Interior Exploration Using Seismic Investigations, Geodesy, and Heat Transport (InSight) Mission

Rotation and Interior Structure Experiment (RISE)

Derived Data Set

PDS Archive

Software Interface Specification

Rev. 1.0

May 1, 2023

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Prepared by

Dustin R. Buccino
Jet Propulsion Lab, California Institute of Technology
Dustin.R.Buccino@jpl.nasa.gov

InSight

RISE

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May 1, 2023

Custodian:

______________________________ ________

Dustin R. Buccino Date

RISE Instrument Operations Engineer

Approved:

______________________________ ________

Veronique Dehant Date

RISE Co-Investigator

______________________________ ________

Sebastien Le Maistre Date

RISE Co-Investigator

______________________________ ________

Paul Byrne Date

PDS Geosciences Node Manager

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1 Introduction

This software interface specification (SIS) describes the format and content of the Rotation and Interior Structure Experiment (RISE) derived Planetary Data System (PDS) data archive. It includes descriptions of the data products and associated metadata, and the archive format, content, and generation pipeline.

1.1 Document Change Log

Table 1: Document change log

Version	Change	Date	Affected portion
0.1	Initial draft	April 13, 2017	All
0.2	Modifications from peer review	June 20, 2017	All
0.3	Addtl peer review corrections	Sept 14, 2017	All
0.4	Added references	July 28, 2020	2.3, 3.2.2
0.5	Added fields to Table 13. Added references	April 11, 2023	2.3, 3.1, 5.1.1.1, Appendix B
1.0	Version for derived product release	May 1, 2023	

1.2 TBD Items

Table 2 lists items that are not yet finalized.

Table 2: List of TBD items

Item	Section(s)	Page(s)

1.3 Abbreviations

Table 3: Abbreviations and their meanings

Abbreviation	Meaning
APSS	Auxiliary Payload Sensor Subsystem
ASCII	American Standard Code for Information Interchange
Atmos	PDS Atmospheres Node (NMSU, Las Cruces, NM)
BWG	Beam Waveguide (DSN Antenna)
CCSDS	Consultative Committee for Space Data Systems
CDR	Calibrated Data Record
CDSCC	Canberra Deep Space Communications Complex
CHDO	Compressed Data Header Object
CODMAC	Committee on Data Management, Archiving, and Computing

Abbreviation	Meaning
CSP	Control Statement Processor language
CSV	Comma-Separated Value (data format)
DOM	Distributed Object Manager
DOY	Day of Year
DSN	Deep Space Network
DSS	Deep Space Station
EDL	Entry Descent and Landing
EDR	Experiment Data Record
FEI	File Exchange Interface
FOV	Field of View
FTP	File Transfer Protocol
GB	Gigabyte(s)
GDSCC	Goldstone Deep Space Communications Complex
GEO	PDS Geosciences Node (Washington University, St. Louis, Missouri)
GNSS	Global Navigation Satellite System (e.g. Global Positioning System)
GSFC	Goddard Space Flight Center (Greenbelt, MD)
HEF	High Efficiency (DSN Antenna)
HGA	High Gain Antenna
HK	Housekeeping
HP3	Heat Flow and Physical Properties Package
HSB	High-Speed Beam Waveguide (DSN Antenna)
HTML	Hypertext Markup Language
ICD	Interface Control Document
IDA	Instrument Deployment Arm
IM	Information Model
ION	Ionosphere (in reference to Ionosphere calibration files)
ISO	International Standards Organization
ITU	International Telecommunication Union
JPL	Jet Propulsion Laboratory (Pasadena, CA)
LGA	Low Gain Antenna

Abbreviation	Meaning
LID	Logical Identifier
LIDVID	Versioned Logical Identifier
LVO	Label Value Object
MAG	Magnetometer
MB	Megabyte(s)
MD5	Message-Digest Algorithm 5
MDSCC	Madrid Deep Space Communications Complex
MGA	Medium Gain Antenna
NAIF	Navigation and Ancillary Information Facility (JPL)
NASA	National Aeronautics and Space Administration
NAV	Navigation
NSSDCA	NASA Space Science Data Coordinated Archive
PDS	Planetary Data System
PDS4	Planetary Data System Version 4
PPI	PDS Planetary Plasma Interactions Node (UCLA)
RA	Restricted ASCII
RAD	Radiometer
RDA	Raw Data Archive
RFS	Radio Frequency Subsystem
RISE	Rotation and Interior Structure Experiment
RS	Radio Science
RSS	Radio Science Subsystem
SCT	Spacecraft Team
SDST	Small Deep Space Transponder
SEIS	Seismic Experiment for Investigating the Subsurface
SFDU	Standard Formatted Data Unit
SIS	Software Interface Specification
SNR	Signal-to-Noise Ratio
SPICE	Spacecraft, Planet, Instrument, C-matrix, and Events (NAIF data format)
SPK	Spacecraft and Planetary ephemeris Kernel (NAIF)

Abbreviation	Meaning
TBD	To Be Determined
TNF	Tracking and Navigation File (TRK 2-34)
TRO	Troposphere (in reference to Troposphere calibration files)
TSAC	Tracking System Analytic Calibration
URN	Uniform Resource Name
VID	Version Identifier
WEA	Weather (in reference to DSN Weather files)
WU	Washington University, St. Louis
XML	eXtensible Markup Language

1.4 Glossary

Many of these definitions are taken from Appendix A of the PDS4 Concepts Document, pds.nasa.gov/pds4/doc/concepts. The reader is referred to that document for more information.

Archive – A place in which public records or historical documents are preserved; also the material preserved – often used in plural. The term may be capitalized when referring to all of PDS holdings – the PDS Archive.

Basic Product – The simplest product in PDS4; one or more data objects and their description objects, which constitute a single observation, document, etc. The only PDS4 products that are *not* basic products are collection and bundle products.

Bundle Product – A list of related collections. 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.

Class – The set of attributes (including a name and identifier) which describes an item defined in the PDS Information Model. A class is generic – a template from which individual items may be constructed.

Collection Product – A list of closely related basic products of a single type (e.g. observational data, browse, documents, etc.). A collection is itself a product, because it is simply a list, but it is not a *basic* product.

Data Object – A generic term for an object that is described by a description object. Data objects include both digital and non-digital objects.

Description Object – An object that describes another object. As appropriate, it has structural and descriptive components. In PDS4 a 'description object' is a digital object – a string of bits with a predefined structure.

Digital Object – An object which consists of electronically stored (digital) data.

Identifier – A unique character string by which a product, object, or other entity may be identified and located. Identifiers can be global, in which case they are unique across all of PDS (and its federation partners). A local identifier must be unique within a label.

Label – The description of a single PDS product. In the PDS4 implementation, labels are constructed using XML.

Logical Identifier (**LID**) – An identifier which identifies the set of all versions of a product.

Versioned Logical Identifier (LIDVID) – The concatenation of a logical identifier with a version identifier, providing a unique identifier for each version of product.

Manifest - A list of contents of a data delivery.

Metadata – Data about data – for example, a description object contains information (metadata) about an object.

Object – A single instance of a class defined in the PDS Information Model.

PDS Information Model – The set of rules governing the structure and content of PDS metadata. The Information Model (IM) has been implemented in XML for PDS4.

Product – One or more tagged objects (digital, non-digital, or both) grouped together and having a single PDS-unique identifier. In the PDS4 implementation, the descriptions are combined into a single XML label. Although it may be possible to locate individual objects within PDS (and to find specific bit strings within digital objects), PDS4 defines 'products' to be the smallest granular unit of addressable data within its complete holdings.

Tagged Object – An entity categorized by the PDS Information Model, and described by a PDS label.

Registry – A data base that provides services for sharing content and metadata.

Repository – A place, room, or container where something is deposited or stored.

XML – eXtensible Markup Language.

XML schema – The definition of an XML document, specifying required and optional XML elements, their order, and parent-child relationships.

2 Overview

2.1 Purpose and Scope

The purpose of this SIS (Software Interface Specification) document is to provide users of the Rotation and Interior Structure Experiment (RISE) archive with a detailed description of the data products and how they are generated, along with a description of the PDS4 archive bundle, the structure in which the data products, documentation, and supporting material are stored. The users for whom this document is intended are the scientists who will analyze the data, including those associated with the project and those in the general planetary science community.

This SIS covers derived data products generated by RISE that are intended to be archived in the Planetary Data System (PDS). In particular, this product is a table of Mars Rotation Parameters.

2.2 SIS Contents

This SIS describes how the RISE team utilizes the Experiment Data Records (EDR) to create the derived data products, and how the data are processed, formatted, labeled, and uniquely identified. The document discusses standards used in generating the data products and software that may be used to access the products. The data structure and organization are described in sufficient detail to enable a user to read and understand the data.

