```
PDS_VERSION_ID         = PDS3
RECORD_TYPE            = STREAM
RECORD_BYTES           = 80
OBJECT                 = TEXT
  PUBLICATION_DATE       = 2011-07-01
  NOTE                         = "Software Interface Specification for
                                  the Spherical Harmonics Binary Data
                                  Record (SHBDR) file. "
END_OBJECT             = TEXT
END
```


SOFTWARE INTERFACE SPECIFICATION

SPHERICAL HARMONICS BINARY DATA RECORD (SHBDR)

prepared by

Frank G. Lemoine

Code 698, Planetary Geodynamics Laboratory
NASA Goddard Space Flight Center
Greenbelt, Maryland, 20771 USA

Peggy L. Jester
SGT, Inc / Code 614.1
NASA GSFC / Wallops Flight Facility
Wallops Island, VA 23337 USA

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DOCUMENT CHANGE LOG

REVISION NUMBER	REVISION DATE	SECTION AFFECTED	REMARK
1.0	06/02/20	All	Adapted MGS SHBDR SIS to include Mars Reconnaissance Orbiter and MESSENGER.
1.0	06/03/15	All	Miscellaneous edits
1.0	06/06/29	All	Integrate PDS review comments
1.1	05/04/29	All	Fix minor formatting issues
1.2	08/07/28	2.3	Updated file naming convention for MRO
1.3	11/07/01	4.2.2.3 4.2.2.4	Added NOTE for LP re-analyzed data sets

Contents

Tables

Figures

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
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
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 Binary Data Record (SHBDR) files. The SHBDR 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 SHBDR is produced.

The SHBDR 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 SHBDR has been adapted for the Mars Global Surveyor (MGS) and the Lunar Prospector (LP) missions; this is the adaptation for the Mars Reconnaissance Orbiter (MRO) and MESSENGER missions. 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 ASCII Data Record is also defined [3], which may be more suitable when error covariances are not included in the final product.

This version adds a note to the object definitions to accomodate new models generated from LP and other historical data[16].

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

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1.4. System Siting

1.4.1. Interface Location and Medium

SHBDR files are created at the institution conducting the science analysis. SHBDR 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

SHBDR 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 SHBDR 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

SHBDR 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 SHBDR uses the appropriate planetocentric fixed body coordinate system [7,8]. This may be an IAU system (e.g. IAU2000 [7] or for 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 coarser frame defined by the IAU [7].

1.5.4.4. Limits of This Document

This document applies only to SHBDR 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 SHBDR product must have access to the data system (or to media) on which SHBDR files are stored.

2.1.2. Special Setup Requirements

None.

2.2. Volume and Size

SHBDR 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 include approximately N**2 terms and therefore the number of terms in the covariance matrix will be of order N**4. For 8-byte storage and N=50, the total SHBDR volume will be about 30 MB. For N=100, the total SHBDR volume will be approximately 416 MB.

Vector quantities (e.g., magnetic field) may be described by a single SHBDR (in which all components are represented) or by a separate SHBDR for each field component. If the single SHBDR 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 is recommended over the SHADR [3] 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 less characters before the period delimeter and 3 characters after the period delimeter.

Each file has a name which describes its contents. The name includes the following structure which uniquely identifies it among SHBDR products. Beginning with the MRO gravity products the following file naming convention is used:

GTsss_nnnnvv_SHB.DAT

where

"G" denotes the generating institution
- "J" for the Jet Propulsion Laboratory
- "G" or Goddard Space Flight Center
- "C" or Centre National d'Etudes Spatiales
- "M" for Massachusetts Institute of Technology

"T" indicates the type of data represented
- "G" for gravity field
- "T" for topography
- "M" for magnetic 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 MRO for the Mars Reconnaisance Orbiter.

"_" 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 SHBDR contains primary data values as specified by "T" or uncertainties/errors, and/or the version number. For MRO, this modifier indicates the degree and order of the solution for the gravity field, topography or magnetic field.

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

"SHB" denotes that this is a Binary file of Spherical Harmonic coefficients and error covariance information

".DAT" indicates the data is stored in binary format.

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

2.4. Interface Medium Characteristics

SHBDR 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 SHBDR 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 SHBDR is a file generated by software at the institution conducting scientific data analysis. Each SHBDR 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 to four 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 SHBDR data file. The SHBDR Header Table Object definition is required. The SHBDR Names Object Definition is required if there is an SHBDR Names Object in the file. The SHBDR Coefficients Table Object definition is required if there is a SHBDR Coefficients Table in the file; the SHBDR Covariance Table Object definition is required if there is a SHBDR 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.

