Lunar Reconnaissance Orbiter
Lunar Orbiter Laser Altimeter
Reduced Data Record and Derived Products
Software Interface Specification

Version 2.2
April 28, 2009
SIGNATURE PAGE

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# TABLE OF CONTENTS

1. Introduction ......................................................................................................................... 1  
   1.1. Purpose and Scope ......................................................................................................... 1  
   1.2. Contents ......................................................................................................................... 2  
   1.3. Applicable Documents and Constraints ...................................................................... 2  
   1.4. Configuration Management and Relationships with Other Interfaces ...................... 3  
2. Data Product Characteristics and Environment .................................................................. 4  
   2.1. Instrument Overview ..................................................................................................... 4  
   2.2. Data Product Overview ............................................................................................... 8  
   2.3. Data Processing ........................................................................................................... 9  
      2.3.1. Data Processing Levels ......................................................................................... 9  
      2.3.2. Data Product Generation ................................................................................... 10  
      2.3.3. Data Flow ............................................................................................................ 10  
      2.3.4. Labeling and Identification .................................................................................. 10  
   2.4. Standards Used in Generating Data Products ............................................................... 11  
      2.4.1. PDS Standards .................................................................................................... 11  
      2.4.2. Time Standards ................................................................................................... 11  
      2.4.3. Coordinate Systems ............................................................................................ 11  
      2.4.4. Data Storage Conventions .................................................................................. 12  
   2.5. Data Validation ............................................................................................................ 12  
3. Detailed Data Product Specifications .................................................................................. 12  
   3.1. Data Product Structure and Organization ................................................................. 12  
   3.2. Data Format Descriptions ........................................................................................... 12  
   3.3. Label and Header Descriptions ................................................................................... 12  
4. Applicable Software ........................................................................................................... 14  
   4.1. Utility Programs .......................................................................................................... 14  
   4.2. Applicable PDS Software Tools ................................................................................ 14  
   4.3. Software Distribution and Update Procedures ............................................................. 14  
5. Appendix ............................................................................................................................ 14  
   5.1. Contents of the LOLARDR.FMT file ......................................................................... 14  
   5.2. Sample LOLA GDR Detached Label ....................................................................... 27  
   5.3. Sample LOLA SHADR Label ................................................................................... 28
TABLES AND FIGURES

Table 1: Processing Levels for Science Data Sets. ................................................................. 1  
Figure 1: LOLA ground spot pattern of four successive shots.............................................. 4
Figure 2: LOLA Optical Transceiver Assembly.................................................................... 5
Table 2: LOLA Instrument Technical Details......................................................................... 6
Table 3: Instrument Modes...................................................................................................... 7
Table 4: Standard Product Sizes and Delivery Rates............................................................... 9
### DOCUMENT CHANGE LOG

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<thead>
<tr>
<th>Change</th>
<th>Date</th>
<th>Affected Portions</th>
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<tr>
<td>GDR and SHADR descriptions added</td>
<td>8/12/08</td>
<td>1.1, 5.2, 5.3</td>
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<tr>
<td>Changes reflecting updated calibrations</td>
<td>9/22/08</td>
<td>2.1</td>
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<tr>
<td>Added Ed Grayzek to signatures</td>
<td>10/26/08</td>
<td>ii</td>
</tr>
<tr>
<td>Figure 1 updated</td>
<td>10/26/08</td>
<td>2.1</td>
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<tr>
<td>Applicable Document versions updated</td>
<td>10/26/08</td>
<td>1.3</td>
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<tr>
<td>NASVIEW added as tool to inspect data</td>
<td>10/26/08</td>
<td>4.1</td>
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<tr>
<td>Selenocentric replaced with planetocentric</td>
<td>10/26/08</td>
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<tr>
<td>Relationships to NAIF and LRO-LR explained</td>
<td>10/26/08</td>
<td>2.2</td>
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<tr>
<td>Acronyms for timing added, other removed</td>
<td>10/26/08</td>
<td>5.1</td>
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<tr>
<td>Reviewers suggested edits adopted</td>
<td>10/26/08</td>
<td>various</td>
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<tr>
<td>Replaced coordinate system text with LDWG text</td>
<td>10/26/08</td>
<td>2.2, 2.4.3</td>
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<tr>
<td>Added Resolution Date to TBD table</td>
<td>11/17/08</td>
<td>v</td>
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<tr>
<td>Explained rational for binary tables and reprocessing</td>
<td>11/17/08</td>
<td>2.2, 2.3</td>
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<td>Revised Figure 1 based on Post-ship survey</td>
<td>4/28/09</td>
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### TBD ITEMS

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Resolution Date</th>
</tr>
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<tbody>
<tr>
<td>Appendix 5.1 - LOLARDR.FMT</td>
<td>Numerous descriptions are incomplete, pending completion of calibration report. In particular, there are many ways to interpret pulse width. The measured width between the leading and trailing edges of the pulse is obtained directly from the data, but must be modeled with respect to laser pulse width, detector threshold, receiver gain, and energy returned, as well as incidence angle and regional slope, as discussed in NEUMANNETAL2003. Likewise, the background noise count requires sophisticated modeling, as in SUNETAL2006. Thus the descriptions of these values are incomplete.</td>
<td>Flight Operations Readiness Review + 1 month</td>
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<td>Appendix 5.2 – Gridded Data Products</td>
<td>The values of surface slope, roughness, and albedo must be averaged over one or more baselines to be useful. The range of baselines and resolution of the product resulting from binned averages will be easier to determine with actual data, since the surface characteristics of the Moon at LOLA scales have yet to be measured.</td>
<td>Launch + 6 months</td>
</tr>
<tr>
<td>Appendix 5.2, 5.3</td>
<td>Samples of GDR and SHADR labels are preliminary. LOLA may employ the JPEG2000 format for GDR products if deemed appropriate for the data acquired.</td>
<td>Launch + 6 months</td>
</tr>
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# ACRONYMS AND ABBREVIATIONS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>ASCII</td>
<td>American Standard Code for Information Interchange</td>
</tr>
<tr>
<td>CODMAC</td>
<td>Committee on Data Management and Computation</td>
</tr>
<tr>
<td>DOE</td>
<td>Diffractive Optic Element</td>
</tr>
<tr>
<td>DU</td>
<td>Data Unit on LRO</td>
</tr>
<tr>
<td>DVD-ROM</td>
<td>Digital Video Disk - Read-Only Memory</td>
</tr>
<tr>
<td>EDR</td>
<td>Experiment Data Record</td>
</tr>
<tr>
<td>FSW</td>
<td>Flight Software</td>
</tr>
<tr>
<td>GDR</td>
<td>Gridded Data Record</td>
</tr>
<tr>
<td>GSFC</td>
<td>Goddard Space Flight Center</td>
</tr>
<tr>
<td>HK</td>
<td>Housekeeping</td>
</tr>
<tr>
<td>ICD</td>
<td>Interface Control Document</td>
</tr>
<tr>
<td>ISO</td>
<td>International Standards Organization</td>
</tr>
<tr>
<td>JPL</td>
<td>Jet Propulsion Laboratory</td>
</tr>
<tr>
<td>LOLA</td>
<td>Lunar Orbiter Laser Altimeter</td>
</tr>
<tr>
<td>LR</td>
<td>Laser Ranging</td>
</tr>
<tr>
<td>LRO</td>
<td>Lunar Reconnaissance Orbiter</td>
</tr>
<tr>
<td>MET</td>
<td>Mission Elapsed Time on the LRO spacecraft</td>
</tr>
<tr>
<td>MOC</td>
<td>LRO Mission Operations Center, B32, NASA-GSFC</td>
</tr>
<tr>
<td>MSB</td>
<td>Most Significant Byte</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NAIF</td>
<td>Navigation and Ancillary Information Facility of the PDS</td>
</tr>
<tr>
<td>PDS</td>
<td>Planetary Data System</td>
</tr>
<tr>
<td>PPS</td>
<td>1 Pulse Per Second signal provided by LRO</td>
</tr>
<tr>
<td>RDR</td>
<td>Reduced Data Record</td>
</tr>
<tr>
<td>SC</td>
<td>Spacecraft</td>
</tr>
<tr>
<td>SHADR</td>
<td>Spherical Harmonic Analysis Data Record</td>
</tr>
<tr>
<td>SIS</td>
<td>Software Interface Specification</td>
</tr>
<tr>
<td>SOC</td>
<td>Science Operations Center</td>
</tr>
<tr>
<td>TBD</td>
<td>To Be Determined</td>
</tr>
<tr>
<td>UTC</td>
<td>Coordinated Universal Time</td>
</tr>
</tbody>
</table>
GLOSSARY

Archive – An archive consists of one or more data sets along with all the documentation and ancillary information needed to understand and use the data. An archive is a logical construct independent of the medium on which it is stored.

