined. Solar orbital coordinates are only available for planetary flyby and orbital data;
2. Mercury body fixed (MBF) coordinates, Cartesian X, Y, Z coordinates defined relative to the planet's center, with +Z parallel to Mercury's rotation axis directed to the north ecliptic, +X directed to the prime meridian in the equator (0º latitude), and +Y completes the right handed system. Body fixed coordinates are only available for planetary flyby and orbital data.

For planetary missions, it is customary to provide magnetic field data in solar magnetospheric coordinates. In the solar magnetospheric coordinate system, the +X axis points from the planet center to the Sun, the +Y axis is defined to be perpendicular to the planet's magnetic pole so that the X-Z plane contains the dipole axis, and +Z completes the right-handed system. The Mercury solar magnetospheric (MSM) coordinates are particularly easy to obtain because the internal dipole field is aligned with the planetary rotation axis. The dipole field is offset from the planet center along the rotation axis by 479 km to the north [*Johnson et al.*, 2012], so that the MSO and MSM coordinate systems are related by a simple translation in which the Z_{MSM} coordinate is obtained as $Z_{MSM} = Z_{MSO} -$ 479 km. Since the MSO and MSM coordinate systems are not rotated with respect to each other, the magnetic field vectors are identical in both coordinate systems.

All DELTA_B RDR data product records contain UTC and mission elapsed time (MET, time since launch) time stamps, and number of samples in the averaging interval. The MET used in the DELTA_B RDRs is a derived quantity as defined in section 6.3. In addition, DELTA_B RDR records contain the mean spacecraft position and the heliocentric distance of Mercury and the magnetospheric magnetic activity.

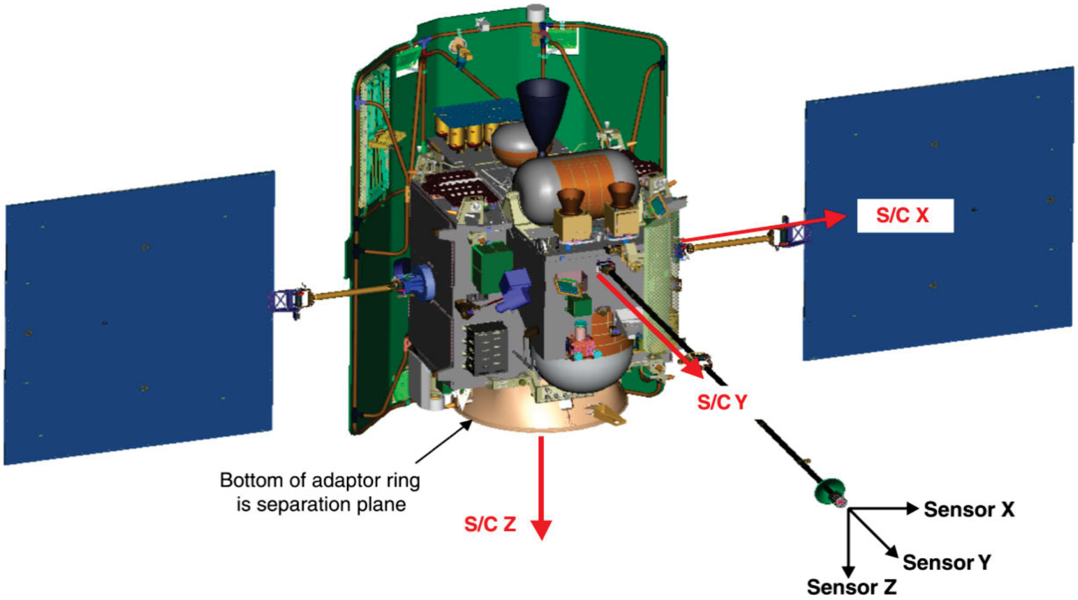

Figure 2: Spacecraft and MAG sensor coordinates.

5.3 Data Processing

5.3.1 Data Processing Level

The MESSENGER data archive processed data according to the CODMAC data processing levels (Appendix 8.6) defined as follows. The spacecraft data downlink was telemetered through NASA's Deep Space Network (DSN) managed by the Jet Propulsion Laboratory in Pasadena, CA, and then forwarded to APL. At APL, these data were transmitted to the MESSENGER Science Operations Center (SOC) in the form of CCSDS packets (Level 1 data). The Level 1 MAG raw time series and engineering data were then broken out of the data stream and stored at the SOC. The Level 1 data were then ingested by an automatic data processing system to generate Level 2 data (EDRs), which were stored in a database reserved for the MAG sensor. Subsequently, the Level 2 data were processed to Level 3 data (CDRs) containing calibrated, UTC time-tagged observations in various coordinate systems and stored at the SOC. The Level 3 data products were time averaged to yield Level 4 data (RDRs).

Finally, the Level 4 data products are used as an input to evaluate the magnetic field models and derive the DELTA_B RDRs. Starting with the PDS4 standard, a simpler system was developed as is described in Appendix 8.6. Under this system, the DELTA_B RDRs are described as 'Derived Data'. Each product has a unique file name and conforms to the file naming convention in section 6.2.

5.3.2 Data Product Generation

The DELTA_B RDR data were generated as follows: First, the 1-s averaged MAG RDR products in MSO and MBF coordinates were obtained from the MESSENGER MAG archive hosted at the PDS PPI Node. These products contain the location of the MESSENGER spacecraft and observed magnetic field measurements. The KT17 model is defined in aberration corrected MSO coordinates. The aberration correction accounts for the deviation in the observed solar wind flow due to the planetary motion of Mercury around the Sun. This causes the magnetotail to lag behind motion of the planet as it evolves in its orbit. As shown in Figure 3, the aberration is defined as a counter-clockwise rotation of the vectors about the MSO +Z axis by an angle a, where $a = \text{atan}\left(v_{M_\phi}/v_{sw}\right)$, v_{M_ϕ} is the longitudinal component of Mercury's heliocentric velocity, and v_{sw} is the negative radial component of the solar wind velocity at the nose of the bow shock. Mercury's heliocentric velocity vector is determined using the SPICE routine SPKEZR. Since the solar wind velocity is not measured by MESSENGER, a purely radial flow with a constant speed of 400 km/s is assumed: $v_{sw} = 400$ km/s.

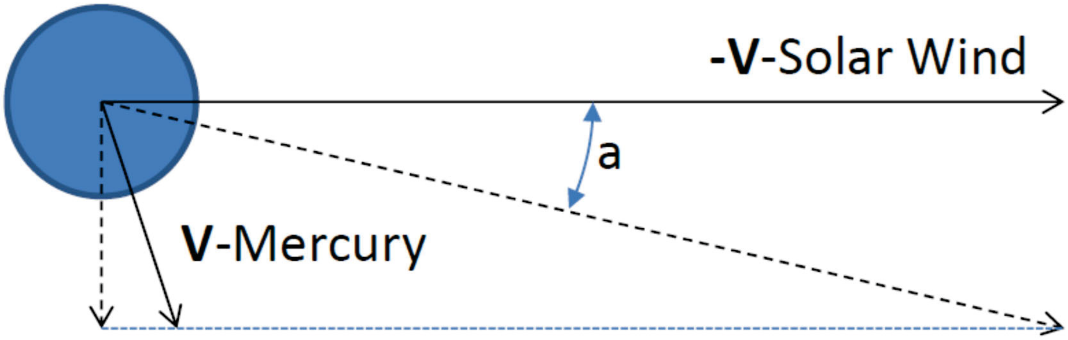

Figure 3: A schematic showing rotation angle that defines the coordinate transformation that rotates a vector from MSO to aberration corrected MSO coordinates.

The resultant rotation matrix $\mathbf{R}$ that rotates a vector in MSO coordinates to aberration corrected MSO coordinates is given by:

$$\mathbf{R} = \begin{bmatrix} +\cos a & -\sin a & 0 \\ +\sin a & +\cos a & 0 \\ 0 & 0 & 1 \end{bmatrix}.$$

Both magnetic field and position vectors can be rotated from MSO to aberration corrected MSO coordinates by: $\mathbf{B}_{MSO,A} = \mathbf{R}\mathbf{B}_{MSO}$ and $\mathbf{r}_{MSO,A} = \mathbf{R}\mathbf{r}_{MSO}$. The transpose of $\mathbf{R}$, $\mathbf{R}^{\mathrm{T}}$, rotates a vector from aberrated corrected MSO to MSO coordinates: $\mathbf{B}_{MSO} = \mathbf{R}^{\mathrm{T}}\mathbf{B}_{MSO,A}$ and $\mathbf{r}_{MSO} = \mathbf{R}^{\mathrm{T}}\mathbf{r}_{MSO,A}$.

