SOFTWARE INTERFACE SPECIFICATION

SPHERICAL HARMONICS ASCII DATA RECORD (SHADR)

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DOCUMENT CHANGE LOG

REVISION NUMBER	REVISION DATE	SECTION AFFECTED	REMARKS
1.0	06/02/20	All	Adapted MGS SHADR SIS to include

			Mars Reconnaissance Orbiter and MESSENGER.
1.0	06/03/15	All	Miscellaneous edits
1.0	06/06/29	All	Integration of PDS review comments
1.1	07/04/04	4.2.2.1 4.2.2.2 Appendix C	Integration of RS review comments
1.2	08/07/28	2.3	Updated file naming convention for MRO
2.0	13/04/17	All	Adapted to include GRAIL
2.1	13/05/22	All	Minor edits

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ACRONYMS AND ABBREVIATIONS

ANSI	American National Standards Institute
APL	Applied Physics Laboratory
ARC	Ames Research Center
ARCDR	Altimetry and Radiometry Composite Data Record
ASCII	American Standard Code for Information Interchange
CCSDS	Consultative Committee for Space Data Systems
CD-WO	Compact-disc write-once
CNES	Centre National d'Etudes Spatiales
CR	Carriage Return
dB	Decibel
DSN	Deep Space Network
DVD	Digital Video Disc or Digital Versatile Disc
EGM96	Earth Gravitational Model 1996
FEA	Front End Assembly
GRAIL	Gravity Recovery and Interior Laboratory
GSFC	Goddard Space Flight Center
IEEE	Institute of Electrical and Electronic Engineers
IAU	International Astronomical Union
JHU	Johns Hopkins University
JPL	Jet Propulsion Laboratory
J2000	IAU Official Time Epoch
K	Degrees Kelvin
kB	Kilobytes
km	Kilometers
LAST	Laser Altimeter Science Team (MESSENGER)
LF	Line Feed
LP	Lunar Prospector (mission or spacecraft)
MB	Megabytes
MESSENGER	MErcury Surface Space ENvironment, GEochemistry, and Ranging (acronym for mission to Mercury)
MGN	Magellan
MGS	Mars Global Surveyor
MIT	Massachusetts Institute of Technology
MLA	MESSENGER Laser Altimeter
MO	Mars Observer

MRO	Mars Reconnaissance Orbiter
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
NAV	Navigation Subsystem/Team
ODL	Object Definition Language (PDS)
PDB	Project Data Base
PDS	Planetary Data System
RST	Radio Science Team
SCET	Space Craft Event Time
SDS	Science Data System
SFDU	Standard Formatted Data Unit
SHADR	Spherical Harmonics ASCII Data Record
SHBDR	Spherical Harmonics Binary Data Record
SHM	Spherical Harmonics Model
SIS	Software Interface Specification
SPARC	Sun Scaleable Processor Architecture
SPK	Spacecraft and Planet Kernel Format, from NAIF
TBD	To Be Determined
UTC	Universal Time Coordinated

1. GENERAL DESCRIPTION

1.1. Overview

This Software Interface Specification (SIS) describes Spherical Harmonics ASCII Data Record (SHADR) files. The SHADR is intended to be general and may contain coefficients for spherical harmonic expansions of gravity, topography, magnetic, and other fields.

1.2. Scope

The format and content specifications in this SIS apply to all phases of the project for which a SHADR is produced.

The SHADR was defined initially for gravity models derived from Magellan (MGN) and Mars Observer (MO) radio tracking data [1], but the format is more generally useful. The original SHADR has been adapted for the Mars Global Surveyor (MGS), Lunar Prospector (LP), Mars Reconnaissance Orbiter (MRO), and MESSENGER missions. This update of the SIS was made to include the Gravity Recovery and Interior Laboratory (GRAIL) mission [16]. Some of the original mission-specific documentation has been omitted, but the file format descriptions should still be applicable for the GRAIL mission.

Specifics of the various models are included in [2], which will be updated as data for new spherical harmonic models are incorporated within the SHADR definition. A Spherical Harmonic Binary Data Record is also defined [3], which may be more suitable for large models or when all error covariances will be included in the final product.

The Jet Propulsion Laboratory (JPL), Pasadena, California, manages the Mars Reconnaissance Orbiter Mission [4], the Mars Global Surveyor Mission, and the GRAIL Mission for the National Aeronautics and Space Administration (NASA). The Johns Hopkins University, Laurel, Maryland, USA manages the MESSENGER Mission [5,6] for NASA.

1.3. Applicable Documents

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1.4. System Siting

1.4.1. Interface Location and Medium

SHADR files are created at the institution conducting the science analysis. SHADR files can be electronic files or can be stored on compact-disc write-once (CD-WO) or DVD type media.

1.4.2. Data Sources, Transfer Methods, and Destinations

SHADR files are created from radio tracking, vertical sounding, in situ, and/or other measurements at the institution conducting the scientific data analysis. They are transferred to and deposited in a data system (such as the PDS) specified by the managing institution.

1.4.3. Generation Method and Frequency

Spherical Harmonic Models are developed separately at each institution conducting scientific analyses on raw data; each model meets criteria specified by the investigators conducting the analysis. Each model requires data with complete sampling (in terms of longitude and latitude coverage on the planet), so that SHADR files will be issued infrequently and on schedules which cannot be predicted at this time.

1.5. Assumptions and Constraints

1.5.1. Usage Constraints

None.

1.5.2. Priority Phasing Constraints

None.

1.5.3. Explicit and Derived Constraints

None.

1.5.4. Documentation Conventions

1.5.4.1. Data Format Descriptions

The reference data unit is the byte. Data may be stored in fields with various sizes and formats, viz. one-, two-, and four-byte binary integers, four- and eight-byte binary floating-point numbers, and character strings. Data are identified throughout this document as:

char 8 bits character
uchar 8 bits integer
short 16 bits integer
long 32 bits integer
float 32 bits floating point (sign, exponent, and mantissa)
double 64 bits floating point (sign, exponent, and mantissa)
u (prefix) unsigned (as with ulong for unsigned 32-bit integer)
other special data structures such as time, date, etc. which are described within this document

If a field is described as containing n bytes of ASCII character string data, this implies that the leftmost (lowest numbered) byte contains the first character, the next lowest byte contains the second character, and so forth.

An array of n elements is written as array[n]; the first element is array[0], and the last is array[n-1]. Array[n][m] describes an n x m element array, with first element array[0][0], second element array[0][1], and so forth.

Floating point (real) numbers are represented as double precision character strings in the FORTRAN 1P1E23.16 format. Fixed point (integer) numbers are represented using the FORTRAN I5 format.