Archive Volume, Archive Volume Set – A volume is a unit of media on which data products are stored; for example, one ISO 9660 CD-ROM or DVD-ROM (applicable document #3). An archive volume is a volume containing all or part of an archive; that is, data products plus documentation and ancillary files. When an archive spans multiple volumes, they are called an archive volume set. Usually the documentation and some ancillary files are repeated on each volume of the set, so that a single volume can be used alone.

Catalog Information – Descriptive information about a data set (e.g. mission description, spacecraft description, instrument description), expressed in Object Description Language (ODL) which is suitable for loading into a PDS catalog.

Data Product – A labeled grouping of data resulting from a scientific observation, usually stored in one file. A product label identifies, describes, and defines the structure of the data. An example of a data product is a planetary image, a spectrum table, or a time series table.

Data Set – An accumulation of data products. A data set together with supporting documentation and ancillary files is an archive.

Profile – A time-ordered set of altimetry and allied data.

SPICE – An information system to assist scientists in planning and interpreting scientific observations from space-based instruments, maintained by the PDS NAIF Node.

Standard Data Product – A data product generated in a predefined way using well-understood procedures, processed in "pipeline" fashion. Data products that are generated in a nonstandard way are sometimes called special data products.
1. Introduction

1.1. Purpose and Scope

The Lunar Orbiter Laser Altimeter (LOLA) will produce a high-resolution global topographic model and geodetic framework that enables precise targeting, safe landing, and surface mobility to carry out exploratory activities. LOLA will characterize the polar illumination environment, and image permanently shadowed polar regions of the Moon to identify possible locations of surface ice crystals in shadowed polar craters.

This Software Interface Specification document provides users of the Lunar Reconnaissance Orbiter (LRO) LOLA Reduced Data Record (RDR), the Gridded Data Record (GDR) and Spherical Harmonic Data Record (SHADR) data products, with a detailed description of the product and how it was generated, including data sources and destinations. Table 1 gives descriptions of Committee on Data Management and Computation (CODMAC) product levels.

Table 1: Processing Levels for Science Data Sets.

<table>
<thead>
<tr>
<th>NASA</th>
<th>CODMAC</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packet</td>
<td>Raw – Level 1</td>
<td>Telemetry data stream as received at the ground station, with science and engineering data embedded.</td>
</tr>
<tr>
<td>Level 0</td>
<td>Edited – Level 2</td>
<td>Instrument science data (e.g., raw voltages, counts) at full resolution, time ordered, with duplicates and transmission errors removed.</td>
</tr>
<tr>
<td>Level 1A</td>
<td>Calibrated - Level 3</td>
<td>Level 0 data that have been located in space and may have been transformed (e.g., calibrated, rearranged) in a reversible manner and packaged with needed ancillary and auxiliary data (e.g., radiances with the calibration equations applied).</td>
</tr>
<tr>
<td>Level 1B</td>
<td>Resampled - Level 4</td>
<td>Irreversibly transformed (e.g., resampled, remapped, calibrated) values of the instrument measurements (e.g., radiances, magnetic field strength).</td>
</tr>
<tr>
<td>Level 1C</td>
<td>Derived- Level 5</td>
<td>Level 1A or 1B data that have been resampled and mapped onto uniform space-time grids. The data are calibrated (i.e., radiometrically corrected) and may have additional corrections applied (e.g., terrain correction).</td>
</tr>
<tr>
<td>Level 2</td>
<td>Derived - Level 5</td>
<td>Geophysical parameters, generally derived from Level 1 data, and located in space and time commensurate with instrument location, pointing, and sampling.</td>
</tr>
<tr>
<td>Level 3</td>
<td>Derived - Level 5</td>
<td>Geophysical parameters mapped onto uniform space-time grids.</td>
</tr>
</tbody>
</table>

This document is intended to provide enough information to enable planetary scientists to read and understand the format and content of the higher-level LOLA Archive. The specifications in this document apply to all LOLA standard product archive volumes that are generated by the LRO Project. The RDR data product contains the time-ordered LOLA measurement data in reduced, calibrated and geolocated form, one record per laser shot. The altimetric and related measurements generate the GDR and SHADR data products. The GDR data products contain the
binned, interpolated altimetric measurements, as well as albedo, roughness, and surface slope, in cylindrical and polar projections. The SHADR products contain the spherical harmonic expansions of the lunar shape and selenopotential reference surface, time-averaged 1064-nm albedo, and static gravitational potential, along with their associated geodetic constants.

1.2. Contents

This Data Product SIS describes how the RDR data product is processed, formatted, labeled, and uniquely identified. The document discusses standards used in generating the product and software that may be used to access the product. The data product structure and organization is described in sufficient detail to enable a user to read the product. Finally, an example of a product label is provided.

1.3. Applicable Documents and Constraints

This SIS is intended to be consistent with the following documents:

6. LRO LOLA Science Team and PDS Geosciences Node ICD, October 9, 2006.
9. Memorandum of Agreement between the PDS Geosciences Node and the LRO LOLA Data Node, Washington University, St. Louis, Missouri, and the LRO LOLA Instrument Team, Goddard Space Flight Center, Greenbelt, Maryland, October 27, 2006.
1.4. **Configuration Management and Relationships with Other Interfaces**

The RDR and higher-level products described in this SIS are used in the production of other archived products of the LRO mission, so that changes to their content and format may result in an interface impact. A change to this specification will require concurrence of the Principal Investigator, the LRO Project Science Data Manager, and the Planetary Data System Geosciences Discipline Node.
2. Data Product Characteristics and Environment

2.1. Instrument Overview

The LOLA instrument, designed, assembled and tested by the NASA Goddard Space Flight Center (GSFC), has two primary objectives. First, it will produce a high-resolution global topographic model and geodetic framework that will assist with precise targeting, safe landing, and surface mobility for future scientific and exploration activities. LOLA will also characterize the polar illumination environment and image the Moon’s permanently-shadowed regions (PSRs) to identify possible locations of surface ice crystals in shadowed polar craters. To achieve these primary objectives, LOLA will make three science measurements:

1) the distance between the surface and the spacecraft,
2) the spreading of the returned laser pulse, and
3) the transmitted and returned laser energies.

LOLA is a pulse detection time-of-flight altimeter that incorporates a five-spot pattern that measures the precise distance to the lunar surface at 5 spots simultaneously, thus providing 5 profiles across the lunar surface (Figure 1), where the solid circles are the transmitted laser footprints, and dashes are receiver fields-of-view. LOLA fires at a fixed, 28-Hz rate, so that for a nominal 1600 m/s ground track speed there is one shot approximately every 57 m. At a nominal 50-km altitude, each spot within the five-spot pattern has a diameter of 5 m; the spots are 25 meters apart, and form a cross pattern canted by 26 degrees counterclockwise to provide five adjacent profiles.

Figure 1: LOLA ground spot pattern sample of four successive shots, with channels numbered.
The 5-spot pattern determines the surface slope in the along-track and across track directions. LOLA’s design is similar to the Mars Orbiter Laser Altimeter (MOLA) and the Mercury Laser Altimeter (MLA), augmented by a novel diffractive optic element (DOE). LOLA has five independent detectors coupled via fiber optics to the receiver telescope and five receiver channels (1-5). Channel 1 is also fiber-optic-coupled through a dichroic beamsplitter to a Laser Ranging (LR) telescope mounted on the High-Gain Antenna. An R-C filter with a decay time constant of 3.4 ns is applied to the detector output for noise suppression prior to the receiver threshold discriminators.

*Figure 2: LOLA Optical Transceiver Assembly.*
Because LOLA will make global observations, the LOLA altimetry data can be used to improve the spacecraft orbit and our knowledge of far side lunar gravity, which is required for precise landing and low-altitude navigation. Timing of one-way pulses fired from Earth to the LR will also be employed to improve navigation and gravity determination. The LOLA instrument is a pulsed laser time-of-flight altimeter, operating continuously during mapping orbit to produce altimetric ranges that are stored on the LRO spacecraft (SC) for playback. Its housekeeping (HK) data are also provided in a realtime data stream and contain information regarding the flight software status and the Laser Ranging signals from Earth stations. The housekeeping and science data comprise a single record each second that forms the EDR.