To evaluate the KT17 model [*Korth et al*., 2015, 2017], the MSO spacecraft location must also be rotated into the aberration corrected MSO coordinates. The source code of the magnetic field model is included for reference in section 8.4. The required input parameters of the model are the aberration corrected MSO position in Mercury radii, the heliocentric distance of Mercury in Astronomical Units (AU), and the Mercury magnetic activity index [*Anderson et al*., 2013]. Mercury radius (R_{M}) is 2,440.0 km. Because the heliocentric distance changes relatively slowly, it is only evaluated once for each data product for the first data record using the SPICE routine SPKEZR. The output of the KT17 model is the magnetospheric magnetic field in units of nT in aberration corrected MSO coordinates. The result is then rotated clockwise back into MSO coordinates. In the model, the internal magnetic field is defined as a dipole field with a moment of 190 nT R_{M}^3 that is offset northward from the planet center along the spin axis by 479 km [*Johnson et al.*, 2012]. The total magnetospheric field magnetic field is the sum of the internal and external magnetic fields generated by magnetospheric current systems at the magnetopause and in the magnetotail. The residuals are defined as the difference between the observed and model field, i.e., data minus model.

For the DELTA_B RDR products in MBF coordinates, both the spacecraft location and magnetic field vectors are given in the MBF coordinates. The SPICE routine PXFORM is used to obtain the rotation matrix that transforms a vector from the MSO to the MBF coordinate system. The magnetopause boundary defines the model's valid spatial domain. Because the magnetic model is not defined outside this boundary, data obtained in the solar wind are omitted from the DELTA_B RDR products. The functional form of the model magnetopause was adopted from *Winslow et al.* [2013].

Following generation of the data products, PDS4 labels were generated using relevant information parsed from the MAG RDR data files and labels and the DELTA_B RDR products. The PDS4 labels consists of ASCII characters in the eXtensible Markup Language (XML) format.

The version number of the DELTA_B RDR data products corresponds to that of the MAG RDR products from which these data were derived, as is indicated by the DELTA_B RDR filename (section 6.2). Note, the <version_id> tag in the label is based upon the delivery of the DELTA_B RDR products to the PDS, and is incremented if/when a new delivery is performed. Thus, the version indicated in the filename does not correspond to the <version_id> tag in the label.

5.3.3 Data Flow

The DELTA_B RDR products including labels were generated after the conclusion of the MESSENGER mission and development of the magnetospheric magnetic field models following the approach detailed in section 5.3.2. The archive bundle consists of data and label files organized by the collection structure described in section 6.6. The initial release also contains the documents and required files for the DELTA_B documentation bundle. In preparation for the delivery, the bundle structure was compressed into as a zip archive for transfer to the PPI node. The zip archive preserves the bundle structure internally so that it can be recreated after delivery to the PDS node. The zip archive file was transferred to the PDS PPI node. A checksum file for the archive was created using the MD5 algorithm and provided an independent method of verifying the integrity of the zip file after it was sent. The PDS node acknowledged receipt of the archive and checksum file.

The PDS node uncompressed the zip archive file and checked the data integrity using the checksum file. The node then performed any additional verification and validation of the data and reported any discrepancies or problems to the archive bundle creators. After inspection was completed to the satisfaction of the PDS node, the node issued an acknowledgment of successful receipt of the data to the model developers. Finally, the PDS node organized the data into a PDS4 bundle archive structure and published them via its online data system.

5.3.4 Labeling and Identification

The DELTA_B RDR detached label files conform to the PDS4 (version 1.15.0.0) standards. PDS4 labels are ASCII text files written in the eXtensible Markup Language (XML). For more information on this standard consult the PDS Standards Reference Document. The purpose of the PDS label is to describe the data and provide ancillary information. The label file is detached and separate from the DELTA_B RDR data file. The data file itself contains the data in table character format. There is one detached PDS label file for every data file. There is a single standard DELTA RDR data product, which is described in section 5.2. The <logical_identifier> (LID) tag uniquely identifies the data product while the <version_id> (VID) tag identifies the version. When the product is revised, the LID remains the same while the VID is incremented. The combined LIDVID is guaranteed to be unique across the whole PDS system. The data products are named via the <file_name> tag and the file naming convention (section 6.2). Example label files for each DELTA_B RDR data product are shown in the Appendix (sections 8.1–8.2). Details about the table structure for each data file are specified in section 6.3.

5.4 Standards Used in Generating Data Products

5.4.1 PDS Standards

The DELTA_B RDR products are constructed according to the data class concepts developed by the PDS. By adopting the PDS format, the DELTA_B RDR products are consistent in content and organization with other planetary data collections. In the PDS standard, the RDR data file is grouped into classes with PDS labels describing each class. Each RDR product consists of two files:

- A data file containing table character classes (the primary data) in fixed-field format. This makes the data easy to read by many commercial programs.
- A xml label file, which serves as a high-level description of the fields in the data file. The xml label file also contains the product release notes specifying and ancillary information.

5.4.2 Time Standards

The time fields in the RDR table classes reference both Coordinated Universal Time (UTC) and the Mission Elapsed Time (MET). The MET is the spacecraft time in seconds that is transmitted to the MESSENGER subsystems by the Integrated Electronics Module (IEM). MET = 0 is August 3, 2004 05:59:16 UTC, which is 1000 seconds prior to MESSENGER launch. Due to relativistic effects, clock drift, and circumstances occurring during the mission, the MET is not a true account of seconds since launch. Following a planned spacecraft clock reset[1] on January 8, 2013, partition numbers (1/, or 2/) were added to product labels to disambiguate MET seconds after the spacecraft clock reset (if partition number is not present, SPICE defaults to partition 1/). The MESSENGER spacecraft clock coefficients file is used in conjunction with the leap seconds kernel file in order to calculate the conversion between MET and UTC. A description of the conversions including both instrument latency corrections and the required calls using the SPICE toolkit is given in the calibration description MAG_EDR2CDR.PDF.

5.4.3 Data Storage Conventions

The data were organized following PDS standards and stored on hard disk. The RDR data and labels are stored in ASCII text files, and the lines are terminated by a carriage return/line feed combination. The model developers transferred data to PDS via the delivery methods detailed in section 5.3.3. After verification of the data transfer, PDS provided public access to DELTA_B science data products through its online data distribution system.

5.5 Data Validation

The DELTA_B RDR archive volume combines MAG RDR data, which have previously been reviewed and data generated from the evaluation of the KT17 magnetospheric magnetic field model, which was developed, among others, for the creation of this archive. The model was validated via standard scientific analysis, including the generation of plots and figures of the model outputs and residuals, and peer-review of the model publications [*Korth et al.*, 2015; 2017]. The DELTA_B RDR data products were validated by independent implementation of the data processing algorithm detailed in 5.3.2. The independent processing codes were written in different programming languages, and the data products were validated by automated comparison. The average difference between

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[1] See instrument host catalog file in MAG document volume for more information on MESSENGER spacecraft clock reset.

the production and validation field values is of the order tenths of nT, which is within the expected range based on slight differences in the two implementations.

PDS standards recommended that all data included in the formal archive be validated through a peer-review process. Only those data indicated as free of contamination or containing correctable contamination were subject to validation of the data quality. This process was designed to ensure that both the data and documentation are of sufficient quality to be useful to future generations of scientists. The process consisted of several steps, most of which occurred in the PDS peer review. This peer review was conducted before any volumes were produced and released to PDS.

The peer review panel consisted of members of the PPI node of PDS, and at least two outside scientists actively working in the field of planetary, terrestrial, or interplanetary magnetic fields research. The PDS personnel were responsible for validating that the volumes are fully compliant with PDS standards. The model developers and the outside science reviewers were responsible for verifying the content of the data set, the completeness of the documentation, and the usability of the data in its archive format.

The peer review validated the documentation and data archive volumes. The review panel reviewed this document and verified that the bundles and DELTA_B RDRs produced to this specification constitute a stand-alone data set with sufficient information to allow independent analysis. The peer review also validated the DELTA_B RDR data in a two-step process. The first step consisted of reviewing a sample data set for compliance with the PDS standards. The sample data set was delivered and reviewed in conjunction with delivery and review of this SIS document. The second step consisted of examination of the data to ensure usability and completeness. The PDS personnel were responsible for validating that the RDR data set is fully compliant with PDS standards. The model developers and the outside science reviewers were responsible for verifying the content of the data set, the completeness of the documentation, and the usability of the data in its archive format.

Any deficiencies in the archive data or documentation volumes were recorded as liens against the product by the review panel. The sample data set was created using software provided by the model developers. Once the sample data were validated, and all liens placed against the product or product generation software were resolved. The same software was used to generate subsequent data products in an automated fashion.

The structure of data files and labels was spot checked by the PPI node for compliance with PDS standards and this SIS.

6. Detailed Data Product Specifications

6.1 Data Product Structure and Organization

The DELTA_B RDR data and documentation was archived at the PDS PPI Node as an archive bundle. The DELTA_B data is split into two different collections and the documentation is included in its own documentation collection and contains the DELTA_B

SIS document and other documents applicable to this data archive bundle. Both the DELTA_B data and documentation collections were included in the release of the DELTA_B RDR data bundle.