1.5.4.2. Time Standards
SHADR files use the January 1.5, 2000 epoch as the standard time. Within the data files, all times are reported in Universal Coordinated Time (UTC) as strings of 23 ASCII characters. The time format is "YYYY-MM-DDThh:mm:ss.fff", where "-", "T", ":", and "." are fixed delimiters; "YYYY" is the year "19nn" or "20nn"; "MM" is a two-digit month of year; "DD" is a two-digit day of month; "T" separates the date and time segments of the string; "hh" is hour of day; "mm" is the minutes of hour (00-59); "ss" is the seconds of minute (00-59); and "fff" is fractional seconds in milliseconds.

The date format is "YYYY-MM-DD", where the components are defined as above.

1.5.4.3. Coordinate Systems
The SHADR uses the appropriate planetocentric fixed body coordinate system [7,8]. This may be an IAU system (e.g. IAU2000 [7]) or the new body-fixed Mars reference frame defined by Konopliv et al. [9]. At present, the MESSENGER mission has adopted the IAU2000 model for Mercury [7]. The coordinate system for lunar geopotential models will be a body figure axis system defined by the lunar librations which are resolved by lunar laser ranging [10], or a more coarse frame defined by the IAU [7].

GRAIL uses the DE 421 Lunar Body-Fixed Frame [17] as defined in the DE 421 planetary ephemeris [18].

1.5.4.4. Limits of This Document
This document applies only to SHADR data files.

1.5.4.5. Typographic Conventions
This document has been formatted for simple electronic file transfer and display. Line lengths are limited to approximately 80 ASCII characters, including line delimiters. No special fonts or structures are included within the file. Constant width characters are assumed for display.

2. INTERFACE CHARACTERISTICS

2.1. Hardware Characteristics and Limitations

2.1.1. Special Equipment and Device Interfaces

Users of the SHADR product must have access to the data system (or media) on which the SHADR files are stored.

2.1.2. Special Setup Requirements

None.

2.2. Volume and Size

SHADR products have variable length, depending on the degree and order of the model and the number of tables included. A model of degree and order N will require approximately (N*(N+1)/2)*137 bytes for storage of spherical harmonic coefficients and associated uncertainties. A SHADR file for the geopotential that contains coefficients and coefficient standard deviations through degree 90 will be 510 kB in size. Vector quantities (e.g., magnetic field) may be described by a single SHADR (in which all components are represented) or by a separate SHADR for each field component. If the single SHADR includes covariances, the file size will be approximately 27 times larger than the combined volumes of the three component files because of the inter-component covariance terms. In general, the SHBDR [3] is recommended when the data include error covariances because of the smaller data volume associated with binary formats.

2.3. Labeling and Identification

The length of file names is limited to 27 or fewer characters before the period delimiter and 3 characters after the period delimiter. Each file has a name which describes its contents. The name includes the following structure which uniquely identifies it among SHADR products. Beginning with the MRO gravity products the following naming convention is used:

GTsss_nnnnvv_SHA.TAB

where

"G" denotes the generating institution
- "J" for the Jet Propulsion Laboratory
- "G" for Goddard Space Flight Center
- "M" for Massachusetts Institute of Technology

"T" indicates the type of data represented
- "G" for gravity field

"sss" is a 3-character modifier specified by the data producer. This modifier is used to indicate the source spacecraft or project, such as GRX for the pair of GRAIL spacecraft.

"_" the underscore character is used to delimit modifiers in the file name for clarity.

"nnnnvv" is a 4- to 6-character modifier specified by the data producer. Among other things, this modifier may be used to indicate the target body, whether the SHADR contains primary data values as specified by "T" or uncertainties/errors, and/or the version number. For GRAIL, this modifier indicates the degree and order of the solution for the gravity field, topography or magnetic field.

"SHA" denotes that this is an ASCII file of Spherical Harmonic coefficients

".TAB" indicates the data is stored in tabular form.

Each SHADR file is accompanied by a detached PDS label; that label is a file in its own right, having the name GTsss_nnnnvv_SHA.LBL.

2.4. Interface Medium Characteristics

SHADR products are electronic files.

2.5. Failure Protection, Detection, and Recovery Procedures

None.

2.6. End-of-File Conventions

End of file labeling complies with standards for the medium on which the files are stored.

3. ACCESS

3.1. Programs Using the Interface

Data contained in SHADR files will be accessed by programs at the home institutions of science investigators. Those programs cannot be identified here.

3.2. Synchronization Considerations

3.2.1. Timing and Sequencing Considerations

N/A

3.2.2. Effective Duration

N/A

3.2.3. Priority Interrupts

None.

3.3. Input/Output Protocols, Calling Sequences

None.

4. DETAILED INTERFACE SPECIFICATIONS

4.1. Structure and Organization Overview

The SHADR is a file generated by software at the institution conducting scientific data analysis. Each SHADR file is accompanied by a detached PDS label.

4.2. Detached PDS Label

The detached PDS label is a file with two parts -- a header, and a set of one, two, or three PDS TABLE object definitions. The header contains information about the origin of the file and its general characteristics such as record type and size. The TABLE object definitions describe the format and content of the tables that make up the SHADR data file. The SHADR Header Table Object definition is required. The SHADR Coefficients Table Object definition is required if there is a SHADR Coefficients Table in the file; the SHADR Covariance Table Object definition is required if there is a SHADR Covariance Table. Each detached PDS label is constructed of ASCII records; each record in the label contains exactly 80 characters. The last two characters in each record are the carriage-return (ASCII 13) and line-feed (ASCII 10) characters. An example of a complete label and data object is given in APPENDIX C.

4.2.1 Label Header

The structure of the label header is illustrated in Figure 4-2-1.
Keyword definitions are given below.

PDS_VERSION_ID =
The version of the Planetary Data System for which these data have been prepared; set to PDS3 by agreement between the mission and PDS.

RECORD_TYPE =
The type of record. Set to "FIXED_LENGTH" to indicate that all logical records have the same length.

RECORD_BYTES =
The number of bytes per (fixed-length) record. It is usually most convenient if this has been set equal to the length of records in the SHADR_COVARIANCE_TABLE.

FILE_RECORDS =
The number of records in the SHADR file: instance dependent.