The instrument hardware consists of laser transmitter, receiver, and passive radiator subsystems mounted in an Optical Transceiver Assembly (Figure 1), together with a Power Converter Assembly and Digital Unit mounted in the Main Electronics Box. There are two redundant lasers coupled to the transmit optics, selectable by software command. Transmit and receive pulses are measured with independent leading and trailing edge times using ACAM TDC-S1 chips designed for space docking applications, offset by a 5 MHz coarse count. Energy is monitored via a gated charge-time measurement circuit with digitizer. The instrument is co-boresighted with the LRO Cameras on the spacecraft +Z optical bench. The main technical details regarding the instrument are given in Table 2.

Table 2: LOLA Instrument Technical Details.

<table>
<thead>
<tr>
<th>Mass</th>
<th>13.2 kg (at Critical Design Review 7/06)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>33.5 W (average)</td>
</tr>
<tr>
<td>Data rate</td>
<td>27 kbps 3424 Bytes, 1 packet per second</td>
</tr>
<tr>
<td>Lasers</td>
<td>2 (1 cold spare) Cr:Nd:YAG cross-Porro resonator, TEM00, TEC cooled</td>
</tr>
<tr>
<td>Wavelength</td>
<td>1064.3±0.1 nm</td>
</tr>
<tr>
<td>Diode bars</td>
<td>2 60 A, 140-160 µs pump, with passive Cr4+:YAG Q-switch</td>
</tr>
<tr>
<td>Pulses</td>
<td>28 Hz, 2.7±0.3 mJ 5.6 ns FWHM</td>
</tr>
<tr>
<td>Thermal</td>
<td>passive radiator Laser operating range: 5°C to 35°C</td>
</tr>
<tr>
<td>Detectors</td>
<td>5 Si-APDs preamp bandwidth 100 Mhz, followed by R-C 3.4 ns filter</td>
</tr>
<tr>
<td>Quantum Efficiency</td>
<td>0.4 @1064 nm</td>
</tr>
<tr>
<td>Detector noise</td>
<td>0.05 pW/Hz^{1/2} Noise equivalent power</td>
</tr>
<tr>
<td>Optics</td>
<td>Receiver Transmitter after 18x Beam Expander and DOE</td>
</tr>
<tr>
<td>Objective</td>
<td>Sapphire BK7G18/fused silica DOE</td>
</tr>
<tr>
<td>Obj. diameter</td>
<td>14 cm 3.24 cm</td>
</tr>
<tr>
<td>Obj. area</td>
<td>0.015 m² 8.245 cm²</td>
</tr>
<tr>
<td>Transmission</td>
<td>&gt;70% &gt;95%</td>
</tr>
<tr>
<td>Effective F. L.</td>
<td>50.0 cm</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------</td>
</tr>
<tr>
<td>F.O.V. $1/e^2$</td>
<td>400 µrad</td>
</tr>
<tr>
<td>Fiber Optic</td>
<td>200 µm, 0.22NA</td>
</tr>
<tr>
<td>Bandpass filter</td>
<td>dichroic beamsplitter</td>
</tr>
</tbody>
</table>

Instrument modes (Table 3) are controlled by ground command. Independent of these modes, the Flight Software (FSW) may be active or commanded to a reset state. The digital unit outputs data directly to the SC over the 1553 bus in either case. Thresholds, gains, and range gates are normally controlled by the FSW algorithm. The algorithm seeks to maximize the probability of detection within a range window under varying background noise conditions, by utilizing hardware noise counters in a fashion similar to that employed on the MOLA and MLA instruments. There are two separate range windows within the LOLA timing electronics, one for the Earth-based LR pulses, and a variable lunar range window that allows only triggers during the interval of time that returns are expected from the surface, according to the FSW return histograms. Since only one range event is recorded, a separate counter records the number of events within the range windows. To accommodate the large dynamic range of lunar return strength, a variable gain amplifier is implemented in hardware prior to the discriminator input. The gain is set according to tables of gain vs. lunar range, one for each detector. Earth laser ranges are recorded by detector 1 during the 8 ms preceding each laser fire, using the same threshold and gain settings as for lunar ranges. Owing to higher background Earth counts, especially during New Moon phases, the detector 1 thresholds are likely higher than those of the detector 2-5 channels.

Table 3: Instrument Modes.

<table>
<thead>
<tr>
<th>MODE</th>
<th>TELEMETRY</th>
<th>LASER</th>
<th>DETECTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement</td>
<td>Housekeeping, Science</td>
<td>Firing enabled, 28Hz trigger</td>
<td>Active-LR and lunar return</td>
</tr>
<tr>
<td>Standby 2</td>
<td>HK, Science</td>
<td>Firing enabled, cap. charged</td>
<td>Active-LR and noise</td>
</tr>
<tr>
<td>Standby 1</td>
<td>HK, Science</td>
<td>Laser TEC active</td>
<td>Active-LR and noise</td>
</tr>
<tr>
<td>Off</td>
<td>Analog temps</td>
<td>Survival heaters enabled</td>
<td>Inactive</td>
</tr>
</tbody>
</table>

2.2. Data Product Overview

The LOLA RDR data product consists of time-of-flight ranges to the lunar surface and ancillary data that have been located in a selenodetic coordinate frame about the center of mass of the Moon. This planetocentric coordinate frame is described further as the Mean-Earth/polar Axis convention in section 2.4.3 and Applicable Document 10. The EDR data product is the source of the measurement data. After range calibration and orbital processing, the range to each laser spot is located on the surface using a spacecraft trajectory, attitude history, and a lunar orientation
model, to produce an altimetric datum. The range profiles are organized into an RDR product containing calibrated, geolocated pulse returns, radii and energies; and higher-level gridded and transformed data products. The RDR data product is a binary table with fixed-length records. The binary table is a PDS standard format that can be stored, managed and reprocessed efficiently without loss of precision, and can be converted to the equivalent engineering and scientific units for import into analysis software by standard formatted output specifications (see Section 4). This choice also maximizes flexibility for users who may wish to handle only selected data values, or who may wish to import them into geographically-organized databases. Record columns consist of uniform-length, 4-byte integer values, stored in Most-Significant Byte (MSB_INTEGER) order that may be converted to Least-Significant Byte (LSB_INTEGER) order by a single global transformation. Both UNSIGNED and SIGNED INTEGER types are employed.

The RDR product is used to generate derived data products that are binned, resampled, and transformed. The GDR products are map-projected digital elevation models and related products. They are transformed into spherical harmonic expansions to produce the SHADR products. Much of the processing of the RDR product may be used to reconstruct and improve the geometric information regarding the spacecraft position, attitude, and clock history. The improved geometry may be archived in the SPICE format through the PDS Navigation and Ancillary Information Facility (NAIF) Node, but will not be included in this archive.

Much of this improvement is anticipated to result from the Laser Ranging Experiments on board LRO, for which data are returned through the LOLA instrument. This investigation is separate from that of the altimeter but is intimately coupled. The Laser Ranging data are originated by ground stations under the auspices of the LRO Project and are collated with Earth returns in the LOLA data stream by the LOLA SOC, provided to the Flight Dynamics Facility and to the participating stations of the International Laser Ranging Service by the Crustal Dynamics Data Information Service at GSFC. These derived LR products will not be included in this archive.

The RDRs will be aggregated by half-orbits.
to keep file sizes manageable (<25 Mbyte per product), where the Northern half-orbit begins at the ascending node and the Southern half-orbit begins at the descending node.

Table 4 summarizes expected sizes and production rates for the LOLA Standard products.

<table>
<thead>
<tr>
<th>Product</th>
<th>Product Size</th>
<th>Production Rate per Day, average</th>
<th>Expected Number of Products for Primary Mission (366 days)</th>
<th>Expected Total Data Volume for Primary Mission</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOLA_EDR</td>
<td>23.3 MByte</td>
<td>12.7</td>
<td>4670</td>
<td>108 GB</td>
</tr>
<tr>
<td>LOLA_RDR</td>
<td>24 MByte</td>
<td>25-26</td>
<td>9400</td>
<td>225 GB</td>
</tr>
<tr>
<td>LOLA_GDR</td>
<td>&lt;2 GByte</td>
<td>monthly revisions of ~100 data products</td>
<td>100</td>
<td>200 GB</td>
</tr>
<tr>
<td>LOLA_SHADR</td>
<td>&lt;5 MByte</td>
<td>release at ~quarterly intervals</td>
<td>4</td>
<td>&lt;1 GB</td>
</tr>
</tbody>
</table>

### 2.3. Data Processing

The pipeline data processing begins by generating an EDR product with a detached PDS label, in one-to-one correspondence with the files generated by the instrument on the LRO spacecraft, corrected for transmission errors, gaps and duplicates where possible. The format of the files is identical to that on the spacecraft. LOLA operates continuously, generating one 3424-byte record each second, with an associated 12-byte telemetry header. The telemetry header information is captured in a detached "PDS3" Version ASCII label. During tracking passes, the instrument housekeeping portion of the telemetry is transmitted via a real-time connection for use by the LR ground system, but is not archived since it is duplicated in the EDR product. The aggregate data rate is approximately 300 Mbytes per day.

