Lunar Reconnaissance Orbiter

LROC
Reduced Data Record
Products
Software Interface Specification

Version 1.6
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Document Change Control

Date	Who	Sections	Descriptions
03/13/2008	Eric E.	All	Draft Outline.
04/21/2008	Eric E.	All	Draft complete for review by LROC team.
05/15/2008	Eric E.	All	LROC team comments incorporated into SIS. DRAFT Version 1.0 completed for PDS review
07/05/2008	Eric E.	All	Incorporated PDS review-team comments into SIS.
07/15/2008	Ernest B-C.	Table 2.2	
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04/30/2009	EBC MSR MT	Various Sections	Corrected numbers for instrument in text and various tables/figures. Completed all TBD items.
01/04/2011	Ernest B-C.	Various Sections	Updates incorporating new knowledge of RDR products based on acquired LROC images. Key changes: - No longer creating JPEG 2000 products, but will create standard PDS image products with various detached headers to support GIS work - Change in tiling for N/S Pole NAC mosaics
03/08/2011	Ernest B-C.	Various Sections	Final edits based on RDR product generation.
08/20/2012	Ernest B-C.		Added sections for NAC DTM and WAC DTM.
5/29/2018	M. Henriksen	Various Sections	Reorganized and Updated all sections.

TBD Items and Open Issues

#	Description

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ACRONYMS AND ABBREVIATIONS

2D	Two-dimensional
ASCII	American Standard Code for Information Interchange
BDR	Basic Data Record
CCD	Charged Coupled Device
CDR	Calibrated Data Record
CLAT	Center latitude of the map projection
CLON	Center longitude of the map projection
DN	Digital Number
DTM	Digital Terrain Model
EDR	Experimental Data Record
EXTRA	Extra data product
FOV	Field of View
FPGA	Field Programmable Gate Array
FWHM	Full Width at Half Maximum
GB	Gigabyte
GeoTIFF	Interchange format for georeferenced raster imagery. Name derived from Georeferenced Tagged Image File Format.
GIS	Geographic Information Systems
GRAIL	Gravity and Interior Laboratory
I/F	Intensity/Flux (Radiance Factor)
IFOV	Instantaneous Field of View
LDWG	LRO Data Working Group
LGCWG	Lunar Geodesy and Cartography Working Group
LPRP	Lunar Precursor Robotic Program
LRO	Lunar Reconnaissance Orbiter
LROC	Lunar Reconnaissance Orbiter Camera
MB	Megabytes
MDR	Multispectral Data Record
MPEG	Moving Picture Experts Group Audio/visual file format
MTF	Modulation Transfer Function
NAC	Narrow Angle Camera
NAC-L	Narrow Angle Camera - Left
NAC-R	Narrow Angle Camera - Right
NAIF	Navigation and Ancillary Information Facility
PDS	Planetary Data System
PSR	Permanently Shadowed Region (near lunar poles)
RDR	Reduced Data Record
ROI	Region of Interest
SCS	Sequence and Compressor System
SDP	Special Data Product
SIS	Software Interface Specification
SNR	Signal-to-Noise Ratio
SOC	Science Operations Center
SPICE	Spacecraft, Planet, Instrument, C-matrix Pointing, and Event
TBD	To Be Determined

TIFF	Tagged Image File Format
UTC	Coordinated Universal Time
UTF-8	Unicode (Universal Coded Character Set) Transformation Format - 8-bit
UUID	Universally Unique Identifier
UV	Ultraviolet
VIS	Visible
WAC	Wide Angle Camera

1 Introduction

The Lunar Reconnaissance Orbiter Camera (LROC) was designed to address two of the prime Lunar Reconnaissance Orbiter (LRO) measurement requirements. 1) Assess meter- and smaller-scale features to *facilitate safety analysis for potential lunar landing sites* near polar resources, and elsewhere on the Moon; 2) Acquire multi-temporal synoptic imaging of the poles every orbit to *characterize the polar illumination environment* (100 m/pixel scale), identifying regions of permanent shadow and permanent or near-permanent illumination over a full year. The LROC consists of two co-aligned narrow-angle cameras (NACs) to provide 0.5 m/pixel scale panchromatic images over a 5 km swath and a wide-angle camera (WAC) component to provide images at a scale of 75 m/pixel in five visible bandpasses and 400 m/pixel in two ultraviolet bandpasses (from an orbital altitude of 50 km).

To meet the measurement requirements summarized in Lunar Reconnaissance Orbiter Camera (LROC) Instrument Overview [1], the LROC team generates digital map products and image mosaics from a subset of the collected archive of images. Additionally, radiometrically-calibrated individual images, described in the "LROC EDR/CDR Data Product Software Interface Specification" companion document, are provided as part of the archive of LROC data products. The team maintains internal RDR products until data calibration and data processing methods are science ready, then releases them in an appropriate manner for public access including their final deposition to NASA's Planetary Data System (PDS). A nominal delivery of RDR derived data products occurs on or before the 15th of every third month (March, July, September, December).

This Software Interface Specification (SIS) provides a description of the derived products provided by the LROC Science Team. It is intended to offer enough information to enable users to read and understand the products. The SIS describes how products are processed, formatted, labeled, and uniquely identified. The document details standards used in generating the products. The SIS also provides a specification of the products delivered to the PDS. Finally, examples of the product labels are provided. Additional documentation about each individual product is available in an archived README file.

1.1 Applicable Documents and References

The LROC Derived Data SIS is consistent with the following documents:

1. Robinson, M., et al. (2010) Lunar Reconnaissance Orbiter Camera (LROC) Instrument Overview*, Space Science Reviews, Vol. 105, Issue 1-4, pp 81-124*. doi:10.1007/s11214-010-9634-2

2. Speyerer, E.J., et al. (2016) Pre-flight and On-orbit Geometric Calibration of the Lunar Reconnaissance Orbiter Camera, *Space Science Reviews*, Vol. 200, Issue 1-4, pp 357-392. doi:10.1007/s11214-014-0073-3

3. Lunar Reconnaissance Orbiter Project Data Management and Archive Plan, 431-PLAN-000182.

4. LROC Instrument Team Data Management and Archive Plan, LROC_SOC_PLAN_001, January 5, 2007.

5. LROC EDR/CDR/RDR Archive Volume Software Interface Specification, LROC_SOC_SPEC_0002, Version 1.14, May 25, 2018.
6. Planetary Data System Data Standards Reference, Version 3.7, JPL D-7669, Part 2, March 20, 2006.
7. Planetary Science Data Dictionary Document, JPL D-7116, Rev. E, August 28, 2002.
8. Planetary Data System Archive Preparation Guide, Version 1.1, JPL D-31224, August 29, 2006.
9. Snyder, J.P. (1987), Map Projections, U.S. Geological Survey Professional Paper 1395.
10. Speyerer, E. J., et al. (2013) Persistently illuminated regions at the lunar poles: Ideal sites for future exploration. *Icarus*, *222*(1), 122-136. doi: 10.1016/j.icarus.2012.10.010
11. Humm, D.C., et al. (2016) Flight Calibration of the LROC Narrow Angle Camera, *Space Science Reviews*, Vol. 200, Issue 1-4, pp 431–473. doi:10.1007/s11214-015-0201-8
12. Mahanti, P., et al. (2016) Inflight Calibration of the Lunar Reconnaissance Orbiter Camera Wide Angle Camera, *Space Science Reviews*, Vol. 200, Issue 1-4, pp 393–430. doi:10.1007/s11214-015-0197-0
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15. Sato, H., (2014) Resolved Hapke parameter maps of the Moon, *J. Geophys. Res., Planets* doi:10.1002/2013JE004580
16. Boyd, A.K. and M.S. Robinson (2017) LROC NAC Photometry: A Global Photometric Function, *3rd Planetary Data Workshop*, Abstract #7076. [available at: https://www.hou.usra.edu/meetings/planetdata2017/pdf/7076.pdf]
17. Acton, Jr., C.H., (1996), Ancillary data services of NASA's Navigation and Ancillary Information Facility, *Planet. Space Sci., Vol. 44, No. 1, pp. 65-70.*
18. Lemoine, F.G., et al. (2014) GRGM900C: A degree 900 lunar gravity model from GRAIL primary and extended mission data, *Geophys. Res. Lett.* Vol 41, pp 3382–3389. doi:10.1002/2014GL060027
19. LRO Project (2008), A Standardized Lunar Coordinate System for the Lunar Reconnaissance Orbiter, LRO Project White Paper, version 4 of May 14 [available at http://lunar.gsfc.nasa.gov/library/451-SCI-000958.pdf.]
20. LGCWG (2009), Recommendations for Formatting Large Lunar Datasets, April 28, draft.
21. Williams, J.G., Boggs, D.H., Folkner, W.M., 2008. DE421 Lunar Orbit, Physical Librations, and Surface Coordinates. JPL Mem. IOM 335-JW, DB, WF-20080314-001, 14 March, Jet Propulsion Lab., Calif. Inst. of Technol., Pasadena, Calif.

1.2 Configuration Management

The LROC Software Development Team controls this document. Requests for changes to its scope and contents are made to the LROC Science Operations Center Manager, Nicholas Estes. An engineering change request will be evaluated against its impact on the LROC ground data processing system before acceptance.

The SIS has undergone a formal PDS peer review where it was determined that the products described herein meet PDS data product standards. Members from the PDS Imaging and Engineering Nodes along with additional members from the planetary science community comprised the review panel.

2 Instrument Overview

The LROC consists of two narrow-angle cameras (NACs), a wide-angle camera (WAC), and a common Sequence and Compressor System (SCS).

Each NAC (see Figure 2.1) has a 700 mm focal-length Cassegrain (Ritchey-Chretien) telescope that images onto a 5,064 pixel charge coupled device (CCD) line-array providing a cross-track field-of-view (FOV) of 2.86°. The NAC readout noise is better than 76 e^- and the data are sampled at 12 bits. By ground command, these 12-bit pixel values are companded to 8-bit pixels using one of several selectable piecewise linear mappings during readout from the CCD. The NAC internal buffer holds 256 MB of uncompressed data, enough for a full-resolution image 52,224 lines long (26 km from 50 km orbit). NAC specifications are summarized in Table 2.1.

The WAC electronics are a copy of those flown on Mars Climate Orbiter, Mars Polar Lander, Mars Odyssey, and Mars Reconnaissance Orbiter. The WAC (see Figure 2.2) has two lenses imaging onto the same 1,024 x 1,024 pixel, electronically shuttered CCD area-array, one imaging in the visible/near infrared (VIS), and the other in the ultraviolet (UV). In monochrome mode, 1,024 x 14 pixels are read out in one visible band (typically 643 nm). In color mode, only the center 704 x 14 visible pixels and 512 x 16 UV pixels, which are binned to 128 x 4, are read out for each band. The VIS optics have a cross-track FOV of 89.9° (monochrome) and 61.2° (color), and the UV optics a 58.3° FOV. From an altitude of 50 km, the WAC provides a nadir ground sample distance of 74.6 m/pixel in the visible, and a swath width of 99.9 km (visible monochrome), 59.1 km (visible color) and 55.8 km (UV color). The orbit of LRO has varied throughout the mission (Figure 2.3). After an initial quasi-stable 30x200 km elliptical orbit during the commissioning phase, LRO entered into a quasi-circular 50-km circular orbit from 15 September 2009. To conserve fuel, the spacecraft was then transitioned back into a more stable elliptical orbit on 11 December 2011.

The seven-band color capability of the WAC is provided by a color filter array (see Figure 2.4) mounted directly over the detector, providing different sections of the CCD with different filters. Consequently, the instrument has no moving parts; it acquires data in the seven channels in a “pushframe” mode, with scanning of the WAC FOV provided by motion of the spacecraft and target. Continuous color coverage of the lunar surface is possible by repeated imaging such that each of the narrow framelets of each color band overlap. The WAC has a readout noise less than 72 e^- and, as with the NAC, pixel values are digitized to 12 bits and are then companded to 8 bit values through a square-root-like lookup table. WAC specifications are summarized in Table 2.2 and the spectral transmissivity of all seven WAC filters are displayed in Figure 2.5. The two UV bands (321 and 360 nm) undergo 4x4 pixel on-chip analog summing before digitization to achieve better signal-to-noise ratio. Thus, UV pixels are recorded at reduced 385.5 m/pixel sampling at a 50 km orbit but have improved signal properties. WAC band passes are arranged first UV (321, 360) then VIS (415, 566, 604, 643, 689) with respect to the spacecraft's positive x-axis.