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

^SHBDR_HEADER_TABLE=
File name and record number at which SHBDR_HEADER_TABLE begins. Set to ("GTsss_nnnnvv_SHB.DAT ",1) where " GTsss_nnnnvv_SHB.DAT " is the file name as described in Section 2.3, and 1 is the record number since this is the first record in the SHBDR file.

```
|====================================================================|
|                                                                    |
|                 Figure 4-2-1   SHBDR Label Header                  |
|                                                                    |
|====================================================================|
|                                                                    |
|  PDS_VERSION_ID = PDS3                                             |
|  RECORD_TYPE = FIXED_LENGTH                                        |
|  RECORD_BYTES = nnn                                                |
|  FILE_RECORDS = nnn                                                |
|  ^SHBDR_HEADER_TABLE = ("GTsss_nnnnvv_SHB.DAT",1)                  |
|  ^SHBDR_NAMES_TABLE = ("GTsss_nnnnvv_SHB.DAT ",1)                  |
|  ^SHBDR_COEFFICIENTS_TABLE = ("GTsss_nnnnvv_SHB.DAT ",nn)          |
|  ^SHBDR_COVARIANCE_TABLE = ("GTsss_nnnnvv_SHB.DAT ",nnn)           |
|  INSTRUMENT_HOST_NAME = "cccccccccccccccccccc"                     |
|  TARGET_NAME = "cccc"                                              |
|  INSTRUMENT_NAME = "cccccccccccccccccccccccc"                      |
|  DATA_SET_ID = "cccccccccccccccccccccccc"                          |
|  OBSERVATION_TYPE = "cccccccccccc"                                 |
|  ORIGINAL_PRODUCT_ID = "cccccccccccc"                              |
|  PRODUCT_ID = "GTnnnnvv.SHB"                                       |
|  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 = "cccccccccc"                          |
|  PRODUCT_VERSION_TYPE = "cccccccccccc"                             |
|  PRODUCER_ID = "ccccccc"                                           |
|  SOFTWARE_NAME = "ccccccc;Vn.m"                                    |
|====================================================================|
```

^SHBDR_NAMES_TABLE =
File name and record number at which the SHBDR_NAMES_TABLE begins. The Names Table is required if the Coefficients Table is included in the file. This pointer will not appear in the SHBDR label if there are no Coefficients Table. Set to ("GTsss_nnnnvv_SHB.DAT ",nn) where " GTsss_nnnnvv_SHB.DAT " is the file name as described in Section 2.3, and "nn" is the record number in the file where the Names Table begins.

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

^SHBDR_COVARIANCE_TABLE=
File name and record number at which SHBDR_COVARIANCE_TABLE begins. The Covariance Table is optional; this pointer will not appear in the SHBDR label if there is no Covariance Table. Set to ("GTsss_nnnnvv_SHB.DAT ",nn) where " GTsss_nnnnvv_SHB.DAT " 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", and "MERCURY SURFACE, SPACE, ENVIRONMENT, GEOCHEMISTRY, AND RANGING".

TARGET_NAME =
A character string that identifies the target body. For MRO- and MGS-derived SHBDR files, the character string will be "MARS". For MESSENGER SHBDR files the character string will be "MERCURY". For Lunar Prospector SHBDR files, the character string will be "MOON".

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.

DATA_SET_ID =
Identifier for the data set of which this SHBDR 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-GLGM3/GRAVITY-Vn.m" for Lunar Prospector;
The suffix Vn.m indicates the version number of the data set.

OBSERVATION_TYPE =
A character string that 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 ^SHBDR_HEADER_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 SHBDR product.

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

STOP_ORBIT_NUMBER =
Optional. The last orbit represented in the SHBDR 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 SHBDR 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 SHBDR file. Expressed as a character string, for example "JOHANNES KEPLER".

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 SHBDR.
Standard values include "PREDICT", "PRELIMINARY", and "FINAL".

PRODUCER_ID =
The entity responsible for creation of the SHBDR 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".

SOFTWARE_NAME =
The name and version number of the program creating this SHBDR 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