The EDR products are geolocated using preliminary and definitive orbits produced by the LRO Flight Dynamics Facility in order to determine approximate nodal crossing times. The Data Records are then aggregated by orbit number in North/South pairs and geolocated into the RDR products using precision orbit reconstructions and calibration algorithms. Each 1-Hz record of the EDR corresponds to 28 laser shots and produces 28 records in the RDR. Instrument engineering values such as algorithm status, detector status (noise counts, temperatures, etc.) from the EDR are not included in the RDR records.

#### 2.3.1. Data Processing Levels

The EDR product is CODMAC level 2 (Table 1), consisting of raw counts, edited to correct transmission errors and eliminate duplicates. In order to be useful for measurement and geological investigations, the data must be classified to determine whether individual laser shots are valid pulses and produce ground returns above the background noise level of detection. These data must be calibrated to engineering and physical units, and located in a center-of-mass coordinate system. The RDR data product is CODMAC level 3. Binned and interpolated data on
a uniformly-spaced grid (GDR) comprise the CODMAC level 4 data products, while transformed spherical harmonic coefficients (SHADR) comprise CODMAC level 5.

2.3.2. Data Product Generation

All data products at CODMAC level 2 and higher are generated by the LOLA SOC. Raw data are not subject to decompression, as the full instrument output counts are stored in the telemetry packets. Following EDR generation, software algorithms perform calibration, geolocation, and editing to eliminate noise. Calibration consists of conversion of raw counts into laser time-of-flight ranges, pulse widths, and energies, using tables and algorithms based on ground test data. Editing consists of generating data quality flags for each laser pulse return, to distinguish between probable lunar returns and noise triggers, and to flag anomalous measurements. Algorithms and ancillary data used in the RDR processing are described in the LOLA Instrument Calibration Document, applicable document #12.

During the primary mission, the LRO spacecraft will perform propulsive orbital adjustment maneuvers at monthly intervals. These maneuvers will terminate the dynamical orbital solutions and provide a natural breakpoint for altimetric reprocessing. Multiple versions of the RDR and some higher-level products will be generated based on a monthly reprocessing and validation step, as orbit knowledge improves and refined crossover adjustments are performed. Each new version of the data products will replace all of the older products and supercede all previous versions in the electronic archive, and will be identified in the PRODUCT_VERSION_ID fields of the PDS labels. This approach of periodic reprocessing is in accordance with the cumulative improvement in coverage density and of orbital knowledge that is inherent in laser altimetric missions.

2.3.3. Data Flow

Data are pushed directly from the LRO MOC through the GSFC Internet backbone to the LOLA SOC, where processing occurs. The LOLA SOC serves as a Data Node of the Planetary Data System. Data products and catalogs are made available to the PDS via a Query Server connection as well as by other electronic means. Sizes and volumes of all the data products generated over the course of the primary mission are given in Table 4. The data products cover variable time spans according to their processing level. A monthly reprocessing cycle will be applied to all CODMAC Level 3 and higher products, following which new versions of current and previous products are redelivered to the Data Node. At 3-month intervals as specified in the Data Management and Archive Plan (Applicable Document 2), validated releases of a cumulative archive will be made. It is anticipated that only the current version of data products will be maintained after the specified releases.

2.3.4. Labeling and Identification

The data set IDs provided by the PDS for the LOLA RDR and higher level data products are:
"LRO-L-LOLA-3-RDR-V1.0", "LRO-L-LOLA-4-GDR-V1.0", and "LRO-L-LOLA-5-SHADR-V1.0".

The file naming convention for LOLA RDR files will be:
LOLARDR_RRRRX.DAT, where RRRRR refers to the orbit number and X refers to the lunar hemisphere, either N or S. PDS detached labels with a suffix of “.LBL” provide information about processing and calibration version. Details about label and header formats are specified in section 6. Labels are subject to revision after monthly reprocessing, but the product filenames will not be modified.

### 2.4. Standards Used in Generating Data Products

#### 2.4.1. PDS Standards

LOLA data products comply with Planetary Data System standards for file formats and labels, as described in the PDS Standards Reference, Applicable Document 5.

#### 2.4.2. Time Standards

All time tags are related to the LRO spacecraft internal clocks, whose performance is monitored by the Project. The PDS labels for LOLA products uses keywords denoting time values, such as start time, stop time, start spacecraft clock count, and stop spacecraft clock count. Each time value standard is defined according to the PDS keyword definitions. Project-supplied conversions from Mission Elapsed Time (MET) to Coordinated Universal Time (UTC) include a Spacecraft Time Correction Factor that is included in the nominal time values. Geolocation software is based rigorously on Barycentric Dynamical Time, a convention that is realized through Terrestrial Dynamical Time and orbital theories. At the Project level, the conversions of MET to UTC are specified to be accurate within 3 ms, during which time the SC ground track travels approximately 5 meters or one laser spot diameter. Laser Ranging and orbital analysis will reconstruct the observation time to a significantly higher level of accuracy.

#### 2.4.3. Coordinate Systems

Spatial information is applied in conversion of laser altimetric bounce points from inertial coordinates to lunar body-fixed coordinates about the center of mass of the Moon, or planetocentric coordinates. In particular, the LOLA RDR adopts the Mean-Earth/polar axis convention. LRO data use lunar planetocentric/body-fixed coordinates with east-positive longitude from 0 to 360 degrees. A mean Earth/polar axis (ME) reference system (also called the mean Earth/rotation system) is used, with the z axis being the mean rotational pole and with the prime meridian (zero degrees longitude) defined by the mean Earth direction.

The ME reference system is used for all LRO archival data. This LRO standard is documented in Applicable Document 10. Using coordinates in the ME system is consistent with recommendations from the International Astronomical Union (IAU)/International Association of Geodesy (IAG) Working Group on Cartographic Coordinates and Rotational Elements.

A Jet Propulsion Laboratory (JPL) planetary and lunar ephemeris and corresponding Euler angle set are used to define an ME frame to which the LRO data are registered. The LRO Data Working Group (LDWG) determines which ephemeris and Euler angle set should be used. Alternatively, LRO data can be registered to an existing or new reference frame in the ME system, via ties to surface points known in the frame (examples include Lunar Laser Ranging (LLR) retroreflectors, points in images and Digital Elevation Models).
When a JPL planetary and lunar ephemeris is used, the NAIF node of the PDS provides the necessary lunar ephemeris file (SPK) and binary lunar orientation file (PCK) in a Principal Axes (PA) reference frame for use with the SPICE Toolkit. NAIF also provides the frames kernel (FK) used for accessing the PA orientation in the PCK and for transforming from the PA frame to the ME frame.

2.4.4. Data Storage Conventions

The Most-significant-byte (MSB) byte order is adopted. Architecture-specific dependencies in the RDR product are mitigated through adoption of a consistent integer byte order and uniform word size.

2.5. Data Validation

Data validation shall be applied to data products by the LOLA Measurement Team to ensure that their contents and format are free of errors and comply with PDS archive standards (Applicable Document 5). For the RDR product this will consist of a combined orbit-determination and crossover residual analysis. The RDR and higher-level products will be re-released monthly after such analysis is completed.

3. Detailed Data Product Specifications

The LOLA RDR data products are stored as fixed-length, fixed-format binary tables. The detached PDS labels for LOLA RDR's are stored as ASCII text in fixed-length records terminated by an ASCII carriage-return and line-feed pair. The product labels will point to the corresponding data files, and contain pointers to format files. The GDR data products will be stored as either binary images or as JPEG-2000 files. The SHADR data products are Comma-Separated Values with attached labels.

3.1. Data Product Structure and Organization

The DATA/LOLA_RDR directory will have subdirectories for each monthly orbital maneuver cycle named LRO_PP_NN, where PP refers to the first two letters of mission phase (CO = Commissioning, NO = Nominal, EX = Extended), and NN is refers to the current monthly orbital cycle, ending with Station Keeping Maneuvers, starting with 01. Typical file paths will therefore be

/Data/LOLA_RDR/LRO_NO_NN/LOLARDR_RRRRX.DAT,

where RRRRR is the mission orbit number and the hemisphere X is either N or S. The DATA/LOLA_GDR directory may have subdirectories for JPEG or IMG files. The DATA/LOLA_SHADR directory will not have subdirectories.