The two NACs and the WAC interface with the Sequencing and Compressor System (SCS), the third element of the instrument (see Figure 2.6). As the name implies, the SCS commands individual image acquisition by the NACs and WAC from a stored sequence, and losslessly compresses the NAC and WAC data as they are read out and passed to the spacecraft data system. The SCS provides a single command and data interface between the LROC and the LRO spacecraft data system through a SpaceWire interface.

The NACs have a combined mass of 16.4 kg, the WAC a mass of 0.9 kg, and the SCS is 1.2 kg, for a total LROC mass of 18.5 kg. Each NAC has a peak power consumption of 9.3 W and 6.4 W on average per orbit; the WAC has a peak power consumption of 2.7 W and 2.6 W on average, and the SCS will use 4.0 W on average and 4.5 W peak, for a total LROC power dissipation of 16.5 W peak, 13 W average.

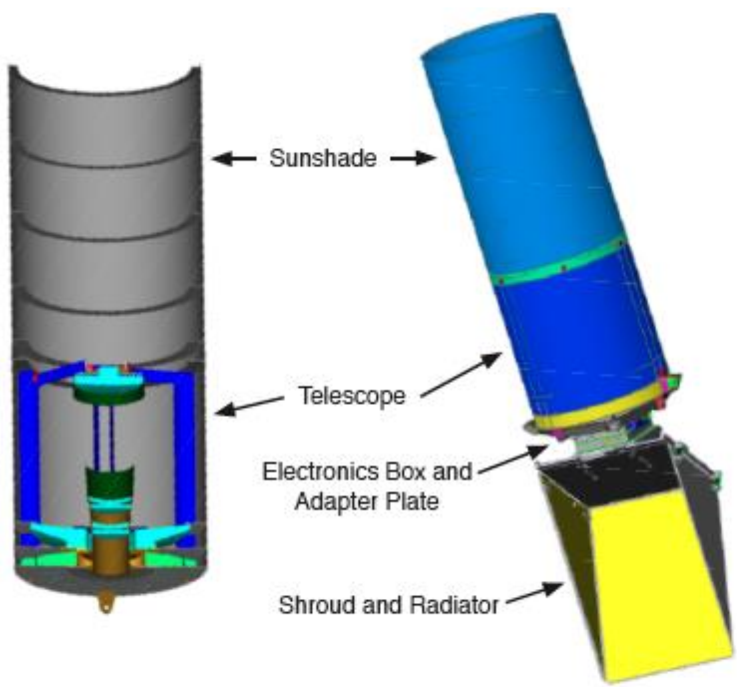

Figure 2.1 - LROC Narrow Angle Camera, 70 cm by 24 cm diameter

Table 2.1 - LROC NAC Specifications

	NAC-L	NAC-R
FOV	2.8502°	2.8412°
IFOV	10.0042 μrad	9.9764 μrad
Image scale at 50 km altitude	0.5 m/pixel	
Maximum Image size at 50 km altitude	2.49 x 26.1 km	2.48 x 26.1 km
f/# (Ritchey-Chretien)	3.577	3.590
Effective Focal Length	699.62 ± 0.08 mm	701.57 ± 0.09 mm
Distortion coefficient	0.0000181 ± 0.0000005	0.0000183 ± 0.0000005
Optical center location	sample 2,548 ± 8	sample 2,496 ± 8
Primary Mirror Diameter	195 mm	
MTF (Nyquist) cross, down	0.19, 0.23	0.18, 0.22
Gain	98 +/- 5 e-/DN	102 +/- 4 e-/DN
Noise	1.2 +/- 0.2 DN	1.1 +/- 0.1 DN
Detector fullwell	380,000 +/- 20,000 e-	380,000 +/- 20,000 e-
SNR (400-750 nm)	> 48	> 39
Detector Digitization	12 bit, encoded to 8 bits	
Compression	1.7:1	
Structure + baffle	Graphite-cyanate composite	
Detector	Kodak KLI-5001G	
Pixel format	1 x 5,064*	
Analog/Digital Converter	Honeywell ADC9225	
FPGA	Actel RT54SX32-S	
Voltage	28 ± 7V DC	
Peak Power	9.3 W	
Orbit Average Power	6.4 W	
Mass (both NACs)	16.4 kg	
Volume (length x diameter)	118 cm x 27 cm (incl. radiator)	

* Of the 5,064 pixels, 39 masked pixels on the right and 21 masked pixels on the left are used for dark reference.

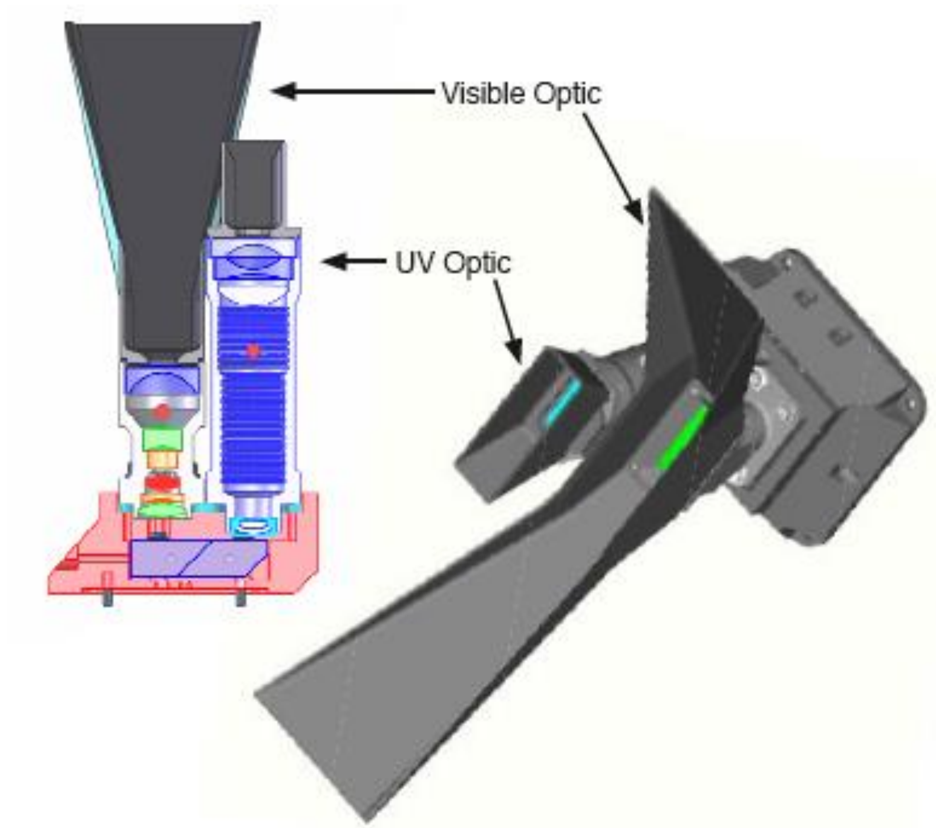

Figure 2.2 - LROC Wide Angle Camera

Table 2.2 – LROC WAC Specifications

	Visible	UV
FOV (monochrome / color)	91.9° / 61.4°	59.0°
IFOV	1.498 mrad	7.672 mrad (4x4 binned)
Image scale (nadir, 50 km altitude)	74.9 m/pixel	383.5 m/pixel (binned)
Image frame width monochrome	104.6 km	-
Image frame width 7-band color	59.6 km	56.8 km
Image format monochrome	1,024 samples x 14 lines	-
Image format color (for each band)	704 samples x 14 lines	128 samples x 4 lines (binned)
f/#	5.052	5.65
Effective Focal Length	6.013 mm	4.693 mm
Entrance Pupil Diameter	1.19 mm	0.85 mm
System MTF (Nyquist)	0.37	

	Visible	UV
Gain	25.9± 0.7 e^-/DN	
Noise	66 ± 4 e^-	
Detector fullwell	46,100 ± 3,600 e^-	
Band ± FWHM	321 ± 32.3 nm 360 ± 14.9 nm	415 ± 36.1 nm 566 ± 20.1 nm 604 ± 20.4 nm 643 ± 22.5 nm 689 ± 38.6 nm
SNR (at 1000 DN)	> 150	
Detector Digitization	11 bit, encoded to 8 bits	
Compression	1.7:1	
Electronics	4 circuit boards	
Detector	Kodak KAI-1001	
Pixel format	1,024 x 1,024	
Voltage	28±7 V DC	
Peak Power	2.7 W	
Orbit Average Power	2.6 W	
Mass	0.9 kg	
Volume (width x length x height)	15.8 cm x 23.2 cm x 32.3 cm (incl. radiator)	

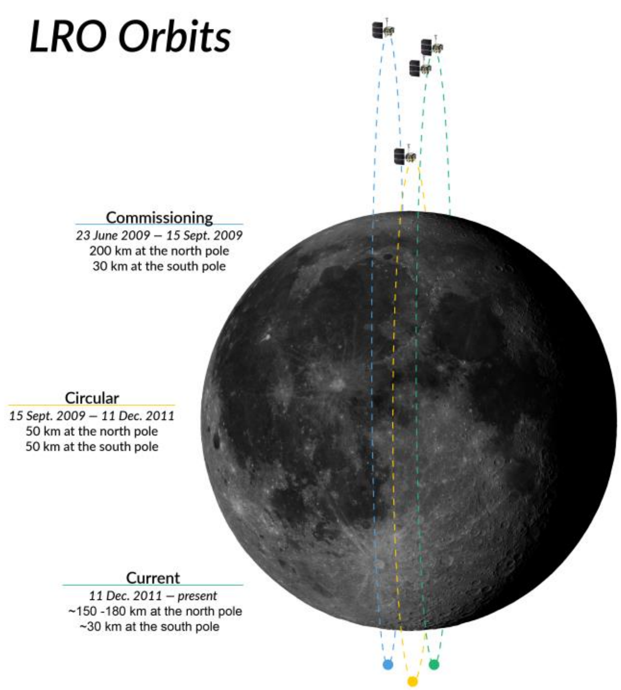

Figure 2.3 - General orbit apoapsides and periapses over time for LRO.