4.2.2.1 SHBDR Header Object Definition

Each SHBDR 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 SHBDR Header Object Definition is a required part of the SHBDR label file. It immediately follows

```
OBJECT = SHBDR_HEADER_TABLE
ROWS                            = 1
COLUMNS                         = 9
ROW_BYTES                       = 56
INTERCHANGE_FORMAT              = BINARY
DESCRIPTION                     = "The SHBDR header includes descriptive
 information about the spherical harmonic coefficients that follow in
 SHBDR_COEFFICIENTS_TABLE.  The header consists of a single record of
 nine data columns requiring 56 bytes. The Header is followed by a
 pad of binary integer zeroes to ensure alignment with RECORD_BYTES."
  OBJECT = COLUMN
      NAME                      = "REFERENCE RADIUS"
```

```
      DATA_TYPE              = IEEE_REAL
      START_BYTE             = 1
      BYTES                  = 8
      UNIT                   = "KILOMETER"
      DESCRIPTION            = "The assumed  reference  radius
 of the spherical planet."
  END_OBJECT = COLUMN

  OBJECT = COLUMN
      NAME                   = "CONSTANT"
      DATA_TYPE              = IEEE_REAL
      START_BYTE             = 9
      BYTES                  = 8
      UNIT                   = "KM^3/S^2"
      DESCRIPTION            = "For a gravity field model
 the assumed gravitational constant GM in kilometers cubed  per seconds
 squared for the planet.  For a topography  model, set to 1."
  END_OBJECT = COLUMN

  OBJECT = COLUMN
        NAME                  = "UNCERTAINTY IN CONSTANT"
        DATA_TYPE             = IEEE_REAL
        START_BYTE            = 17
        BYTES                 = 8
        UNIT                  = "KM^3/S^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             = MSB_INTEGER
       START_BYTE            = 25
       BYTES                 = 4
       UNIT                  = "N/A"
       DESCRIPTION           = "The degree of model field."
  END_OBJECT  = COLUMN

  OBJECT  = COLUMN
       NAME                  = "ORDER OF FIELD"
       DATA_TYPE             = MSB_INTEGER
       START_BYTE            = 29
       BYTES                 = 4
       UNIT                  = "N/A"
       DESCRIPTION           = "The order of the model field."
  END_OBJECT = COLUMN

OBJECT  = COLUMN
       NAME                  = "NORMALIZATION STATE"
       DATA_TYPE             = MSB_INTEGER
       START_BYTE            = 33
       BYTES                 = 4
       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                   = "NUMBER OF NAMES"
      DATA_TYPE              = MSB_INTEGER
      START_BYTE             = 37
      BYTES                  = 4
      UNIT                   = "N/A"
      DESCRIPTION            = "Number of valid names in the SHBDR Names
 Table.  Also, the number of valid coefficients in the SHBDR
  Coefficients Table."
  END_OBJECT = COLUMN

  OBJECT = COLUMN
      NAME                         = "REFERENCE LONGITUDE"
      POSITIVE_LONGITUDE_DIRECTION = "EAST"
      DATA_TYPE                    = IEEE_REAL
      START_BYTE                   = 41
      BYTES                        = 8
      UNIT                         = "DEGREE"
      DESCRIPTION                  = "The reference longitude
for the spherical harmonic expansion; normally 0."
  END_OBJECT  = COLUMN

  OBJECT = COLUMN
      NAME                 = "REFERENCE LATITUDE"
      DATA_TYPE            = IEEE_REAL
      START_BYTE           = 49
      BYTES                = 23
      FORMAT               = "E23.16"
      UNIT                 = "DEGREE"
      DESCRIPTION          = "The reference latitude
for  the spherical harmonic expansion; normally 0."
  END_OBJECT  = COLUMN

END_OBJECT  = SHBDR_HEADER_TABLE
```

4.2.2.2 SHBDR Names Object Definition

The SHBDR Names Object is completely defined by the Names Object Definition in the label. The definition below illustrates general structural form. The SHBDR Names Object is an optional part of the SHBDR file. If the Names Object is not included, either the Names Object Definition will be omitted or the number of rows will be set to zero (ROWS = 0). If the Names Object is not included, the pointer ^SHBDR_NAMES_TABLE will not appear in the Standard Keywords and Values. If the Coefficients Object is included in the SHBDR file, the Names Object is required.

```
OBJECT = SHBDR_NAMES_TABLE
        ROWS                     = *
        COLUMNS                  = 1
        ROW_BYTES                = 8
        INTERCHANGE_FORMAT       = BINARY
        DESCRIPTION              = "The SHBDR Names Table contains names
 for the solution parameters (including gravity field coefficients) which
 will follow in the SHBDR_COEFFICIENTS_TABLE.  The order of the names
 in the SHBDR_NAMES_TABLE corresponds identically to the order
 of the parameters in the  SHBDR_COEFFICIENTS_TABLE.  Each coefficient
 name is of the form  Cnm  or  Snm   where  n  is the degree of the
 coefficient and  m  is  the order of the coefficient.
 Both indices are three-digit zero-filled right-justified ASCII
```

character strings (for example, C010005 for the 10th degree 5th order C coefficient, or S002001 for the 2nd degree 1st order S coefficient). The eighth byte in the table is an ASCII blank used to ensure that the row length is equal to RECORD_BYTES. Names of other solution parameters are limited to 8 ASCII characters; if less than 8, they will be left-justified and padded with ASCII blanks. The Names Table itself will be padded with ASCII blanks, if necessary, so that its length is an integral multiple of RECORD_BYTES."

```
  OBJECT  = COLUMN
        NAME                    = "PARAMETER NAME"
        DATA_TYPE               = CHARACTER
        START_BYTE              = 1
        BYTES                   = 8
        UNIT                    = "N/A"
        DESCRIPTION             = "The name of the coefficient or other
  solution parameter, left-justified and padded with ASCII blanks
 (if needed) to 8 characters."
END_OBJECT = COLUMN
END_OBJECT = SHBDR_NAMES_TABLE
```

4.2.2.3 SHBDR Coefficients Object Definition

The SHBDR 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 SHBDR Coefficients Object is an optional part of the SHBDR data file. This allows the SHBDR 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 Covariance Object is included in the SHBDR, the Coefficients Object is required.

If the Coefficients Object is not included in the SHBDR file, either the SHBDR Coefficients Object Definition will be omitted or the number of rows will be set to zero (ROWS = 0). If the SHBDR Coefficients Object is not included, the pointer ^SHBDR_COEFFICIENTS_TABLE will not appear in the label header. If the SHBDR Coefficients Object Definition is included in the label, it immediately follows the SHBDR Names Object Definition.