3.2. Data Format Descriptions

The LOLA RDR table format description is given in Appendix 1. The RDR format file is “LOLARDR.FMT”. This column definition file is stored in the LABEL directory of the LOLA archive. The GDR and SHADR formats are contained in their respective labels.
3.3. Label and Header Descriptions

An example of a detached PDS RDR label follows. The SOURCE_PRODUCT_ID contains information regarding the raw datasets and geometry processed for a given version. The PRODUCT_VERSION_TYPE contains the instrument range calibration, energy calibration, pulse spreading calibration, background illumination calibration (radiometry from noise counts), gravity model, and reprocessing level. The INSTRUMENT_MODE_ID is relevant to the slight offset in alignment of the two redundant lasers, for geolocation, and the timing source for firing. The LRO:STCF_FILE_NAME gives the file containing a nominal offset from spacecraft clock counts to Coordinated Universal Time relative to January 1, 2001, 0 hours. The remainder of the parameters are generic and need not be described in detail. Sample PDS GDR and SHADR labels are given in Appendices.

PDS_VERSION_ID = "PDS3"
FILE_NAME = "LOLARDR_00111N.DAT"
FILE_RECORDS = 3136
RECORD_TYPE = FIXED_LENGTH
RECORD_BYTES = 256

PRODUCT_ID = "LOLARDR_00111N_DAT"
PRODUCT_VERSION_ID = "V1"
PRODUCT_CREATION_TIME = 2008-11-03T12:00:00
PRODUCT_TYPE = "RDR"
STANDARD_DATA_PRODUCT_ID = "DATA"
SOFTWARE_NAME = "LOLA_RDR"
SOFTWARE_VERSION_ID = "1.0"
SOURCE_PRODUCT_ID = {"LOLA_2010084_0000835.DAT"}
SPICE_FILE_NAME = {"FDF29_2010084_2010085_N01.BSP","CK08307.BC","LOLA01.IK","DE421.BPC"}
COORDINATE_SYSTEM_NAME = "MEAN EARTH/POLAR AXIS OF DE421"
INSTRUMENT_HOST_NAME = "LUNAR RECONNAISSANCE ORBITER"
INSTRUMENT_NAME = "LUNAR ORBITER LASER ALTIMETER"
INSTRUMENT_ID = "LOLA"
DATA_SET_ID = "LRO-L-LOLA-3-RDR-V1.0"
DATA_SET_NAME = "LRO MOON LASER ALTIMETER 3 RDR V1.0"
MISSION_PHASE_NAME = "COMMISSIONING"
TARGET_NAME = "MOON"
PRODUCER_ID = LRO_LOLA_TEAM
PRODUCER_FULL_NAME = "DAVID E. SMITH"
PRODUCER_INSTITUTION_NAME = "GODDARD SPACE FLIGHT CENTER"
PRODUCT_RELEASE_DATE = 2008-11-03
ORBIT_NUMBER = 00111
PRODUCT_VERSION_TYPE = {"RNG_CAL_01","EN_CAL_01","PW_CAL_01",
"BKG_CAL_01","LGM001","XOVER001"}
START_TIME = 2008-11-02T00:00:00.000
STOP_TIME = 2008-11-02T00:01:52.000
SPACECRAFT_CLOCK_START_COUNT = "9132"
SPACECRAFT_CLOCK_STOP_COUNT = "9244"
INSTRUMENT_MODE_ID = {"SC_A","LASER_1", "ENABLED"}
LRO:STCF_FILE_NAME = "LOLA_SC_2010087_0000864.HK"
^TABLE
OBJECT = TABLE
This product contains time-ordered, calibrated, geolocated data reduced by the LRO Lunar Orbiter Laser Altimeter (LOLA) Science Operations Center at NASA Goddard Space Flight Center. Orbit and geometry data describing the observations has been supplied by the LRO Flight Dynamics Facility and the LOLA Science Team. The complete column definitions are contained in a structure file LOLARDR.FMT. Additional details are contained in the RDR SIS document."

4. **Applicable Software**

Signed and unsigned four-byte integers represent the RDR data values with sufficient precision to avoid roundoff errors. Because the LOLA RDR data products are formatted as binary tables, they must be read by software that understands PDS table formats and can manipulate byte-order-dependent fields. The primary access to the data product is through the table definitions herein described. Software to read and format the data into ASCII text will be maintained by the LOLA Team for commonly used platforms. The PDS Geosciences Node will maintain the most current versions of software for download by users through the Internet, along with the data. The general public may also access the data through geographically-based queries to databases.

4.1. **Utility Programs**

A stand-alone utility 'rdr2csv' converts an RDR into a 28-Hz, Comma Separated Values-style (CSV) text file. It should be noted that this text file may contain as many as ~95,000 records and may not be supported as a single table by legacy spreadsheet software. A similar utility 'edr2csv' converts the instrument 1-Hz status records into an ASCII text file.

4.2. **Applicable PDS Software Tools**

The PDS-D query software is available to extract metadata from catalogs and download specific data products from a web browser. Software tools are also being developed by the PDS Geosciences Node. NASAVIEW, a generic software reader for PDS-formatted files, can be also be used to inspect the binary RDR data files but is not fully supported on all operating systems.

4.3. **Software Distribution and Update Procedures**

Software to read the binary tables and output CSV tables will be provided as stand-alone executable binaries, maintained by the LOLA Team. Current platforms supported are Intel and PowerPC MacOS X, Linux, and SunOS Sparc. Software will be ported to non-Unix systems as time permits. Source code is distributed as part of the LOLA Archive. Updates will be made available at the PDS Geosciences Node.
5. Appendix

5.1. Contents of the LOLARDR.FMT file

/* LOLARDR.FMT v. 26 October 2008 */
/* LOLARDR.FMT v. 26 October 2008 with edits 26 March 2009 */
/* Each record represents one 28-Hz LOLA minor frame with 5 spots. */
/* A complete description of the calibrations and algorithms */
/* is given in RIRISETAL2009. */
/* Definition of T0: */
/* Shot reference time, the clock tick starting each 28-Hz minor frame, */
/* relative to the 1 pulse-per-second signal provided by the LRO clock. */
/* Definition of T0: */
/* Shot reference time, the clock tick starting each 28-Hz minor frame, */
/* relative to the 1 pulse-per-second signal provided by the LRO clock. */

OBJECT = COLUMN
COLUMN_NUMBER = 1
BYTES = 4
START_BYTE = 1
NAME = MET_SECONDS
DATA_TYPE = MSB_INTEGER
MISSING_CONSTANT = -1
DESCRIPTION = "LRO Data Unit (DU) mission elapsed time (MET) passed to LOLA at the LRO 1 PPS (one pulse per second) tick."
END_OBJECT

OBJECT = COLUMN
COLUMN_NUMBER = 2
BYTES = 4
START_BYTE = 5
NAME = SUBSECONDS
DATA_TYPE = MSB_UNSIGNED_INTEGER
DESCRIPTION = "Transmit time as fractional seconds of MET time, roughly 9.4872 ms after the shot reference time T0. If no fire is detected, set to T0."
END_OBJECT

OBJECT = COLUMN
COLUMN_NUMBER = 3
BYTES = 8
ITEMS = 2
ITEM_BYTES = 4
START_BYTE = 9
NAME = TRANSMIT_TIME
DATA_TYPE = MSB_UNSIGNED_INTEGER
MISSING_CONSTANT = 4294967295
DESCRIPTION = "Transmit time in Terrestrial Dynamical Time (TDT) at the LRO spacecraft, in seconds from the J2000 epoch. The LRO Project counts time from 2001-01-01T00:00:00, thus a constant offset of 365*86400 + 43200 has been added to match J2000. TDT is the independent argument of apparent geocentric ephemerides. TDT is related to Coordinated Universal Time (UTC) through
International Atomic Time (TAI) and leap seconds.

TDT = TAI + 32.184 seconds.
TAI = UTC + leap seconds (34 seconds in 2009).