6.2 File Naming Conventions

The PDS data products have file names defined a fixed naming convention and a 3-character extension name with a period separating the file and extension names. For all DELTA_B RDR data products the base form of the RDR file name (without the file extension) is: “MAGCCCRRRTTTYYDDD_II_V##”.
The ASCII table files are defined by the file extension “.TAB” and the detached PDS4 label file with the file extension “.xml”. The file naming convention of the presently existing RDR products is as follows.

MAG: Instrument name
CCC: Coordinate system:
    MSO – Mercury solar orbital
    MBF – Mercury body fixed

RRR: Record type:
    SCI – Science

TTT: Data Reduction Method:
    DBM – Delta B-field Model

YY: Last two digits of the year in which the data were acquired.
DDD: Three-digit day of year in which the data where acquired.

II: Averaging time interval in seconds.

V##: Two-digit version number. For simplicity, the version number of the DELTA_B RDR data products corresponds to that of the MAG RDR products from which these data were derived. The initial version number for DELTA_B RDR products is “V08”. The version number increments to “V09”, “V10”, etc., for each successive version of the DELTA_B RDR product that is produced. A new version of the DELTA_B RDR product may be produced as a result of an error in the product or as a result of errors discovered in the product generation process.

6.3 Data Format Description

The DELTA_B RDR data are stored in table character format, which is an ASCII text file. A detached PDS4 label file provides a detailed description of the structure of the ASCII xml file and the product release notes. The following tables present the structure of the data tables in a user-friendly format. The fields are numbered according to their column order in the table. Data_Type refers to the PDS standards data type for a particular column in the table.

6.3.1 DELTA_B Mercury Solar Orbital (MSO) Coordinates Science RDR Table Character

The file naming convention for these products is MAGMSOSCIDBMYYDDD_II_V## as defined in section 6.2. The columns contain the following data:

1. **DATE_TIME_UTC**
   Bytes: 21 Data_Type: ASCII_DATE_TIME_DOY

   UTC date and time associated with the center time of the averaging interval for the magnetic field samples Bx, By, Bz in each record.

2. **TIME_TAG**
   Bytes: 13 Data_Type: ASCII_REAL

   A derived value for the timetag associated with the center time of the averaging interval of the Bx, By, Bz samples in each record. The derived value is created by the following formula:
   MET + 0.05 * delta_ts + (dt_sample)*(I-1) - latency.
   MET is the mission elapsed time for the entire science packet.
   delta_ts is the delta time in seconds between the MET and the first sample in the downloaded science packet.
   dt_sample is the time between samples in seconds and given by
   dt_sample = 1/sample_rate where sample_rate is the reported sample rate in samples per second.
   I is the incremental counter for each data sample in the science packet. I=1 is the first sample in the packet.
   Latency is the sample rate-dependent delay of the time stamp recording relative to the actual time of observation.

3. **NAVG**
   Bytes: 6 Data_Type: ASCII_INTEGER

   Number of samples in averaging interval.

4. **X_MSO**
   Bytes: 14 Data_Type: ASCII_REAL

   Average X position in Mercury solar orbital (MSO) coordinates in units of kilometers.

5. **Y_MSO**
   Bytes: 14 Data_Type: ASCII_REAL

   Average Y position in Mercury solar orbital (MSO) coordinates in units of kilometers.

6. **Z_MSO**
   Bytes: 14 Data_Type: ASCII_REAL

   Average Z position in Mercury solar orbital (MSO) coordinates in units of kilometers.

7. **BX_MSO**
   Bytes: 10 Data_Type: ASCII_REAL

   Average X axis magnetic field value in Mercury solar orbital (MSO) coordinates in units of nano-Tesla.

8. **BY_MSO**

Bytes: 10 Data_Type: ASCII_REAL

Average Y axis magnetic field value in Mercury solar orbital (MSO) coordinates in units of nano-Tesla.

9. **BZ_MSO**
Bytes: 10 Data_Type: ASCII_REAL

Average Z axis magnetic field value in Mercury solar orbital (MSO) coordinates in units of nano-Tesla.

10. **DBX_MSO**
Bytes: 10 Data_Type: ASCII_REAL

The KT17 modeled residual X axis magnetic field values in Mercury solar orbital (MSO) coordinates and units of nano-Tesla.

11. **DBY_MSO**
Bytes: 10 Data_Type: ASCII_REAL

The KT17 modeled residual Y axis magnetic field values in Mercury solar orbital (MSO) coordinates and units of nano-Tesla.

12. **DBZ_MSO**
Bytes: 10 Data_Type: ASCII_REAL

The KT17 modeled residual Z axis magnetic field values in Mercury solar orbital (MSO) coordinates and units of nano-Tesla.

13. **BXMI_MSO**
Bytes: 10 Data_Type: ASCII_REAL

The internal magnetic field model X axis magnetic field values in Mercury solar orbital (MSO) coordinates and units of nano-Tesla.

14. **BYMI_MSO**
Bytes: 10 Data_Type: ASCII_REAL

The internal magnetic field model Y axis magnetic field values in Mercury solar orbital (MSO) coordinates and units of nano-Tesla.

15. **BZMI_MSO**
Bytes: 10 Data_Type: ASCII_REAL

The internal magnetic field model Z axis magnetic field values in Mercury solar orbital (MSO) coordinates and units of nano-Tesla.

16. **BXME_MSO**
Bytes: 10 Data_Type: ASCII_REAL

The external magnetic field model X axis magnetic field values in Mercury solar orbital (MSO) coordinates and units of nano-Tesla.

17. **BYME_MSO**
Bytes: 10 Data_Type: ASCII_REAL

The external magnetic field model Y axis magnetic field values in Mercury solar orbital (MSO) coordinates and units of nano-Tesla.

18. **BZME_MSO**
    Bytes: 10 Data_Type: ASCII_REAL

    The external magnetic field model Z axis magnetic field values in Mercury solar orbital (MSO) coordinates and units of nano-Tesla.

19. **RHEL**
    Bytes: 12 Data_Type: ASCII_REAL

    The heliocentric distance of Mercury in astronomical units (AU).

20. **ACT**
    Bytes: 5 Data_Type: ASCII_REAL

    The magnetic disturbance index value ranging from 0 (quiet) to 100 (highly disturbed).

6.3.2 DELTA_B Mercury Body-fixed (MBF) Coordinates Science RDR Table Character

The file naming convention for these products is MAGMBFSCIDBMYYDDD_II_V## as defined in section 6.2. The columns contain the following data:

1. **DATE_TIME_UTC**
   Bytes: 21 Data_Type: ASCII_DATE_TIME_DOY

   UTC date and time associated with the center time of the averaging interval for the magnetic field samples Bx, By, Bz in each record.

2. **TIME_TAG**
   Bytes: 13 Data_Type: ASCII_REAL

   A derived value for the timetag associated with the center time of the averaging interval of the Bx, By, Bz samples in each record. The derived value is created by the following formula:
   MET + 0.05 * delta_ts + (dt_sample)*(I-1) - latency.
   MET is the mission elapsed time for the entire science packet.
   delta_ts is the delta time in seconds between the MET and the first sample in the downloaded science packet.
   dt_sample is the time between samples in seconds and given by
   dt_sample = 1/sample_rate where sample_rate is the reported sample rate in samples per second.
   I is the incremental counter for each data sample in the science packet. I=1 is the first sample in the packet.
   Latency is the sample rate-dependent delay of the time stamp recording relative to the actual time of observation.

3. **NAVG**
   Bytes: 6 Data_Type: ASCII_INTEGER

   Number of samples in averaging interval.

4. **X_MBF**

Bytes: 14 Data_Type: ASCII_REAL

Average X position in Mercury body-fixed (MBF) coordinates in units of kilometers.

5. **Y_MBF**
Bytes: 14 Data_Type: ASCII_REAL

Average Y position in Mercury body-fixed (MBF) coordinates in units of kilometers.

6. **Z_MBF**
Bytes: 14 Data_Type: ASCII_REAL

Average Z position in Mercury body-fixed (MBF) coordinates in units of kilometers.

7. **BX_MBF**
Bytes: 10 Data_Type: ASCII_REAL

Average X axis magnetic field value in Mercury body-fixed (MBF) coordinates in units of nano-Tesla.

8. **BY_MBF**
Bytes: 10 Data_Type: ASCII_REAL

Average Y axis magnetic field value in Mercury body-fixed (MBF) coordinates in units of nano-Tesla.

9. **BZ_MBF**
Bytes: 10 Data_Type: ASCII_REAL

Average Z axis magnetic field value in Mercury body-fixed (MBF) coordinates in units of nano-Tesla.