^SHADR_HEADER_TABLE =
File name and record number at which SHADR_HEADER_TABLE begins. Set to ("GTsss_nnnnvv_SHA.TAB ",1) where " GTsss_nnnnvv_SHA.TAB " is the file name as described in Section 2.3, and 1 is the record number since this is the first record in the SHADR file.

```
|=========================================================================|
|                                                                         |
| Figure 4-2-1 SHADR Label Header                                         |
|=========================================================================|
|                                                                         |
| PDS_VERSION_ID = PDS3                                                   |
| RECORD_TYPE = FIXED_LENGTH                                              |
| RECORD_BYTES = nnn                                                      |
| FILE_RECORDS = nnn                                                      |
| ^SHADR_HEADER_TABLE = ("GTsss_nnnnvv_SHA.TAB",1)                        |
| ^SHADR_COEFFICIENTS_TABLE = ("GTsss_nnnnvv_SHA.TAB ",nn)                |
| ^SHADR_COVARIANCE_TABLE = ("GTsss_nnnnvv_SHA.TAB ",nnn)                 |
| INSTRUMENT_HOST_NAME = "cccccccccccccccccccc"                           |
| TARGET_NAME = "cccc"                                                    |
| INSTRUMENT_NAME = "cccccccccccccccccccccccc"                            |
| DATA_SET_ID = "cccccccccccccccccccccccc"                                |
| OBSERVATION_TYPE = "cccccccccccc"                                       |
| ORIGINAL_PRODUCT_ID = "cccccccccccc"                                    |
| PRODUCT_ID = " GTsss_nnnnvv_SHA.TAB "                                   |
| PRODUCT_RELEASE_DATE = YYYY-MM-DD                                       |
| DESCRIPTION = "cccccccccccccccccc"                                      |
| START_ORBIT_NUMBER = nnnn                                               |
| STOP_ORBIT_NUMBER = nnnn                                                |
| START_TIME = YYYY-MM-DDThh:mm:ss                                        |
| STOP_TIME = YYYY-MM-DDThh:mm:ss                                         |
| PRODUCT_CREATION_TIME = YYYY-MM-DDThh:mm:ss.fff                         |
| PRODUCER_FULL_NAME = "cccccccccccc"                                     |
| PRODUCER_INSTITUTION_NAME = "ccccccccccc"                               |
| PRODUCT_VERSION_TYPE = "cccccccccccc"                                   |
| PRODUCER_ID = "ccccccc"                                                 |
| SOFTWARE_NAME = "ccccccc;Vn.m"                                          |
|=========================================================================|
```

^SHADR_COEFFICIENTS_TABLE =
File name and record number at which the SHADR_COEFFICIENTS_TABLE begins. The Coefficients Table is optional; this pointer will not appear in the SHADR label if there is no Coefficients Table. Set to ("GTsss_nnnnvv_SHA.TAB",nn) where "GTsss_nnnnvv_SHA.TAB" is the file name as described in Section 2.3, and "nn" is the record number in the file where the Coefficients Table begins.

^SHADR_COVARIANCE_TABLE=
File name and record number at which SHADR_COVARIANCE_TABLE begins. The Covariance Table is optional; this pointer will not appear in the SHADR label if there is no Covariance Table. Set to ("GTsss_nnnnvv_SHA.TAB",nn) where "GTsss_nnnnvv_SHA.TAB" is the file name as described in Section 2.3, and "nn" is the record number in the file where the Covariance Table begins.

INSTRUMENT_HOST_NAME =
Name of the spacecraft; acceptable names include "MARS GLOBAL SURVEYOR" "LUNAR PROSPECTOR", "MARS RECONNAISSANCE ORBITER", "MERCURY SURFACE, SPACE, ENVIRONMENT, GEOCHEMISTRY, AND RANGING", "MAGELLAN", and "GRAVITY RECOVERY AND INTERIOR LABORATORY".
TARGET_NAME =
A character string which identifies the target body.
For MRO or MGS SHADR files, the character string "MARS".
For MESSENGER SHADR files the character string will be "MERCURY".
For LP and GRAIL SHADR files, the character string will be "MOON".
For Magellan SHADR files, the character string will be "VENUS".

INSTRUMENT_NAME =
Name of the instrument; set to "RADIO SCIENCE SUBSYSTEM" for products

generated from radio science data, or set to other instrument names as appropriate. Set to "LUNAR GRAVITY RANGING SYSTEM" for GRAIL.

DATA_SET_ID =
Identifier for the data set of which this SHADR product is a member.
-Set to "MRO-M-RSS-5-SDP-Vn.m" for Mars Reconnaissance Orbiter;
-Set to "MESS-H-RSS-5-SDP-Vn.m" for MESSENGER;
-Set to "MGS-M-RSS-5-SDP-Vn.m" for MGS; and "
-Set to "LP-L-RSS-5-SHGBDR-L2-Vn.m" for Lunar Prospector;
-Set to "GRAIL-L-LGRS-5-RDR-Vn.m" for GRAIL.
The suffix Vn.m indicates the version number of the data set.

OBSERVATION_TYPE=
A character string which identifies the data in the product. For the spherical harmonic model of a gravity field, the character string "GRAVITY FIELD". For a model of planet topography, the character string "TOPOGRAPHY".

ORIGINAL_PRODUCT_ID =
Optional. An identifier for the product provided by the producer. Generally a file name, different from PRODUCT_ID, which would be recognized at the producer's home institution.

PRODUCT_ID =
A unique identifier for the product within the collection identified by DATA_SET_ID. Generally, the file name used in pointers ^SHADR_HEADER_TABLE, ^SHADR_COEFFICIENTS_ TABLE, and/or ^SHADR_COVARIANCE_TABLE. The naming convention is defined in Section 2.3.

PRODUCT_RELEASE_DATE =
The date on which the product was released to the Planetary Data System; entered in the format "YYYY-MM-DD", where components are defined in Section 1.5.4.2.

DESCRIPTION =
A short description of the SHADR product.

START_ORBIT_NUMBER =
Optional. The first orbit represented in the SHADR product. An integer.

STOP_ORBIT_NUMBER =
Optional. The last orbit represented in the SHADR product. An integer.

START_TIME =
Optional. The date/time of the first data included in the model, expressed in the format "YYYY-MM-DDThh:mm:ss" where the components are defined in section 1.5.4.2.

STOP_TIME =
Optional. The date/time of the last data included in the model, expressed in the format "YYYY-MM-DDThh:mm:ss" where the components are defined in section 1.5.4.2.

PRODUCT_CREATION_TIME =
The time at which this SHADR was created; expressed in the format "YYYY-MM-DDThh:mm:ss.fff" where the components are defined in Section 1.5.4.2.

PRODUCER_FULL_NAME =
The name of the person primarily responsible for production of this SHADR file. Expressed as a character string, for example "JAMES T. KIRK".