For portability, time will be stored as an integer number of seconds and a 32-bit fractional number of seconds, as two unsigned values.

```
END_OBJECT  = COLUMN

OBJECT      = COLUMN
COLUMN_NUMBER = 4
BYTES       = 4
NAME        = LASER_ENERGY
DATA_TYPE   = MSB_INTEGER
UNIT        = 'NANOJOULES'
START_BYTE  = 17
MISSING_CONSTANT = -1
DESCRIPTION = "Laser transmit energy."
END_OBJECT  = COLUMN

OBJECT      = COLUMN
COLUMN_NUMBER = 5
BYTES       = 4
NAME        = TRANSMIT_WIDTH
DATA_TYPE   = MSB_INTEGER
UNIT        = 'PICOSECONDS'
START_BYTE  = 21
MISSING_CONSTANT = -1
DESCRIPTION = "Laser transmit pulse width."
END_OBJECT  = COLUMN

OBJECT      = COLUMN
COLUMN_NUMBER = 6
BYTES       = 4
NAME        = SC_LONGITUDE
DATA_TYPE   = MSB_INTEGER
UNIT        = 'DEGREES * (10**7)'
MISSING_CONSTANT = -2147483648
START_BYTE  = 25
DESCRIPTION = "Spacecraft Center-of-Mass position in Moon-fixed coordinates of longitude in the range -180 to 180 degrees."
END_OBJECT  = COLUMN

OBJECT      = COLUMN
COLUMN_NUMBER = 7
BYTES       = 4
NAME        = SC_LATITUDE
DATA_TYPE   = MSB_INTEGER
UNIT        = 'DEGREES * (10**7)'
MISSING_CONSTANT = -2147483648
START_BYTE  = 29
DESCRIPTION = "Spacecraft Center-of-Mass position in Moon-fixed coordinates of latitude, in the range -90 to 90 degrees."
END_OBJECT  = COLUMN
```

```
START_BYTE = 33
NAME = SC_RADIUS
DATA_TYPE = MSB_UNSIGNED_INTEGER
UNIT = 'MILLIMETERS'
MISSING_CONSTANT = 4294967295
DESCRIPTION = "Spacecraft Center-of-Mass position in Moon-centered radial coordinates."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 9
BYTES = 4
START_BYTE = 37
NAME = SELENOID_RADIUS
DATA_TYPE = MSB_UNSIGNED_INTEGER
MISSING_CONSTANT = 4294967295
UNIT = 'MILLIMETERS'
DESCRIPTION = "Equipotential radius (geoid) at Spot 1, relative to an equipotential surface whose mean equatorial radius is 1737.4 kilometers."
END_OBJECT = COLUMN

/* The science shot structure 5x10 fields */
/* Spot 1, the center spot */

OBJECT = COLUMN
COLUMN_NUMBER = 10
NAME = LONGITUDE_1
DATA_TYPE = MSB_INTEGER
BYTES = 4
START_BYTE = 1
UNIT = 'DEGREES * (10**7)'
MISSING_CONSTANT = -2147483648
DESCRIPTION = "The planetocentric longitude of the spot 1 centroid, in the range -180 to 180 degrees. Negative values should be adjusted by adding 360 degrees to conform with LRO conventions."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 11
NAME = LATITUDE_1
DATA_TYPE = MSB_INTEGER
START_BYTE = 45
BYTES = 4
UNIT = 'DEGREES * (10**7)'
MISSING_CONSTANT = -2147483648
DESCRIPTION = "The planetocentric latitude of the spot 1 centroid, in the range -90 to 90 degrees."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 12
NAME = RADIUS_1
DATA_TYPE = MSB_INTEGER
START_BYTE = 49
BYTES = 4
UNIT = 'MILLIMETERS'
MISSING_CONSTANT = 4294967295
DESCRIPTION = "The distance from the Moon center to the Spot 1 centroid."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 13
NAME = RANGE_1
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 53
BYTES = 4
UNIT = 'MILLIMETERS'
MISSING_CONSTANT = 4294967295
DESCRIPTION = "LOLA 2-way range to the spot 1 centroid."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 14
NAME = PULSE_1
DATA_TYPE = MSB_INTEGER
START_BYTE = 57
BYTES = 4
UNIT = 'PICOSECOND'
MISSING_CONSTANT = -1
DESCRIPTION = "Pulse width of spot 1 centroid."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 15
NAME = ENERGY_1
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 61
BYTES = 4
UNIT = 'ZEPTOJOULES'
DESCRIPTION = "Received Energy of detected return."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 16
NAME = BACKGROUND_1
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 65
BYTES = 4
UNIT = 'PICOWATTS'
DESCRIPTION = "Background noise power at detector 1 using the noise counter interval, minus the Earth and lunar events, accounting for glitches resulting from the energy measurement, as calibrated by the receiver noise model."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 17
NAME = THRESHOLD_1
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 69
BYTES = 4
UNIT = 'NANOVOLTS'
DESCRIPTION = "Threshold at detector 1."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 18
NAME = GAIN_1
DATA_TYPE = MSB_U
START_BYTE = 73
BYTES = 4
DESCRIPTION = "Gain at detector 1 scaled by 1.E6."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 19
NAME = SHOT_FLAG_1
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 77
BYTES = 4
DESCRIPTION = "Describes the probability that spot 1 is a lunar range
and its associated quality using flags in the least significant byte. Any
values other than 0 should be regarded as an invalid measurement.
bit 0 = ground/not ground
bit 1 = xmt LE
bit 2 = xmt TE
bit 3 = rcv LE
bit 4 = rcv TE
bit 5 = xmt energy invalid
bit 6 = rcv energy invalid
bit 7 = TDC status invalid

The next most significant byte gives the RMU phase status for TX and RX:
bit 8 = RMU Phase of transmit pulse, A=0, B=1
bit 9 = RMU Phase of receive channel, A=0, B=1
bits 10-15 unassigned
The succeeding two bytes represent an unsigned 16-bit value.
bits 16-31 are used as a numeric indicator of range quality in TBD units."
END_OBJECT = COLUMN

/* Spot 2 */

OBJECT = COLUMN
COLUMN_NUMBER = 20
NAME = LONGITUDE_2
DATA_TYPE = MSB_INTEGER
START_BYTE = 81
BYTES = 4
UNIT = 'DEGREES * (10**7)'
MISSING_CONSTANT = -2147483648
DESCRIPTION = "The planetocentric longitude of the spot 2 centroid,
in the range -180 to 180 degrees. Negative values should be adjusted by
adding 360 degrees to conform with LRO conventions."
END_OBJECT = COLUMN
OBJECT = COLUMN
COLUMN_NUMBER = 21
NAME = LATITUDE_2
DATA_TYPE = MSB_INTEGER
START_BYTE = 85
BYTES = 4
UNIT = 'DEGREES * (10**7)'
MISSING_CONSTANT = -2147483648
DESCRIPTION = "The planetocentric latitude of the spot 2 centroid."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 22
NAME = RADIUS_2
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 89
BYTES = 4
UNIT = 'MILLIMETERS'
DESCRIPTION = "The distance from the Moon center to the Spot 2 centroid."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 23
NAME = RANGE_2
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 93
BYTES = 4
UNIT = 'MILLIMETERS'
DESCRIPTION = "LOLA range to the spot 2 centroid."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 24
NAME = PULSE_2
DATA_TYPE = MSB_INTEGER
START_BYTE = 97
BYTES = 4
UNIT = 'PICOSECOND'
MISSING_CONSTANT = -1
DESCRIPTION = "Pulse width of spot 2 centroid."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 25
NAME = ENERGY_2
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 101
BYTES = 4
UNIT = 'ZEPTOJOULES'
DESCRIPTION = "Received Energy of detected return."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 26
NAME               = BACKGROUND_2
DATA_TYPE          = MSB_UNSIGNED_INTEGER
START_BYTE         = 105
BYTES              = 4
UNIT               = 'PICOWATTS'
DESCRIPTION        = "Background noise power at detector 2."
END_OBJECT          = COLUMN

OBJECT              = COLUMN