10. **DBX_MBF**
Bytes: 10 Data_Type: ASCII_REAL

The KT17 modeled residual X axis magnetic field values in Mercury body fixed (MBF) coordinates and units of nano-Tesla.

11. **DBY_MBF**
Bytes: 10 Data_Type: ASCII_REAL

The KT17 modeled residual Y axis magnetic field values in Mercury body fixed (MBF) coordinates and units of nano-Tesla.

12. **DBZ_MBF**
Bytes: 10 Data_Type: ASCII_REAL

The KT17 modeled residual Z axis magnetic field values in Mercury body fixed (MBF) coordinates and units of nano-Tesla.

13. **BXMI_MBF**
Bytes: 10 Data_Type: ASCII_REAL

The internal magnetic field model X axis magnetic field values in Mercury body-fixed (MBF) coordinates and units of nano-Tesla.

14. **BYMI_MBF**
Bytes: 10 Data_Type: ASCII_REAL

The internal magnetic field model Y axis magnetic field values in Mercury body-fixed (MBF) coordinates and units of nano-Tesla.

15. **BZMI_MBF**
Bytes: 10 Data_Type: ASCII_REAL

The internal magnetic field model Z axis magnetic field values in Mercury body-fixed (MBF) coordinates and units of nano-Tesla.

16. **BXME_MBF**
Bytes: 10 Data_Type: ASCII_REAL

The external magnetic field model X axis magnetic field values in Mercury body-fixed (MBF) coordinates and units of nano-Tesla.

17. **BYME_MBF**
Bytes: 10 Data_Type: ASCII_REAL

The external magnetic field model Y axis magnetic field values in Mercury body-fixed (MBF) coordinates and units of nano-Tesla.

18. **BZME_MBF**
Bytes: 10 Data_Type: ASCII_REAL

The external magnetic field model Z axis magnetic field values in Mercury body-fixed (MBF) coordinates and units of nano-Tesla.

19. **RHEL**
Bytes: 12 Data_Type: ASCII_REAL

The heliocentric distance of Mercury in astronomical units (AU).

20. **ACT**
Bytes: 5 Data_Type: ASCII_REAL

The magnetic disturbance index value ranging from 0 (quiet) to 100 (highly disturbed).

6.4 Label and Header Descriptions

Each DELTA_B RDR product is accompanied by a detached PDS4 label. PDS4 labels are ASCII text files written in the eXtensible Markup Language (XML). Product labels are detached from the files they describe and there is one label for every product. A PDS4 label file has the same name as the data product it describes, but uses the extension ".xml". The following are the keyword definitions for the detached PDS4 label file accompanying the ASCII data file. The detached PDS4 label file has the same name as the data file it describes, except for the extension .xml to distinguish it as a label file. The xml data format consists of different areas. The first area is the XML header contains links to schemas. A description of the other areas is as follows:

The **`<Identification_Area>`** provides information that uniquely identifies the product. Some of the useful elements contained in this area are:

`<Identification_Area><logical_identifier>`

`Represents a unique identifier for the data product in accordance to the PDS4 standards.`

`<Identification_Area><version_id>`

`Represents the version id of the data product in accordance to the PDS4 standards. When the product is revised, the logical identifier remains the same but the version id is incremented. When combined, the identifier and version id are guaranteed to be unique across the whole PDS system.`

`<Identification_Area><title>`

`The formal title of the data product.`

The **`<Observation_Area>`** provides information detailing the observation. Some of the useful elements contained in this area are:

`<Observation_Area><Time_Coordinates> <start_date_time>`

`Provides the date and time at the beginning of a time period of interest in UTC system format.`

`<Observation_Area><Time_Coordinates> <stop_date_time>`

`Provides the date and time at the end of a time period of interest in UTC system format.`

`<Observation_Area><Mission_Area>`
`<mess:MESSENGER><mess:mission_phase_name>`

`Provides the commonly used identifier of a mission phase.`

`<Observation_Area><Mission_Area>`
`<mess:MESSENGER><mess:spacecraft_clock_start_count>`

`Provides the value of the spacecraft clock at the beginning of a time period of interest.`

`<Observation_Area><Mission_Area>`
`<mess:MESSENGER><mess:spacecraft_clock_stop_count>`

`Provides the value of the spacecraft clock at the end of a time period of interest.`

The **`<Reference_List>`** provides information on other products and journal articles relevant to understanding this product. Some of the useful elements contained in this area are:

`<Reference_List><External_Reference>`

`Lists the DOIs to the relevant journal articles.`

`<File_Area_Observational>` provides a detailed description of the files.

`<File_Area_Observational> <File> <file_name>`

`The file name of the corresponding ASCII data file, the file naming convention (section 6.2) without the file extensions.`

`<File_Area_Observational> <File> <creation_date_time>`

`Provides the creation date and time for the corresponding ASCII data file.`

`<File_Area_Observational> <File> <file_size>`

`Provides the filesize for the corresponding ASCII data file.`

`<File_Area_Observational> <File> <md5_checksum>`

`Provides the MD5 checksum for the corresponding ASCII data file.`

6.5 Bundle and File Size

The PDS DELTA_B bundle consists of the RDR data split into two collections, the data-sci-mbf and data-sci-mso collections, as well as the documentation collection. The latter includes the ReleaseNotes.txt file along with this document (SIS). The data volumes for the data-sci-mbf and data-sci-so collections are given in Table 3. The record lengths for data in MSO and MBF coordinates are identical.

Table 3: DELTA_B RDR data collection volume estimates.

Data Collection	Record Bytes	Avg. RDR size [MB]	Volume [GB]
data-sci-mbf (MAGMBFSCIDBM_01 files)	240	3.15	4.5
data-sci-mso (MAGMSOSCIDBM_01 files)	240	3.15	4.5

The DELTA_B documentation collection contains documents related to the DELTA_B RDR data archive with each level of documentation provided with the initial release of the corresponding dataset and updated as needed with subsequent data releases.

6.6 Structure and Contents for the DELTA_B Data and Documentation Bundle

The DELTA_B bundle is structured into three collections. The Document Collection contains reference documents needed to understand and analyze the contents of the bundle including this document (the DELTA_B RDR SIS). There are two data bundles for the MBF and MSO products. These collections contain the RDR products and the xml label files.

6.6.1 Bundle Contents

Bundle Level

This is the top-level of the bundle. The following are files contained here:

readme_DELTA_B_RDR_1.0.txt – This general information file provides users with an overview of the contents and organization of the associated bundle and the associated collections, general instructions for its use, and contact information.

Document Collection

This collection contains the documentation that is needed to understand and analyze the DELTA_B RDR bundle. The following are files contained here:

DELTA_B_RDR_SIS: This document.

ReleaseNotes.txt: This file describes and dates the various releases of the DELTA_B RDR bundle.

Data-sci-mbf Collection

This data collection contains the DELTA_B RDR data files in the Mercury Body Fixed (MBF) coordinates system.

Data-sci-mso Collection

This data collection contains the DELTA_B RDR data files in the Mercury Solar Orbital(MSO) coordinates system.

6.7 Error Handling

The possibility existed that errors be discovered in the archive during the ongoing validation effort detailed in section 5.5. If errors are found, an ERRATA report file can be created to document any uncorrectable errors.

7. Archive Delivery to PDS

The DELTA_B data archives were transferred from the model developers to the PDS PPI Node using the transfer process detailed in section 5.3.3.

8. Appendices

8.1 Appendix – DELTA_B MSO Coordinates Science RDR PDS Label

```
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      https://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1B00.xsd

      http://pds.nasa.gov/pds4/mission/mess/v1
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            <publication_year>2021</publication_year>
            <description>
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```

```
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                Korth, H., Tsyganenko, N. A., Johnson, C. L., Philpott, L. C., Anderson,
B. J.,
                Al Asad, M. M., et al. (2015). Modular model for Mercury's magnetospheric
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                field confined within the average observed magnetopause. Journal of
Geophysical
                Research: Space Physics, 120, https://doi.org/10.1002/2015JA021022
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J.
                (2017). A dynamic model of Mercury's magnetospheric magnetic field.
Geophysical
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       MET is the mission elapsed time for the entire science packet.
       delta_ts is the delta time in seconds between the MET and
       the first sample in the downloaded science packet.
       dt_sample is the time between samples in seconds and given by
       dt_sample = 1/sample_rate where sample_rate is the reported
       sample rate in samples per second.
       I is the incremental counter for each data sample in the
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       Latency is the sample rate-dependent delay of the time stamp
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Tesla.</description>
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```
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         in astronomical units.</description>
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                <Field_Character>
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                    <field_location unit="byte">234</field_location>
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         as percentage of maximum observed during the MESSENGER mission.</description>
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            </Record_Character>
        </Table_Character>
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</Product_Observational>
```

8.2 Appendix – MAG MBF Coordinates Science RDR PDS Label