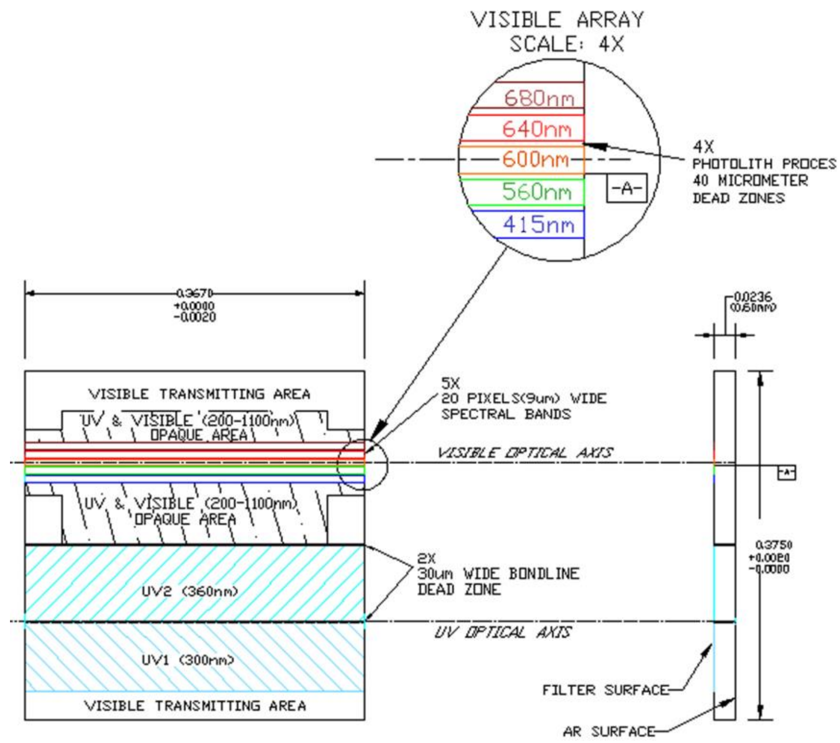

Figure 2.4 - Diagram of LROC Wide Angle Camera filter assembly

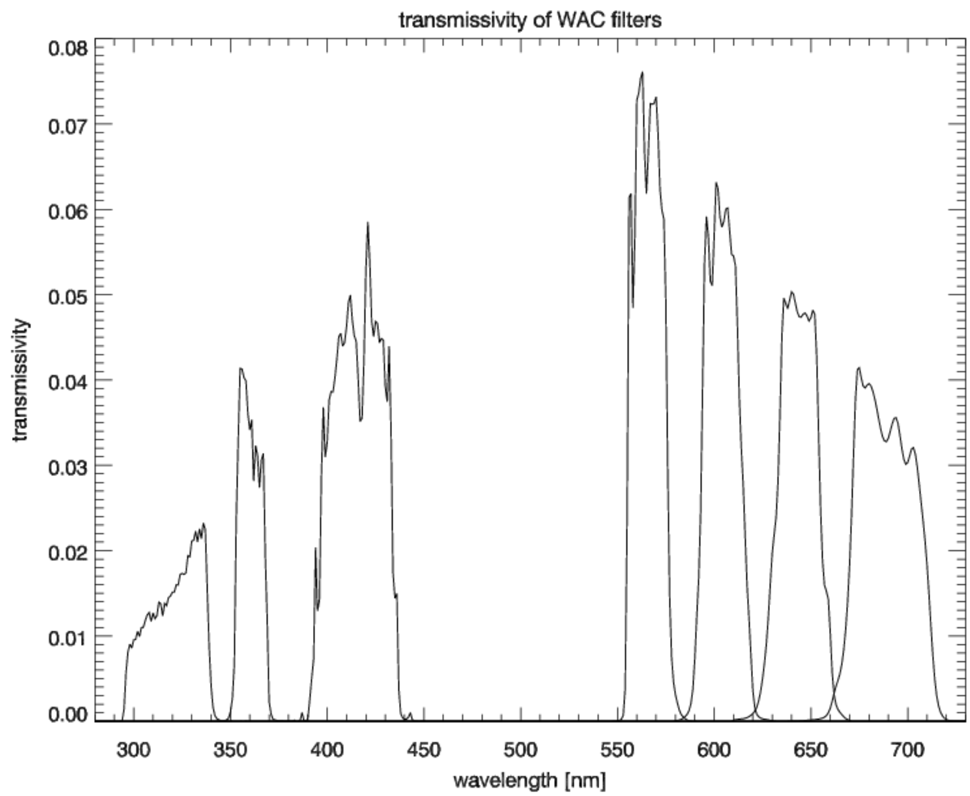

Figure 2.5 - The spectral transmissivity of the 7 WAC filters. The values of the y-axis represent the relative system throughput for each wavelength.

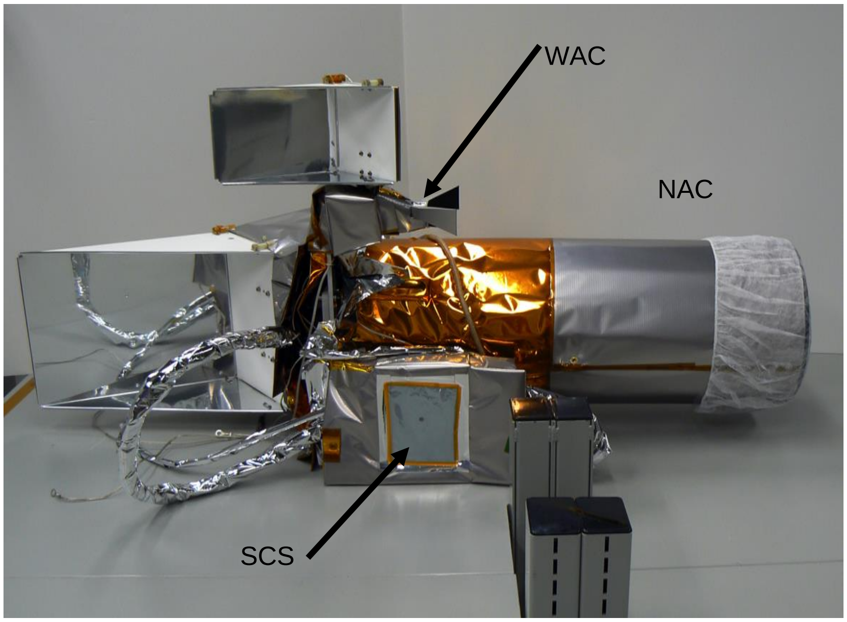

Figure 2.6 - LROC components include the WAC, NAC, and SCS

3 Product Overview

LROC derived products, summarized in Table 3.1, are organized into four data set types: 1) Map-projected single-band basemaps (BDR) derived from NAC and WAC single-band imaging; 2) Map-projected multispectral basemaps (MDR) from WAC seven-band imaging; 3) Special data products (SDP) are higher order derived products such as digital terrain models, mineral abundance maps, and illumination maps; and 4) Extra data products (EXTRA) include products that do not conform to PDS file formats or are not map-projected. EXTRAs include NAC anaglyphs, vector maps in the Esri shapefile format and video time-lapse movies of the north and south pole organized in the MPEG-2 and QuickTime video formats. Many products are in directories with more specific names than those provided in Table 3.1 - Product Summary below. This keeps a group of all the associated products (including lower resolution options) together, and allows for one README specific to those products. See Table 6.2 - Hierarchal List of Possible Product Name Elements for more details related to product naming conventions.

Table 3.1 - Product Summary

Type	Product Name	Description	Purpose
BDR	NAC_POLE	NAC 1.0 m/pixel uncontrolled best-effort mosaics of polar regions 90 to 85.5˚ latitude	Provide detailed synoptic maps of polar regions
BDR	NAC_POLE_PSR	NAC 20 m/pixel best-effort mosaics of permanently shadowed regions (PSRs) ≥10 km in diameter for each pole.	Provide detailed maps of PSRs
BDR	NAC_ROI	NAC high-resolution controlled and semi-controlled image mosaics are created in support of high-priority landing site areas and other regions of interest at 0.5 – 2.0 m/pixel sampling.	Support science investigations. Assess meter-scale features to facilitate safety analysis of potential landing sites.
BDR	WAC_GLOBAL	WAC monochrome global uncontrolled best-effort basemap mosaic of high-incidence angle imaging (48˚-72˚ at the equator) at 100.0 m/pixel scale	High-incidence angle imaging supports morphological analysis of the lunar surface
BDR	WAC_ORBITS	WAC monochrome global uncontrolled mosaics at 1 km/pixel scale created from images taken during a single month.	Provides information about WAC coverage and views of the surface under illumination conditions that vary each month
BDR	WAC_ROI	Regional WAC monochrome uncontrolled basemap mosaics covering specific regions with internally consistent illumination conditions at 100 m/pixel scale.	Illumination conditions for each ROI were selected to facilitate analyses of high scientific interest
BDR	WAC_MOVIE	WAC single-band multi-temporal uncontrolled synoptic mosaics of polar regions at 100 m/pixel scale	Identify regions of permanent shadow and permanent or near-permanent illumination over a full lunar year

MDR	WAC_EMP	WAC uncontrolled mosaics at 64 pixel/degree (~400 m) for each of the 7 WAC spectral bands, photometrically normalized using an empirically derived photometric function.	Supports multispectral analysis of the lunar surface
MDR	WAC_HAPKE	WAC uncontrolled mosaics at 64 pixel/degree (~400 m/pixel) for each of the 7 WAC spectral bands, photometrically normalized using Hapke parameter maps	Supports multispectral analysis of the lunar surface
SDP	WAC_HAPKEPARAMMAP	Hapke parameter maps in 1°/pixel tiles with 9 parameters for each of the 7 WAC spectral bands	Supports multispectral analysis of the lunar surface
SDP	NAC_DTM	NAC Digital Terrain Models (DTM) and orthophotos created from geometric stereo observations at 2-5 m/pixel.	Supports high resolution topographic and photometric analysis
SDP	NAC_PHO	Geometrically controlled NAC products for photometric series. Product includes calibrated, map-projected image (band 1) and backplanes for incidence (2), emission (3), and phase (4).	Controlled images facilitate photometric studies of scientific ROIs
SDP	WAC_CSHADE	Color-shaded relief map of the WAC GLD100 product at 100 m/pixel with the LOLA gridded product (originally 30 m/pixel) used for the poles.	Supports visualization of lunar topography
SDP	WAC_GLD100	WAC Digital Terrain Model (DTM) constructed from WAC stereo images. This map is called the Global Lunar DTM 100 m topographic model, or "GLD100", and covers 98.2% of the lunar surface.	Facilitates map-projection and supports topographic analysis of the Moon
SDP	WAC_POLE_ILL	WAC polar illumination maps constructed from multi-temporal images acquired during a single lunar year at 100 m/pixel extending 2° from each pole.	Supports identification of PSRs and permanent or near-permanent illumination over a full lunar year
SDP	WAC_TIO2	WAC TiO2 abundance map in units of weight % TiO2, derived from Hapke normalized WAC 321/415 nm band ratio at 400 m/pixel.	Supports compositional analysis
EXTRA	ANAGLYPH	NAC 3-band anaglyph created from geometric stereo observations with the right eye in band 1 and the left eye in bands 2 and 3 in GeoTIFF format.	Facilitates visualization of geometric stereo images
EXTRA	SHAPEFILE	Vector maps in Esri shapefile format of key observations and features.	Facilitates location of key types of observations and geologic features, as well as supporting geospatial analysis

EXTRA	WAC_MOVIE	WAC_MOVIE mosaics organized as a movie formatted in the MPEG-2 and QuickTime video formats.	Identify regions of permanent shadow and permanent or near-permanent illumination over a full lunar year

The BDR and MDR products are mosaics of individual LROC observations that have been radiometrically calibrated, photometrically normalized to standard illumination conditions, and resampled to a standard map projection. Radiometric calibration corrects for varying instrument detector sensitivities, dark current, and nonlinearity, enabling the conversion of pixel values to reflectance. The radiometric calibration is discussed in more detail in section 4.2. Observations that compose a mosaic are typically acquired under varying illumination conditions so a photometric normalization is applied in order to balance the overall brightness of the images. The photometric normalization is discussed in more detail in section 4.3. The basemaps produced by the LROC team are geodetically uncontrolled, except for regional NAC mosaics. This means observations are map-projected using the spacecraft ephemerides and instrument-pointing data provided by the LRO project and a lunar ephemeris, and are not tied to a geodetic control system. A basemap's positional accuracy is limited by the overall accuracy of these data; however, most WAC images have sub-pixel geodetic accuracy [2]. Geometric processing is described in more detail in section 4.5. READMEs (section 3.1) containing specific details on data generation for each product are archived alongside the data.

SDPs are higher order, derived products that use non-standard processing. Processing is unique to each type of SDP. This may, but does not necessarily, include standard processing such as radiometric calibration, photometric normalization, and map projection. For specific details on each data product, refer to the README archived alongside the data.

The MDR, BDR, and SDP products are formatted and organized according to the LRO Archive Plan [3,4,5] and the PDS standards [6,7,8]. They are stored in the PDS image format convention [6].

3.1 READMEs

There are many different types of products archived in the LROC RDR PDS Volume; therefore READMEs in UTF-8 formatting are archived for each data product alongside the data products in the DATA directory and provide specific details about product generation. A README text file contains any additional information about the product and its creation that is not otherwise mentioned in this SIS. This includes information on the naming scheme, a list of images or information on image selection, any available resolutions, and applicable tiling schemes. It will also contain citations for any papers or abstracts describing the product as well as references and links to this SIS. Separate images lists stored at UTF-8 formatted text files may also be archived with the READMEs and data products, especially for datasets derived from a large number of LROC images.

3.2 Browse Products

The Browse products are reduced-size, easily viewed versions of data products to be used to help identify products of interest. Browse products are intended for viewing purposes only and should not be used for measurement and analysis. The lowest-resolution browse products are stored as 8-bit unsigned integer values (0 to 255) in PNG format and have file names ending .BROWSE.PNG. Additional full-resolution TIFF browse products are also available, primarily created for use with the LROC website. For very large mosaics, these TIFs may be down-sampled to fit within the size limits of the TIFF format (4 GB). They are stored as 8-bit unsigned integer values (0 to 255) in GeoTIFF and Pyramidal TIFF formats. Masks for null pixels are also available in TIFF format. For products with more than 3 bands, a single band or subset of 3 bands is used to make the browse products. BROWSE products are located in the BROWSE sub-directory inside the EXTRAS directory, due to some incompatibility of the file-formats with PDS3 standards.