NOTE: For Lunar Prospector data modelled with GLGM-3 the data is in little-endian format and the covariance data is a row ordered upper triangular matrix.

The order in which coefficients appear in the Coefficients Object is defined by the Names Object [2].

```
OBJECT = SHBDR_COEFFICIENTS_TABLE
        ROWS                    = *
        COLUMNS                 = 1
        ROW_BYTES               = 8
        INTERCHANGE_FORMAT      = BINARY
        DESCRIPTION             = "The SHBDR Coefficients Table
  contains the coefficients and other solution parameters
  for the spherical harmonic model.  The order of the
  coefficients in this table corresponds exactly to the
  order of the coefficient and parameter names in
```

```
  SHBDR_NAMES_TABLE.  The SHBDR Coefficients Table will be
  padded with double precision DATA_TYPE zeroes so that
  its total length is an integral multiple of RECORD_BYTES."

 OBJECT  = COLUMN
    NAME                         = "COEFFICIENT VALUE"
    DATA_TYPE                    = *
    START_BYTE                   = 1
    BYTES                        = 8
    UNIT                         = "N/A"
    DESCRIPTION                  = "A coefficient Cnm or
    Snm or other solution parameter as specified in the
    SHBDR Names Table."
  END_OBJECT = COLUMN
END_OBJECT  = SHBDR_COEFFICIENTS_TABLE
```

4.2.2.4 SHBDR Covariance Object Definition

The SHBDR 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 SHBDR Covariance Object is an optional part of the SHBDR 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 SHBDR Covariance Object is not included, the pointer ^SHBDR_COVARIANCE_TABLE will not appear in the label header. If the SHBDR Covariance Object Definition is included in the label, it immediately follows the SHBDR Coefficients Object Definition.

NOTE: For Lunar Prospector data modelled with GLGM-3 the data is in little-endian format and the covariance data is a row ordered upper triangular matrix.

The order in which covariance terms appear in the Covariance Object is defined by the Names Object [2].

```
OBJECT               = SHBDR_COVARIANCE_TABLE
  ROWS                     = *
  COLUMNS                  = 1
  ROW_BYTES                = 8
  INTERCHANGE_FORMAT       = BINARY
  DESCRIPTION              = "The SHBDR Covariance Table
  contains the covariances for the spherical harmonic model
  coefficients and other solution parameters.  The order of
  the covariances in this table is defined by the product
  of the SHBDR Names Table with its transpose, except that
  redundant terms are omitted on their second occurrence.
  The SHBDR Covariance Table will be padded with double
  precision DATA_TYPE zeroes so that its total length is
  an integral multiple of RECORD_BYTES."

  OBJECT                   = COLUMN
    NAME                         = "COVARIANCE VALUE"
    DATA_TYPE                    = *
    START_BYTE                   = 1
    BYTES                        = 8
```

```
    UNIT                          = "N/A"
    DESCRIPTION                   = "The covariance value
    for the coefficients and other solution parameters
    specified by the product of SHBDR_NAMES_TABLE with
    its transpose, after omitting redundant terms."
  END_OBJECT                = COLUMN

END_OBJECT            = SHBDR_COVARIANCE_TABLE
```

4.3. Data File

Each SHBDR data file comprises one or more data blocks. The data objects were defined in Section 4.2. The data blocks are illustrated below.

The Header Object is required in each SHBDR file; the Names Object, the Coefficients Object, and the Covariance Object are optional. If the Covariance Object is included, both the Coefficients Object and the Names Object are required; if the Coefficients Object is included, the Names Object is required.

4.3.1. SHBDR Header Object/Block

The SHBDR Header Object contains the parameters necessary to interpret the data in the SHBDR file. The structure and content of the SHBDR Header Object are defined in Section 4.2.2.1. The SHBDR 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.

Table 4-3-1. SHBDR Header Block

Col No	Offset	Length	Format	Column Nam
1	+0	8	double	Planetary Radius
2	8	8	double	Constant
3	16	8	double	Uncertainty in Constant
4	24	4	long	Degree of Field
5	28	4	long	Order of Field
6	32	4	long	Normalization State
7	36	4	long	Number of Names
8	40	8	double	Reference Longitude
9	48	8	double	Reference Latitude
	+56			

4.3.2. SHBDR Names Block

The SHBDR Names Object comprises one or more SHBDR Names Blocks. Each block contains the name of one coefficient or solution parameter in the Spherical Harmonic Model. The structure and content of the SHBDR Names Object are defined in Section 4.2.2.2. The structure of an individual block is shown in Table 4-3-2.

Table 4-3-2. SHBDR Names Block

Col No	Offset	Length	Format	Column Name
1	+0	8	A8	Coefficient or Solution Parameter Name
	+8			

4.3.3. SHBDR Coefficients Block

The SHBDR Coefficients Object comprises one or more SHBDR Coefficients Blocks. Each block contains the value of one coefficient or other solution parameter for the overall model defined by the SHBDR product. The structure and content of the SHBDR Coefficients Object are defined in Section 4.2.2.3. The structure of an individual block is shown in Table 4-3-3.