Appendices include a description of the file naming conventions used in the RISE archive, and a list of cognizant persons involved in generating the archive.

2.3 Applicable Documents

[1] Planetary Data System Standards Reference, Version 1.8.0, March 21, 2017.

[2] Planetary Science Data Dictionary Document, Version 1.8.0.0, March 10, 2017.

[3] Planetary Data System (PDS) PDS4 Information Model Specification, Version 1.8.0.0, March 10, 2017.

[4] InSight Archive Generation, Validation, and Transfer Plan, Version 1.1, April 30, 2014.

[5] DSN Telecommunications Link Design Handbook, DSN No. 810-005, Rev E. JPL D-19379. October 28, 2015. http://deepspace.jpl.nasa.gov/dsndocs/810-005/

[6] Folkner, W.M., Asmar, S.W., Dehant, V., and Warwick, R.W., The Rotation and Interior Structure Experiment (RISE) for the InSight mission to Mars (2012). 43rd Lunar and Planetary Science Conference, 1721. http://www.lpi.usra.edu/meetings/lpsc2012/pdf/1721.pdf

[7] Asmar, S.W., R.G. Herrera, and T. Priest, Radio Science Handbook, JPL D-7938 Vol. 6, Jet Propulsion Laboratory, Pasadena, CA, 1995.

[8] Kahan, D. S., Folkner, W. M., Buccino, D. R., Dehant, V., Le Maistre, S., Rivoldini, A., Van Hoolst, T., Yseboodt, M., Marty, J. C. (2021). Mars precession rate determined from radiometric tracking of the InSight Lander. *Planetary Space Science*, Vol. 199, Id. 105208, DOI: 10.1016/j.pss.2021.105208..

[9] Le Maistre, S., Rivoldini, A., Caldiero, A., Yseboodt, M., Baland, R.-M., Beuthe, M., Van Hoolst, T., Dehant, V., Folkner, W. M., Buccino, D., Kahan, D., Marty, J.-C., Antonangeli, D., Badro, J., Drilleau, M., Konopliv, A., Peters, M.-J., Plesa, A.-C., Samuel, H., Tosi, N.,

Wieczorek, M., Lognonne, P., Panning, M., Smrekar, S., and Banerdt, W. B, "Spin state and deep interior structure of Mars from InSight radio tracking," *Nature*, In press, 2023.

[10] Kuchynka, Petr, Folkner, William M., Konopliv, Alex S., Parker, Timothy J., Park, Ryan S., Le Maistre, Sebastien, and Dehant, Veronique. *New Constraints on Mars rotation determined from radiometric tracking of the Opportunity Mars Exploration Rover*. Icarus, 229 (2014), pp. 340–347. doi:10.1016/j.icarus.2013.11.015

[11] Konopliv, A.S., Yoder, C.F., and Standish, E.M., *A global solution for the Mars static and seasonal gravity, Mars orientation, Phobos and Deimos masses, and Mars ephemeris*. Icarus, 182 (2006), pp. 23–50. doi:10.1016/j.icarus.2005.12.025

[12] Baland, RM., Yseboodt, M., Le Maistre, S. et al. The precession and nutations of a rigid Mars. Celest Mech Dyn Astr 132, 47 (2020). https://doi.org/10.1007/s10569-020-09986-0

[13] Reasenberg, R.D., King, R.W., 1979. *The rotation of Mars*. J. Geophys. Res. 84, 6231–6240. doi:10.1029/JB084iB11p06231

[14] Folkner, W.M., Kahn, R.D., Preston, R.A., Yoder, C.F., Standish, E.M., Williams, J.G., Edwards, C.D., Hellings, R.W., Eubanks, T.M., Bills, B.G., 1997a. *Mars dynamics from Earth-based tracking of the Mars Pathfinder lander*. J. Geophys. Res. 102, 4057–4064. doi:10.1029/96JE02125

[15] Folkner, W.M., Yoder, C.F., Yuan, D.N., Standish, E.M., Preston, R.A., 1997b. *Interior structure and seasonal mass redistribution of Mars from radio tracking of Mars Pathfinder*. Science 278, 1749–1752. doi:10.1126/science.278.5344.1749

[16] Buccino, D.R., *InSight Rotation and Interior Structure Experiment PDS EDR Archive Software Interface Specification*, 2015. PDS LID urn:nasa:pds:insight_documents:document_rise:rise_insight_sis_raw.

[17] Evans, S., Taber, W., Drain, T., Smith, J., Wu, H. C., Guevara, M., ... & Evans, J. (2018). MONTE: *The next generation of mission design and navigation software.* CEAS Space Journal, 10(1), 79-86. https://trs.jpl.nasa.gov/bitstream/handle/2014/46063/CL%2316-0971.pdf

[18] Schutz, B., Tapley, B., & Born, G. H. (2004). *Statistical orbit determination*. Elsevier.

The PDS4 Documents [1] through [3] are subject to revision. The most recent versions may be found at http://pds.nasa.gov/pds4. The RISE PDS4 products specified in this SIS have been designed based on the versions current at the time, which are those listed above.

2.4 Audience

This document serves both as a Data Product SIS and an Archive SIS. It describes the format and content of RISE derived data products in detail, and the structure and content of the archive in which the data products, documentation, and supporting material are stored. This SIS is intended to be used both by the instrument team in generating the archive, and by data users wishing to understand the format and content of the archive. Typically these individuals would include scientists, data analysts, and software engineers.

2.5 InSight Mission

InSight was launched in May 2018 and placed a single geophysical lander on Mars to study its deep interior. The Surface Phase consists of Deployment and Penetration, and Science Monitoring. The primary mission ends after one Mars year plus 40 sols.

The science payload comprises two instruments: the Seismic Experiment for Interior Structure (SEIS) and the Heat-Flow and Physical Properties Probe (HP^3). In addition, the Rotation and Interior Structure Experiment (RISE) uses the spacecraft X-band communication system to provide precise measurements of planetary rotation. SEIS and HP^3 are placed on the surface with an Instrument Deployment System (IDS) comprising an Instrument Deployment Arm (IDA), Instrument Deployment Camera (IDC), and Instrument Context Camera (ICC). There are also several supporting instruments. The Auxiliary Payload Sensor Subsystem (APSS) includes the pressure sensor, the magnetometer, and Temperature and Wind for InSight (TWINS) sensors and collects environmental data in support of SEIS. These data are used by SEIS to reduce and analyze their data. The radiometer (RAD) is used by the HP^3 team to measure surface temperature and thermal properties to support their data analysis.

2.5.1 Landing Site

The landing site is targeted for Elysium Planitia with estimated coordinates of 4 deg N latitude and 138 deg E longitude. The predicted Cartesian coordinates are shown in Table 4 in the IAU_MARS reference frame relative to the Mars center (SPICE code 499). Please note that these are pre-launch estimated position of the lander in the IAU_MARS frame, and should not be confused with the any estimated positions or coordinate systems after InSight landing.

Table 4: Predicted InSight lander location in IAU_MARS frame

	x (km)	y (km)	z (km)
InSight Lander	-2432.124	2351.137	263.853

Important Note: the RISE investigation has estimated a new set of coordinates describing the position of the lander as part of the analysis process. The information provided above is only an estimate of the landing site coordinates. See Section 3.1 and Section 5 for details.

2.6 RISE Instrument Description

The RISE instrument utilizes the X-band telecommunications capability of the InSight lander in combination with the coherent Doppler tracking equipment at the Deep Space Network (DSN) to perform radio science experiments to determine the precession and nutation of the Martian spin axis. A brief summary of the instrument follows. For a complete description of the RISE instrument, refer to the RISE EDR SIS [16].

For more information about RISE, refer to Folkner et.al. (2012) [7].

2.6.1 Science Objectives

The objective of RISE is to estimate the precession and nutation (the "wobble") of the Martian spin axis, as well as the variations in the rotation of Mars. Through the estimation of the spin wobble, the size and density of the Martian core can be derived. The estimations of precession and nutation are based on the Doppler tracking between the InSight lander and the Earth-based observing stations of the Deep Space Network. A DSN station transmits a carrier at a known frequency to the InSight lander where the signal is detected and retransmitted coherently back to the DSN, where the received frequency is measured.

The Doppler is a measurement of the relative velocity between InSight and the DSN station. The measurements are crucial for navigation of the spacecraft during cruise before arrival at Mars. RISE measurements begin once the spacecraft has landed on the surface. These measurements are used as the input to the orbit determination process, where the Martian spin axis parameters are estimated alongside the coordinates of the lander.

Because RISE is a radio science experiment, other radio science investigations may be performed using the Doppler data, for example, length-of-day (LOD) variations. The derived data products included in the RISE Derived data set, which are strictly related to the measurements of the Martian spin and positioning of the lander.