PRODUCER_INSTITUTION_NAME =

The name of the institution primarily responsible for production of this SHADR. Standard values include:

"STANFORD UNIVERSITY"
"GODDARD SPACE FLIGHT CENTER"
"JET PROPULSION LABORATORY"
"CENTRE NATIONAL D'ETUDES SPATIALES"
"MASSACHUSETTS INSTITUTE OF TECHNOLOGY"

PRODUCT_VERSION_TYPE =
The version of this SHADR. Standard values include "PREDICT", "PRELIMINARY", and "FINAL".

PRODUCER_ID =
The entity responsible for creation of the SHADR product. For products generated by the Mars Reconnaissance Orbiter Gravity Science Team set to "MRO GST". For products generated by the MESSENGER Laser Altimeter Science Team set to "MESS LAST". For products generated by the Mars Global Surveyor Radio Science Team, set to "MGS RST". For products generated by the GRAIL Science Data System, set to "SDS".

SOFTWARE_NAME =
The name and version number of the program creating this SHADR file; expressed as a character string in the format "PROGRAM_NAME;n.mm" where "PROGRAM_NAME" is the name of the software and "n.mm" is the version number. (e.g. "SOLVE;200201.02")

4.2.2 TABLE Object Definitions

TABLE object definitions completely define the TABLE objects for each SHADR file. Minor tailoring of the definitions for different OBSERVATION_TYPES precludes specification of exact definitions here. DESCRIPTION values, for example, will likely be tailored for each product type. In no case should there be a need to change the structure of the file, however. Entries "*" are provided by the label generating program based on information supplied elsewhere.

4.2.2.1 SHADR Header Object Definition

Each SHADR Header Object is completely defined by the Header Object Definition in its Label. The Definition which follows gives the structure of the Header Object; some of the DESCRIPTION values may vary from product to product. The SHADR Header Object Definition is a required part of the SHADR label file. It immediately follows the label header.

```
OBJECT = SHADR_HEADER_TABLE
ROWS = 1
COLUMNS = 8
ROW_BYTES = 137
ROW_SUFFIX_BYTES = 107
INTERCHANGE_FORMAT = ASCII
DESCRIPTION = "The SHADR header includes descriptive
information about the spherical harmonic coefficients which follow
in SHADR_COEFFICIENTS_TABLE. The header consists of a single record
of eight (delimited) data columns requiring 137 bytes, a pad of
105 ASCII blank characters, an ASCII carriage-return, and an ASCII
line-feed."

OBJECT = COLUMN
NAME = "REFERENCE RADIUS"
DATA_TYPE = "ASCII REAL"
START_BYTE = 1
BYTES = 23
FORMAT = "E23.16"
```

```
UNIT = "KILOMETER"
DESCRIPTION = "The assumed reference radius of the
spherical body."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "CONSTANT"
DATA_TYPE = "ASCII REAL"
START_BYTE = 25
BYTES = 23
FORMAT = "E23.16"
UNIT = "KM^3/SEC^2"
DESCRIPTION = "For a gravity field model the assumed
gravitational constant GM in kilometers cubed per seconds squared
for the body. For a topography model, set to 1."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "UNCERTAINTY IN CONSTANT"
DATA_TYPE = "ASCII REAL"
START_BYTE = 49
BYTES = 23
FORMAT = "E23.16"
UNIT = "KM^3/SEC^2"
DESCRIPTION = "For a gravity field model the
uncertainty in the gravitational constant GM in kilometers cubed per
seconds squared for the planet. For a topography, set to 0."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "DEGREE OF FIELD"
DATA_TYPE = "ASCII INTEGER"
START_BYTE = 73
BYTES = 5
FORMAT = "I5"
UNIT = "N/A"
DESCRIPTION = "The degree of model field."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "ORDER OF FIELD"
DATA_TYPE = "ASCII INTEGER"
START_BYTE = 79
BYTES = 5
FORMAT = "I5"
UNIT = "N/A"
DESCRIPTION = "The order of the model field."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "NORMALIZATION STATE"
DATA_TYPE = "ASCII INTEGER"
START_BYTE = 85
BYTES = 5
FORMAT = "I5"
UNIT = "N/A"
DESCRIPTION = "The normalization indicator.
For gravity fields:
0 coefficients are unnormalized
1 coefficients are normalized
2 other."
END_OBJECT = COLUMN
```

```
OBJECT = COLUMN
NAME = "REFERENCE LONGITUDE"
POSITIVE_LONGITUDE_DIRECTION = "EAST"
DATA_TYPE = "ASCII REAL"
START_BYTE = 91
BYTES = 23
FORMAT = "E23.16"
UNIT = "DEGREE"
DESCRIPTION = "The reference longitude for
the spherical harmonic expansion; normally 0."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "REFERENCE LATITUDE"
DATA_TYPE = "ASCII REAL"
START_BYTE = 115
BYTES = 23
FORMAT = "E23.16"
UNIT = "DEGREE"
DESCRIPTION = "The reference latitude for
the spherical harmonic expansion; normally 0."
END_OBJECT = COLUMN

END_OBJECT = SHADR_HEADER_TABLE
```

4.2.2.2 SHADR Coefficients Object Definition

The SHADR Coefficients Object is completely defined by the Coefficients Object Definition in the label. Small differences in DESCRIPTION values should be expected from product to product. The structure outlined in the Definition below should not vary, however.

The SHADR Coefficients Object is an optional part of the SHADR data file. This allows the SHADR to be used for targets which are too small or too remote to have easily discerned coefficients, but for which estimates of mass have been obtained (e.g., satellites Phobos and Deimos). If the Coefficients Object is not included in the SHADR file, either the SHADR Coefficients Object Definition will be omitted or the number of rows will be set to zero (ROWS = 0). If the SHADR Coefficients Object is not included, the pointer ^SHADR_COEFFICIENTS_TABLE will not appear in the label header. If the SHADR Coefficients Object Definition is included in the label, it immediately follows the SHADR Header Object Definition.