Table 4-3-3. SHBDR Coefficients Block

Col No	Offset	Length	Format	Column Name
1	+0	8	double	Coefficient Cnm or Snm or other solution parameter
	+8			

4.3.4. SHBDR Covariance Block

The SHBDR Covariance Object comprises one or more SHBDR Covariance Blocks. Each SHBDR Covariance Block contains one covariance for the overall model defined by the SHBDR product. The structure and content of the SHBDR Covariance Object are defined in Section 4.2.2.4. The structure of an individual block is shown in Table 4-3-4. The SHBDR Covariance Object is an optional component of the SHBDR file.

Table 4-3-4. SHBDR Covariance Block

Col No	Offset	Length	Format	Column Name
1	+0	8	double	Covariance Value
	+8			

5. SUPPORT STAFF AND COGNIZANT PERSONNEL

The following persons may be contacted for information.

Mars Reconnaissance Orbiter Gravity Science Team

Frank G. Lemoine
Code 698, Planetary Geodynamics Laboratory
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771 U.S.A.
Phone: 301-614-6109
FAX: 301-614-6522
Electronic mail: Frank.Lemoine@gsfc.nasa.gov

MESSENGER Laser Altimeter Science Team

Maria T. Zuber
Department of Earth, Atmospheric, and Planetary Sciences
Massachusetts Institute of Technology
54-918
Cambridge, MA 02139-4307
Phone: 617-253-0149
FAX: 617-253-8298

Planetary Data System:

PDS Operator
Planetary Data System
MS 202-101
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109-8099

Phone: 818-354-4321
Electronic Mail: pds_operator@jpl.nasa.gov

Appendix A. Description of Spherical Harmonic Model Normalization

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).

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 of the planet Mercury, solutions 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].

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 meridian N-S in other words they represent only latitudinal varations 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 S22" = -.14001668365394E-05
(normalized from the Earth Gravitational Model 1996, EGM96, [13])

Thus,

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

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

Appendix B. BINARY DATA FORMAT

B.1. IEEE INTEGER FIELDS

```
 0       7                                     1-byte (char; uchar)
 ---------
|   [0]   |
 ---------

 0                15                           2-byte (short; ushort)
 --------- ---------
|   [0]   |   [1]   |
 --------- ---------

 0                                  31         4-byte (long; ulong)
 --------- --------- --------- ---------
|   [0]   |   [1]   |   [2]   |   [3]   |
 --------- --------- --------- ---------
```

IEEE binary integers are stored in one, two, or four consecutive 8-bit bytes. Unsigned integers uchar, ushort, ulong, which always represent positive values, contain 8, 16, or 32 binary bits, respectively. As illustrated above, the significance increases from the rightmost bit to the leftmost (bit 0). Signed integers (char, short, long) are stored in the same way, except that negative values are formed by taking the corresponding positive value, complementing each bit, then adding unity -- known as "two's complement" format. As a consequence, a negative value always has bit 0 set "on". Integers are written externally in increasing byte-number order, i.e. [0], [1], etc., so that more significant bits always precede less significant ones. For example, the short value -2 is stored as a pair of bytes valued 0xff, 0xfe.

B.2. IEEE Floating-Point Fields

```
 0 1      8 9                       31               4-byte (float)
 --------- --------- --------- ---------
| |  [0]  | |  [1]  |   [2]   |   [3]   |
 --------- --------- --------- ---------

 0 1      8 9                       31               8-byte (double)
 --------- --------- --------- ---------
| |  [0]  | |  [1]  |   [2]   |   [3]   |
 --------- --------- --------- ---------
           32                            63
           --------- --------- --------- ---------
          |   [4]   |   [5]   |   [6]   |   [7]   |
           --------- --------- --------- ---------
```

IEEE single- (double-) precision floating point numbers (known to IEEE enthusiasts as E-type floating-point formats, respectively) are stored in four (eight) consecutive bytes. Bit number 0 contains a sign indicator, S. Bits 1 through 8 (11) contain a binary exponent, E. The significance increases from bit 8 (11) through bit 1. Bits 9 (12) through 31 (63) contain a mantissa M, a 23-bit (52-bit) binary fraction whose binary point lies immediately to the left of bit 9 (12). The significance increases from bit 31 (63) through bit 9 (11). The value of the single-precision field is given by

$$(-1)^{S} * 2^{E-127} * (1+M)$$

The value of the double-precision field is given by

$$(-1)^{S} * 2^{E-1023} * (1+M)$$

The numbers are stored externally in increasing byte-number order, i.e. [0], [1], etc. For example, the maximum single-precision float value +3.40282347E+38 is stored as four bytes valued 0x7f, 0x7f, 0xff, 0xff.

Special single-precision float values are represented as +Infinity (0x7f800000), -Infinity (0xff800000), quiet NaN (not a number) (0xffffffff), and signaling NaN (0x7f800001).