2.6.2 Instrument Summary

RISE is a Radio Science instrument and contains both the telecommunications equipment onboard the InSight lander and a ground element, the Earth-observing stations of the Deep Space Network (DSN).

The InSight telecommunications system uses both X-band and UHF systems for communications. The X-band system utilizes a Small Deep Space transponder (SDST) for uplink and downlink tracking and communications during cruise and surface operations. The UHF system is used during EDL for downlink-only communications and uplink and downlink communications during surface operations. The UHF system is used in relay-mode: the lander communicates with current Martian orbiter assets which relay the information to and from Earth. RISE utilizes the X-band systems onboard the InSight lander to provide direct-to-Earth measurements of Doppler shift caused by the rotation of Mars.

The Deep Space Network (DSN) is the ground network that provides tracking and communications for InSight. Three Deep Space Communications Complexes (DSCCs) comprise the DSN tracking network. The Goldstone DSCC (GDSCC) is located near Barstow, CA; the Canberra DSCC (CDSCC) is located near Canberra, Australia; and the Madrid DSCC (MDSCC) is located near Madrid, Spain. The complexes are strategically placed roughly 120 degrees in longitude apart to give continuous coverage of the sky. Each complex is equipped with several antennas, including at least one each 70-m, 34-m High Efficiency (HEF), and 34-m Beam Wave Guide (BWG), and associated electronics, and operational systems.

Primary activity at each complex is radiation of commands to and reception of telemetry data from active spacecraft. Transmission and reception is possible in several radio-frequency bands, the most common being S-band (nominally a frequency of 2100-2300 MHz), X-band (7100-8500 MHz), and Ka-band (31800-32300 MHz). Transmitter output powers of up to 400 kW are available.

The Deep Space Network is managed by the Jet Propulsion Laboratory of the California Institute of Technology for the U.S. National Aeronautics and Space Administration.

2.6.3 Measured Parameters

The primary radiometric data type utilized in the RISE investigation is measurement of the Doppler shift caused by the relative motion between a transmitter (InSight lander) and receiver (the DSN antenna). The frequency received at the ground station differs from the frequency as transmitted by the lander. Doppler data collected for the RISE investigation are primarily two-way Doppler (coherent), where the DSN station transmits a signal and the uplink carrier phase is then measured and recorded as the transmitted frequency. This transmitted frequency is calculated so that the received frequency at the spacecraft is the one assigned to it by the Consultative Committee for Space Data Systems (CCSDS) and the International Telecommunication Union (ITU). The spacecraft receives the signal, which is then multiplied by the turn-around ratio and re-transmitted back to the DSN station. The DSN station then measures and records the downlink carrier phase. The Doppler measurement is then constructed as the difference between transmitted frequency and received frequency divided by the turn-around ratio. A three-way Doppler measurement can be constructed in the same manner as a two-way measurement using a different DSN station for transmission and reception.

Additional radiometric data types not utilized for the RISE scientific investigation include radiometric ranging and VLBI. These are described in more detail in the RISE EDR SIS [16] or the DSN Telecommunications Link Design Handbook [5], but are not used in the RISE investigation.

2.6.4 Operational Modes

Both the DSN and InSight's X-band telecommunications system can be configured in different modes for the desired link type.

Nominally, four tracking passes were scheduled per week for RISE science, 45 minutes in duration each. Depending on the project requirements, there may or may not be telemetry modulated onto the transmission back to the DSN. For RISE, Doppler measurements are made at times at low elevation at the lander, where the Doppler signature due to the rotation of Mars is at its largest and when the Earth is in the antenna Field of View (FOV) (East for rising Earth and West for an Earth-set).

2.6.5 Operational Considerations

The InSight mission is divided into five phases: launch, cruise, EDL, deployment, and science monitoring. RISE did not begin until the deployment phase after landing, when instrument checkout was performed. Since RISE is not a deployed instrument, nominally one pass was conducted each week using the X-band telecommunications system for RISE. During science monitoring, nominally four passes were conducted per week, except when the energy of the spacecraft became low.

On rare occasions the spacecraft may enter safe mode to protect itself from anomalous circumstances. During these times, RISE data were not collected.

2.6.6 System Calibration

System-level or hardware calibrations are performed routinely by DSN personnel and before each pass during "pre-cal", or pre-calibration.

Earth's troposphere and ionosphere cause delays and phase changes on the transmitted and received signals. The collected Doppler data are corrected for these delays and phase changes. The methods and processes are described in detail in the RISE EDR SIS [16].

3 RISE Derived Data Products

3.1 Data Product Overview

RISE derived data products contain the parameters used to describe the rotation of Mars. A brief summary is given below on the definition of the Mars rotation. **In addition to this summary, the user of these data should read the following publications for details on how to perform the coordinate transform using the rotation parameters in the RISE Derived data set:**

Kahan, D. S., Folkner, W. M., Buccino, D. R., Dehant, V., Le Maistre, S., Rivoldini, A., Van Hoolst, T., Yseboodt, M., and Marty, J. C. (2021). Mars precession rate determined from radiometric tracking of the InSight Lander. *Planetary Space Science*, Vol. 199, Id. 105208, DOI: 10.1016/j.pss.2021.105208. [8]

Le Maistre, S., Rivoldini, A., Caldiero, A., Yseboodt, M., Baland, R.-M., Beuthe, M., Van Hoolst, T., Dehant, V., Folkner, W. M., Buccino, D., Kahan, D., Marty, J.-C., Antonangeli, D., Badro, J., Drilleau, M., Konopliv, A., Peters, M.-J., Plesa, A.-C., Samuel, H., Tosi, N., Wieczorek, M., Lognonne, P., Panning, M., Smrekar, S., and Banerdt, W. B. (2023). Spin state and deep interior structure of Mars from InSight radio tracking. *Nature*, in press, 2023. [9]

Kuchynka, P., Folkner, W. M., Konopoliv, A. S., Parker, T. J., Park, R. S., Le Maistre, S., and Dehant, V. (2014). New Constraints on Mars rotation determined from radiometric tracking of the Opportunity Mars Exploration Rover. *Icarus*, 229, pp. 340–347, DOI: 10.1016/j.icarus.2013.11.015. [10]

Konopliv, A.S., Yoder, C.F., Standish, E.M., Yuan, D.-N., and Sjogren, W. L. (2006). A global solution for the Mars static and seasonal gravity, Mars orientation, Phobos and Deimos masses, and Mars ephemeris. *Icarus*, 182, pp. 23–50, DOI: 10.1016/j.icarus.2005.12.025. [11]

Baland, R. M., Yseboodt, M., Le Maistre, S., Van Hoolst, T., and Dehant, V. (2020). The precession and nutations of a rigid Mars. *Celest. Mech. Dyn. Astr.,* 132, Id. 47, DOI: 10.1007/s10569-020-09986-0. [12]

Reasenberg, R.D., and King, R.W. (1979). The rotation of Mars. *J. Geophys. Res.*, 84, pp. 6231–6240, DOI: 10.1029/JB084iB11p06231. [13]

Folkner, W.M., Kahn, R.D., Preston, R.A., Yoder, C.F., Standish, E.M., Williams, J.G., Edwards, C.D., Hellings, R.W., Eubanks, T.M., and Bills, B.G. (1997a). Mars dynamics from Earth-based tracking of the Mars Pathfinder lander. *J. Geophys. Res.*, 102, E2, pp. 4057–4064, DOI: 10.1029/96JE02125. [14]

Folkner, W.M., Yoder, C.F., Yuan, D.N., Standish, E.M., and Preston, R.A. (1997b). *Interior structure and seasonal mass redistribution of Mars from radio tracking of Mars Pathfinder*. Science 278, Id. 5344, pp. 1749–1752, DOI: 10.1126/science.278.5344.1749. [15]

Each Mars Rotation Parameters data product contains coefficients utilized in the coordinate transformation between inertial space defined as the International Celestial Reference Frame (ICRF) and the Mars body-fixed coordinate frame. Each Mars Rotation Parameters data product is a tabular list. The file format is described in detail in Section 5.1.1.1.

The parameters in the Mars Rotation Parameters data product correspond with the coordinate transformation as described in Kuchynka et al. (2014) [10], Konopliv et al. (2006) [11], Folkner et al. (1997b) [15], and Reasenberg and King (1979) [13]. Figure 1 illustrates the definition of the coordinate frame transformation.