```
<?xml version="1.0" encoding="UTF-8"?>
<?xml-model href="https://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1B00.sch"
    schematypens="http://purl.oclc.org/dsdl/schematron" ?>
<?xml-model href="https://pds.nasa.gov/pds4/mission/mess/v1/PDS4_MESS_1B00_1100.sch"
    schematypens="http://purl.oclc.org/dsdl/schematron" ?>
<Product_Observational
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   xmlns:mess="http://pds.nasa.gov/pds4/mission/mess/v1"
   xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
   xsi:schemaLocation="
      http://pds.nasa.gov/pds4/pds/v1
      https://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1B00.xsd
```

```
      http://pds.nasa.gov/pds4/mission/mess/v1
      https://pds.nasa.gov/pds4/mission/mess/v1/PDS4_MESS_1B00_1100.xsd
     ">
    <Identification_Area>
        <logical_identifier>urn:nasa:pds:mess-mag-calibrated:data-sci-
mbf:magmbfscidbm11108_01</logical_identifier>
        <version_id>1.0</version_id>
        <title>MESSENGER Magnetometer Calibrated Mercury Body Fixed Residual Data - 2011-
04-18</title>
        <information_model_version>1.11.0.0</information_model_version>
        <product_class>Product_Observational</product_class>
        <Citation_Information>
            <author_list>Korth, H.</author_list>
            <publication_year>2021</publication_year>
            <description>
    The table contains the timetags, spacecraft position, and 3-axis
    calibrated samples of the magnetic field in Mercury body fixed (MBF)
    coordinates in units of nano-Tesla. The data represent averages from MAG
    science packets over the interval given in the file name in units of
    seconds generated on a given day. START_TIME and STOP_TIME correspond to
    the TIME_TAG values of the first row and last row in the table,
    respectively.</description>
        </Citation_Information>
        <Modification_History>
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                <version_id>1.0</version_id>
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label.</description>
            </Modification_Detail>
        </Modification_History>
    </Identification_Area>
    <Observation_Area>
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            <start_date_time>2011-04-18T04:57:04.000Z</start_date_time>
            <stop_date_time>2011-04-18T18:12:03.000Z</stop_date_time>
        </Time_Coordinates>
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            <processing_level>Derived</processing_level>
            <Science_Facets>
                <domain>Magnetosphere</domain>
                <discipline_name>Fields</discipline_name>
                <facet1>Magnetic</facet1>
            </Science_Facets>
        </Primary_Result_Summary>
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            <type>Mission</type>
            <Internal_Reference>

<lid_reference>urn:nasa:pds:context:investigation:mission.messenger</lid_reference>
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            </Internal_Reference>
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                </Internal_Reference>
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                <type>Spacecraft</type>
                <Internal_Reference>

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```

```
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            <type>Planet</type>
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                <reference_type>data_to_target</reference_type>
            </Internal_Reference>
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<mess:spacecraft_clock_stop_count>1/211637791.300</mess:spacecraft_clock_stop_count>
            </mess:MESSENGER>
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    </Observation_Area>
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            <reference_type>data_to_document</reference_type>
        </Internal_Reference>
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            <lid_reference>urn:nasa:pds:mess-mag-calibrated:document:delta-b-rdr-
sis</lid_reference>
            <reference_type>data_to_document</reference_type>
            <comment>
               This document describes the MAG DBM processing and the structure
               of the various data files in this archive.
            </comment>
        </Internal_Reference>
        <External_Reference>
            <doi>https://doi.org/10.1002/2015JA021022</doi>
            <reference_text>
                Korth, H., Tsyganenko, N. A., Johnson, C. L., Philpott, L. C., Anderson,
B. J.,
                Al Asad, M. M., et al. (2015). Modular model for Mercury's magnetospheric
magnetic
                field confined within the average observed magnetopause. Journal of
Geophysical
                Research: Space Physics, 120, https://doi.org/10.1002/2015JA021022
            </reference_text>
            <description>Published model paper</description>
        </External_Reference>
        <External_Reference>
            <doi>https://doi.org/10.1002/2017GL074699</doi>
            <reference_text>
                Korth, H., Johnson, C. L., Philpott, L., Tsyganenko, N. A., Anderson, B.
J.
                (2017). A dynamic model of Mercury's magnetospheric magnetic field.
Geophysical
                Research Letters, 44, https://doi.org/10.1002/2017GL074699
            </reference_text>
            <description>Published model paper</description>
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                <field_length unit="byte">21</field_length>
                <description>UTC date and time associated with the center time
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  each record.</description>
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                <data_type>ASCII_Real</data_type>
                <field_length unit="byte">13</field_length>
                <description>A derived value for the timetag associated
  with the center time of the averaging interval of the Bx,By,Bz samples
  in each record. The derived value is created by the following formula:
       MET + 0.05 * delta_ts + (dt_sample)*(I-1) - latency.
       MET is the mission elapsed time for the entire science packet.
       delta_ts is the delta time in seconds between the MET and
       the first sample in the downloaded science packet.
       dt_sample is the time between samples in seconds and given by
       dt_sample = 1/sample_rate where sample_rate is the reported
       sample rate in samples per second.
       I is the incremental counter for each data sample in the
       science packet. I=1 is the first sample in the packet.
       Latency is the sample rate-dependent delay of the time stamp
       recording relative to the actual time of observation.
</description>
            </Field_Character>
            <Field_Character>
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  (MBF) coordinates in units of kilometers.</description>
```

```
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values with respect to KT17 magnetic field model (data minus model)
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values with respect to KT17 magnetic field model (data minus model)
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values with respect to KT17 magnetic field model (data minus model)
   in Mercury body fixed (MBF) coordinates and units of nano-Tesla.</description>
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   and units of nano-Tesla.</description>
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```

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          and units of nano-Tesla.</description>
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          and units of nano-Tesla.</description>
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                    <name>ACTIDX</name>
                    <field_number>20</field_number>
                    <field_location unit="byte">234</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">5</field_length>
                    <description>Activity index of Mercury's magnetosphere
          as percentage of maximum observed during the MESSENGER mission.</description>
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            </Record_Character>
        </Table_Character>
    </File_Area_Observational>
</Product_Observational>
```

8.3 Appendix – SPICE Kernel Files Used in DELTA_B Data Products

The following SPICE kernel files are used to compute the UTC time and any geometric quantities found in the PDS labels. Kernel files were generated throughout the mission with a file-naming convention specified by the MESSENGER project. The SPICE kernels are archived separately in the SPICE data volume with the VOLUME_SET_NAME “MESSENGER: GEOMETRY” and the VOLUME_SET_ID “USA_NASA_PDS_MESSNAIF_1001”.

msgr_040803_150430_150430_od431sc_2.bsp:
MESSENGER spacecraft ephemeris file. Also known as the Spacecraft and Planet Kernel (SPK) file. Also contains the planetary ephemeris.

msgr_v231.tf:
MESSENGER reference frame file. Also known as the Frames Kernel. Contains the MESSENGER spacecraft, science instrument, and communication antennae frame definitions.

msgr_dyn_v600.tf:
MESSENGER dynamic frame file. Also known as the Frames Kernel. Contains the Mercury solar orbital (MSO) frame definition.

messenger_2548 .tsc:
MESSENGER spacecraft clock coefficients file. Also known as the Spacecraft Clock Kernel (SCLK) file.

pck00010_msgr_v23.tpc:
Planetary constants file. Also known as the Planetary Constants Kernel (PcK) file. Contains the Mercury body fixed (MBF) frame definition.

naif0012 .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.