Appendix C. EXAMPLE DATA PRODUCTS

APPENDIX C.1 EXAMPLE LABEL

The following lists an example SHBDR LBL file for a
Mars gravity solution, GGM2BC80.SHB, prepared by Frank Lemoine
of NASA GSFC.
For MESSENGER the "INSTRUMENT_HOST_NAME" would be listed
instead of "MESSENGER" instead of "MARS RECONNAISSANCE ORBITER".
The DESCRIPTION would be changed to reflect the data content of the
MESSENGER 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.

```
PDS_VERSION_ID              = "PDS3"
FILE_NAME                   = "GGM2BC80.SHB"
RECORD_TYPE                 = FIXED_LENGTH
RECORD_BYTES                = 512
FILE_RECORDS                = 336254
^SHBDR_HEADER_TABLE         = ("GGM2BC80.SHB",1)
^SHBDR_NAMES_TABLE          = ("GGM2BC80.SHB",2)
^SHBDR_COEFFICIENTS_TABLE   = ("GGM2BC80.SHB",105)
^SHBDR_COVARIANCE_TABLE     = ("GGM2BC80.SHB",208)

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"
PRODUCT_ID                  = "GGM2BC80.SHB"
PRODUCT_RELEASE_DATE        = 2006-02-28
DESCRIPTION                 = "

 The data in this covariance matrix are stored row-wise,
 in upper triangular form. The error covariance contains
 21506961 elements and has 336254 records. There are 6558
 parameters in the GGM2BC80.SHB covariance matrix: the
 C and S gravity coefficients from degree 2 to 80 (inclusive)
 and the GM of the Mars gravity field. The data format is big endian.

 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 1991 (Davies
 et al., Celestial Mechanics and Dynamical Astronomy, 53, 377-397,
 1992).

 The model was constructed from 955,115 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
 February 2000 after the orbit was circularized.
       Time Periods                      Total
                                          Arcs  Observations
       -----------------------            ----  ------------
       Hiatus                               2       24119
       SPO-1                                8       31001
       SPO-2                               16      157972
```

```
       Feb-Mar 1999                            9       76813
       Apr 1999 - Feb 2000                    47      665210
       -----------------------              ----  ------------
       Total                                          955115

 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 21343 points were included in the orbit
 solutions.

 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).

 The analysis and results were described by F.G. Lemoine,
 D.D. Rowlands, D.E. Smith, D.S. Chinn, G.A. Neumann, and M.T. Zuber
 at the Spring Meeting of the American Geophysical Union, May 30 -
 June 3, 2000, Washington. DC.

 Further improvements to the model are expected as additional MGS
 data are incorporated.

 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.

 A reference for this gravity model is as follows:

 An improved solution of the gravity field of Mars (GMM-2B)
 from Mars Global Surveyor, F.G. Lemoine, D.E. Smith, D.D. Rowlands,
 M.T. Zuber, G.A. Neumann, D.S. Chinn, and D.E. Pavlis,
 J. Geophys. Res., 106(E10), pp. 23359-23376. October 25, 2001."

START_TIME                    = 1997-10-13T00:00:00
STOP_TIME                     = 2000-02-29T12:05:00
START_ORBIT_NUMBER            = 19
STOP_ORBIT_NUMBER             = 4375
PRODUCT_CREATION_TIME         = 2000-09-18T00:00:00.000
PRODUCER_FULL_NAME            = "FRANK G. LEMOINE"
PRODUCER_INSTITUTION_NAME     = "GODDARD SPACE FLIGHT CENTER"
PRODUCT_VERSION_TYPE          = "FINAL"
PRODUCER_ID                   = "MRO GST"
SOFTWARE_NAME                 = "SOLVE.F90INLINE3;2000.01"

OBJECT                = SHBDR_HEADER_TABLE
ROWS                        = 1
COLUMNS                     = 9
ROW_BYTES                   = 56
INTERCHANGE_FORMAT          = BINARY
DESCRIPTION                 = "The SHBDR Header includes
descriptive information about the spherical harmonic
coefficients that follow in SHBDR_COEFFICIENTS_TABLE.
The header consists of a single record of nine data
columns requiring 56 bytes.  The Header is followed by
a pad of binary integer zeroes to ensure alignment
with RECORD_BYTES."

  OBJECT                    = COLUMN
```

```
  NAME                          = "REFERENCE RADIUS"
  DATA_TYPE                     = IEEE_REAL
  START_BYTE                    = 1
  BYTES                         = 8
  UNIT                          = "KILOMETER"
  DESCRIPTION                   = "The assumed reference
  radius of the spherical planet."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                          = "CONSTANT"
  DATA_TYPE                     = IEEE_REAL
  START_BYTE                    = 9
  BYTES                         = 8
  UNIT                          = "KM^3/S^2"
  DESCRIPTION                   = "For a gravity field model
  the gravitational constant GM in km cubed per seconds
  squared for the planet.  For a topography model, set to 1"
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                          = "UNCERTAINTY IN CONSTANT"
  DATA_TYPE                     = IEEE_REAL
  START_BYTE                    = 17
  BYTES                         = 8
  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.  For a topography
  model, set to 0."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                          = "DEGREE OF FIELD"
  DATA_TYPE                     = MSB_INTEGER
  START_BYTE                    = 25
  BYTES                         = 4
  UNIT                          = "N/A"
  DESCRIPTION                   = "Degree of the model field."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                          = "ORDER OF FIELD"
  DATA_TYPE                     = MSB_INTEGER
  START_BYTE                    = 29
  BYTES                         = 4
  UNIT                          = "N/A"