4 Product Generation

4.1 Map Projection and Layout

LROC digital map products use the Equirectangular and Polar Stereographic map projections [9]. The Polar Stereographic projection, ideal for maps covering polar regions, minimizes scale and shape distortion at high-latitudes. The Equirectangular projection is typically used at middle and lower latitudes. With this projection, all lines of latitude are parallel and evenly spaced; the same is true for lines of longitude. Additional products in Orthographic map projection are available for many of the WAC mosaics. The Orthographic projection is a perspective projection, and depicts a single hemisphere of a sphere. It is primarily included for use in visualizations. The transformation equations for these projections are discussed in Appendix B – Map Projection Equations.

Many of the LROC digital basemaps and other large area products are organized into map quadrangles (or tiles) with each quadrangle covering a subarea of the lunar globe. Map quadrangles are then stored as image files where the column and row coordinate of the image array can be translated to a geographic latitude and longitude coordinate through a map transformation equation (see Appendix B – Map Projection Equations). The sizes and areal extents of the map quadrangles are chosen to accommodate a reasonable areal extent while having manageable image file sizes. The quadrangle layouts for the basemap mosaics are summarized below. For specific details on map projection and quadrangle layout as well as other pertinent details, refer to the READMEs that accompany each derived product.

4.1.1 NAC Polar Products

NAC polar basemap mosaics are organized into quadrangles such that the non-compressed pyramidal TIFFs (included with the Browse products; section 3.2) are less than 4 GB, and the latitude and longitude boundaries are round numbers. At l meter pixel scales, products are organized into 40 quadrangles for each pole covering 90 to 85.5˚ (N or S) latitude and 0 to 360˚ longitude as shown in Figure 4.1. The four quadrangles adjacent to the pole cover 1.5° of latitude, while each of the other quadrangles cover 1.0˚ of latitude. The longitude range for each quadrangle depends on the latitude coverage. At 1-meter scale the images will typically be about 45,000 x 45,000 pixels or about 2,000 megapixels. At lower resolutions, mosaics are organized to have similar quadrangle sizes. For the 20-meter scaled NAC_POLE_PSR mosaics of the permanently shadowed regions with a latitude range of 80° (N or S) to the pole, each mosaic is stored as a single quadrangle with a file size of 3.44 GB for the PDS product. The basemaps are available in a Polar Stereographic projection. For the Polar Stereographic projection, the quadrangles share the same reference center latitude (CLAT = ±90.0) and longitude (CLON = 0.0). With a common reference, it is possible to generate composite quadrangles by mosaicking individual quadrangles without the need for reprojection.

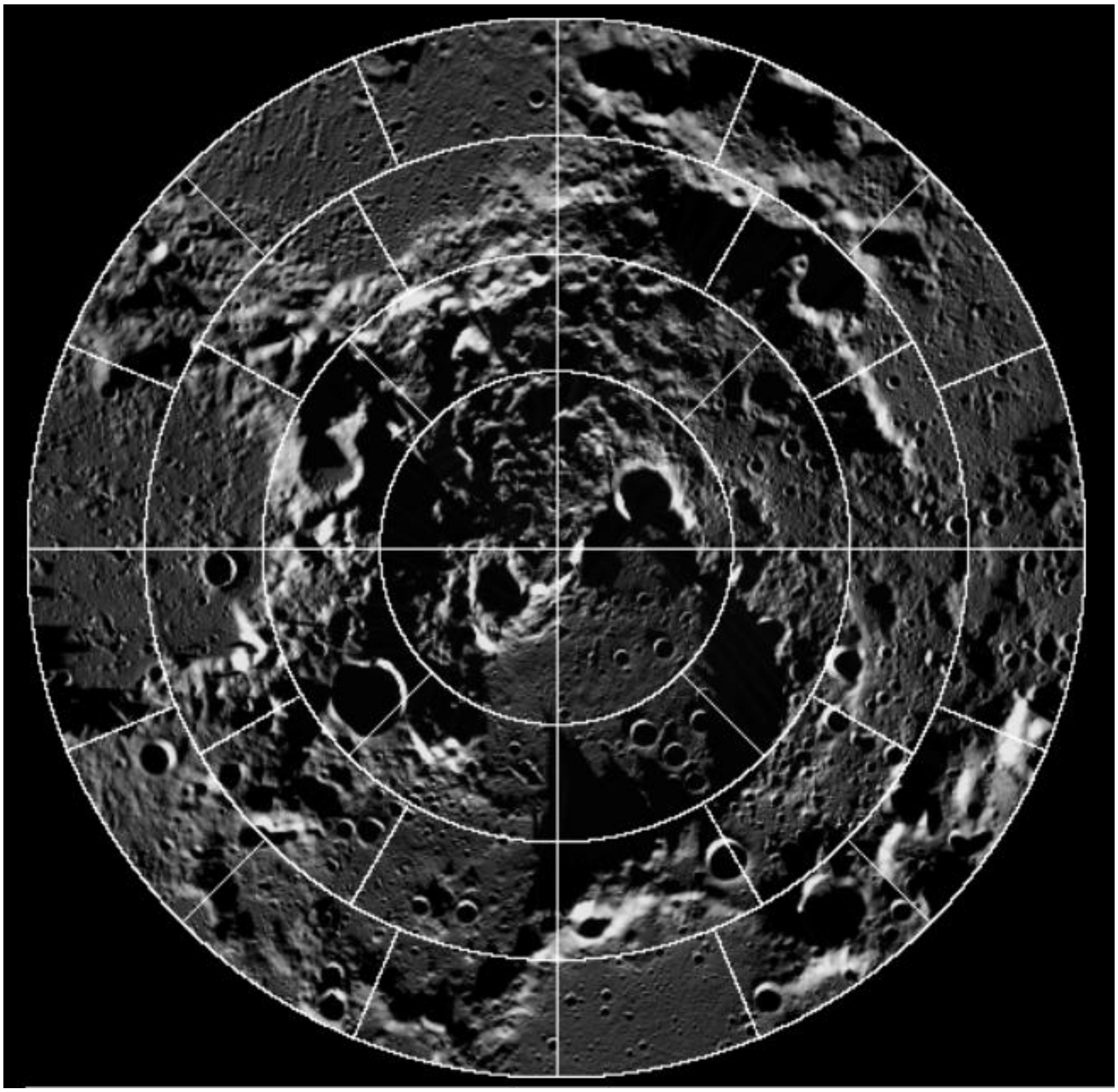

Figure 4.1 - Quadrangle layout of NAC_POLE basemap with 40 quadrangles covering latitude range 90 - 85.5° at each pole. Quadrangle longitude ranges depend on latitude coverage as shown in the table below.

Latitude Range	# Quads	Quadrangle Longitude Coverage
90.0 – 88.5	4	90˚ / 0-90, 90-180, 180-270, 270-360
88.5 – 87.5	8	45˚ / 0-45, 45-90, 90-135, etc.

87.5 – 86.5	12	30˚ / 0-30, 30-60, 60-90, etc.
86.5 – 85.5	16	22.5°/ 0-22.5, 22.5-45, 45-67.5, etc.
Total:	40	

4.1.2 NAC Regional Products

NAC regional products include map-projected derived products such as NAC region of interest (NAC_ROI) basemap mosaics, NAC photometry series (NAC_PHO), and NAC digital terrain models (NAC_DTM). Polar regions and areas with center latitudes above 65˚N and below 65°S latitude are mapped to the Polar Stereographic projection. For other latitude regions, the Equirectangular projection is used. To minimize scale and shape distortion, center latitude and longitude are selected to be at the center of the map. The image size of each mosaic will depend on the chosen areal coverage of the mosaic and the pixel scale of the input images. Whenever possible, products are generated at native pixel scales (0.5-2 m/pixel). Because these high-resolution products often create very large files, these NAC_ROI products are also available at 5 meter and 20 meter pixel scales. The long exposure images used to generate products of permanently shadowed regions are much lower resolution and result in 10-20 m/pixel scales. NAC DTMs are generated at a minimum of 3 times the native pixel scale of the input stereo observations (2 – 5 m).

4.1.3 WAC Map Products

WAC products are frequently at a pixel scale (up to 100 m/pixel) and of an area that would result in an inconveniently large file if stored as a single image. Therefore, the global WAC tiling scheme consists of 10 quadrangles, 8 covering equatorial regions of the lunar globe and 2 covering the polar regions as shown in Figure 4.2. The quadrangles are chosen so that at 100 m/pixel, the files are < 2 GB. Each equatorial quadrangle has 60˚ of latitude and 90˚ longitude coverage mapped into the Equirectangular projection with center reference latitude 0˚ (CLAT = 0.0) and center reference longitude 180˚ (CLON = 180.0). Polar quadrangles have latitudes of 60˚ to the pole with center reference latitude ±90˚ (CLAT = ±90.0) and center reference longitude 0˚ (CLON = 0.0) mapped into the Polar Stereographic projection. When orthographic tiles are included, there are six maps in orthographic projections centered every 60° of longitude at 0.0° latitude and two maps in orthographic projections centered at each pole for a global WAC product. This tiling scheme is used for basemap, multispectral, and special data products. Global map products using this tiling scheme include WAC_GLOBAL, WAC_ORBITS, and WAC_CSHADE. For WAC products not covering the entire lunar globe, the same tiling scheme is used, including quadrangle sizes, extents, and map projections. An exception is made if the mosaic does not exceed ±70° in latitude and the pixel scale of the WAC product allows for quadrangle file sizes of 2 GB or less, such as was done for the 400 m/pixel WAC Hapke normalized basemaps (WAC_HAPKE). Often, lower resolution versions of a WAC product are also available, which may have different quadrangle extents. READMEs (section 3.1) provided with each RDR product contains the specific details for pixel scale, included quadrangles, possible lower resolution versions, as well as other pertinent information.

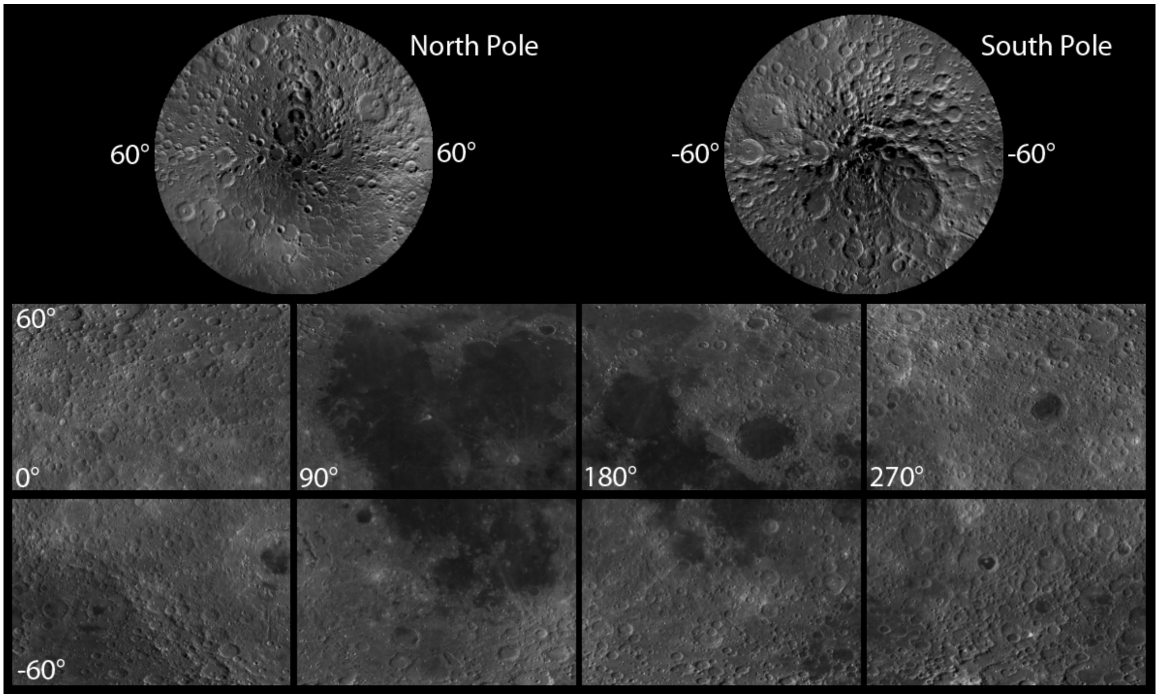

Figure 4.2 - Quadrangle layout of the WAC_GLOBAL basemap with 8 quadrangles covering -60° to 60° latitude (equatorial region) mapped in the Equirectangular projection and 2 quadrangles in Polar Stereographic projection covering ±60° latitude to the poles.