No requirements are placed on the order in which coefficient values appear in the table or that all possible combinations of the pairs {m,n} be included. The coefficients are defined by their COEFFICIENT DEGREE and COEFFICIENT ORDER; see [2] for interpretation.

```
OBJECT = SHADR_COEFFICIENTS_TABLE
ROWS = *
COLUMNS = 6
ROW_BYTES = 107
ROW_SUFFIX_BYTES = 15
INTERCHANGE_FORMAT = ASCII
DESCRIPTION = "The SHADR coefficients table contains the
coefficients for the spherical harmonic model. Each row in the table
contains the degree index n, the order index m, the coefficients Cnm
and Snm, and the uncertainties in Cnm and Snm. The (comma delimited)
data require 107 ASCII characters; these are followed by a pad of 13
ASCII blank characters, an ASCII carriage-return, and an ASCII
line-feed."
```

```
OBJECT = COLUMN
NAME = "COEFFICIENT DEGREE"
DATA_TYPE = "ASCII INTEGER"
START_BYTE = 1
BYTES = 5
FORMAT = "I5"
UNIT = "N/A"
DESCRIPTION = " The degree index n of the C and S
coefficients in this record."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "COEFFICIENT ORDER"
DATA_TYPE = "ASCII INTEGER"
START_BYTE = 7
BYTES = 5
FORMAT = "I5"
UNIT = "N/A"
DESCRIPTION = "The order index m of the C and S
coefficients in this record."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "C"
DATA_TYPE = "ASCII REAL"
START_BYTE = 13
BYTES = 23
FORMAT = "E23.17"
UNIT = "N/A"
DESCRIPTION = "The coefficient Cnm for this
spherical harmonic model."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "S"
DATA_TYPE = "ASCII REAL"
START_BYTE = 37
BYTES = 23
FORMAT = "E23.17"
UNIT = "N/A"
DESCRIPTION = "The coefficient Snm for this spherical
harmonic model."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "C UNCERTAINTY"
DATA_TYPE = "ASCII REAL"
START_BYTE = 61
BYTES = 23
FORMAT = "E23.17"
UNIT = "N/A"
DESCRIPTION = "The uncertainty in the coefficient Cnm
for this spherical harmonic model."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "S UNCERTAINTY"
DATA_TYPE = "ASCII REAL"
START_BYTE = 85
BYTES = 23
FORMAT = "E23.17"
```

```
UNIT = "N/A"
DESCRIPTION = "The uncertainty in the coefficient Snm
for this spherical harmonic model."
END_OBJECT = COLUMN

END_OBJECT = SHADR_COEFFICIENTS_TABLE
```

4.2.2.3 SHADR Covariance Object Definition

The SHADR Covariance Object is completely defined by the Covariance Object Definition in the label. Small differences in DESCRIPTION values should be expected from product to product. The structure established by the Definition below should not change, however. The SHADR Covariance Object is an optional part of the SHADR data file. If the Covariance Object is not included, either the Covariance Object Definition will be omitted or the number of rows will be set to zero (ROWS = 0). If the SHADR Covariance Object is not included, the pointer ^SHADR_COVARIANCE_TABLE will not appear in the label header. If the SHADR Covariance Object Definition is included in the label, it immediately follows the SHADR Coefficients Object Definition.

No requirements are placed on the order in which covariance values appear in the table. Nor is there a requirement that all possible combinations of the quadruplet values {i,j,n,m} be included. By careful editing and use of symmetry arguments, it may be possible to define all covariances with fewer than the maximum number of rows in the table.

```
OBJECT = SHADR_COVARIANCE_TABLE
ROWS = *
COLUMNS = 8
ROW_BYTES = 119
ROW_SUFFIX_BYTES = 3
INTERCHANGE_FORMAT = ASCII
DESCRIPTION = "The SHADR covariance table contains
the covariances for the spherical harmonic model coefficients.
For each index quadruplet {i,j,n,m} the covariances of CijCnm,
SijSnm, CijSnm, and SijCnm are given. In each row of the table the
(comma delimited) indices occupy 24 ASCII characters and the (comma
delimited) covariances occupy 95 ASCII characters. These are followed
by an ASCII blank, an ASCII carriage-return and an ASCII line-feed."

OBJECT = COLUMN
NAME = "COEFFICIENT DEGREE I"
DATA_TYPE = "ASCII INTEGER"
START_BYTE = 1
BYTES = 5
FORMAT = "I5"
UNIT = "N/A"
DESCRIPTION = "The degree index i of the C and S terms
in this record."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "COEFFICIENT ORDER J"
DATA_TYPE = "ASCII INTEGER"
START_BYTE = 7
BYTES = 5
FORMAT = "I5"
UNIT = "N/A"
DESCRIPTION = "The order index j of the C and S terms
in this record."
END_OBJECT = COLUMN
```

```
OBJECT = COLUMN
NAME = "COEFFICIENT DEGREE N"
DATA_TYPE = "ASCII INTEGER"
START_BYTE = 13
BYTES = 5
FORMAT = "I5"
UNIT = "N/A"
DESCRIPTION = "The degree index n of the C and S terms
in this record."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "COEFFICIENT ORDER M"
DATA_TYPE = "ASCII INTEGER"
START_BYTE = 19
BYTES = 5
FORMAT = "I5"
UNIT = "N/A"
DESCRIPTION = "The order index m of the C and S terms
in this record."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "COVARIANCE (C_IJ,C_NM)"
DATA_TYPE = "ASCII REAL"
START_BYTE = 25
BYTES = 23
FORMAT = "E23.16"
UNIT = "N/A"
DESCRIPTION = "Covariance (C_IJ,C_NM) the coefficients
of this spherical harmonic model."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "COVARIANCE (S_IJ,S_NM)"
DATA_TYPE = "ASCII REAL"
START_BYTE = 49
BYTES = 23
FORMAT = "E23.16"
UNIT = "N/A"
DESCRIPTION = "Covariance (S_IJ,S_NM) for the
coefficients of this spherical harmonic model."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "COVARIANCE (C_IJ,S_NM)"
DATA_TYPE = "ASCII REAL"
START_BYTE = 73
BYTES = 23
FORMAT = "E23.16"
UNIT = "N/A"
DESCRIPTION = "Covariance (C_IJ,S_NM) for the
coefficient of this spherical harmonic model."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "COVARIANCE (S_IJ,C_NM)"
DATA_TYPE = "ASCII REAL"
START_BYTE = 97
BYTES = 23
FORMAT = "E23.16"
UNIT = "N/A"
```

```
DESCRIPTION = "Covariance (S_IJ,C_NM) for the
coefficients of this spherical harmonic model."
END_OBJECT = COLUMN

END_OBJECT = SHADR_COVARIANCE_TABLE
```

4.3. Data File

Each SHADR data file comprises a SHADR Header TABLE Object, an (optional) Coefficients TABLE Object, and an (optional) Covariances TABLE Object.

Each TABLE Object comprises one or more data blocks. The TABLE Objects were defined in Section 4.2. The data blocks are illustrated below.

4.3.1. SHADR Header Object/Block

The SHADR Header Object contains the parameters necessary to interpret the data in the SHADR file. The structure of the SHADR Header Object is defined in Section 4.2.2.1. The SHADR Header Object is a one-row table; hence the Header Object and the Header Block are logically synonymous. The structure of the Header Block is shown in Table 4-3-1. Note that the logical content of the Header Object is delimited by the ASCII carriage return and line feed characters. The physical block is padded to 244 bytes (an integral multiple of RECORD_BYTES).