COLUMN_NUMBER      = 27
NAME               = THRESHOLD_2
DATA_TYPE          = MSB_UNSIGNED_INTEGER
START_BYTE         = 109
BYTES              = 4
UNIT               = 'NANOVOLTS'
DESCRIPTION        = "Threshold at detector 2."
END_OBJECT          = COLUMN

OBJECT              = COLUMN
COLUMN_NUMBER      = 28
NAME               = GAIN_2
DATA_TYPE          = MSB_UNSIGNED_INTEGER
START_BYTE         = 113
BYTES              = 4
DESCRIPTION        = "Gain at detector 2 scaled by 1.E6."
END_OBJECT          = COLUMN

OBJECT              = COLUMN
COLUMN_NUMBER      = 29
NAME               = SHOT_FLAG_2
DATA_TYPE          = MSB_UNSIGNED_INTEGER
START_BYTE         = 117
BYTES              = 4
DESCRIPTION        = "Describes the probability that spot 2 is a lunar range and its associated quality as in SHOT_FLAG_1."
END_OBJECT          = COLUMN

/* Spot 3 */

OBJECT              = COLUMN
COLUMN_NUMBER      = 30
NAME               = LONGITUDE_3
DATA_TYPE          = MSB_INTEGER
START_BYTE         = 121
BYTES              = 4
UNIT               = 'DEGREES * (10**7)'
MISSING_CONSTANT   = -2147483648
DESCRIPTION        = "The planetocentric longitude of the spot 3 centroid, in the range -180 to 180 degrees. Negative values should be adjusted by adding 360 degrees to conform with LRO conventions."
END_OBJECT          = COLUMN

OBJECT              = COLUMN
COLUMN_NUMBER      = 31
NAME               = LATITUDE_3
DATA_TYPE          = MSB_INTEGER
<table>
<thead>
<tr>
<th>Column Number</th>
<th>Name</th>
<th>Data Type</th>
<th>Start Byte</th>
<th>Bytes</th>
<th>Unit</th>
<th>Missing Constant</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>RADIUS_3</td>
<td>MSB_UNSIGNED_INTEGER</td>
<td>129</td>
<td>4</td>
<td>'DEGREES * (10**7)'</td>
<td>-2147483648</td>
<td>The planetocentric latitude of the spot 3 centroid.</td>
</tr>
<tr>
<td>33</td>
<td>RANGE_3</td>
<td>MSB_UNSIGNED_INTEGER</td>
<td>133</td>
<td>4</td>
<td>'MILLIMETERS'</td>
<td>4294967295</td>
<td>The distance from the Moon center to the Spot 3 centroid.</td>
</tr>
<tr>
<td>34</td>
<td>PULSE_3</td>
<td>MSB_INTEGER</td>
<td>137</td>
<td>4</td>
<td>'PICOSECOND'</td>
<td>-1</td>
<td>Pulse width of spot 3 centroid.</td>
</tr>
<tr>
<td>35</td>
<td>ENERGY_3</td>
<td>MSB_UNSIGNEDINTEGER</td>
<td>141</td>
<td>4</td>
<td>'ZEPTOJOULES'</td>
<td></td>
<td>Received Energy of detected return 3.</td>
</tr>
<tr>
<td>36</td>
<td>BACKGROUND_3</td>
<td>MSB_UNSIGNED_INTEGER</td>
<td>145</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
BYTES = 4
UNIT = 'PICOWATTS'
DESCRIPTION = "Background noise power at detector 3."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 37
NAME = THRESHOLD_3
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 149
BYTES = 4
UNIT = 'NANOVOLTS'
DESCRIPTION = "Threshold at detector 3."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 38
NAME = GAIN_3
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 153
BYTES = 4
DESCRIPTION = "Gain at detector 3 scaled by 1.E6."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 39
NAME = SHOT_FLAG_3
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 157
BYTES = 4
DESCRIPTION = "Describes the probability that spot 3 is a lunar range and its associated quality as in SHOT_FLAG_1."
END_OBJECT = COLUMN

/* Spot 4 */

OBJECT = COLUMN
COLUMN_NUMBER = 40
NAME = LONGITUDE_4
DATA_TYPE = MSB_INTEGER
START_BYTE = 161
BYTES = 4
UNIT = 'DEGREES * (10**7)'
MISSING_CONSTANT = -2147483648
DESCRIPTION = "The planetocentric longitude of the spot 4 centroid, in the range -180 to 180 degrees. Negative values should be adjusted by adding 360 degrees to conform with LRO conventions."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 41
NAME = LATITUDE_4
DATA_TYPE = MSB_INTEGER
START_BYTE = 165
BYTES = 4
UNIT = 'DEGREES * (10**7)'
MISSING_CONSTANT = -2147483648
DESCRIPTION = "The planetocentric latitude of the spot 4 centroid."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 42
NAME = RADIUS_4
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 169
BYTES = 4
UNIT = 'MILLIMETERS'
MISSING_CONSTANT = 4294967295
DESCRIPTION = "The distance from the Moon center to the
Spot 4 centroid."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 43
NAME = RANGE_4
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 173
BYTES = 4
UNIT = 'MILLIMETERS'
MISSING_CONSTANT = 4294967295
DESCRIPTION = "LOLA range to the spot 4 centroid."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 44
NAME = PULSE_4
DATA_TYPE = MSB_INTEGER
START_BYTE = 177
BYTES = 4
UNIT = 'PICOSECOND'
MISSING_CONSTANT = -1
DESCRIPTION = "Pulse width of spot 4 centroid."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 45
NAME = ENERGY_4
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 181
BYTES = 4
UNIT = 'ZEPTOJOULES'
DESCRIPTION = "Received Energy of detected return 4."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 46
NAME = BACKGROUND_4
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 185
BYTES = 4
UNIT = 'PICOWATTS'
DESCRIPTION = "Background noise power at detector 4."

OBJECT = COLUMN
COLUMN_NUMBER = 47
NAME = THRESHOLD_4
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 189
BYTES = 4
UNIT = 'NANOVOLTS'
DESCRIPTION = "Threshold at detector 4."

/* Spot 5 */

OBJECT = COLUMN
COLUMN_NUMBER = 50
NAME = LONGITUDE_5
DATA_TYPE = MSB_INTEGER
START_BYTE = 201
BYTES = 4
UNIT = 'DEGREES * (10**7)'
MISSING_CONSTANT = -2147483648
DESCRIPTION = "The planetocentric longitude of the spot 5 centroid, in the range -180 to 180 degrees. Negative values should be adjusted by adding 360 degrees to conform with LRO conventions."

OBJECT = COLUMN
COLUMN_NUMBER = 51
NAME = LATITUDE_5
DATA_TYPE = MSB_INTEGER
START_BYTE = 205
BYTES = 4
UNIT = 'DEGREES * (10**7)'
MISSING_CONSTANT = -2147483648
DESCRIPTION = "The planetocentric latitude of the spot 5 centroid."

OBJECT = COLUMN
COLUMN_NUMBER = 52
NAME = RADIUS_5
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 209
BYTES = 4
UNIT = 'MILLIMETERS'
MISSING_CONSTANT = 4294967295
DESCRIPTION = "The distance from the Moon center to the Spot 5 centroid."

OBJECT = COLUMN
COLUMN_NUMBER = 53
NAME = RANGE_5
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 213
BYTES = 4
MISSING_CONSTANT = 4294967295
UNIT = 'MILLIMETERS'
DESCRIPTION = "LOLA range to the spot 5 centroid."

OBJECT = COLUMN
COLUMN_NUMBER = 54
NAME = PULSE_5
DATA_TYPE = MSB_INTEGER
START_BYTE = 217
BYTES = 4
UNIT = 'PICOSECOND'
MISSING_CONSTANT = -1
DESCRIPTION = "Pulse width of spot 5 centroid."

OBJECT = COLUMN
COLUMN_NUMBER = 55
NAME = ENERGY_5
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 221
BYTES = 4
UNIT = 'ZEPTOJOULES'
DESCRIPTION = "Received Energy of detected return 5."

OBJECT = COLUMN
COLUMN_NUMBER = 56
NAME = BACKGROUND_5
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 225
BYTES = 4
UNIT = 'PICOWATTS'
DESCRIPTION = "Background noise power at detector 5."
OBJECT = COLUMN
COLUMN_NUMBER = 57
NAME = THRESHOLD_5