4.1.4 WAC Illumination Movie Products

The WAC_MOVIE products, made from the WAC's 643-nm imaging, are used in the generation of uncontrolled illumination movies at both poles with an average time interval between each frame of approximately two hours. The movie sequence is intended to identify regions of permanent shadow and permanent or near-permanent illumination over a full lunar year. WAC_MOVIE is mapped into the Polar Stereographic projection and scaled at 100-m/pixel with latitude coverage of 80˚ to 90˚. The image dimensions are about 6,060 x 6,060 pixels. Approximately 8,700 images are map-projected for each pole. The WAC FOV covers a swath ~100 km wide, resulting in repeat coverage every orbit for the region between 88˚ and 90˚ at each pole. Figure 4.3 shows two WAC footprints taken 156 hours apart overlaid on the WAC North Pole basemap (summer). The individual frames for each pole are compiled into a movie sequence formatted in MPEG-2 and QuickTime video formats. PDS3 standards do not exist for video formats so these products are available in the EXTRAS directory of the archive volume of the LROC Derived Data Products.

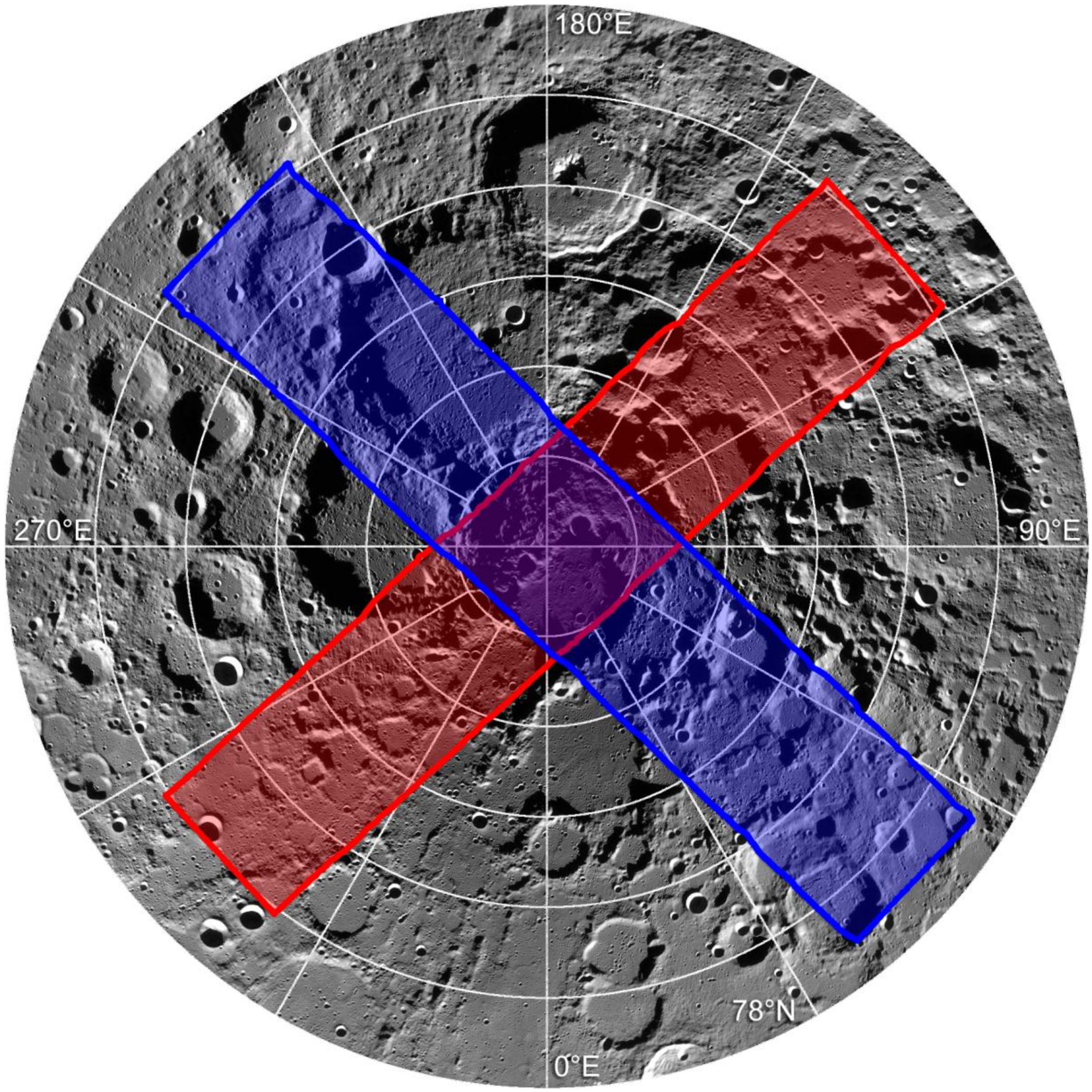

Figure 4.3 - Two WAC swaths (one shown in blue and one shown in red) taken 156 hours apart at the North Pole. Every orbit has repeat coverage between 88° and 90° latitude [10].

4.2 Radiometric Calibration Correction

Before launch, members of the LROC Instrument Development and Science Team calibrated the NAC and WAC at Malin Space Science Systems. Complete details of the pre-flight derived radiometric calibration corrections can be found in the peer-reviewed publication Lunar Reconnaissance Orbiter Camera (LROC) Instrument Overview [1]. After launch, additional observations were collected and used to further refine the radiometric calibration for each camera. Those results are highlighted in two peer-reviewed papers: Flight Calibration of the LROC Narrow Angle Camera [11] and Inflight Calibration of the Lunar Reconnaissance Orbiter Camera Wide Angle Camera [12].

Due to the different detector characteristics and formats (NAC's linear array vs. WAC's 2D array), the approach to apply the radiometric correction differs for the NAC and WAC. During standard processing, the corrections are applied using a series of pipeline procedures that convert the decompanded digital number (DN) value into a calibrated signal in radiance units of μW/(cm^2·sr·nm).

For the NAC, the radiometric calibration correction is expressed with the following equation:

$$I_{cal}(x,t,T) = \frac{(I_{raw}(x,t,T) - m_I(t,T)) - (D(x,t,T) - m_D(t,T)) - S(x) - L(x)}{F(x)\times t \times r},$$

where:

$I_{cal}(x,\tau,T)$ is the calibrated signal value of pixel x in radiance units of μW/(cm^2·sr·nm),

$I_{raw}(x,\tau,T)$ is the pixel's raw signal in DN (already decompanded from 8-bit to 12-bit values),

τ is the exposure time,

m is the mean DN value of the masked pixels,

$D(x,\tau,T)$ is the library dark image correction array,

$S(x)$ is the non-linearity offset array,

$L(x)$ is the logistic function value for low-signal non-linearity correction (only if $I(x, \tau)_{raw}$ < 400 DN),

$F(x)$ is the sensitivity non-uniformity array (flat-field), and

r is the spectral responsivity for conversion of DN into radiance units.

For the WAC, the radiometric calibration correction is expressed with the following equation:

$$I_{cal}(x,y,f,t,T) = \frac{I_{raw}(x,y,f,t,T) - D(x,y,f,t,T) + N(x,y,f)}{F(x,y,f)\times t \times r_f},$$

where $I_{cal}(x,y,f,\tau,T)$ is the calibrated signal of the pixel at position (x,y) in radiance units of μW/(cm^2·sr·nm),

$I_{raw}\ (x,y,f,\tau,T)$ is the pixel's raw signal in DN (already decompanded from 8-bit to 11-bit values),

f is the filter,

τ is the exposure time,

T is the temperature,

$D(x,y,f,\tau,T)$ is the library dark image,

$N(x,y,f)$ is non-linearity correction (term above some DN)

F(x,y,f) is the sensitivity non-uniformity correction matrix (flat-field), and

r_f is a filter's responsivity coefficient to convert DN to radiance

Not represented in the correction is the decompanding from 8-bit to 11-bit values. In a further post-processing step the radiometrically calibrated WAC bandpasses of several frames can be combined into a color image of a chosen point on the lunar surface.

After the radiometric calibration is applied to a NAC and WAC observation, the radiance values calculated in the previous equations are converted into reflectivity (*I/F)* [13], with *I* being the observed radiance depending on the observational geometry and the solar radiance *F* coming from a normally illuminated Lambertian surface. The *I/F* term is sometimes referred to as the radiance factor [14] and can be calculated with the following equation:

$$\frac{I}{F} = \frac{(I_L \cdot \pi \cdot d^2)}{\Phi_E}$$

where,

I_L is the spectral radiance of the lunar surface

d is the Sun-Moon distance (AU)

Φ_E is the solar irradiance at 1 AU

4.3 Photometric Normalization

In addition to radiometric calibration, a photometric normalization is required for most WAC and occasional NAC observations due to variations in viewing and illumination geometries. This process is vital when constructing global and other large-scale mosaics derived from tens to thousands of observations. The photometric normalization for most WAC products is based on the work of Sato et al. [15], while the NAC products are based on Boyd et al. [16]. These processes use the local illumination angles (incidence, emission and phase) of a spherical or topographic model. The photometric correction adjusts the I/F values to a common geometry.

4.4 Geometric Processing

Following photometric normalization, geometric processing corrects for the optical distortion of the instrument and projects the image from spacecraft viewing orientation to the map projections described in section 4.1 and Appendix B – Map Projection Equations. Geometric processing employs the NAIF Toolkit (http://naif.jpl.nasa.gov) using reconstructed SPICE kernels [17] generated by the LRO project as well as updated ephemeris derived using the gravity fields modeled from the Gravity and Interior Laboratory (GRAIL) mission [18]. Using the best digital terrain model (DTM) available at the time of the production, the geometry processing performs orthorectification wherein the geometric distortion introduced by the varying terrain is minimized. The map-projected products are generally uncontrolled and are not tied to a surface control net so there may be small spatial displacements among the images in the mosaic due to uncertainties in spacecraft pointing and position and lunar ephemeris as found in the SPICE kernels. However, refinement of the camera distortions and relative orientation by Speyerer et al.

[2] reduce the displacements to less than 20 m in the NAC and 40 m (sub-pixel) in WAC. During transformation from camera to object space, a cubic convolution resampling is used, unless otherwise mentioned in a product's README (section 3.1). There are a few types of products that are always controlled, including NAC_DTMs, a majority of NAC_ROIs, and NAC_PHOs. If a product is geometrically controlled, it will be mentioned in the product's README.

4.5 Brightness Equalization

The radiometric calibration and photometric normalization processing steps for local NAC mosaics may not be perfect, and as a result, residual brightness differences can exist among neighboring NAC images mosaicked together into a regional mosaic. To minimize the residual brightness differences, an empirical method is employed. Following geometric processing, image statistics (mean and standard deviation) are compiled for each of the overlapping areas of all neighborhood images. Typically, each image in a mosaic might have 1-5 neighbors where there is spatial overlap. Ideally, if the calibration and photometric normalization were perfect then the statistics of the overlap areas would be identical and no additional processing would be required. However, experience shows this situation may not be the case. With the statistics computed for each overlap area, multiplicative adjustments are determined to minimize the brightness differences of the overlap regions. These corrections are then applied to the image collection before the final mosaic assembly.

4.6 Mosaicking and Quadrangle Assembly

The final step in the processing is to mosaic together the individual map-projected brightness-equalized images that make up a regional mosaic. In this process, an empty image file is initially created. The images that go into the mosaic are then individually placed into the map at the appropriate spatial location. The geometric processing step ensures all of the images in the map have identical scale and map projection parameters. In overlap areas among neighboring images, the last image placed into the mosaic will generally overwrite the common area of the images previously inserted into the mosaic.

5 Standards

5.1 PDS Standards

The LROC Derived Data products comply with the LRO Archive Plan [3, 4, 5] and the PDS standards [6, 7, 8] for file formats and metadata labels, specifically using the PDS image object.

5.2 GeoTIFF Standard

The GeoTIFF standard is an extension to the TIFF (Tagged Image File Format) format that contains additional TIFF tags relating the (x, y) Cartesian coordinates to geographic (latitude and longitude) positions on planetary surfaces. GeoTIFF is an industry standard recognized by many Geographic Information Systems (GIS) software packages. The GeoTIFF UUID box is identified by its first sixteen UUID byte values (shown here in hexadecimal notation): B1, 4B, F8, BD, 08, 3D, 4B, 43, A5, AE, 8C, D7, D5, A6, CE, 03.

The remainder of the box contains a standard TIFF data set composed of TIFF tags with geospatial reference information derived from the IMAGE_MAP_PROJECTION parameters of the PDS label. The details of the GeoTIFF specification, and other related information, can be found at the Remote Sensing organization GeoTIFF web site (http://www.remotesensing.org/geotiff/).