Table 4-3-1. SHADR Header Block

Col No	Offset	Length	Format	Column Name
1	+0	23	E23.16	Planetary Radius
2	24	23	E23.16	Constant
3	48	23	E23.16	Uncertainty in Constant
4	72	5	I5	Degree of Field
5	78	5	I5	Order of Field
6	84	5	I5	Normalization State
7	90	23	E23.16	Reference Longitude
8	114	23	E23.16	Reference Latitude
	137	105		blanks
	242	1		carriage return
	243	1		line feed
	+244			

|========|========|========|========|================================|

4.3.2. SHADR Coefficients Block

The SHADR Coefficients Object is made up of one or more SHADR Coefficient Blocks. Each block contains one pair of coefficients and associated uncertainties for the overall model defined by the SHADR product. The structure of the SHADR Coefficients Object is defined in Section 4.2.2.2.

The structure of an individual block is shown in Table 4-3-2.
Note that the logical content of the Coefficients Block is delimited by the ASCII carriage return and line feed characters. The Coefficients Block is, by definition, an integral multiple of RECORD_BYTES.

Table 4-3-2. SHADR Coefficients Block

Col No	Offset	Length	Format	Column Name
1	+0	5	I5	Coefficient Degree n
2	6	5	I5	Coefficient Order m
3	12	23	E23.16	Cnm
4	36	23	E23.16	Snm
5	60	23	E23.16	Uncertainty in Cnm
6	84	23	E23.16	Uncertainty in Snm
	107	13		blanks
	120	1		carriage return
	121	1		line feed
	+122			

4.3.3. SHADR Covariance Block

The SHADR Covariance Object is made up of one or more SHADR Covariance Blocks. Each block contains the CijCnm, SijSnm, CijSnm, and SijCnm covariances for the overall model defined by the SHADR product. The structure of the SHADR Covariance Object is defined in Section 4.2.2.3. The structure of an individual block is shown in Table 4-3-3. Note that the logical content of the Covariance Block is delimited by the ASCII carriage return and line feed characters. The SHADR Covariance Block is, by definition, an integral multiple of RECORD_BYTES.

Table 4-3-3. SHADR Covariance Block

Col No	Offset	Length	Format	Column Name
1	+0	5	I5	Coefficient Degree i
2	6	5	I5	Coefficient Order j
3	12	5	I5	Coefficient Degree n
4	18	5	I5	Coefficient Order m
5	24	23	E23.16	Covariance {Cij,Cnm}
6	48	23	E23.16	Covariance {Sij,Snm}
7	72	23	E23.16	Covariance {Cij,Snm}
8	96	23	E23.16	Covariance {Sij,Cnm}
	119	1		blank
	120	1		carriage return
	121	1		line feed
	+122			

APPENDIX A.

A.1 Definition of Spherical harmonic models for the geopotential.

Spherical harmonics satisfy Laplace's equation in spherical coordinates. The gravity potential field of the planets and the mathematical representation of magnetic fields and topographic fields are readily expressed in terms of spherical harmonics. Useful reviews are by Lambeck [11] (Section 2.2, Elements of Potential Theory) and Kaula [12] (Section 1.1 Potential Theory, and Section 1.2 Spherical Harmonics).

The expression for the geopotential takes the form

V = (GM/r) + (GM/r)*SUMMATION_n SUMMATION_m (Re/r)**n [Cnm" cos(mL) + Snm" sin(mL)]* Pnm"(sin(phi))
(Equation A-1-1)

where GM is the gravitational constant of the planet, r is the radial distance of the test point from the origin, and Re is the assumed reference radius of the spherical planet for which the coefficients were calculated. The summations take place from degree n=1 to infinity, and order m=0 to n; Cnm" and Snm" refer to the normalized spherical harmonic coefficients (see Section A.2 below); L is the longitude; the Pnm" are the normalized associated Legendre functions of degree n and order m; and phi is the latitude of the test point. If we assume the origin is at the center of mass, the degree one terms vanish, and the summation in degree starts at degree n=2.

A "solution" for a spherical harmonic model of the geopotential refers to a solution for these spherical harmonic coefficients and the gravitational constant, GM, of the body.

In practice the spherical harmonic series is truncated at a maximum degree nmax. For MRO, the likely degree of truncation will be between n=100 and n=120. For MESSENGER, gravity solutions for the planet Mercury will likely be truncated at degree 20. The degree of truncation depends on the quality of the tracking data and the orbits of the spacecraft in the geopotential solution. For Lunar Prospector derived gravity solutions, the maximum degree has ranged from n=100 to n=165 [10]. For GRAIL, which used a different measurement technique, the gravity signal to noise ratio was very strong and the truncation was at a high degree. nmax was unprecedented 660 for the Prime Mission. The field size is expected to exceed 1000 for the combined Prime and Extended missions solution.

If the origin is placed at the center of mass, the degree 1 terms vanish from the spherical harmonic expansion, and the first summation above is then from (n=2) to the maximum degree, nmax.

Figure 1, section 1.2 from Kaula [11] gives examples of spherical harmonics. The zonal terms, m=0, have n zeros in a distance pi along a north-south meridian; in other words, they represent only latitudinal variations in the potential.

Zonal terms may be represented in the literature as Jn = - Cn0.

Aside from GM, C20 is the most significant term in the gravity field (for planets such as the Earth and Mars), and reflects the dynamical expression of the planet's polar flattening.

Tesseral harmonics (coefficients where n is not equal to m, and m > 0, have n-m zeros in a distance pi along a meridian (like the tesserae of a mosaic).

Sectoral harmonics are coefficients where n=m and are constant in sectors of longitude (N-S) and have n zero crossings in a distance pi along a meridian of latitude (E-W).

A.2 Definition of the normalization used for geopotential coefficients.
The normalization for spherical harmonic coefficients is given by Lambeck[11]

Cnm" = Cnm/PI_nm (Equation A-2-1)

where Cnm" is normalized and Cnm is un-normalized, and

[PI_nm]**2 = (2 - delta_0m) * (2n+1) * (n-m)! / (n+m)! (Equation A-2-2)

delta_0m refers to the Kronecker delta function -- unity for coefficients where m=0 (the zonal terms), zero for order m > 0.

For zonal coefficients (m=0) the relation reduces to
Cnm" = Cnm / sqrt(2n+1)

For example, for the Earth C20 = -1.08262668355E-03 (un-normalized) so

C20" = C20 / sqrt(5) = -4.8416537173572E-04 (normalized)

Working the process backwards for Earth's C22 we have

C22" = .24391435239839D-05

from the Earth Gravitational Model 1996, EGM96, [13].