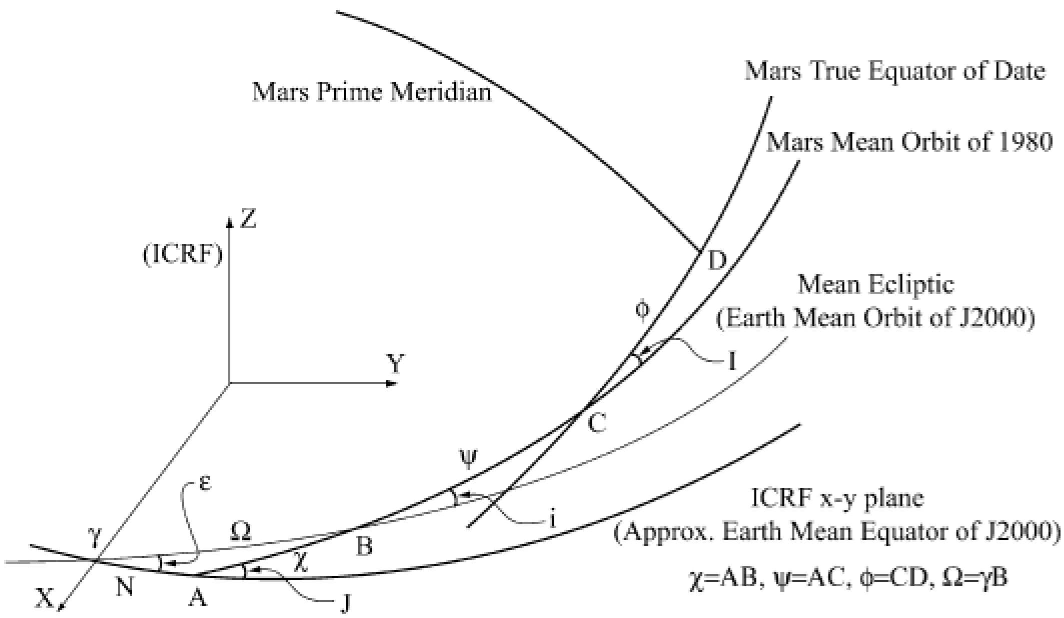

Figure 1. Illustration for transformation between Mars body-fixed coordinate system and ICRF (Konopliv et al., 2006) [11].

The order of transforms are described as [10], [11]:

$$\vec{r}_{in} = R_z(-N)R_x(-J)R_z(-\psi)R_x(-I)R_z(-\phi)R_y(X_p)R_x(Y_p)\vec{r}_{bf} \tag{1}$$

Where the functions $R_n(\theta)$ define rotations about the n-axis ($n = X, Y, Z$) by angle θ:

$$R_x(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{bmatrix} \tag{2}$$

$$R_y(\theta) = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \tag{3}$$

$$R_z(\theta) = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{4}$$

Angles N and J are non-varying constants with values 3.37919183 degrees and 24.67682669 degrees, respectively. Angles X_p and Y_p describe the body-fixed components of polar motion in the x and y direction, respectively, and are nominally equal to zero ($X_p = 0$, $Y_p = 0$). Angles ϕ,

ψ, and I are described in detail below. The time varying parameters t and l' are time past the J2000 epoch and Mars mean anomaly, respectively. The spin angle (ϕ) is defined [10], [11]:

$$\phi = \phi_0 + \dot{\phi}_0 t - \sum_{m=0}^{9} \cos(I)\sin(\alpha_m t + \theta_m) + \sum_{j=1}^{4}(\phi_{cj}\cos(jl') + \phi_{sj}\sin(jl')) + \sum_{j=1}^{3}\phi_{rj}\sin(jl') \tag{5}$$

The angle from the node of the Mars mean orbit and the ICRF x-y plane to the node of the Mars true equator of date and Mars mean orbit (ψ) is given as [10], [11]:

$$\psi = \psi_0 + \dot{\psi}_0 t + \sum_{m=0}^{9}\psi_m \sin(\alpha_m t + \theta_m) \tag{6}$$

The inclination of the Mars true equator of date relative to the Mars mean orbit (I) is given as [10], [11]:

$$I = I_0 + \dot{I}_0 t + \sum_{m=0}^{9} I_m \cos(\alpha_m t + \theta_m) \tag{7}$$

Summations indexed using m describe nutation motion. The nutation amplitudes ψ_m and I_m are computed as [10], [11]:

$$\psi_m = \psi_m^0 + \frac{F\alpha_m}{\alpha_m^2 - \sigma_0^2}\left(\alpha_m \psi_m^0 + \frac{\sigma_0 I_m^0}{\sin(I_0)}\right) \tag{8}$$

$$I_m = I_m^0 + \frac{F\alpha_m}{\alpha_m^2 - \sigma_0^2}(\alpha_m I_m^0 + \sigma_0 \psi_m^0 \sin(I_0)) \tag{9}$$

Values α_m, θ_m, ψ_m^0, I_m^0 are defined in Reasenberg and King (1979) [13] and Konopliv et al. (2006) [11] and are summarized in Table 5, where n' is the mean motion of Mars, l'_o is the mean anomaly of Mars at the J2000 epoch. Angle q is a slowly changing angle which can be described by $q = q_0 + \dot{q}t$, where q_0 is the angle at the J2000 epoch (q =142.0 degrees and $\dot{q}$ is the rate of 1.3 degrees per century).

Table 5. Mars nutation values from Eq. (8) and Eq. (9). [11]

Index m	$\boldsymbol{\alpha_m}$	$\boldsymbol{\theta_m}$	$\boldsymbol{I_m^0}$ **(mas)**	$\boldsymbol{\psi_m^0}$ **(mas)**
0	0	0	-1.4	0

Index m	α_m	θ_m	I_m^0 (mas)	ψ_m^0 (mas)
1	n'	l'_o	-0.4	-632.6
2	$2n'$	$2l'_o$	0	-44.2
3	$3n'$	$3l'_o$	0	-4.0
4	n'	$l'_o + q$	-49.1	-104.5
5	$2n'$	$2l'_o + q$	515.7	1097.0
6	$3n'$	$3l'_o + q$	112.8	240.0
7	$4n'$	$4l'_o + q$	19.2	40.9
8	$5n'$	$5l'_o + q$	3.0	6.5
9	$6n'$	$6l'_o + q$	0.4	1.0

The value σ_0 is the free core nutation rate of the fluid core and can be estimated. Its value is included in the Mars Rotation Parameters data product. The Core Factor F is a dimensionless unit described by [10], [11] is a function of the polar moment of inertia C, polar moment of inertia of the fluid core C_f, and the parameters γ (dynamic elasticity of the core-mantle boundary) and e_f (elastic correction). The value for F can be estimated and is given in the Mars Rotation Parameters data product.

$$F = \frac{C_f}{C - C_f}\left(1 - \frac{\gamma}{e_f}\right) \tag{10}$$

The coefficients $\phi_0, \dot{\phi}_0, \psi_0, \dot{\psi}_0, I_0, \dot{I}_0, \phi_{c1} \dots \phi_{c4}, \phi_{s1} \dots \phi_{s4}, F$, and σ_0 are the primary parameters included in the Mars Rotation Parameters data product. The remaining coefficients are constants based on models and are described above or included in the above references.

3.2 Data Processing

This section describes the processing of RISE data products, their structure and organization, and their labeling.

3.2.1 Data Processing Levels

Data processing levels mentioned in this SIS refer to the PDS4 processing level described in Table 6.

Table 6: Data processing level definitions

PDS4 processing level	PDS4 processing level description	CODMAC Level (used in PDS3)	NASA Level (used in PDS3)
n/a	Telemetry data with instrument data embedded. PDS does not archive telemetry data.	1	0
Raw	Original data from an instrument. If compression, reformatting, packetization, or other translation has been applied to facilitate data transmission or storage, those processes are reversed so that the archived data are in a PDS approved archive format. Often called EDRs (Experimental Data Records).	2	1A
Partially Processed	Data that have been processed beyond the raw stage but which have not yet reached calibrated status. These and more highly processed products are often called RDRs (Reduced Data Records).	3	1A
Calibrated	Data converted to physical units, which makes values independent of the instrument.	4	1B
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, such as calibration tables or tables of viewing geometry, used to interpret observational data should also be classified as 'derived' data if not easily matched to one of the other three categories.	4+	2+

RISE derived data products described in this SIS are considered NASA Level 2 (Derived) data products.

3.2.2 Data Product Generation

Updated Mars Rotation Parameters and Lander Coordinate data are computed directly from the RISE EDR data. A version of JPL's legacy Orbit Determination Program (ODP) called MONTE is utilized for these computations. The MONTE software set can be licensed from JPL/Caltech and can be requested online (https://montepy.jpl.nasa.gov/). See [17] for further information on MONTE. For the orbit determination process in general, see [18]. Figure 2 is a flowchart that describes how the data products are computed.