5.3 Data Storage Conventions

The LROC derived data products contain binary data. Image pixel values are generally stored as 32-bit floating-point values. Exceptions include stretched versions of products and false color products stored in 8-bit values and WAC GLD100 quadrangles and NAC DTM orthophotos, which are stored in 16-bit signed values. The PDS label sections are stored as ASCII character strings conforming to the requirements defined in the PDS Standards Reference. PDS labels are stored as attached labels for images in PDS image format. Images in the GeoTIFF format and Legends in TIFF format are stored with detached PDS labels. READMEs describing each RDR product and image lists are also stored as UTF-8 character strings.

5.3.1 Reading 16-bit Data

Pixel values have been scaled to fit in the 16-bit range. Where pixel values have been stored as 16-bit integers, they must be scaled to recover the original floating-point value. To convert the 16-bit digital number (DN) values back to original units (e.g. radiance factor (I/F)), a multiplicative and additive constant is applied. The *SCALING_FACTOR* and *OFFSET* values, found in the PDS label IMAGE object, are used for the conversion. The equation is as follows:

ORIGINAL UNITS = (DN * SCALING_FACTOR) + OFFSET

5.4 Time Standards

LROC labels include time specifications in Coordinated Universal Time (UTC). The UTC has uniform seconds defined by the International Atomic Time, with leap second changes announced at irregular intervals to compensate for the Earth's varying rotation. Processing at the LROC Science Operations Center (SOC) converts onboard spacecraft clock counts to UTC time using the NAIF toolkit [15]. Start and stop times, where provided, refer to the observation acquisition times of the collection of source products used to compile the derived products.

5.5 Geodetic and Cartographic Standards

The LROC derived products are compatible with the recommendations of the LRO Data Working Group (LDWG) [19] and draft recommendations and mapping conventions identified by the Lunar Geodesy and Cartography Working Group (LGCWG) [20]. The coordinate system used is the mean Earth/polar axis system, using planetocentric latitude and east positive longitude direction. The planetocentric latitude is the angle from the equator to a point on the surface of an oblate planet. The longitude increases from west to east (left to right on an Equirectangular projection).

The planetary constants used in the camera model to produce the LROC derived products are obtained from the NAIF SPICE kernels. The SPICE kernel de421.bsp and associated Euler angles are used for the Moons ephemeris definition [21]. For more information regarding the planetary constants please refer to the NAIF Node at http://naif.jpl.nasa.gov/naif/

6 Derived Product Specification

6.1 Data Volume

Table 6.1 - Product summarizes the typical product sizes for each of the product types described in the SIS. The number of products and data volumes may vary as image campaigns are further refined.

Table 6.1 - Product Sizes

Product Type	Typical Product Size	Comments
NAC_DTM	6.5 GB	Map boundaries and areal coverage tailored to study areas. Size is given for the DTM and all associated subproducts.
NAC_PHO	85 GB	Map boundaries and areal coverage tailored to study areas. Size is given for a typical photometric series.
NAC_POLE	8.5 GB	North and South Pole coverage from 90˚ to 85.5˚ Latitude. Approximate size for one NAC_POLE quadrangle at 1 m/pixel.
NAC_POLE_PSR	3.5 GB	North and South Pole PSR coverage from 90° to 80° Latitude
NAC_PSR	5 GB	Map boundaries and areal coverage tailored to study areas.
NAC_ROI	8 GB	Map boundaries and areal coverage tailored to study areas. Size given for full-resolution PDS formatted file.
WAC_CSHADE	100 MB	Global coverage in Equirectangular projection. Polar coverage from 90˚ to 60˚ latitude in Polar Stereographic projection. Orthographic coverage is every 60˚ of longitude.
WAC_EMP	2 GB (304 ppd) 85 MB (64 ppd)	Coverage in Equirectangular projection from 65°S to 65°N. Size provided for a quadrangle of the high resolution 643 nm band mosaic and the lower resolution mosaics available for each of the 7 bands.

WAC_HAPKE	139 MB	Coverage in Equirectangular projection from 70°S to 70°N. Size provided for one quadrangle of a single band mosaic at 400 m/pixel.
WAC_HAPKEPARAMMAP	1.8 MB	Coverage in Equirectangular projection from 70°S to 70°N. Size provided for the set of Hapke parameters for a single WAC band at 1 pixel/degree.
WAC_GLD100	1 GB	Coverage in Equirectangular projection from 60°S to 60°N. Polar coverage from 79˚ to 60˚ latitude in Polar Stereographic projection. Size provided for one quadrangle at 100 m/pixel.
WAC_GLOBAL	2 GB	Global coverage in Equirectangular projection. Polar coverage from 90˚ to 60˚ latitude in Polar Stereographic projection. Size provided for a single quadrangle at 100 m/pixel.
WAC_MOVIE	141 MB	Movie frames spaced ~2 hours over a lunar year. Polar coverage for each pole from 90˚ to 80˚. Size provided for a single movie frame (1 WAC image).
WAC_ORBITS	247 MB	Global coverage in Equirectangular projection. Size provided for a single mosaic.
WAC_POLE_ILL	6.5 MB	Polar coverage from 90° to 88°. Size provided for a single illumination map at 100 m/pixel.
WAC_ROI	2.5 GB	Coverage in Equirectangular projection from 60°S to 60°N. Polar coverage from 90˚ to 60˚ latitude in Polar Stereographic projection. Size provided for a single quadrangle at 100 m/pixel.
WAC_TIO2	139 MB	Coverage in Equirectangular projection from 70°S to 70°N. Size provided for a single quadrangle.

6.2 Data Validation

The LRO Data Working Group (LDWG) oversees and coordinates the validation of instrument team data products for release to the PDS in a process by which the science teams and the PDS participate. The LROC team is responsible for verifying that the products meet their science and engineering objectives and technical specifications identified in the SIS. The PDS Imaging Node verifies that the products conform to this SIS. The LROC team has made data products available to the LROC Data Node starting March 15, 2011 and continues to release them every three months as new products are generated. The LROC SOC data processing pipeline includes data validation steps in the processing flow to help ensure engineering and technical specifications for these data are met.

6.3 Product Identification and File Naming Conventions

Each LROC derived product is uniquely identified with a product identifier (PRODUCT_ID keyword in PDS labels). The file names are built directly from this unique identifier. The product identifier is constructed using some, but not all, the elements of a ordered list of the element in Table 6.2 for a total character count ≤ 32 characters. Figure 6.1 shows examples of how the product IDs are constructed. For example, the NAC_POLE quadrangle centered at 88.0˚ North latitude and 27.0˚ East longitude in the Equirectangular projection would have the product identification "NAC_POLE_E880N0270". The file name for the GeoTIFF or TIFF image product would have the extension ".TIF" and the detached PDS label would have the extension ".LBL". Additional file name examples are shown in Table 6.3. For details specific to each data product, see the README (section 3.1) archived alongside the data.

Table 6.2 - Hierarchal List of Possible Product Name Elements

Name Element	**Comments**
Instrument	Typically WAC or NAC
Product_Type	See Table 3.1 for examples. These can have underscores.
Unique_Attribute	Generally related to the site's name or a short description of the product
Band	For multispectral Products; formatted as XXXNM or 3BAND, where XXX is the WAC filter.
Location	Includes projection and center lat/lon information. Formatted as PXXXHxxxx where: • P is the projection (E=equirectangular, P=Polar Stereographic or O=Orthopgraphic) • XXX is the 3 digit representation of center latitude multiplied by 10 to retain the geographic position to the nearest 10th of a degree • H is the center latitude's hemisphere (N=north and S=south) • xxxx is the 4 digit representation of center longitude, always in 0 to 360, positive east. Center longitude is also multiplied by 10 to retain the geographic position to the nearest 10th of a degree. See Figure 6.1 for examples. Map center here is defined as the center of the product bounding box.

Image_Name	Derived from the target, mission elapse time, and instrument mode.
Resolution	1-3 digits followed by a unit of measurement designator: M for meters/pixel, CM for centimeters/pixel, and P for pixels/degree.
More_Description	Additional descriptor, usually used for sub-products. Examples include CLRSHDE (for colorshade), STRETCH (stretched version), or GRID (gridded version)

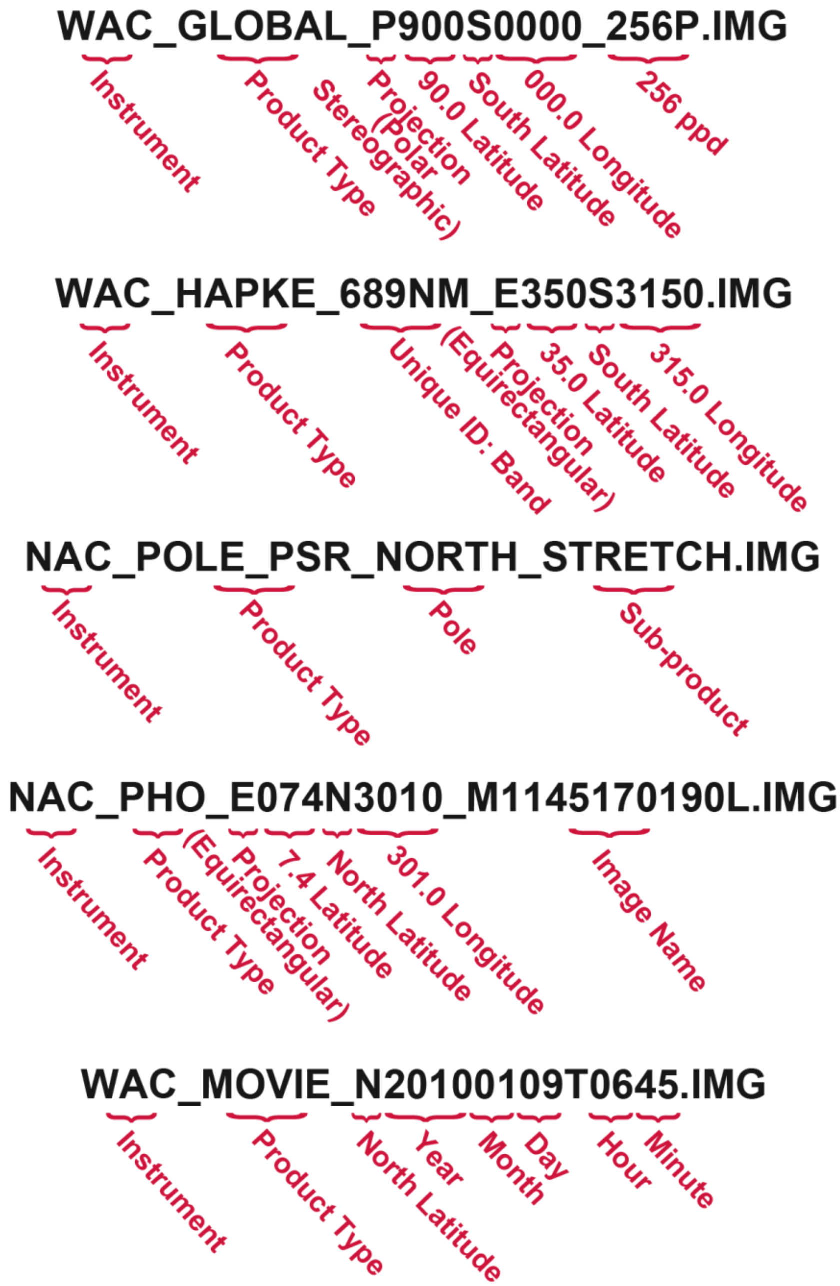

Figure 6.1 - Illustration for how RDR file names are constructed

For temporal products, such as WAC_MOVIE products, the product identification includes a date and time stamp prefaced by the product name (see Figure 6.1). The UTC time of the earliest observation in the mosaic is used in the construction of the file name. An "S" or "N" is inserted in front of the time field to indicate a North or South Pole frame. For example, if a polar movie product at the North pole were created whose earliest observation was at UTC time 2009-11-08T02:30:23.406, then the product identification would be: "WAC_MOVIE_N20091108T0230".