  DESCRIPTION                   = "Order of the model field."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                          = "NORMALIZATION STATE"
  DATA_TYPE                     = MSB_INTEGER
  START_BYTE                    = 33
  BYTES                         = 4
  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                          = "NUMBER OF NAMES"
    DATA_TYPE                     = MSB_INTEGER
    START_BYTE                    = 37
    BYTES                         = 4
    UNIT                          = "N/A"
    DESCRIPTION                   = "Number of valid names in
    the SHBDR Names Table.  Also, the number of valid
    coefficients in the SHBDR Coefficients Table."
  END_OBJECT                = COLUMN

  OBJECT                    = COLUMN
    NAME                          = "REFERENCE LONGITUDE"
    POSITIVE_LONGITUDE_DIRECTION = "EAST"
    DATA_TYPE                     = IEEE_REAL
    START_BYTE                    = 41
    BYTES                         = 8
    UNIT                          = "DEGREE"
    DESCRIPTION                   = "The reference longitude for
    the spherical harmonic expansion; normally 0."
  END_OBJECT                = COLUMN

  OBJECT                    = COLUMN
    NAME                          = "REFERENCE LATITUDE"
    DATA_TYPE                     = IEEE_REAL
    START_BYTE                    = 49
    BYTES                         = 8
    UNIT                          = "DEGREE"
    DESCRIPTION                   = "The reference latitude for
    the spherical harmonic expansion; normally 0."
  END_OBJECT                = COLUMN

END_OBJECT            = SHBDR_HEADER_TABLE

OBJECT                = SHBDR_NAMES_TABLE
  ROWS                      = 6558
  COLUMNS                   = 1
  ROW_BYTES                 = 8
  INTERCHANGE_FORMAT        = BINARY
  DESCRIPTION               = "The SHBDR Names Table
  contains names for the solution parameters (including
  gravity field coefficients) which will follow in
  SHBDR_COEFFICIENTS_TABLE.  The order of the names
  in SHBDR_NAMES_TABLE corresponds identically to the
  order of the parameters in SHBDR_COEFFICIENTS_TABLE.
  Each coefficient  name is of the form  Cij  or  Sij
  where  i  is the degree of the coefficient and  j  is
  the order of the coefficient.  Both indices are three-
  digit zero-filled right-justified ASCII character strings
  (for example,  C010005  for the 10th degree 5th order C
  coefficient, or  S002001  for the 2nd degree 1st order
  S  coefficient).  The eighth byte in the table is an
  ASCII blank used to ensure that the row length
  is equal to RECORD_BYTES.  Names of other solution
  parameters are limited to 8 ASCII characters; if less
  than 8, they will be left-justified and padded with
  ASCII blanks.  The Names Table itself will be padded
```

```
  with ASCII blanks, if necessary, so that its length is
  an integral multiple of RECORD_BYTES."

  OBJECT                       = COLUMN
    NAME                             = "PARAMETER NAME"
    DATA_TYPE                        = CHARACTER
    START_BYTE                       = 1
    BYTES                            = 8
    UNIT                             = "N/A"
    DESCRIPTION                      = "The name of the
    coefficient or other solution parameter, left-
    justified and padded with ASCII blanks (if needed)
    to 8 characters."
  END_OBJECT                   = COLUMN

END_OBJECT             = SHBDR_NAMES_TABLE

OBJECT                 = SHBDR_COEFFICIENTS_TABLE
  ROWS                         = 6558
  COLUMNS                      = 1
  ROW_BYTES                    = 8
  INTERCHANGE_FORMAT           = BINARY
  DESCRIPTION                  = "The SHBDR Coefficients Table
  contains the coefficients and other solution parameters
  for the spherical harmonic model.  The order of the
  coefficients in this table corresponds exactly to the
  order of the coefficient and parameter names in
  SHBDR_NAMES_TABLE.  The SHBDR Coefficients Table will be
  padded with double precision DATA_TYPE zeroes so that
  its total length is an integral multiple of RECORD_BYTES."

  OBJECT                       = COLUMN
    NAME                             = "COEFFICIENT VALUE"
    DATA_TYPE                        = IEEE_REAL
    START_BYTE                       = 1
    BYTES                            = 8
    UNIT                             = "N/A"
    DESCRIPTION                      = "A coefficient Cij or
    Sij or other solution parameter as specified in the
    SHBDR Names Table."
  END_OBJECT                   = COLUMN

END_OBJECT             = SHBDR_COEFFICIENTS_TABLE

OBJECT                 = SHBDR_COVARIANCE_TABLE
  ROWS                         = 21506961
  COLUMNS                      = 1
  ROW_BYTES                    = 8
  INTERCHANGE_FORMAT           = BINARY
  DESCRIPTION                  = "The SHBDR Covariance Table
  contains the covariances for the spherical harmonic model
  coefficients and other solution parameters.  The order of
  the covariances in this table is defined by the product
  of the SHBDR Names Table with its transpose, except that
  redundant terms are omitted on their second occurrence.
  The SHBDR Covariance Table will be padded with double
  precision DATA_TYPE zeroes so that its total length is
  an integral multiple of RECORD_BYTES."

  OBJECT                       = COLUMN
```

```
    NAME                         = "COVARIANCE VALUE"
    DATA_TYPE                    = IEEE_REAL
    START_BYTE                   = 1
    BYTES                        = 8
    UNIT                         = "N/A"
    DESCRIPTION                  = "The covariance value
    for the coefficients and other solution parameters
    specified by the product of SHBDR_NAMES_TABLE with
    its transpose, after omitting redundant terms."
  END_OBJECT               = COLUMN

END_OBJECT           = SHBDR_COVARIANCE_TABLE

END
```