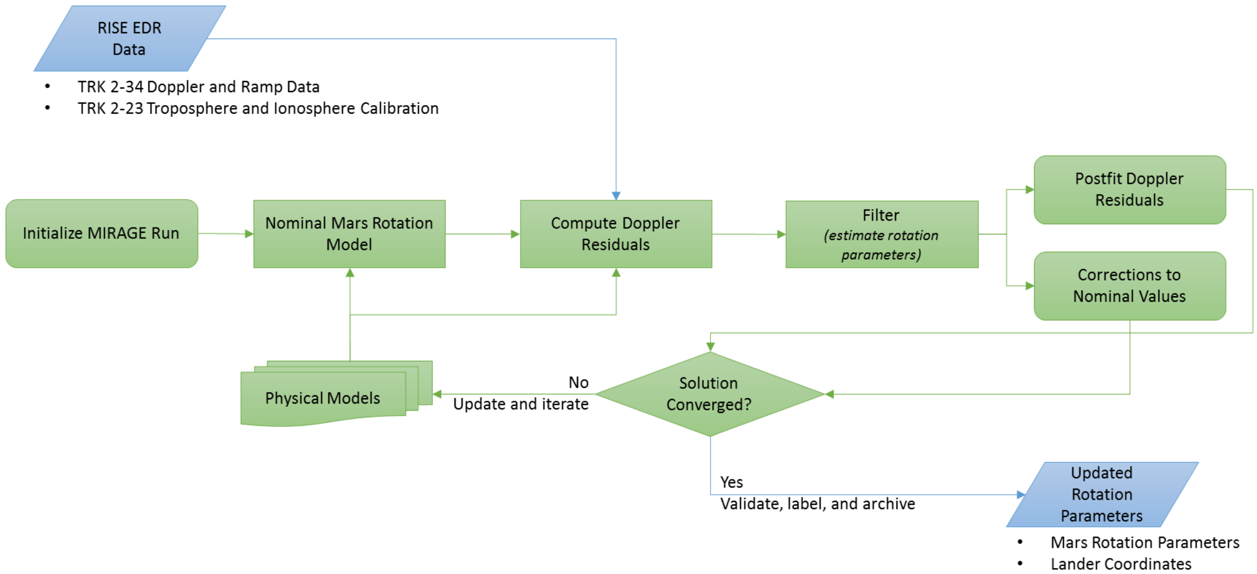

Figure 2. Flowchart for how RISE derived data products are computed from RISE EDR data.

First, the Mars rotation models are evaluated based upon physical models of planetary and spacecraft motion, or in the case of InSight, the lander position on the surface of Mars is modeled. Then, MONTE ingests the DSN Doppler data (TRK 2-34) and calibrations (TRK 2-23) from the RISE EDR data set, calibrates the Doppler measurements, and computes residual frequency for each Doppler measurement (observed minus computed). The residuals are fed into a filter, which estimates corrections to the parameters to be estimated (in the case of RISE, Mars Rotation Parameters and lander coordinates are estimated, among others). The physical models are updated and the process is repeated until convergence. Once the solution converges, the rotation parameters are thoroughly validated and tested. If the analysts and investigators deem the solution valid, it is published, labeled and archived.

3.2.3 Data Flow

This section describes only those portions of the InSight data flow that are directly connected to RISE archiving. A full description of InSight data flow is provided in the InSight Archive Generation, Validation, and Transfer Plan [4].

The RISE team utilizes the RISE EDR to estimate the Mars rotation parameters (Section 3.2.2). These parameters are published in a scientific paper and delivered to the PDS Geosciences node directly by the RISE team.

The RISE team generates PDS4 labels, assembles the data and documentation into archive bundles, and delivers the bundles to the PDS Geosciences Node. Deliveries take place according to the release schedule agreed upon by the InSight project and PDS as specified in the InSight Archive Plan [4]. The Geosciences Node validates the bundles and makes them available to the public online.

3.3 Standards Used in Generating Data Products

RISE products and labels comply with Planetary Data System standards, including the PDS4 data model, as specified in applicable documents [1], [2] and [3].

3.3.1 Time Standards

All data products in this archive use the UTC (Universal Time Coordinated) standard time format.

3.3.2 Coordinate Systems

The primary data products contained in this archive describe a derived Mars-fixed coordinate system(s). The coordinate systems are relative to inertial space, i.e. ICRF. The lander coordinates in the archive are relative to the coordinate system described in the label.

3.3.3 Data Storage Conventions

RISE derived products are stored as ASCII text in a Comma-Separated Value (CSV) table format. The accompanying PDS4 XML label describes the contents and format of the table.

3.4 Applicable Software

Software for parsing, reducing, and analyzing data have been developed at several institutions. Because such software must usually operate at the bit-level and is written for a narrow range of platforms, it is not suitable for general distribution. No software is included with this archival data set.

The SPICE toolkit is generally useful for analyzing data of this type and is available on the NAIF node of PDS: http://naif.jpl.nasa.gov/naif/toolkit.html.

3.5 Backups and duplicates

The Geosciences Node keeps two copies of each archive product. One copy is the primary online archive copy, another is a backup copy. Once the archive products are fully validated and approved for inclusion in the archive, a third copy of the archive is sent to the NASA Space Science Data Coordinated Archive (NSSDCA) for long-term preservation in a NASA-approved deep-storage facility. The Geosciences Node may maintain additional copies of the archive products, either on or off-site as deemed necessary.

4 RISE Archive Organization, Identifiers and Naming Conventions

This section describes the basic organization of the RISE derived data archive under the PDS4 Information Model (IM) (Applicable Documents [1] and [3]), including the naming conventions used for the bundle, collection, and product unique identifiers.

4.1 Logical Identifiers

Every product in PDS is assigned an identifier which allows it to be uniquely identified across the system. This identifier is referred to as a Logical Identifier or LID. A LIDVID (Versioned Logical Identifier) includes product version information, and allows different versions of a specific product to be referenced uniquely. Product's LID and VID are defined as separate attributes in the product label. LIDs and VIDs are assigned by PDS and are formed according to the conventions described in Sections 4.1.1 and 4.1.2 below. The uniqueness of a product's LIDVID may be verified using the PDS Registry and Harvest tools.

4.1.1 LID Formation

LIDs take the form of a Uniform Resource Name (URN). LIDs are restricted to ASCII lower case letters, digits, dash, underscore, and period. Colons are also used, but only to separate prescribed components of the LID. Within one of these prescribed components dash, underscore, or period are used as separators. LIDs are limited in length to 255 characters.

InSight RISE LIDs are formed according to the following conventions:

- Bundle LIDs are formed by appending a bundle specific ID to the base ID:

  urn:nasa:pds:<bundle ID>

  Example: urn:nasa:pds:insight_rise_derived

  The bundle ID must be unique across all products archived with the PDS.

- Collection LIDs are formed by appending a collection specific ID to the collection's parent bundle LID:

  urn:nasa:pds: <bundle ID>:<collection ID>

  Example: urn:nasa:pds:insight_rise_derived:data_rotation

  Since the collection LID is based on the bundle LID, which is unique across PDS, the only additional condition is that the collection ID must be unique across the bundle. Collection IDs correspond to the collection type (e.g. "browse", "data", "document", etc.). Additional descriptive information may be appended to the collection type (e.g. "data-raw", "data-calibrated", etc.) to insure that multiple collections of the same type within a single bundle have unique LIDs.

- Basic product LIDs are formed by appending a product specific ID to the product's parent collection LID:

  urn:nasa:pds: <bundle ID>:<collection ID>:<product ID>

  Example: urn:nasa:pds:insight_rise_derived:data_rotation:jrnst_ro003_rot

  Since the product LID is based on the collection LID, which is unique across PDS, the only additional condition is that the product ID must be unique across the collection. Often the product LID is set to be the same as the data file name without the extension. See Section 4.5 below for examples of RISE data product LIDs.

4.1.2 VID Formation

Product Version IDs consist of major and minor components separated by a "." (M.n). Both components of the VID are integer values. The major component is initialized to a value of "1", and the minor component is initialized to a value of "0". The minor component resets to "0" when the major component is incremented. The PDS Standards Reference [1] specifies rules for incrementing major and minor components.

4.1.3 File Naming Convention

RISE files are named per the following convention. In the table below, *G* denotes the generating institution (e.g., *J* = JPL, *B* = Royal Observatory of Belgium), *T* indicates the type of data (e.g. *R* = Rotation parameters, *L* = Lander position), *SSS* is a 3-character modifier specified by the data producer, typically the mission ID, *NNNNVV* is a 4- to 6-character modifier specified by the data producer, typically the name of the solution. For lander coordinate files, *LLLL* denotes the 4-digit identifier of the lander (e.g. *nsyt* = InSight, *mera* = Mars Exploration Rover A, etc).