8.4 Appendix – Model Source Code

```
!
! Reference implementation of the KT17 model of Mercury's magnetospheric
! magnetic field in FORTRAN 90 programming language.
!

program kt17

  implicit none

  integer*4     id

  real*8        f,x,y,z,bx,by,bz

  include 'kt17_common.f90'
```

```
  include 'kt17_param.f90'

  rhel=0.39
  act=50.0

  x=-2.0d0
  y=0.0d0
  z=0.5d0

  f=2.06873-0.00279*act
  rss=f*rhel**(1.0/3.0)
  tamp1=6.4950+0.0229*act
  tamp2=1.6245+0.0088*act

  call kt17_bfield(1,x,y,z,bx,by,bz)

  print *,x,y,z,bx,by,bz

end


!
!----------------------------------------------------------------------
!     Subroutine KT17_BFIELD
!----------------------------------------------------------------------
!
subroutine kt17_bfield(n,x_a,y_a,z_a,bx_a,by_a,bz_a)

  implicit none

  include 'kt17_common.f90'

  integer*4     n,id_a(n),mode,msm,noshield,id,i
  real*8        x_a(n),y_a(n),z_a(n)
  real*8        x,y,z
  real*8        x_mso,y_mso,z_mso
  real*8        bx_mso,by_mso,bz_mso
  real*8        bx_msm,by_msm,bz_msm
  real*8        bx_dcf,by_dcf,bz_dcf
  real*8        bx_dsk,by_dsk,bz_dsk
  real*8        bx_slb,by_slb,bz_slb
  real*8        bx_a(n),by_a(n),bz_a(n)
  real*8        kappa,kappa3
  real*8        fi,gradfix,gradfiy,gradfiz
  real*8        fx,fy,fz,hx,hy,hz

!
! initialize variables
!
  kappa=r0/rss
  kappa3=kappa**3

!
! magnetic field computation
!
  do i=1,n
    x=x_a(i)
    y=y_a(i)
    z=z_a(i)

    x=x*kappa
```

```
    y=y*kappa
    z=z*kappa

    call kt17_mpdist(0,x,y,z,fi,id,gradfix,gradfiy,gradfiz)
    if (fi .lt. mptol) id=1
    if (noshield .eq. 1) id=1

    if (id .eq. 1) then
      bx_dcf=0.0d0
      by_dcf=0.0d0
      bz_dcf=0.0d0
      bx_dsk=0.0d0
      by_dsk=0.0d0
      bz_dsk=0.0d0
      bx_slb=0.0d0
      by_slb=0.0d0
      bz_slb=0.0d0

      fx=0.0d0
      fy=0.0d0
      fz=0.0d0
      hx=0.0d0
      hy=0.0d0
      hz=0.0d0
      call kt17_dipole(x,y,z,fx,fy,fz)
      call kt17_shield(n_dipshld,r_dipshld,x,y,z,hx,hy,hz)
      bx_dcf=kappa3*(fx+hx)
      by_dcf=kappa3*(fy+hy)
      bz_dcf=kappa3*(fz+hz)

      fx=0.0d0
      fy=0.0d0
      fz=0.0d0
      hx=0.0d0
      hy=0.0d0
      hz=0.0d0
      call kt17_taildisk(x,y,z,fx,fy,fz)
      call kt17_shield(n_diskshld,r_diskshld,x,y,z,hx,hy,hz)
      bx_dsk=tamp1*(fx+hx)
      by_dsk=tamp1*(fy+hy)
      bz_dsk=tamp1*(fz+hz)

      fx=0.0d0
      fy=0.0d0
      fz=0.0d0
      hx=0.0d0
      hy=0.0d0
      hz=0.0d0
      call kt17_tailslab(x,y,z,fx,fy,fz)
      call kt17_shield(n_slabshld,r_slabshld,x,y,z,hx,hy,hz)
      bx_slb=tamp2*(fx+hx)
      by_slb=tamp2*(fy+hy)
      bz_slb=tamp2*(fz+hz)

      bx_msm=bx_dcf+bx_dsk+bx_slb
      by_msm=by_dcf+by_dsk+by_slb
      bz_msm=bz_dcf+bz_dsk+bz_slb

      bx_a(i)=bx_msm
      by_a(i)=by_msm
      bz_a(i)=bz_msm
```

```
    else
      bx_a(i)=1.0d-8
      by_a(i)=1.0d-8
      bz_a(i)=1.0d-8
    endif
  enddo

  return
end


!
!-----------------------------------------------------------------------
!     Subroutine KT17_DIPOLE
!-----------------------------------------------------------------------
!
subroutine kt17_dipole(xmsm,ymsm,zmsm,bx,by,bz)

! calculates components of dipole field
!
! input parameters: x,y,z - msm coordinates in rm (1 rm = 2440 km)
!
! output parameters: bx,by,bz - field components in msm system, in nanotesla.

  implicit none

  include 'kt17_common.f90'

  real*8        xmsm,ymsm,zmsm
  real*8        bx,by,bz
  real*8        psi,sps,cps
  real*8        p,u,v,t,q

! dipole tilt
  psi=0.0d0
  sps=sin(psi/57.29577951d0)
  cps=sqrt(1.0d0-sps**2)

! compute field components
  p=xmsm**2
  u=zmsm**2
  v=3.0d0*zmsm*xmsm
  t=ymsm**2
  q=mu/sqrt(p+t+u)**5
  bx=q*((t+u-2.0d0*p)*sps-v*cps)
  by=-3.0d0*ymsm*q*(xmsm*sps+zmsm*cps)
  bz=q*((p+t-2.0d0*u)*cps-v*sps)

  return
end


!
!-----------------------------------------------------------------------
!     Subroutine KT17_MPDIST
!-----------------------------------------------------------------------
!
subroutine kt17_mpdist(mode,x,y,z,fi,id,gradfix,gradfiy,gradfiz)

  implicit none
```

```
  include 'kt17_common.f90'

  integer*4   mode,id
  real*8      x,y,z,fi,gradfix,gradfiy,gradfiz
  real*8      rho2,r,rho
  real*8      ct,st,t,sp,cp
  real*8      rm,drm_dt
  real*8      gradfir,gradfit,gradfip

  rho2=y**2+z**2
  r=sqrt(x**2+rho2)
  rho=sqrt(rho2)

  id=1

  if (rho .gt. 1.0d-8) then          ! not on the x-axis - no singularities to worry
                                     ! about
    ct=x/r
    st=rho/r
    t=atan2(st,ct)
    sp=z/rho
    cp=y/rho
  else                               ! on the x-axis
    if (x .gt. 0.0d0) then           ! on the dayside
      ct=x/r
      st=1.0d-8/r                    ! set rho=10**-8, to avoid singularity of
                                     ! grad_fi (if mode=1, see gradfip=... below)
      t=atan2(st,ct)
      sp=0.0d0
      cp=1.0d0
    else                             ! on the tail axis! to avoid singularity:
      fi=-1000.0d0                   ! assign rm=1000 (a conventional substitute
                                     ! value)
      return                         ! and exit
    endif
  endif

  rm=r0/sqrt(alfa*(1.0d0+ct))        ! standard form of shue et al.,1997,
                                     ! magnetopause model

  if (rm .lt. r) id=-1

  fi=r-rm
  if (mode .eq. 0) return            ! skip calculation of the gradient of fi

  drm_dt=0.25d0*rm**3/r0**2*st

  gradfir=1.0d0
  gradfit=-drm_dt/r
  gradfip=0.0d0                      ! axial symmetry

  gradfix=gradfir*ct-gradfit*st
  gradfiy=(gradfir*st+gradfit*ct)*cp-gradfip*sp
  gradfiz=(gradfir*st+gradfit*ct)*sp+gradfip*cp

  return
end


!
!-----------------------------------------------------------------------
```

```
!     Subroutine KT17_SHIELD
!----------------------------------------------------------------------
!
subroutine kt17_shield(n,r,x,y,z,bx,by,bz)

  implicit none

  integer*4   jmax,kmax,j,k,n,o
  real*8      r(n),x,y,z
  real*8      c(n),p(n),cypj,sypj,szpk,czpk,sqpp,epp
  real*8      hx,hy,hz
  real*8      bx,by,bz

  o=nint(-0.5+sqrt(n+0.25))
  c(1:o*o)=r(1:o*o)
  p(1:o)=r(o*o+1:o*o+o)

  jmax=o
  kmax=o

  bx=0.0d0
  by=0.0d0
  bz=0.0d0
  do j=1,jmax
    do k=1,kmax
      cypj=cos(y*p(j))
      sypj=sin(y*p(j))
      szpk=sin(z*p(k))
      czpk=cos(z*p(k))
      sqpp=sqrt(p(j)**2+p(k)**2)
      epp=exp(x*sqpp)

      hx=-sqpp*epp*cypj*szpk
      hy=+epp*sypj*szpk*p(j)
      hz=-epp*cypj*czpk*p(k)

      bx=bx+hx*c((j-1)*kmax+k)
      by=by+hy*c((j-1)*kmax+k)
      bz=bz+hz*c((j-1)*kmax+k)
    enddo
  enddo

  return
end


!
!----------------------------------------------------------------------
!     Subroutine KT17_TAILDISK
!----------------------------------------------------------------------
!
subroutine kt17_taildisk(xmsm,ymsm,zmsm,bx,by,bz)

! calculates msm components of the field from a t01-like 'long-module' equatorial
! current disk with a 'hole' in the center and a smooth inner edge
! (see tsyganenko, jgra, v107, no a8, doi 10.1029/2001ja000219, 2002, fig.1, right
! panel).
!
!------------input parameters:
!
! d0       - basic (minimal) half-thickness
```

```
! deltadx  - sunward expansion factor for the current sheet thickness
! deltady  - flankward expansion factor for the current sheet thickness
! x,y,z    - msm coordinates
!
!------------output parameters:
! bx,by,bz - field components in msm system, in nanotesla.

  implicit none

  include 'kt17_common.f90'

  integer*4   nr3,i
  real*8      xmsm,ymsm,zmsm,bx,by,bz
  real*8      f(n_taildisk),b(n_taildisk),c(n_taildisk)
  real*8      xshift,sc,x,y,z,d0_sc,deltadx_sc,deltady_sc
  real*8      rho,drhodx,drhody
  real*8      dex,d,dddy,dddx
  real*8      dzeta,ddzetadx,ddzetady,ddzetadz
  real*8      bi,ci,s1,s2,ds1drho
  real*8      ds2drho,ds1ddz,ds2ddz
  real*8      ds1dx,ds1dy,ds1dz,ds2dx,ds2dy,ds2dz
  real*8      s1ts2,s1ps2,s1ps2sq,fac1,as,dasds1,dasds2
  real*8      dasdx,dasdy,dasdz

  nr3=n_taildisk/3
  f(1:nr3)=r_taildisk(1:nr3)
  b(1:nr3)=r_taildisk(nr3+1:2*nr3)
  c(1:nr3)=r_taildisk(2*nr3+1:3*nr3)

  xshift=0.3d0             ! shift the center of the disk to the dayside by xshift
  sc=7.0d0                 ! renormalize length scales

  x=(xmsm-xshift)*sc
  y=ymsm*sc
  z=zmsm*sc
  d0_sc=d0*sc
  deltadx_sc=deltadx*sc
  deltady_sc=deltady*sc