APPENDIX C.2 EXAMPLE SHBDR DATA OBJECT OUTPUT

The following lists the first few lines from an example SHBDR file, the GGM2BC80.SHB Gravity field solution covariance.

We describe below the extracts from a FORTRAN program to read the above GGM2BC280.SHB covariance file, the error covariance of the gravity solution GMM2B.

The SHB file is opened with the following FORTRAN open statement. The key is that the SHB file is a direct access binary file with a record length (in this example) of 512 bytes.
i.e.

```
open (10, file='ggm2bc80.shb', status ='old', access='DIRECT', RECL=512)
```

The first record reads the general solution information, where the variables have been carefully predefined at the top of the program.

```
        ...................................
        real*8 ae, gm, gmsig, reflon, reflat
        integer*4 lmax,mmax,inorm, nvar
        read(10,rec=1)ae, gm, gmsig, lmax, mmax, inorm, nvar, reflon, reflat
        ...................................
```

On output these records are:

```
        ae      =  3397.0
        gm      =  42828.371901      | GM in km**3/sec**2
        gmsig   =  7.40E-05          | GM sigma in km**3/sec**2
        lmax    =  80
        mmax    =  80
        inorm   =  1
        nvar    =  6558        | total number of parameters in the solution.
        reflon  =  0.0E+0
        reflat  =  0.0E+0
```

The next step is to read the coefficient name table and compute the number of lines in the coefficient name table. In this example file there are 64 8 byte characters per record of 512 bytes.

```
           .....................
           nline = (nvar/64) + 1
           .....................
c integer multiplication on the following line is intentional
c we need to know number of variables on the last line
           ..........................
           jend = nvar - (nvar/64)*64
           ..........................
```

```
Record 2, or the first record of the names table contains the following:
 C002000  C002001  C002002  C003000  C003001  C003002  C003003  C004000
 C004001  C004002  C004003  C004004  C005000  C005001  C005002  C005003
 C005004  C005005  C006000  C006001  C006002  C006003  C006004  C006005
 C006006  C007000  C007001  C007002  C007003  C007004  C007005  C007006
 C007007  C008000  C008001  C008002  C008003  C008004  C008005  C008006
 C008007  C008008  C009000  C009001  C009002  C009003  C009004  C009005
 C009006  C009007  C009008  C009009  C010000  C010001  C010002  C010003
 C010004  C010005  C010006  C010007  C010008  C010009  C010010  C011000

Record 104 contains the last few coefficient names of the solution+GM:
 S080052  S080053  S080054  S080055  S080056  S080057  S080058  S080059
 S080060  S080061  S080062  S080063  S080064  S080065  S080066  S080067
 S080068  S080069  S080070  S080071  S080072  S080073  S080074  S080075
 S080076  S080077  S080078  S080079  S080080  GM

The Coefficients table begins at Record 105:
The first eight variables of that record are:

 -0.87451D-03  0.13938D-09 -0.84178D-04 -0.11887D-04  0.39053D-05
 -0.15863D-04  0.35339D-04  0.51258D-05

The first coefficient value is for C20.

The Coefficients table ends at Record 207 with 30 valid records and
 the remainder zero filled:
 -0.39660D-07  0.25145D-08  0.27213D-07  0.60636D-07  0.25307D-07
  0.40813D-08  0.16849D-07  0.16050D-07
 -0.30849D-07 -0.26461D-07 -0.79262D-08  0.35247D-07  0.53467D-08
  0.33029D-07 0.35339D-07  0.28539D-07
 -0.30311D-10  0.38384D-07 -0.19836D-07  0.75625D-07 -0.19420D-07
  0.34309D-09 -0.17577D-07  0.36022D-07
  0.42967D-07  0.42482D-07 -0.40326D-07 -0.19721D-07 -0.53860D-07
  0.42828D+14
  ..........

The last valid record is the value of GM for this solution, as per
the order specified  in the names record.
```