Table 7: RISE data product file naming convention

Data Product Type	Naming Convention
Mars Rotation Parameters	GTSSS_NNNNVV_rot.csv
Lander Coordinates	GTSSS_NNNNVV_LLLL_coord.csv

4.2 Bundles

The highest level of organization for a PDS archive is the bundle. A bundle is a set of one or more related collections which may be of different types. A collection is a set of one or more related basic products which are all of the same type. Bundles and collections are logical structures, not necessarily tied to any physical directory structure or organization.

The complete InSight RISE archive is organized into the bundles described in Table 8. This SIS addresses only the Derived Data Bundle.

Table 8: RISE Bundles

Bundle Logical Identifier	PDS4 Processing Level	Description
urn:nasa:pds:insight_rise_raw	Raw	RISE Raw Data Bundle
urn:nasa:pds:insight_rise_derived	Derived	RISE Derived Data Bundle

4.3 Collections

Collections consist of basic products all of the same type. The RISE Derived Data Bundle contains the collections listed in Table 9. These are described in Section 4.5.

Table 9: Collections in the RISE Derived Data Bundle

Collection Logical Identifier	Collection Type	Description
urn:nasa:pds:insight_rise_derived:data_rotation	Data	Mars Rotation Parameter Files
urn:nasa:pds:insight_rise_derived:data_lander_coord	Data	Lander Coordinate Files
urn:nasa:pds:insight_document:document_rise	Document	Documentation in support of the data contained in the InSight bundles

4.4 Products

A PDS product consists of one or more data objects and an accompanying PDS label file. PDS labels provide identification and description information for labeled objects. The PDS label includes a Logical Identifier (LID) by which any PDS labeled product is uniquely identified throughout all PDS archives. PDS4 labels are XML-formatted ASCII files.

For RISE derived products, the LID is the same as the file name without the extension. The tables below give examples of LIDs for RISE products.

4.4.1 RISE Derived Data Collection

The following table gives examples of LIDs for derived data.

Table 10: Examples of RISE Derived Data LIDs

Data Product Type	Example LID
Mars Rotation Parameter File	urn:nasa:pds:insight_rise_derived:data_rotation:jrnst_ro003_rot
Lander Coordinate File	urn:nasa:pds:insight_rise_derived:data_lander_coord:jrnst_ro003_nsyt_coord

4.5 InSight Document Bundle and Collections

Documents are also considered as products by PDS, and have LIDs, VIDs and PDS4 labels just as data products do. The InSight archives include an InSight Document Bundle, which consists of collections of documents relevant to the mission itself and all the science experiments. The RISE Team is responsible for the RISE document collection in this bundle.

Table 11: Collections in the InSight Document Bundle

Collection Logical Identifier	Description
urn:nasa:pds:insight_documents:document_mission	InSight mission, spacecraft and lander descriptions
urn:nasa:pds:insight_documents:document_apss	APSS SIS, instrument description, and other relevant documents
urn:nasa:pds:insight_documents:document_camera	Camera SIS, instrument description, and other relevant documents
urn:nasa:pds:insight_documents:document_hp3rad	HP^3/RAD SIS, instrument description, and other relevant documents
urn:nasa:pds:insight_documents:document_ida	IDA SIS, instrument description, and other relevant documents
urn:nasa:pds:insight_documents:document_mag	MAG SIS, instrument description, and other relevant documents
urn:nasa:pds:insight_documents:document_rise	RISE SIS (this document), instrument description, and other relevant documents
urn:nasa:pds:insight_documents:document_seis	SEIS SIS, instrument description, and other relevant documents
urn:nasa:pds:insight_documents:document_spice	SPICE relevant documents

Documents in the InSight Document Collections are assigned LIDs based on file names such that they are unique identifiers.

5 RISE Archive Product Formats

Data that comprise the RISE derived data archive are formatted in accordance with PDS specifications (see Applicable Documents [1], [2] and [3]). This section provides details on the formats used for each of the products included in the archive.

5.1 Data Product Formats

This section describes the format and record structure of each of the data file types.

5.1.1 Derived data file data structure

5.1.1.1 Mars Rotation Parameter Files

The Mars Rotation Parameter file is a comma-delimited ASCII text file (CSV file) containing four columns. Each has multiple rows (minimum of 14), with each row corresponding to a parameter name, value of the parameter, and formal uncertainty of the parameter. The number of digits printed corresponds with the uncertainty of the value. If the fourth column (formal uncertainty) is set to zero (i.e. 0.0), then the parameter is considered fixed. Table 12 describes the format of each file.

Table 12: Format description for the Mars Rotation Parameters data files

Column	Max Width	Type	Description	Example
1	12	String	Parameter Name	PHI_0
2	10	String	Unit	deg
3	15	Float	Value of Parameter	133.385601
4	15	Float	Formal Uncertainty of Parameter	0.000123

Each Mars Rotation Parameters data product has a corresponding XML label with the same naming convention.

Although any parameter from the equations in Section 3.1 may be present in the data file, Table 13 describes the required parameters ("Parameter Name") each Mars Rotation Parameters file must contain along with its corresponding mathematical expression and description of where the term is located within the equations from Section 3.1. See also [9] for more information.

Table 13: Valid Mars Rotation Parameters and mathematical expressions

Parameter	Mathematical Expression	Description
PHI_0	ϕ_0	Section 3.1, Equation 5, Term 1
PHI_0_RATE	$\dot{\phi}_0$	Section 3.1, Equation 5, Term 2
PHI_C1	ϕ_{c1}	Section 3.1, Equation 2, Term 3

Parameter	Mathematical Expression	Description
PHI_C2	ϕ_{c2}	Section 3.1, Equation 5, Term 3
PHI_C3	ϕ_{c3}	Section 3.1, Equation 5, Term 3
PHI_C4	ϕ_{c4}	Section 3.1, Equation 5, Term 3
PHI_S1	ϕ_{s1}	Section 3.1, Equation 5, Term 3
PHI_S2	ϕ_{s2}	Section 3.1, Equation 5, Term 3
PHI_S3	ϕ_{s3}	Section 3.1, Equation 5, Term 3
PHI_S4	ϕ_{s4}	Section 3.1, Equation 5, Term 3
PSI_0	ψ_0	Section 3.1, Equation 6, Term 1
PSI_0_RATE	$\dot{\psi}_0$	Section 3.1, Equation 6, Term 2
I_0	I_0	Section 3.1, Equation 7, Term 1
I_0_RATE	$\dot{I}_0$	Section 3.1, Equation 7, Term 2
F	F	Section 3.1, Equation 8, Term 2
SIGMA_0	σ_0	Section 3.1, Equation 8, Term 2
TOTAL_MOMENT_OF_INERTIA	C	Section 3.1, Equation 10, Term 1
CORE_MOMENT_OF_INERTIA	C_f	Section 3.1, Equation 10, Term 1
CORE_RADIUS	Function of F, σ_0	See [9]
CORE_DENSITY	Function of F, σ_0	See [9]

5.1.1.2 Lander Coordinate Files

The Lander Coordinate file is a comma-delimited ASCII text file containing eight columns. Each file has one row per lander, corresponding to the *(x,y,z)*-position and uncertainty of the respective lander in the Mars body-fixed coordinate system described in the file's label and first column. The number of digits printed corresponds with the uncertainty of the value. Table 14 describes the format of each file.

Table 14: Format description for the Lander Coordinate files

Column	Max Width	Type	Description	Example
1	11	String	Solution Description/Coordinate System	JRNST_SAMPL
2	4	String	Spacecraft Name	NSYT
3	15	Float	*x*-position, in kilometers	-2432.124
4	15	Float	Uncertainty in *x*-position, in kilometers	0.001
5	15	Float	*y*-position, in kilometers	2351.137
6	15	Float	Uncertainty in *y*-position, in kilometers	0.001
7	15	Float	*z*-position, in kilometers	263.853
8	15	Float	Uncertainty in *z*-position, in kilometers	0.001

Each Lander Coordinate data product has a corresponding XML label with the same naming convention.

5.2 Document Product Formats

Documents in this archive are provided as PDF/A (www.pdfa.org/download/pdfa-in-a-nutshell) or as plain ASCII text if no special formatting is required.

5.3 PDS Labels

Each RISE product is accompanied by a PDS4 label. PDS4 labels are ASCII text files written in the eXtensible Markup Language (XML). Product labels are detached from the files they describe (with the exception of the Product_Bundle label). There is one label for every product. A product, however, may consist of one or more data objects. The data objects of a given product may all reside in a single file, or they may be stored in multiple files, in which case the PDS4 label points to all the files. A PDS4 label file usually has the same name as the data product it describes, but always with the extension ".xml".

Documents are also considered to be products; they have PDS4 labels just as other products do.