  rho=sqrt(x**2+y**2)
  drhodx=x/rho
  drhody=y/rho

  dex=exp(x/7.0d0)
  d=d0_sc+deltady_sc*(y/20.0d0)**2+deltadx_sc*dex   ! the last term makes the
                                                    ! sheet thicken sunward, to
  dddy=deltady_sc*y*0.005d0                         ! avoid problems in the
                                                    ! subsolar region

  dddx=deltadx_sc/7.0d0*dex

  dzeta=sqrt(z**2+d**2)                             ! this is to spread out the
                                                    ! sheet in z direction over
                                                    ! finite thickness 2d

  ddzetadx=d*dddx/dzeta
  ddzetady=d*dddy/dzeta
  ddzetadz=z/dzeta

  bx=0.0d0
  by=0.0d0
  bz=0.0d0
```

```
  do i=1,5
    bi=b(i)
    ci=c(i)

    s1=sqrt((rho+bi)**2+(dzeta+ci)**2)
    s2=sqrt((rho-bi)**2+(dzeta+ci)**2)

    ds1drho=(rho+bi)/s1
    ds2drho=(rho-bi)/s2
    ds1ddz=(dzeta+ci)/s1
    ds2ddz=(dzeta+ci)/s2

    ds1dx=ds1drho*drhodx+ds1ddz*ddzetadx
    ds1dy=ds1drho*drhody+ds1ddz*ddzetady
    ds1dz=ds1ddz*ddzetadz

    ds2dx=ds2drho*drhodx+ds2ddz*ddzetadx
    ds2dy=ds2drho*drhody+ds2ddz*ddzetady
    ds2dz=ds2ddz*ddzetadz

    s1ts2=s1*s2
    s1ps2=s1+s2
    s1ps2sq=s1ps2**2
    fac1=sqrt(s1ps2sq-(2.0d0*bi)**2)
    as=fac1/(s1ts2*s1ps2sq)
    dasds1=(1.0d0/(fac1*s2)-as/s1ps2*(s2*s2+s1*(3.0d0*s1+4.0d0*s2)))/(s1*s1ps2)
    dasds2=(1.0d0/(fac1*s1)-as/s1ps2*(s1*s1+s2*(3.0d0*s2+4.0d0*s1)))/(s2*s1ps2)

    dasdx=dasds1*ds1dx+dasds2*ds2dx
    dasdy=dasds1*ds1dy+dasds2*ds2dy
    dasdz=dasds1*ds1dz+dasds2*ds2dz

    bx=bx-f(i)*x*dasdz
    by=by-f(i)*y*dasdz
    bz=bz+f(i)*(2.0d0*as+x*dasdx+y*dasdy)
  enddo

  return
end


!
!-----------------------------------------------------------------------
!     Subroutine KT17_TAILSLAB
!-----------------------------------------------------------------------
!
subroutine kt17_tailslab(xmsm,ymsm,zmsm,bx,by,bz)

! calculates msm components of the field from an equatorial harris-type current
! sheet, slowly expanding sunward
!
!------------input parameters:
!
! d0       - basic (minimal) half-thickness
! deltadx  - sunward expansion factor for the current sheet thickness
! deltady  - flankward expansion factor for the current sheet thickness
! scalex   - e-folding distance for the sunward expansion of the current sheet
! scaley   - scale distance for the flankward expansion of the current sheet
! zshift   - z shift of image sheets
! x,y,z    - msm coordinates
!
```

```
!------------output parameters:
! bx,by,bz - field components in msm system, in nanotesla.

  implicit none

  include 'kt17_common.f90'

  real*8   xmsm,ymsm,zmsm,bx,by,bz
  real*8   d,dddx,zpzi,zmzi

  d=d0+deltadx*exp(xmsm/scalex)+deltady*(ymsm/scaley)**2
  dddx=deltadx/scalex*exp(xmsm/scalex)
  zpzi=zmsm+zshift
  zmzi=zmsm-zshift
  bx=(tanh(zmsm/d)-0.5d0*(tanh(zmzi/d)+tanh(zpzi/d)))/d
  by=0.0d0
  bz=(zmsm*tanh(zmsm/d)-0.5d0*(zmzi*tanh(zmzi/d)+zpzi*tanh(zpzi/d)))*dddx/d**2
  return
    end


!*******************************************
! Save the following code as kt17_common.f90
!*******************************************

!
!-----------------------------------------------------------------------
!     KT17 Common Blocks
!-----------------------------------------------------------------------
!
integer*4     n_taildisk,n_dipshld,n_diskshld,n_slabshld
parameter     (n_taildisk=15,n_dipshld=20,n_diskshld=42,n_slabshld=42)

common /par/  mu,tilt,pdip,psun,rdx,rdy,rdz,rss,r0,alfa,tamp1,tamp2,d0, &
  deltadx,deltady,scalex,scaley,zshift,r_taildisk,r_dipshld,r_diskshld, &
  r_slabshld,mptol
real*8        mu,tilt
real*8        pdip,psun
real*8        rdx,rdy,rdz
real*8        rss,r0,alfa
real*8        tamp1,tamp2
real*8        d0,deltadx,deltady,scalex,scaley,zshift
real*8        r_taildisk(n_taildisk),r_dipshld(n_dipshld)
real*8        r_diskshld(n_diskshld),r_slabshld(n_slabshld)
real*8        mptol
real*8        rhel,act


!*******************************************
! Save the following code as kt17_param.f90
!*******************************************

!
! *** Parameters v1.0 ***
!

! Model parameters from Korth et al., Modular model for Mercury’s magnetospheric
! magnetic field confined within the average observed magnetopause, J. Geophys.
! Res. Space Physics, 120, doi: 10.1002/2015JA021022, 2015.

mu=      190.0d0                        ! dipole moment [nT Rp^3]
```

```
tilt=    0.0d0*3.14159265d0/180.0d0     ! dipole tilt angle [radians]
pdip=    0.0d0*3.14159265d0/180.0d0     ! dipole longitude [radians]
rdx=     0.0d0                          ! dipole x offset
rdy=     0.0d0                          ! dipole y offset
rdz=     0.196d0                        ! dipole z offset
rss=     1.41d0                         ! distance from Mercury center to sub-
                                        ! solar magnetopause [Rp]
r0=      1.42d0                         ! distance from Mercury center to fitted
                                        ! sub-solar magnetopause [Rp]
alfa=    0.5d0                          ! magnetopause flaring factor
tamp1=   7.64d0                         ! tail disk current magnitude
tamp2=   2.06d0                         ! harris sheet current magntidue
d0=      0.09d0                         ! half-width of current sheet in Z at
                                        ! inner edge of tail current [Rp]
deltadx= 1.0d0                          ! expansion magnitudes of tail current
                                        ! sheet in x direction
deltady= 0.1d0                          ! expansion magnitudes of tail current
                                        ! sheet in y direction
scalex=  1.5d0                          ! e-folding distance for the sunward
                                        ! expansion of the harris sheet
scaley=  9.0d0                          ! scale distance for the flankward
                                        ! expansion of the harris sheet
zshift=  3.5d0                          ! location of image sheets for harris
                                        ! sheet
mptol=   1.0d-3                         ! Tolerance for magnetopause encounter

r_taildisk=(/ &
   59048.35734, &
  -135664.4246, &
  -913.4507339, &
   209989.1008, &
  -213142.9370, &
   19.69235037, &
  -18.16704312, &
   12.69175932, &
  -14.13692134, &
   14.13449724, &
   7.682813704, &
   9.663177797, &
  0.6465427021, &
   1.274059603, &
   1.280231032  &
  /)

r_dipshld=(/ &
  7.792407683, &
  74.37654983, &
  4.119647072, &
 -131.3308600, &
  546.6006311, &
 -1077.694401, &
  52.46268495, &
  1057.273707, &
 -74.91550119, &
 -141.8047123, &
  3.876004886, &
  156.2250932, &
 -506.6470185, &
  1439.804381, &
 -64.55225925, &
 -1443.754088, &
```

```
 0.1412297078, &
 0.7439847555, &
  1.042798338, &
 0.7057116022  &
 /)

r_diskshld=(/ &
 -398.4670279, &
 -1143.001682, &
 -1836.300383, &
 -73.92180417, &
 -326.3986853, &
 -29.96868107, &
 -1157.035602, &
 -604.1846034, &
 -52.04876183, &
 -2030.691236, &
 -1529.120337, &
 -6.382209946, &
  2587.666032, &
  213.8979183, &
 -28.30225993, &
  630.1309859, &
  2968.552238, &
  888.6328623, &
  497.3863092, &
  2304.254471, &
  858.4176875, &
  1226.958595, &
  850.1684953, &
 -20.90110940, &
 -203.9184239, &
 -792.6099018, &
  1115.955690, &
  527.3226825, &
  22.47634041, &
-0.0704405637, &
 -1405.093137, &
 -97.20408343, &
  5.656730182, &
 -138.7129102, &
 -1979.755673, &
  5.407603749, &
  1.091088905, &
 0.6733299808, &
 0.3266747827, &
 0.9533161464, &
  1.362763038, &
 0.0014515208  &
 /)

r_slabshld=(/ &
 -91.67686636, &
 -87.31240824, &
  251.8848107, &
  95.65629983, &
 -80.96810700, &
  198.1447476, &
 -283.1968987, &
 -269.1514899, &
  504.6322310, &
```

```
  166.0272150, &
 -214.9025413, &
  623.7920115, &
 -35.99544615, &
 -322.8644690, &
  345.7105790, &
  928.8553184, &
  810.1295090, &
  19.62627762, &
 -12.70326428, &
  490.4662048, &
 -814.0985363, &
 -1781.184984, &
 -1371.261326, &
  60.31364790, &
  116.6305510, &
 -178.3347065, &
  604.0308838, &
  1155.151174, &
  770.3896601, &
 -202.8545948, &
  298.6337705, &
  304.7964641, &
  33.70850254, &
  393.6080147, &
  308.1194271, &
 -660.1691658, &
  1.677629714, &
  1.292226584, &
 0.3116253398, &
-0.4392669057, &
 0.7578074817, &
  1.497779521  &
 /)
```