Table 6.3 - Example product identifications for LROC derived products

PRODUCT_ID	Lat. Center (degrees)	Lon. Center (degrees)	Description
NAC_POLE_SOUTH_README			README archived with each data product. In this example, the readme belongs with the NAC_POLE_SOUTH polar basemap. The portion of the name that comes before _README will match the name of the data product's directory
WAC_GLOBAL_E300S0450_100M	-30.0	45.0	One of the WAC Global mosaics quadrangles in the Equirectangular Projection at 100 m/pixels
NAC_POLE_P860N0045	86.0	4.5	One of 40 quadrangles of the NAC high-resolution north polar basemap in the Polar Stereographic projection
NAC_POLE_PSR_SOUTH	-90	0	A NAC south pole PSR mosaic in Polar Stereographic projection.
WAC_ROI_NORTH_SUMMER_100M	90	0	A WAC North pole summer mosaic in Polar Stereographic projection at 100 m/pixel.
NAC_ROI_APOLBASNLOA_E202S1005	-37.0	206.3	A NAC Region of Interest mosaic mapped in the Equirectangular projection with low-Sun. An 8-character region of interest name ("APOLBASN" in the example) is included in the file name.
NAC_PHO_E190N0050_M1234567890	19.0	5.0	NAC photometry product map in Equirectangular Projection created from the NAC M1234567890 observation.
WAC_ORBITS_05360_05788	0	180	Monthly WAC global mosaic of images taken during orbits 5360 to 5788.
WAC_MOVIE_S20090708T0230	-90.0	0.0	WAC polar movie for the south pole whose first image was acquired on UTC 2009-07-08T02:30:23.406.

Browse products have the same base name as their data products with file extensions of .BROWSE.PNG for low-resolution PNGs, .TIF for the 8-bit GeoTIFF, .PYR.TIF for the Pyramidal TIFF, and .MASK.TIF for the mask.

6.4 PDS labels

An example derived product label from the WAC global morphology mosaic quadrangle centered on 30°N and 135°E in PDS form is shown below. Appendix A – PDS Label Definitions provides a definition of each keyword listed.

****************************** Example PDS Label *******************************

```
PDS_VERSION_ID            = PDS3

/* The source image data definition. */
RECORD_TYPE   = FIXED_LENGTH
RECORD_BYTES  = 109164
FILE_RECORDS  = 18195
LABEL_RECORDS = 1
^IMAGE        = 2

/* Identification Information  */
DATA_SET_ID               = LRO-L-LROC-5-RDR-V1.0
DATA_SET_NAME             = "LRO MOON LROC 5 RDR V1.0"
VOLUME_ID                 = LROLRC_2001
PRODUCER_INSTITUTION_NAME = "ARIZONA STATE UNIVERSITY"
PRODUCER_ID               = LRO_LROC_TEAM
PRODUCER_FULL_NAME        = "MARK ROBINSON, PH.D"
PRODUCT_ID                = WAC_GLOBAL_E300N1350_100M
PRODUCT_VERSION_ID        = v1.2
PRODUCT_TYPE              = RDR
INSTRUMENT_HOST_NAME      = "LUNAR RECONNAISSANCE ORBITER"
INSTRUMENT_HOST_ID        = LRO
INSTRUMENT_NAME           = "LUNAR RECONNAISSANCE ORBITER CAMERA"
INSTRUMENT_ID             = LROC
TARGET_NAME               = MOON
MISSION_PHASE_NAME        = ("NOMINAL MISSION", "SCIENCE MISSION")
RATIONALE_DESC            = "Created at the request of NASA's Exploration
                            Systems Mission Directorate to support future
                            human exploration"
SOFTWARE_NAME             = "ISIS 3.4.3 with SER enhancements"

/* Time Parameters */
START_TIME                   = "N/A"
STOP_TIME                    = "N/A"
SPACECRAFT_CLOCK_START_COUNT = "N/A"
SPACECRAFT_CLOCK_STOP_COUNT  = "N/A"
PRODUCT_CREATION_TIME        = 2015-07-28T02:54:18

/* NOTE:                                                                */
/* This raster image is composed of a set of pixels that represent finite  */
/* areas, and not discrete points.  The center of the upper left pixel is  */
/* defined as line and sample (1.0,1.0). The                            */
/* [LINE,SAMPLE]_PROJECTION_OFFSET elements are the pixel offset from line */
/* and sample (1.0,1.0) to the map projection origin (defined by the      */
/* CENTER_LATITUDE and CENTER_LONGITUDE elements).  These offset values    */
/* are positive when the map projection origin is to the right or below    */
/* the center of the upper left pixel. This definition was adopted in      */
/* November 2011 by the LROC team.                                        */

OBJECT = IMAGE_MAP_PROJECTION
    ^DATA_SET_MAP_PROJECTION     = DSMAP.CAT
    MAP_PROJECTION_TYPE          = EQUIRECTANGULAR
    PROJECTION_LATITUDE_TYPE     = PLANETOCENTRIC
    A_AXIS_RADIUS                = 1737.4 <KM>
    B_AXIS_RADIUS                = 1737.4 <KM>
    C_AXIS_RADIUS                = 1737.4 <KM>
    COORDINATE_SYSTEM_NAME       = PLANETOCENTRIC
    POSITIVE_LONGITUDE_DIRECTION = EAST
    KEYWORD_LATITUDE_TYPE        = PLANETOCENTRIC
    /* NOTE:  CENTER_LATITUDE and CENTER_LONGITUDE describe the location   */
```

```
    /* of the center of projection, which is not necessarily equal to the  */
    /* location of the center point of the image.                          */
    CENTER_LATITUDE              = 0.0 <DEG>
    CENTER_LONGITUDE             = 0.0 <DEG>
    LINE_FIRST_PIXEL             = 1
    LINE_LAST_PIXEL              = 18194
    SAMPLE_FIRST_PIXEL           = 1
    SAMPLE_LAST_PIXEL            = 27291
    MAP_PROJECTION_ROTATION      = 0.0 <DEG>
    MAP_RESOLUTION               = 303.23350424149 <PIX/DEG>
    MAP_SCALE                    = 100.0 <METERS/PIXEL>
    MAXIMUM_LATITUDE             = 59.999966182861 <DEG>
    MINIMUM_LATITUDE             = 0.0 <DEG>
    EASTERNMOST_LONGITUDE        = 179.99989854858 <DEG>
    WESTERNMOST_LONGITUDE        = 89.999949274291 <DEG>
    LINE_PROJECTION_OFFSET       = 18193.5 <PIXEL>
    SAMPLE_PROJECTION_OFFSET     = -27291.5 <PIXEL>
END_OBJECT = IMAGE_MAP_PROJECTION

OBJECT = IMAGE
    DESCRIPTION                = "WAC monochrome global mosaic with large
                                 incidence angles (53-70 degrees at the
                                 equator) to support morphologic
                                 interpretations of the lunar surface (see
                                 [SPEYERERETAL2011]). Simple Cylindrical
                                 projection tile of the north-western quadrant
                                 of the far side at 100 m/px."
    LINES                      = 18194
    LINE_SAMPLES               = 27291
    SAMPLE_TYPE                = PC_REAL
    SAMPLE_BITS                = 32
    SAMPLE_BIT_MASK            = 2#11111111111111111111111111111111#
    CORE_NULL                  = 16#FF7FFFFB#
    CORE_LOW_REPR_SATURATION   = 16#FF7FFFFC#
    CORE_LOW_INSTR_SATURATION  = 16#FF7FFFFD#
    CORE_HIGH_REPR_SATURATION  = 16#FF7FFFFF#
    CORE_HIGH_INSTR_SATURATION = 16#FF7FFFFE#

    BAND_STORAGE_TYPE          = BAND_SEQUENTIAL
    BANDS                      = 1
    CENTER_FILTER_WAVELENGTH   = 643
    FILTER_NAME                = "643"
    BANDWIDTH                  = 23


END_OBJECT = IMAGE
END
```

Appendix A – PDS Label Definitions

Table A – Definition of keywords used in the LROC Product Labels	
Keyword	Definition
PDS_VERSION_ID	Always "PDS3", the version number of the PDS standards used in the construction of the labels.
DATA_SET_ID	"LRO-L-LROC-3-RDR-V1.0" The DATA_SET_ID element is a unique alphanumeric identifier for a data set or a data product. The value for a given data set or product is constructed according to flight project naming conventions.
DATA_SET_NAME	" LRO MOON LROC 5 RDR V1.0" The DATA_SET_NAME element provides the full name given to a data set or a data product.
PRODUCER_INSTITUTION_NAME	"ARIZONA STATE UNIVERSITY", "UNIVERSITY OF ARIZONA", or "German Aerospace Center (DLR)" The PRODUCER_INSTITUTION_NAME element identifies university, research center, NASA center or other institution associated with the production of a data set.
PRODUCER_ID	LRO_LROC_TEAM The PRODUCER_ID element provides a short name or acronym for the producer or producing team/group of a data set.
PRODUCER_FULL_NAME	"MARK ROBINSON, PH.D" The PRODUCER_FULL_NAME element provides the full name of the individual mainly responsible for the production of a data set.
PRODUCT_ID	The PRODUCT_ID data element represents a permanent, unique identifier assigned to a data product by its producer.
PRODUCT_VERSION_ID	The PRODUCT_VERSION_ID element identifies the version of an individual product within a data set.
INSTRUMENT_HOST_NAME	Always "LUNAR RECONNAISSANCE ORBITER" The INSTRUMENT_HOST_NAME element provides the full name of the host on which an instrument is based. This host can be either a spacecraft or an Earth base.
INSTRUMENT_HOST_ID	Always "LRO" The INSTRUMENT_HOST_ID element provides a unique identifier for the host where an instrument is mounted.
INSTRUMENT_NAME	Always "LUNAR RECONNAISSANCE ORBITER CAMERA" The INSTRUMENT_NAME element provides the full name of an instrument.
INSTRUMENT_ID	Always "LROC"

	The INSTRUMENT_ID element provides an abbreviated name or acronym that identifies an instrument.
TARGET_NAME	"MOON", "EARTH", etc. The TARGET_NAME element identifies the primary target of the observation.
MISSION_PHASE_NAME	"COMMISSIONING", "NOMINAL MISSION", "SCIENCE MISSION", "EXTENDED SCIENCE MISSION", "SECOND EXTENDED SCIENCE MISSION", or "THIRD EXTENDED SCIENCE MISSION" The MISSION_PHASE_NAME element provides the commonly used identifier of a mission phase.
SOURCE_PRODUCT_ID	The SOURCE_PRODUCT_ID data element identifies a product used as input to create a new product.
RATIONALE_DESC	The RATIONALE_DESC element describes the rationale for the provided product.
SOFTWARE_NAME	The SOFTWARE_NAME element identifies data processing software such as a program or a program library.
START_TIME	For LROC mosaic products this is the START_TIME of the earliest acquired observation in the mosaic. The time is in the UTC system, formatted as: YYYY-MM-DDThh:mm:ss.fff.
SPACECRAFT_CLOCK_START_COUNT	Always "N/A" This required keyword is not applicable for LROC mosaic products.
STOP_TIME	For LROC mosaic products, this is the STOP_TIME of the latest acquired observation in the mosaic. The time is in the UTC system, formatted as: YYYY-MM-DDThh:mm:ss.fff.
SPACECRAFT_CLOCK_STOP_COUNT	Always "N/A" This required keyword is not applicable for LROC mosaic products.
PRODUCT_CREATION_TIME	The PRODUCT_CREATION_TIME element defines the UTC system format time when a product was created, formatted as: YYYY-MM-DDThh:mm:ss.fff.
IMAGE_MAP_PROJECTION	**Object within label**
^DATA_SET_MAP_PROJECTION	The DATA_SET_MAP_PROJECTION object is one of two distinct objects that define the map projection used in creating the digital images in a PDS data set. The name of other associated object that completes the definition is called IMAGE_MAP_PROJECTION. The map projection information resides in these two objects, essentially to reduce data redundancy and at the same time allow the inclusion of elements needed to process the data at the image level. Static information applicable to the complete data set resides in the DATA_SET_MAP_PROJECTION object, while dynamic information that is applicable to the individual images resides in the IMAGE_MAP_PROJECTION object. The DATA_SET_MAP_PROJECTION object is to be included in an Archive Quality Data Product Label, and

	used to load the map projection catalog data into a PDS Catalog.
MAP_PROJECTION_TYPE	"EQUIRECTANGULAR", "POLAR STEROGRAPHIC", or "ORTHOGRAPHIC" The MAP_PROJECTION_TYPE element identifies the type of projection characteristic of a given map.
PROJECTION_LATITUDE_TYPE	"PLANETOCENTRIC" Identifies the type of latitude that is sampled in equal increments by successive image lines.
A_AXIS_RADIUS	1737.4 <KM> The A_AXIS_RADIUS element provides the value of the semimajor axis of the ellipsoid that defines the approximate shape of a target body. 'A' is usually in the equatorial plane.
B_AXIS_RADIUS	1737.4 <KM> The B_AXIS_RADIUS element provides the value of the intermediate axis of the ellipsoid that defines the approximate shape of a target body. 'B' is usually in the equatorial plane.
C_AXIS_RADIUS	1737.4 <KM> The C_AXIS_RADIUS element provides the value of the semiminor axis of the ellipsoid that defines the approximate shape of a target body. 'C' is normal to the plane defined by 'A' and 'B'.
COORDINATE_SYSTEM_NAME	PLANETOCENTRIC The COORDINATE_SYSTEM_NAME element provides the full name of the coordinate system to which the state vectors are referenced. PDS has currently defined body-fixed rotating coordinate systems. The Planetocentric system has an origin at the center of mass of the body. The planetocentric latitude is the angle between the equatorial plane and a vector connecting the point of interest and the origin of the coordinate system. Latitudes are defined to be positive in the northern hemisphere of the body, where north is in the direction of Earth's angular momentum vector (i.e., pointing toward the hemisphere north of the solar system invariant plane). Longitudes increase toward the east making the Planetocentric system right-handed. Note that the reference coordinate system used is the mean Earth/polar axis system.
POSITIVE_LONGITUDE_DIRECTION	"EAST" The POSITIVE_LONGITUDE_DIRECTION element identifies the direction of longitude (e.g. EAST, WEST) for a body.
KEYWORD_LATITUDE_TYPE	"PLANETOCENTRIC" Identifies the type of latitude (planetographic or planetocentric) used in the labels (e.g., for the maximum, minimum, center, reference, and standard-parallel latitudes).