For the InSight mission, the structure and content of PDS labels conform to the PDS master schema and Schematron files based upon the PDS Information Model [3]. By use of an XML editor the schema and Schematron files may be used to validate the structure and content of the product labels. In brief, the schema is the XML model that PDS4 labels must follow, and the Schematron files are a set of validation rules that are applied to PDS4 labels.

The PDS master schema and Schematron files documents are produced, managed, and supplied to InSight by the PDS. In addition to these documents, the InSight mission has produced additional XML schemas and Schematron files which govern the products in this archive. These documents contain attribute and parameter definitions specific to the InSight mission. A list of the XML documents associated with this archive is provided at http://pds.nasa.gov/pds4/schema/released/.

Examples of PDS labels for the RISE archive are shown in Appendix B.

Acknowledgements

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Appendix A Support staff and cognizant persons

Table 15: Archive support staff

RISE Team		
Name	**Affiliation**	**Email**
Dustin R. Buccino RISE Instrument Operations Engineer	JPL	Dustin.R.Buccino@jpl.nasa.gov
Sami W. Asmar RISE Co-Investigator	JPL	Sami.W.Asmar@jpl.nasa.gov
William M. Folkner RISE Co-Investigator	JPL	William.M.Folkner@jpl.nasa.gov
Daniel S. Kahan RISE Operations Task Lead	JPL	Daniel.S.Kahan@jpl.nasa.gov
Sébastien Le Maistre RISE Co-Investigator	ROB	sebastien.lemaistre@oma.be
Véronique Dehant RISE Co-Investigator	ROB	veronique.dehant@oma.be
PDS Geosciences Node		
Name	**Affiliation**	**Email**
Paul Byrne Director	Washington University	paul.byrne@wustl.edu
Edward Guinness	Washington University	guinness@wustl.edu
Jennifer Ward	Washington University	jgward@wustl.edu

Appendix B Example Data Product Labels

This section provides examples of product labels for the various data types described in this document. The content of actual RISE labels may vary from these examples.

Mars Rotation Parameter File


```
<?xml version="1.0" encoding="UTF-8"?>
<?xml-model
  href="http://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1900.sch"
    schematypens="http://purl.oclc.org/dsdl/schematron"?>
<?xml-model
  href="http://pds.nasa.gov/pds4/mission/insight/v1/PDS4_INSIGHT_1600.sch"
    schematypens="http://purl.oclc.org/dsdl/schematron"?>

<Product_Observational
  xmlns="http://pds.nasa.gov/pds4/pds/v1"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:pds="http://pds.nasa.gov/pds4/pds/v1"
  xmlns:insight="http://pds.nasa.gov/pds4/mission/insight/v1"
  xsi:schemaLocation="http://pds.nasa.gov/pds4/pds/v1
  http://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1900.xsd

  http://pds.nasa.gov/pds4/mission/insight/v1
  http://pds.nasa.gov/pds4/mission/insight/v1/PDS4_INSIGHT_1600.xsd">
  <Identification_Area>

<logical_identifier>urn:nasa:pds:insight_rise_derived:data_rotation:brnst_ro001_rot</logical_id
entifier>
    <version_id>1.0</version_id>
    <title>Mars Rotation Parameters</title>
    <information_model_version>1.9.0.0</information_model_version>
    <product_class>Product_Observational</product_class>
    <Modification_History>
      <Modification_Detail>
        <modification_date>2023-04-05</modification_date>
        <version_id>1.0</version_id>
        <description>
          PDS4 label for Mars Rotation Parameters for RISE Derived dataset
        </description>
      </Modification_Detail>
    </Modification_History>
  </Identification_Area>
  <Observation_Area>
    <Time_Coordinates>
      <start_date_time>1950-01-01T00:00:00Z</start_date_time>
      <stop_date_time>2050-01-01T00:00:00Z</stop_date_time>
    </Time_Coordinates>
```

<Primary_Result_Summary>
<purpose>Science</purpose>
<processing_level>Derived</processing_level>
<description>
The Mars Rotation Parameter file is a comma-delimited ASCII text file containing coefficients utilized in the coordinate transformation between inertial space defined as the International Celestial Reference Frame (ICRF) and the Mars body-fixed coordinate frame. In essence, the rotation parameters define a Mars body-fixed coordinate frame themselves.

This file describes the ro001 Mars body-fixed coordinate frame. The frame was derived utilizing a least-squares fit of the Doppler data collected by the InSight lander. The reference for this coordinate frame is:

S. Le Maistre, A. Rivoldini, A. Caldiero, M. Yseboodt, R.-M. Baland, M. Beuthe, T. Van Hoolst, V. Dehant, W. M. Folkner, D. Buccino, D. Kahan, J.-C. Marty, D. Antonangeli, J. Badro, M. Drilleau, A. Konopliv, M.-J. Peters, A.-C. Plesa, H. Samuel, N. Tosi, M. Wieczorek, P. Lognonne, M. Panning, S. Smrekar and W. B. Banerdt, "Spin state and deep interior structure of Mars from InSight radio tracking," Nature, 2023.

Each parameter in this data product corresponds with a parameter in the dynamic equations that describe the rotation of Mars. In addition to the publication listed above, it is recommended that the user of the data read the following additional publications for background on how to interpret each parameter, its meaning, and how to utilize the parameters to perform the coordinate transformation between ICRF and the Mars body-fixed coordinate frame. A summary is provided in Section 3 of the RISE Derived data product Software Interface Specification document included in this archive.

Kuchynka, Petr, Folkner, William M., Konopoliv, Alex S., Parker, Timothy J., Park, Ryan S., Le Maistre, Sebastien, and Dehant, Veronique. New Constraints on Mars rotation determined from radiometric tracking of the Opportunity Mars Exploration Rover. Icarus, 229 (2014), pp. 340–347.
Konopliv, A.S., Yoder, C.F., and Standish, E.M., A global solution for the Mars static and seasonal gravity, Mars orientation, Phobos and Deimos masses, and Mars ephemeris. Icarus, 182 (2006), pp. 23–50.

Reasenberg, R.D., King, R.W., 1979. The rotation of Mars. J. Geophys. Res. 84, 6231–6240.

Folkner, W.M., Kahn, R.D., Preston, R.A., Yoder, C.F., Standish, E.M., Williams, J.G., Edwards, C.D., Hellings, R.W., Eubanks, T.M., Bills, B.G., 1997a. Mars dynamics from Earth-based tracking of the Mars Pathfinder lander. J. Geophys. Res. 102, 4057–4064.

Folkner, W.M., Yoder, C.F., Yuan, D.N., Standish, E.M., Preston, R.A., 1997b. Interior structure and seasonal mass redistribution of Mars from radio tracking of Mars Pathfinder. Science 278, 1749–1752.

Baland, R. M., Yseboodt, M., Le Maistre, S., Van Hoolst, T., and Dehant, V., 2020. The precession and nutations of a rigid Mars. Celest. Mech. Dyn. Astr., 132, Id. 47, DOI: 10.1007/s10569-020-09986-0.

</description>
</Primary_Result_Summary>
<Investigation_Area>
<name>InSight</name>
<type>Mission</type>
<Internal_Reference>

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</Internal_Reference>
</Investigation_Area>
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<Observing_System_Component>
<name>NSYT</name>
<type>Spacecraft</type>
<Internal_Reference>

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<reference_type>is_instrument_host</reference_type>
</Internal_Reference>
</Observing_System_Component>
<Observing_System_Component>
<name>RISE</name>
<type>Instrument</type>
<description>Rotation and Interior Structure Experiment</description>
<Internal_Reference>
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<reference_type>is_instrument</reference_type>
</Internal_Reference>
</Observing_System_Component>
</Observing_System>
<Target_Identification>
<name>Mars</name>
<type>Planet</type>
<Internal_Reference>
<lidvid_reference>urn:nasa:pds:context:target:target.mars::1.0</lidvid_reference>
<reference_type>data_to_target</reference_type>

```
      </Internal_Reference>
    </Target_Identification>
    <Mission_Area>
      <insight:Observation_Information>
        <insight:release_number>0017</insight:release_number>
        <insight:mission_phase_name>SURFACE MISSION</insight:mission_phase_name>
        <insight:product_type>ROTATION_PARAMETERS</insight:product_type>
      </insight:Observation_Information>
    </Mission_Area>
    <Discipline_Area></Discipline_Area>
  </Observation_Area>

  <Reference_List>
    <Internal_Reference>

<lidvid_reference>urn:nasa:pds:insight_documents:document_mission::1.0</lidvid_reference>
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    </Internal_Reference>
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erence>
      <reference_type>data_to_document</reference_type>
    </Internal_Reference>
  </Reference_List>

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      <file_size unit="byte">636</file_size>
      <records>16</records>
      <md5_checksum>d7953144d9d37b2e67a98b4b11b283aa</md5_checksum>
    </File>
    <Table_Delimited>
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      <records>16</records>
      <record_delimiter>Carriage-Return Line-Feed</record_delimiter>
      <field_delimiter>Comma</field_delimiter>
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        <fields>4</fields>
        <groups>0</groups>
```