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 229
BYTES = 4
UNIT = 'NANOVOLTS'
DESCRIPTION = "Threshold at detector 5."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 58
NAME = GAIN_5
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 233
BYTES = 4
DESCRIPTION = "Gain at detector 5 scaled by 1.E6."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 59
NAME = SHOT_FLAG_5
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 237
BYTES = 4
DESCRIPTION = "Describes the probability that spot 5 is a lunar range and its associated quality as in SHOT_FLAG_1."
END_OBJECT = COLUMN

OBJECT = COLUMN
COLUMN_NUMBER = 60
BYTES = 16
ITEMS = 4
ITEM_BYTES = 4
NAME = SPARES
DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BYTE = 241
DESCRIPTION = "Unassigned spares. May use for lat/lon-rad/time adjustment, or Earth return information."
END_OBJECT = COLUMN

5.2. Sample LOLA GDR Detached Label
PDS_VERSION_ID = "PDS3"
/*** FILE FORMAT ***/
FILE_RECORDS = "UNK"
RECORD_TYPE = [FIXED_LENGTH or JPEG2000]
RECORD_BYTES = "UNK"
IMAGE = "LDEM_0064_xxxxx.IMG"
/*** GENERAL DATA DESCRIPTION PARAMETERS ***/
PRODUCT_ID = "LOLAGDR_xxxxx_DAT"
PRODUCT_VERSION_ID = "V1"
PRODUCT_CREATION_TIME = 2008-11-04T12:00:00
PRODUCT_TYPE = "GDR"
STANDARD_DATA_PRODUCT_ID = "DATA"
SOFTWARE_NAME = "LOLA_GDR"
SOFTWARE_VERSION_ID = "1.0"
COORDINATE_SYSTEM_NAME = "MEAN EARTH/ POLAR AXIS OF DE421"

OBJECT = IMAGE
NAME = PLANETARY_RADIUS
DESCRIPTION = "Each sample represents median observed radius within a 1/64 by 1/64 degree pixel area. Where no observations lie within the area, an interpolated value is supplied using minimum-curvature splines with tension. Height is the planetary radius minus the reference radius. Planetopotential topography is the planetary radius minus the radius of an equipotential surface whose mean at the equator is 1737.4 km."
LINES = 5760
LINE_SAMPLES = 11520
SAMPLE_TYPE = MSB_UNSIGNED_INTEGER
SAMPLE_BITS = 16
UNIT = METER
SCALING_FACTOR = 0.3048
OFFSET = 1728216.
END_OBJECT = IMAGE

OBJECT = IMAGE_MAP_PROJECTION
^DATA_SET_MAP_PROJECTION = "DSMAP.CAT"
MAP_PROJECTION_TYPE = "SIMPLE CYLINDRICAL"
A_AXIS_RADIUS = 1737.4 <KM>
B_AXIS_RADIUS = 1737.4 <KM>
C_AXIS_RADIUS = 1737.4 <KM>
FIRST_STANDARD_PARALLEL = "N/A"
SECOND_STANDARD_PARALLEL = "N/A"
POSITIVE_LONGITUDE_DIRECTION = "EAST"
CENTER_LATITUDE = 0.0 <DEGREE>
CENTER_LONGITUDE = 180.0 <DEGREE>
REFERENCE_LATITUDE = "N/A"
REFERENCE_LONGITUDE = "N/A"
LINE_FIRST_PIXEL = 1
LINE_LAST_PIXEL = 5760
SAMPLE_FIRST_PIXEL = 1
SAMPLE_LAST_PIXEL = 11520
MAP_PROJECTION_ROTATION = 0.0
MAP_RESOLUTION = 64.0 <PIXEL/DEGREE>
MAP_SCALE = 0.4738 <KM/PIXEL>
MAXIMUM_LATITUDE = 90.0 <DEGREE>
MINIMUM_LATITUDE = 0.0 <DEGREE>
WESTERNMOST_LONGITUDE = 0.0 <DEGREE>
EASTERNMOST_LONGITUDE = 180.0 <DEGREE>
LINE_PROJECTION_OFFSET = 2880.5
SAMPLE_PROJECTION_OFFSET = 11520.5
COORDINATE_SYSTEM_TYPE = "BODY- FIXED ROTATING"
COORDINATE_SYSTEM_NAME = "MEAN EARTH/ POLAR AXIS OF DE421"
END_OBJECT = IMAGE_MAP_PROJECTION

END

5.3. Sample LOLA SHADR Label

PDS_VERSION_ID = PDS3
RECORD_TYPE = FIXED_LENGTH
RECORD_BYTES = 122
FILE_RECORDS = 4185
^SHADR_HEADER_TABLE = ("LGM2009A.SHA",1)
^SHADR_COEFFICIENTS_TABLE = ("LGM2009A.SHA",3)

/** GENERAL DATA DESCRIPTION PARAMETERS ***/
PRODUCT_ID = "LOLASHADR_2009A"
PRODUCT_VERSION_ID = "V1"
PRODUCT_CREATION_TIME = 2008-11-04T12:00:00
PRODUCT_TYPE = "SHADR"
STANDARD_DATA_PRODUCT_ID = "DATA"
SOFTWARE_NAME = "LOLA_SHADR"
SOFTWARE_VERSION_ID = "1.0"
COORDINATE_SYSTEM_NAME = "MEAN EARTH/POLAR AXIS OF DE421"
INSTRUMENT_HOST_NAME = "LUNAR RECONNAISSANCE ORBITER"
INSTRUMENT_NAME = "LUNAR ORBITER LASER ALTIMETER"
INSTRUMENT_ID = "LOLA"
DATA_SET_ID = "LRO-L-LOLA-5-SHADR-V1.0"
DATA_SET_NAME = "LRO MOON LASER ALTIMETER 5 SHADR V1.0"
MISSION_PHASE_NAME = "COMMISSIONING"
TARGET_NAME = "MOON"
PRODUCER_ID = LRO_LOLA_TEAM
PRODUCER_FULL_NAME = "DAVID E. SMITH"
PRODUCER_INSTITUTION_NAME = "GODDARD SPACE FLIGHT CENTER"
PRODUCT_RELEASE_DATE = 2008-11-04
OBSERVATION_TYPE = "GRAVITY FIELD"
DESCRIPTION = "This file contains coefficients and related data for a spherical harmonic model of the lunar gravity field."

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 planet."

END_OBJECT = COLUMN

OBJECT = COLUMN
NAME = "CONSTANT"
<table>
<thead>
<tr>
<th>Name</th>
<th>Data Type</th>
<th>Start Byte</th>
<th>Bytes</th>
<th>Format</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATA_TYPE</td>
<td>ASCII_REAL</td>
<td>25</td>
<td>23</td>
<td>&quot;E23.16&quot;</td>
<td>&quot;N/A&quot;</td>
<td>For a gravity field model the assumed gravitational constant GM in km cubed per seconds squared for the planet. For a topography model, set to 1.</td>
</tr>
<tr>
<td>OBJECT</td>
<td>= COLUMN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NAME</td>
<td>&quot;UNCERTAINTY IN CONSTANT&quot;</td>
<td>49</td>
<td>23</td>
<td>&quot;E23.16&quot;</td>
<td>&quot;N/A&quot;</td>
<td>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.</td>
</tr>
<tr>
<td>OBJECT</td>
<td>= COLUMN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NAME</td>
<td>&quot;DEGREE OF FIELD&quot;</td>
<td>73</td>
<td>5</td>
<td>&quot;I5&quot;</td>
<td>&quot;N/A&quot;</td>
<td>Degree of the model field.</td>
</tr>
<tr>
<td>OBJECT</td>
<td>= COLUMN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NAME</td>
<td>&quot;ORDER OF FIELD&quot;</td>
<td>79</td>
<td>5</td>
<td>&quot;I5&quot;</td>
<td>&quot;N/A&quot;</td>
<td>Order of the model field.</td>
</tr>
<tr>
<td>OBJECT</td>
<td>= COLUMN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NAME</td>
<td>&quot;NORMALIZATION STATE&quot;</td>
<td>85</td>
<td>5</td>
<td>&quot;I5&quot;</td>
<td>&quot;N/A&quot;</td>
<td>The normalization indicator. For gravity field: 0 coefficients are unnormalized 1 coefficients are normalized 2 other.</td>
</tr>
<tr>
<td>OBJECT</td>
<td>= COLUMN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 m, the order index n, the coefficients Cmn and Smn, and the uncertainties in Cmn and Smn. 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."
END_OBJECT   = COLUMN

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

OBJECT = COLUMN
NAME = "C"
DATA_TYPE = ASCII_REAL
START_BYTE = 13
BYTES = 23
FORMAT = "E23.16"
UNIT = "N/A"
DESCRIPTION = "The coefficient Cmn for this spherical harmonic model."
END_OBJECT

OBJECT = COLUMN
NAME = "S"
DATA_TYPE = ASCII_REAL
START_BYTE = 37
BYTES = 23
FORMAT = "E23.16"
UNIT = "N/A"
DESCRIPTION = "The coefficient Smn for this spherical harmonic model."
END_OBJECT

OBJECT = COLUMN
NAME = "C UNCERTAINTY"
DATA_TYPE = ASCII_REAL
START_BYTE = 61
BYTES = 23
FORMAT = "E23.16"
UNIT = "N/A"
DESCRIPTION = "The uncertainty in the coefficient Cmn for this spherical harmonic model."
END_OBJECT

OBJECT = COLUMN
NAME = "S UNCERTAINTY"
DATA_TYPE = ASCII_REAL
START_BYTE = 85
BYTES = 23
FORMAT = "E23.16"
UNIT = "N/A"
DESCRIPTION = "The uncertainty in the coefficient Smn for this spherical harmonic model."
END_OBJECT

END_OBJECT = SHADR_COEFFICIENTS_TABLE
END