[PI_nm]**2 = (2-0)*(2n+1) (2-2)! / (4)!
= 2*5*1/(4!) = 5/12

which yields

C22 = sqrt(5/12) * (.24391435239839E-05)
= 1.5744604E-06
closely matching Lambeck's [11] result (page 14).

Likewise for Earth's S22, we have the normalized value [13]

S22" = -.14001668365394E-05

Thus,

S22= sqrt(5/12) * (-.14001668365394E-05)
= -9.038038E-07 (un-normalized)

which matches closely the example given by Lambeck [11].

APPENDIX B EXAMPLE DATA PRODUCTS

APPENDIX B.1 Example Label

The following lists an example SHADR LBL file for a Mars Global Surveyor derived gravity solution. For GRAIL the "INSTRUMENT_HOST_NAME" would be listed instead of MARS GLOBAL SURVEYOR. The DESCRIPTION would be changed to reflect the data content of the GRAIL-derived gravity solutions. Other fields (e.g., PRODUCT_RELEASE_DATE, PRODUCT_ID, INSTRUMENT NAME, START_TIME, STOP_TIME, PRODUCT_CREATION TIME) would also be changed as appropriate.

This example can be found in its original electronic form at the URL http://pds-geosciences.wustl.edu/geodata/mgs-m-rss-5-sdp-v1/mors_1021/sha/

```
PDS_VERSION_ID = PDS3
RECORD_TYPE = FIXED_LENGTH
RECORD_BYTES = 122
FILE_RECORDS = 4185
^SHADR_HEADER_TABLE = ("GGM1041C.SHA",1)
^SHADR_COEFFICIENTS_TABLE = ("GGM1041C.SHA",3)
INSTRUMENT_HOST_NAME = "MARS RECONNAISSANCE ORBITER"
TARGET_NAME = "MARS"
```

INSTRUMENT_NAME = "RADIO SCIENCE SUBSYSTEM"
DATA_SET_ID = "MRO-M-RSS-5-SDP-V1.0"
OBSERVATION_TYPE = "GRAVITY FIELD"
ORIGINAL_PRODUCT_ID = "MGM1041C"
PRODUCT_ID = "GGM1041C.SHA"
PRODUCT_RELEASE_DATE = 2003-03-28
DESCRIPTION = "
This file contains coefficients and related data for a spherical harmonic model of the Mars gravity field. Input data are from radio tracking of the Mars Global Surveyor spacecraft; no Mariner 9 or Viking data are included. Coordinate system is IAU 2000 (Seidelmann et al., Celestial Mechanics and Dynamical Astronomy, 82(1), 83-110, January 2002).
Constants relevant for Mars in IAU 2000 are:
alpha (right ascension) = 317.68143 deg - 0.1061 deg/century
delta (declination) = 52.88650 deg - 0.0609 deg/century
Wo (prime meridian) = 176.630 deg
Wdot = 350.89198226 deg/day
Gravitational constants obtained from the solution are:
GM (Mars) = 4.282837024529127 E+13 m**3/s**2
sigma = 0.617 E+05 m**3/s**2
GM (Phobos) = 0.68012569 E+06 m**3/s**2
sigma = 0.842 E+04 m**3/s**2

The model was constructed from 2,568,683 observations, summarized in the table below. MGS data are limited to tracking from the Aerobraking Hiatus and Science Phasing Orbit (SPO) subphases of the Orbit Insertion phase of the mission and to February 1999 to May 2002 after the orbit was circularized.
Time Periods Total
Arcs Observations

----------------------- ---- ------------

Hiatus 2 24119
SPO-1 8 31014
SPO-2 17 144253
Feb-Mar 1999 10 86069
2 Apr 1999 - 22 May 2002 167 2186533
Doppler + Crossovers 5 96875

----------------------- ---- ------------

Total 2568863
Orbit reconstruction was improved using Mars Orbiter Laser Altimeter (MOLA) data on 5 arcs between March and December 1999. Inter-arc and intra-arc crossovers at 21679 points were included in the orbit solutions. Crossovers poleward of 60 degrees north and south were excluded to avoid possible contamination by any time-varying signature in the polar caps. The altimeter data were edited for large off-nadir angles as well as for the roughness and slope of the terrain. The crossovers supplemented the normal radiometric tracking for these arcs, which included 75196 Doppler and range observations.
One-way Doppler data were included once these data started to become available in March 2000 (just after the start of the first Beta Supplement operations). Range biases were adjusted on a pass by pass basis, and frequency biases were adjusted for the one-way data.
The Gravity Calibration Orbit (GCO, February 1999) data were weighted at 0.0044 Hz (0.16 mm/s). Data for 2000 and for 2001 through the start of Relay 16 operations were weighted at 0.18 mm/s. Data after the start of Relay 16 operations in 2001 were weighted at 0.357 mm/s in light of the higher RMS fit for these data. The one-way data were downweighted with respect to the two-way data by a factor of 2, and are thus weighted at 0.36 mm/s

for the 2000-2001 data and at 0.71 mm/s for Relay 16.
Compared to the GMM2B model, this model contains about 2.5 times as much data. The data were also rigorously re-edited to remove spurious signatures which were particularly apparent in some of the arcs with one-way Doppler data. Finally, the non-conservative force model was refined to include the high gain antenna. This improvement reduced the average solar radiation reflectivity (Cr)from 1.15 to 1.05.
The gravity model was derived using a Kaula type constraint: sqrt(2)*13*10**(-5)/L**2 (Kaula, W.M., Theory of Satellite Geodesy, Blaisdell, Waltham, MA, 1966).
Further improvements to the model are expected as additional MGS data are incorporated.