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  <field_number>1</field_number>
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  <maximum_field_length unit="byte">12</maximum_field_length>
  <description>
    Name of the parameter in the dynamical equations that
    describe the coordinate transformation between ICRF and
    the Mars body-fixed coordinate frame.
  </description>
</Field_Delimited>
<Field_Delimited>
  <name>UNIT</name>
  <field_number>2</field_number>
  <data_type>ASCII_String</data_type>
  <maximum_field_length unit="byte">10</maximum_field_length>
  <description>
    The unit the parameter is defined in. Valid units include:
      Angle units:
        deg (degrees)
        arcsec (arcsecond)
        mas (milli-arcseconds)
        mdeg (milli-degrees)
      Time units:
        year
        day
        second
      Mass units:
        kg (kilograms)
      Distance units:
        km (kilometers)
        m (meters)
      Dimensionless units are described with 'NULL'
  </description>
</Field_Delimited>
<Field_Delimited>
  <name>PARAMETER_VALUE</name>
  <field_number>3</field_number>
  <data_type>ASCII_Real</data_type>
  <maximum_field_length unit="byte">16</maximum_field_length>
  <description>
    The numeric value of the parameter.
  </description>
</Field_Delimited>
```

```
            <Field_Delimited>
                <name>PARAMETER_UNCERTAINTY</name>
                <field_number>4</field_number>
                <data_type>ASCII_Real</data_type>
                <maximum_field_length unit="byte">16</maximum_field_length>
                 <description>
                    Formal uncertainty of the parameter.
                </description>
            </Field_Delimited>

        </Record_Delimited>
    </Table_Delimited>
  </File_Area_Observational>

</Product_Observational>
```


Lander Coordinate File


```
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<?xml-model
   href="http://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1900.sch"
      schematypens="http://purl.oclc.org/dsdl/schematron"?>
<?xml-model
   href="http://pds.nasa.gov/pds4/mission/insight/v1/PDS4_INSIGHT_1600.sch"
      schematypens="http://purl.oclc.org/dsdl/schematron"?>

<Product_Observational
   xmlns="http://pds.nasa.gov/pds4/pds/v1"
   xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
   xmlns:pds="http://pds.nasa.gov/pds4/pds/v1"
   xmlns:insight="http://pds.nasa.gov/pds4/mission/insight/v1"
   xsi:schemaLocation="http://pds.nasa.gov/pds4/pds/v1
                  http://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1900.xsd

                  http://pds.nasa.gov/pds4/mission/insight/v1
                  http://pds.nasa.gov/pds4/mission/insight/v1/PDS4_INSIGHT_1600.xsd">
   <Identification_Area>

<logical_identifier>urn:nasa:pds:insight_rise_derived:data_lander_coord:blnst_ro001_nsyt_coor
d</logical_identifier>
      <version_id>1.0</version_id>
      <title>InSight Lander Coordinates</title>
      <information_model_version>1.9.0.0</information_model_version>
      <product_class>Product_Observational</product_class>
      <Modification_History>
```

<Modification_Detail>
<modification_date>2023-04-04</modification_date>
<version_id>1.0</version_id>
<description>
PDS4 label for InSight Lander Coordinate data product for RISE Derived dataset
</description>
</Modification_Detail>
</Modification_History>
</Identification_Area>
<Observation_Area>
<Time_Coordinates>
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<stop_date_time>2050-01-01T00:00:00Z</stop_date_time>
</Time_Coordinates>
<Primary_Result_Summary>
<purpose>Science</purpose>
<processing_level>Derived</processing_level>
<description>
The Lander Coordinate file describes the location of the InSight (NSYT)
lander in the ro001 Mars body-fixed coordinate system. The definition of
this coordinate system relative to the International Celestial Reference
Frame (ICRF) is defined in the Rotation Parameters file with the logical
identifier (LID):

urn:nasa:pds:insight_rise_derived:data_rotation:brnst_ro001_rot

The location of the lander is provided as X-Y-Z cartesian coordinates.
</description>
</Primary_Result_Summary>

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<type>Mission</type>
<Internal_Reference>

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</Internal_Reference>
</Investigation_Area>
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<name>InSight</name>
<Observing_System_Component>
<name>NSYT</name>
<type>Spacecraft</type>
<Internal_Reference>

```
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      </Observing_System_Component>
      <Observing_System_Component>
        <name>RISE</name>
        <type>Instrument</type>
        <description>Rotation and Interior Structure Experiment</description>
        <Internal_Reference>
          <lid_reference>urn:nasa:pds:context:instrument:rise.insight</lid_reference>
          <reference_type>is_instrument</reference_type>
        </Internal_Reference>
      </Observing_System_Component>
    </Observing_System>
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      <name>Mars</name>
      <type>Planet</type>
      <Internal_Reference>
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      </Internal_Reference>
    </Target_Identification>
    <Mission_Area>
      <insight:Observation_Information>
        <insight:release_number>0017</insight:release_number>
        <insight:mission_phase_name>SURFACE MISSION</insight:mission_phase_name>
        <insight:product_type>LANDER_COORD</insight:product_type>
      </insight:Observation_Information>
    </Mission_Area>
    <Discipline_Area></Discipline_Area>
  </Observation_Area>

  <Reference_List>
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    </Internal_Reference>
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<lid_reference>urn:nasa:pds:insight_documents:document_rise:rise_insight_sis_derived</lid_ref
erence>
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    </Internal_Reference>
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```

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  </File>
  <Table_Delimited>
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    <offset unit="byte">0</offset>
    <parsing_standard_id>PDS DSV 1</parsing_standard_id>
    <records>1</records>
    <record_delimiter>Carriage-Return Line-Feed</record_delimiter>
    <field_delimiter>Comma</field_delimiter>
    <Record_Delimited>
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      <groups>0</groups>

      <maximum_record_length unit="byte">98</maximum_record_length>

      <Field_Delimited>
        <name>SOLUTION_DESCRIPTION</name>
        <field_number>1</field_number>
        <data_type>ASCII_String</data_type>
        <maximum_field_length unit="byte">11</maximum_field_length>
        <description>
          Identifier to describe which Mars body-fixed coordinate
          system this position applies to. The solution description
          will correspond with the first 11 characters of the filename
          of a Mars Rotation Parameters product.
        </description>
      </Field_Delimited>

      <Field_Delimited>
        <name>SPACECRAFT</name>
        <field_number>2</field_number>
        <data_type>ASCII_String</data_type>
        <maximum_field_length unit="byte">4</maximum_field_length>
        <description>
          An abbreviation of the spacecraft name. Examples include:
            NSYT = InSight Lander
            NSTE = InSight East Antenna
            NSTW = InSight West Antenna
```

PHNX = Phoenix Lander
MERA = Mars Exploration Rover A (Spirit)
MERB = Mars Exploration Rover B (Opportunity)
VIK1 = Viking 1
VIK2 = Viking 2
</description>
</Field_Delimited>
<Field_Delimited>
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<field_number>3</field_number>
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<description>
The X-coordinate of the specified lander, in kilometers
</description>
</Field_Delimited>

<Field_Delimited>
<name>X_POSITION_UNCERTAINTY</name>
<field_number>4</field_number>
<data_type>ASCII_Real</data_type>
<maximum_field_length unit="byte">15</maximum_field_length>
<unit>km</unit>
<description>
The uncertainty X-coordinate of the specified lander, in kilometers
</description>
</Field_Delimited>
<Field_Delimited>
<name>Y_POSITION</name>
<field_number>5</field_number>
<data_type>ASCII_Real</data_type>
<maximum_field_length unit="byte">15</maximum_field_length>
<unit>km</unit>
<description>
The Y-coordinate of the specified lander, in kilometers.
</description>
</Field_Delimited>

<Field_Delimited>
<name>Y_POSITION_UNCERTAINTY</name>
<field_number>6</field_number>
<data_type>ASCII_Real</data_type>
<maximum_field_length unit="byte">15</maximum_field_length>
<unit>km</unit>
<description>

The uncertainty Y-coordinate of the specified lander, in kilometers
</description>
</Field_Delimited>
<Field_Delimited>
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<data_type>ASCII_Real</data_type>
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<unit>km</unit>
<description>
The Z-coordinate of the specified lander, in kilometers.
</description>
</Field_Delimited>

<Field_Delimited>
<name>Z_POSITION_UNCERTAINTY</name>
<field_number>8</field_number>
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<unit>km</unit>
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The uncertainty Z-coordinate of the specified lander, in kilometers
</description>
</Field_Delimited>

</Record_Delimited>
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</Product_Observational>