8.5 Appendix – Data Archive Terms

Definition of Terms:

Archive	A place in which public records or historical documents are preserved; also the material preserved — often used in plural. Sometimes capitalized when referring to all of PDS holdings — the PDS Archive.
Bundle	A list of collections. Product Bundle, the bundle's manifestation, is itself a product (because it is simply a list embedded within a label); but it is not a basic product. For example, a bundle could list a collection of raw data obtained by an instrument during its mission lifetime, a collection of the calibration products associated with the instrument, and a collection of all documentation relevant to the first two collections.
Collection	A list of basic products, all of which are closely related in some way. The collection's manifestation, Product Collection, is itself a product (because it is simply a list, with its label); but it is not a basic product.
Label	The aggregation of one or more description objects such that the aggregation describes a single PDS product. In the PDS4 implementation, labels are constructed using XML, which imposes a small amount of overhead.
Logical Identifier	An identifier which identifies the set of all versions of an object.
Table	A two-dimensional data structure composed of records, which themselves are heterogeneous but which repeat throughout the table. For example, a table could have 20 ASCII records, each of which has a 10-character date field, a comma, an 8- character time field, a comma, a 3-digit integer temperature field, and a 'carriage- return line-feed' record delimiter.

Tag	Fundamental syntax in XML; a tag is a character string delimited by "<" and ">". For example "<date>" is a tag.
XML attribute	An attribute-value pair that is inserted into an XML element to provide additional information, such as units; the value is always enclosed in double quotes. For example <date unit="year">2009</date>
XML document	A file that contains syntactically correct XML-formatted text.
XML element	An XML structure that begins with <tag>, contains 'content', and ends with </tag>. For example, "<date>2009</date>" is an XML element establishing the date as 2009. The allowed 'content' is specified in the PDS4 Information Model, which is propagated to the PDS4 Data Dictionary.
XML label	A label written using XML.
Experiment Data Records	NASA Level 0 data for a given instrument; raw data. Same as CODMAC Level 2.
Reduced data records	Science data that have been processed from raw data to NASA Level 1 or higher. See Section 8.9 for definitions of processing levels.
Standard data product	A data product that has been defined during the proposal and selection process and that is contractually promised by the PI as part of the investigation. Standard data products are generated in a predefined way, using well-understood procedures, and processed in "pipeline" fashion.

8.6 Appendix – CODMAC/NASA and PDS4 Data Processing Levels

CODMAC/NASA Definition of processing levels for science data sets

CODMAC Level	**Proc. Type**	**Data Processing Level Description**
1	Raw Data	Telemetry data stream as received at the ground station, with science and engineering data embedded. Corresponds to NASA packet data.
2	Edited Data	Instrument science data (e.g. raw voltages, counts) at full resolution, time ordered, with duplicates and transmission errors removed. Referred to in the MESSENGER program as Experiment Data Records (EDRs). Corresponds to NASA Level 0 data.
3	Calibrated Data	Edited data that are still in units produced by instrument, but have transformed (e.g. calibrated, rearranged) in a reversible manner and packaged with needed ancillary and auxiliary data (e.g. radiances with calibration equations applied). Referred to in the MESSENGER Program as Calibrated Data Records (CDRs). In some cases these also qualify as derived data products (DDRs). Corresponds to NASA Level 1A.
4	Resampled data	Irreversibly transformed (e.g. resampled, remapped, calibrated) values of the instrument measurements (e.g. radiances, magnetic field strength). Referred to in the MESSENGER program as either derived data products (DDPs) or derived analysis products (DAPs). Corresponds to NASA Level 1B.
5	Derived Data	Derived results such as maps, reports, graphics, etc. Corresponds to NASA Levels 2 through 5
6	Ancillary Data	Non-Science data needed to generate calibrated or resampled data sets. Consists of instrument gains, offsets; pointing information for scan platforms, etc.
7	Corrective Data	Other science data needed to interpret space-borne data sets. May include ground based data observations such as soil type or ocean buoy measurements of wind drift.
8	User Description	Description of why the data were required, any peculiarities associated with the data sets., and enough documentation to allow secondary user to extract information from the data.

The above is based on the national research council committee on data management and computation (CODMAC) data levels.

PDS4 Definition of processing levels for science data sets

PDS4 Processing Level	**Definition**

Telemetry	An encoded byte stream used to transfer data from one or more instruments to temporary storage where the raw instrument data will be extracted. PDS does not archive telemetry data.
Raw	Original data from an instrument. If compression, reformatting, packetization, or other translation has been applied to facilitate data transmission or storage, those processes will be reversed so that the archived data are in a PDS-approved archive format.
Partially Processed	Data that have been processed beyond the raw stage, but have not yet reached calibrated status.
Calibrated	Data converted to physical units, which makes values independent of the instrument.
Derived	Results that have been distilled from one or more calibrated data products (for example, maps, gravity or magnetic fields, or ring particle size distributions). Supplementary data used to interpret observational data, such as calibration tables or tables of viewing geometry, should also be classified as derived data if not easily matched to one of the other categories.

The above is from the PDS4 Data Provider's Handbook.

8.7 Appendix – Acronyms

APL	The Johns Hopkins University Applied Physics Laboratory
ASCII	American Standard Code for Information Interchange
CCSDS	Consultative Committee for Space Data Systems
CDR	Calibrated Data Record
CK	Camera Kernel (SPICE)
CoDMAC	Committee on Data Management and Computation
Co-I	Co-Investigator
DSN	Deep Space Network
EDR	Experiment Data Records
ET	Ephemeris Time
GP	Geophysics Group
IEM	Integrated Electronic Module
KT17	Korth et al., [2017] magnetospheric magnetic field model
LSK	Leapseconds Kernel (SPICE)
MAG	Magnetometer
MBF	Mercury Body Fixed Coordinate System
MESSENGER	MErcury, Surface, Space ENvironment, Geochemistry, and Ranging
MET	Mission Elapsed Time
MSM	Mercury Solar Magnetospheric Coordinate System
MSO	Mercury Solar Orbital Coordinate System
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
PCK	Planetary Constant Kernel (SPICE)
PDS	Planetary Data System
PDS4	Planetary Data System version 4
RDR	Reduced Data Record
SCLK	Spacecraft Clock Kernel (SPICE)
SOC	Science Operations Center
SPICE	Spacecraft, Planet, Instrument, C-matrix Events, refers to the kernel files and NAIF Software used to generate viewing geometry
SPK	Spacecraft and Planets Kernel (SPICE)
UTC	Coordinated Universal Time
XML	eXtensible Markup Language