The C20 coefficient is given in the zero-tide system, meaning that the deformation due to the (solar-induced) permanent tide is included in the coefficient. An apriori K2 Love number of 0.10 was used in the derivation of this model.
This product is a set of two ASCII tables: a header table and a coefficients table. Definitions of the tables follow.
This Mars gravity model was produced by F.G. Lemoine under the direction of D.E. Smith of the MGS Radio Science Team."

```
START_TIME = 1997-10-13T00:00:00
STOP_TIME = 2002-05-27T23:59:59
PRODUCT_CREATION_TIME = 2003-02-05T20:34:50
PRODUCER_FULL_NAME = "FRANK G. LEMOINE"
PRODUCER_INSTITUTION_NAME = "GODDARD SPACE FLIGHT CENTER"
PRODUCT_VERSION_TYPE = "FINAL"
PRODUCER_ID = "MRO GST"
SOFTWARE_NAME = "SOLVE;200201.02"

OBJECT = SHADR_HEADER_TABLE
ROWS = 1
COLUMNS = 8
ROW_BYTES = 137
ROW_SUFFIX_BYTES = 107
INTERCHANGE_FORMAT = ASCII
DESCRIPTION = "The SHADR header includes
descriptive information about the spherical harmonic coefficients
which follow in SHADR_COEFFICIENTS_TABLE. The header consists of
a single record of eight (delimited) data columns requiring 137
bytes, a pad of 105 unspecified ASCII characters, an ASCII
carriage-return, and an ASCII line-feed."

OBJECT = COLUMN
NAME = "REFERENCE RADIUS"
DATA_TYPE = "ASCII REAL"
START_BYTE = 1
BYTES = 23
FORMAT = "E23.16"
UNIT = "KILOMETER"
DESCRIPTION = "The assumed reference radius
of the spherical body."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "CONSTANT"
DATA_TYPE = "ASCII REAL"
START_BYTE = 25
BYTES = 23
FORMAT = "E23.16"
UNIT = "KM^3/S^2"
```

```
DESCRIPTION = "For a gravity field model the
assumed gravitational constant GM in km cubed per seconds
squared for the body. For a topography model, set to 1."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "UNCERTAINTY IN CONSTANT"
DATA_TYPE = "ASCII REAL"
START_BYTE = 49
BYTES = 23
FORMAT = "E23.16"
UNIT = "KM^3/S^2"
DESCRIPTION = "For a gravity field model the
uncertainty in the gravitational constant GM in km cubed per
seconds squared for the planet (or, set to 0 if not known).
For a topography model, set to 0."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "DEGREE OF FIELD"
DATA_TYPE = "ASCII INTEGER"

START_BYTE = 73
BYTES = 5
FORMAT = "I5"
UNIT = "N/A"
DESCRIPTION = "Degree of the model field."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "ORDER OF FIELD"
DATA_TYPE = "ASCII INTEGER"
START_BYTE = 79
BYTES = 5
FORMAT = "I5"
UNIT = "N/A"
DESCRIPTION = "Order of the model field."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "NORMALIZATION STATE"
DATA_TYPE = "ASCII INTEGER"
START_BYTE = 85
BYTES = 5
FORMAT = "I5"
UNIT = "N/A"
DESCRIPTION = "The normalization indicator.
For gravity field:
0 coefficients are unnormalized
1 coefficients are normalized
2 other."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "REFERENCE LONGITUDE"
POSITIVE_LONGITUDE_DIRECTION = "EAST"
DATA_TYPE = "ASCII REAL"
START_BYTE = 91
BYTES = 23
FORMAT = "E23.16"
UNIT = "DEGREE"
DESCRIPTION = "The reference longitude for
```

```
the spherical harmonic expansion; normally 0."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "REFERENCE LATITUDE"
DATA_TYPE = "ASCII REAL"
START_BYTE = 115
BYTES = 23
FORMAT = "E23.16"
UNIT = "DEGREE"
DESCRIPTION = "The reference latitude for the
spherical harmonic expansion; normally 0."
END_OBJECT = COLUMN

END_OBJECT = SHADR_HEADER_TABLE

OBJECT = SHADR_COEFFICIENTS_TABLE
ROWS = 4183
COLUMNS = 6
ROW_BYTES = 107
ROW_SUFFIX_BYTES = 15
INTERCHANGE_FORMAT = ASCII
DESCRIPTION = "The SHADR coefficients table
contains the coefficients for the spherical harmonic model. Each
row in the table contains the degree index n, the order index m,
the coefficients Cnm and Snm, and the uncertainties in Cnm and
Snm. The (delimited) data require 107 ASCII characters; these are
followed by a pad of 13 unspecified ASCII characters, an ASCII
carriage-return, and an ASCII line-feed."

OBJECT = COLUMN
NAME = "COEFFICIENT DEGREE"
DATA_TYPE = "ASCII INTEGER"
START_BYTE = 1
BYTES = 5
FORMAT = "I5"
UNIT = "N/A"
DESCRIPTION = "The degree index n of the
C and S coefficients in this record."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "COEFFICIENT ORDER"
DATA_TYPE = "ASCII INTEGER"
START_BYTE = 7
BYTES = 5
FORMAT = "I5"
UNIT = "N/A"
DESCRIPTION = "The order index m of the C and S
coefficients in this record."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "C"
DATA_TYPE = "ASCII REAL"
START_BYTE = 13
BYTES = 23
FORMAT = "E23.17"
UNIT = "N/A"
DESCRIPTION = "The coefficient Cnm for this
spherical harmonic model."
END_OBJECT = COLUMN
```

```
OBJECT = COLUMN
NAME = "S"
DATA_TYPE = "ASCII REAL"
START_BYTE = 37
BYTES = 23
FORMAT = "E23.17"
UNIT = "N/A"
DESCRIPTION = "The coefficient Snm for this
spherical harmonic model."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "C UNCERTAINTY"
DATA_TYPE = "ASCII REAL"
START_BYTE = 61
BYTES = 23
FORMAT = "E23.17"
UNIT = "N/A"
DESCRIPTION = "The uncertainty in the
coefficient Cnm for this spherical harmonic model."
END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "S UNCERTAINTY"
DATA_TYPE = "ASCII REAL"
START_BYTE = 85
BYTES = 23
FORMAT = "E23.17"
UNIT = "N/A"
DESCRIPTION = "The uncertainty in the
coefficient Snm for this spherical harmonic model."
END_OBJECT = COLUMN
END_OBJECT = SHADR_COEFFICIENTS_TABLE
END
```

APPENDIX B.2 Example SHADR Data Object

The following lists the first few lines from an example SHADR file, the MGM1041C Gravity solution.

Note that the lines here wrap after 70 characters whereas the header record length is 244 and the coefficient record length is 122.

```
3.3970000000000000E+03, 4.2828370245291269E+04,
6.1699999999999995E-05, 90, 90, 1, 0.0000000000000000E+00,
0.0000000000000000E+00
2, 0,-8.7450461309664714E-04, 0.0000000000000000E+00,
8.6998585172904000E-11, 0.0000000000000000E+00
2, 1, 3.4361530466444738E-10,-2.6812730136287860E-10,
```

```
5.2026417903363999E-11, 5.1856231628722999E-11
2, 2,-8.4585864260034122E-05, 4.8905472151326622E-05,
2.4262638528121999E-11, 2.4711067535925999E-11
3, 0,-1.1889488636438340E-05, 0.0000000000000000E+00,
7.1845677542599005E-11, 0.0000000000000000E+00
```