CENTER_LATITUDE	The CENTER_LATITUDE element provides the reference latitude of the map projection. The MAP_SCALE (or MAP_RESOLUTION) is typically defined at the CENTER_LATITUDE and CENTER_LONGITUDE of the map projection.
CENTER_LONGITUDE	The CENTER_LONGITUDE element provides a reference longitude for certain map projections. For example, in an Orthographic projection, the CENTER_LONGITUDE, along with the CENTER_LATITUDE, defines the point or tangency between the sphere of the planet and the plane of the projection. The MAP_SCALE (or MAP_RESOLUTION) is typically defined at the CENTER_LATITUDE and CENTER_LONGITUDE. In unprojected images, CENTER_LONGITUDE represents the longitude at the center of the image frame.
LINE_FIRST_PIXEL	The LINE_FIRST_PIXEL element provides the line (row) index for the first pixel that was physically recorded at the beginning of the image array. Note: For a fuller explanation on the use of this data element in the Image Map Projection Object, please refer to the PDS Standards Reference.
LINE_LAST_PIXEL	The LINE_LAST_PIXEL element provides the line (rows) index for the last pixel that was physically recorded at the end of the image array. Note: For a fuller explanation on the use of this data element in the Image Map Projection Object, please refer to the PDS Standards Reference.
SAMPLE_FIRST_PIXEL	The SAMPLE_FIRST_PIXEL element provides the sample (column) index for the first pixel that was physically recorded at the beginning of the image array. Note: For a fuller explanation on the use of this data element in the Image Map Projection Object, please refer to the PDS Standards Reference.
SAMPLE_LAST_PIXEL	The SAMPLE_LAST_PIXEL element provides the sample (column) index for the last pixel that was physically recorded at the end of the image array. Note: For a fuller explanation on the use of this data element in the Image Map Projection Object, please refer to the PDS Standards Reference.
MAP_PROJECTION_ROTATION	Always 0.0 The MAP_PROJECTION_ROTATION element provides the clockwise rotation, in degrees, of the line and sample coordinates with respect to the map projection origin (LINE_PROJECTION_OFFSET, LINE_PROJECTION_OFFSET).
MAP_RESOLUTION	The MAP_RESOLUTION element identifies the resolution of a map in pixels/degree at the center latitude and longitude of the projection.
MAP_SCALE	The MAP_SCALE element identifies the scale of a given map in meters/pixel at the center latitude and longitude of the projection.

MAXIMUM_LATITUDE	The MAXIMUM_LATITUDE element specifies the northernmost latitude of the map.
MINIMUM_LATITUDE	The MINIMUM_LATITUDE element specifies the southernmost latitude of a spatial area, such as a map, mosaic, bin, feature, or region.
LINE_PROJECTION_OFFSET	The LINE_PROJECTION_OFFSET element provides the line offset value of the map projection origin position from the line and sample 1,1 (line and sample 1,1 is considered the upper left corner of the upper left pixels of the digital array) Note: that the positive direction is to the right and down.
SAMPLE_PROJECTION_OFFSE0T	The SAMPLE_PROJECTION_OFFSET element provides the sample offset value of the map projection origin position from line and sample 1,1 (line and sample 1,1 is considered the upper left corner of the digital array). Note: that the positive direction is to the right and down.
EASTERNMOST_LONGITUDE	The following definitions describe easternmost longitude for the body-fixed, rotating coordinate systems: For Planetocentric coordinates and for Planetographic coordinates in which longitude increases toward the east, the easternmost (rightmost) longitude of a spatial area (e.g., a map, mosaic, bin, feature or region) is the maximum numerical value of longitude unless it crosses the Prime Meridian.
WESTERNMOST_LONGITUDE	The following definitions describe westernmost longitude for the body-fixed, rotating coordinate systems: For Planetocentric coordinates and for Planetographic coordinates in which longitude increases toward the east, the westernmost (leftmost) longitude of a spatial area (e.g., a map, mosaic, bin, feature or region) is the minimum numerical value of longitude unless it crosses the Prime Meridian.
IMAGE	**Object within label**
DESCRIPTION	Description of the product.
LINES	Number of image lines (rows) in the image object.
LINE_SAMPLES	Number of samples (columns) per image line. This dimension is the most rapidly varying dimension of the image array.
BANDS	Number of bands.
SAMPLE_TYPE	“PC_REAL”, "LSB_UNSIGNED_INTEGER" Sample or pixel type.
SAMPLE_BITS	32, 16, or 8: number of bits per sample or pixel.
SAMPLE_BIT_MASK	Always 2#1111111111111111# The SAMPLE_BIT_MASK element identifies the active bits in each sample. Note: The domain of

	SAMPLE_BIT_MASK is dependent upon the currently described value in the SAMPLE_BITS element and only applies to integer values.
SCALING_FACTOR	The SCALING_FACTOR and OFFSET elements provide the constant values by which the stored pixel values are converted to their original units (i.e. I/F or elevation) Note: Expressed as an equation: true value = offset value + (scaling factor x stored value).
OFFSET	See SCALING_FACTOR keyword above.
BAND_STORAGE_TYPE	Always "BAND_SEQUENTIAL" The BAND_STORAGE_TYPE element indicates the storage sequence of lines, samples and bands in an image. The values describe, for example, how different samples are interleaved in image lines, or how samples from different bands are arranged sequentially. Example values: "BAND SEQUENTIAL", "SAMPLE INTERLEAVED", "LINE INTERLEAVED".
CENTER_FILTER_WAVELENGTH	The CENTER_FILTER_WAVELENGTH element provides the middle point wavelength value between the minimum and maximum instrument filter wavelength values.
CORE_NULL	The CORE_NULL element identifies a special value whose presence indicates missing data.
CORE_LOW_REPR_SATURATION	The CORE_LOW_REPR_SATURATION element identifies a special value whose presence indicates the true value cannot be represented in the chosen data type and length.
CORE_LOW_INSTR_SATURATION	The CORE_LOW_INSTR_SATURATION element identifies a special value whose presence indicates the measuring instrument was saturated at the low end.
CORE_HIGH_REPR_SATURATION	The CORE_HIGH_REPR_SATURATION element identifies a special value whose presence indicates the true value cannot be represented in the chosen data type and length.
CORE_HIGH_INSTR_SATURATION	The CORE_HIGH_INSTR_SATURATION element identifies a special value whose presence indicates the measuring instrument was saturated at the high end.
FILTER_NAME	WAC band pass: 321, 360, 415, 566, 604, 643, and/or 689; NAC: BROADBAND The FILTER_NAME element provides the commonly used name of the instrument filter through which an image or measurement was acquired or which is associated with a given instrument mode.
BANDWIDTH	The BANDWIDTH element provides a measure of the spectral width of a filter or channel.
BAND_NAME	The BAND_NAME is the name given to a single band in a multi-band image. Note: Keyword is used for multi-band files that contain non-spectral bands. Examples include:

	Local Incidence Angle, Phase Angle, w (Hapke parameter), and phi (Hapke parameter).

Appendix B – Map Projection Equations

Equirectangular Projection

The Equirectangular projection is based on the formula for a sphere. To eliminate confusion in the IMAGE_MAP_PROJECTION object we have set all three values, A_AXIS_RADIUS, B_AXIS_RADIUS, and C_AXIS_RADIUS to the same number, which is R below.

The Equirectangular projection [9] is a simple projection providing a linear relationship between the geographic coordinates of latitude and longitude and the Cartesian space of the map. In continuous form, the equations relating map coordinates (x, y) to geographic coordinates (Lat, Lon) are:

$$x = R \cdot (Lon - LonP) \cdot COS(LatP)$$

$$y = R \cdot Lat$$

where LonP is the center longitude of the map projection, LatP is the center latitude of the projection at which scale is given, and R the radius of the body. For the Moon R is assumed to be 1734.4 km [19].

The inverse formulas for Lat and Lon from x and y position in the projection are:

$$Lat = y/R$$

$$Lon = LonP + x/(R \cdot COS(LatP))$$

The Conversion from (x, y) map coordinates to image array coordinates (sample, line) is standard for all map projections and is:

$$x = (Sample - S_0) \cdot Scale$$

$$y = (-L_0 - Line) \cdot Scale$$

where "Scale" is the map resolution in km/pixel (located at the center planetocentric latitude of the projection). "Line" and "Sample" are the coordinates of the image array, and line (L_0) and sample offsets (S_0) are the respective image coordinate displacements from pixel (1,1) to the origin of the projection (x,y) = (0,0). Please note, pixel (1,1) is spatially located in the upper-left corner of the image array.

The equations from (x, y) to (Sample, Line) are:

$$Sample = x/Scale + S_0 + 1$$

$$Line = -y/Scale - L_0 + 1$$

The equation from (Sample, Line) to (Lat, Lon) is:

$$\mathbf{Lat = y/R}$$
$$\mathbf{y\ \ = (1\text{-}L_0\text{-}Line)\cdot Scale}$$
$$\mathbf{Lat = (1\text{-}L_0\text{-}Line)\cdot Scale/R}$$

$$\mathbf{Lon = LonP + x/(R\cdot COS(LatP))}$$
$$\mathbf{x\ \ = (Sample\text{-}S_0\text{-}1)\cdot Scale}$$
$$\mathbf{Lon = LonP + (Sample\text{-}S_0\text{-}1)\cdot Scale/(R\cdot COS(LatP))}$$

The keywords corresponding to the Equirectangular projection parameters are located in the IMAGE_MAP_PROJECTION object found in the PDS labels. The keywords for each equation parameter are shown below

Table B - PDS Keywords for corresponding Equirectangular projection equation parameters	
Equation	Keyword
LonP	CENTER_LONGITUDE
LatP	CENTER_LATITUDE
L_0	LINE_PROJECTION_OFFSET
S_0	SAMPLE_PROJECTION_OFFSET
Scale	MAP_SCALE
R	A_AXIS_RADIUS (same as B_AXIS_RADIUS and C_AXIS_RADIUS)

Polar Stereographic Projection

The Polar Stereographic projection [9], used for observations acquired at higher latitudes, is ideally suited for observations near the poles as shape and scale distortion are minimized. The LROC derived products in Polar Stereographic projection use the ellipsoid form of the equations.

In continuous form, the spherical equations relating map coordinates (x, y) to planetocentric coordinates (Lat, Lon) are:

North Polar Stereographic:

$$\mathbf{x = 2\cdot R\cdot TAN(Pi/4\text{-}Lat/2)\cdot SIN(Lon\text{-}LonP)}$$

$$\mathbf{y = \text{-}2\cdot R\cdot TAN(Pi/4\text{-}Lat/2)\cdot COS(Lon\text{-}LonP)}$$

South Polar Stereographic:

$$\mathbf{x = 2\cdot R\cdot TAN(Pi/4+Lat/2)\cdot SIN(Lon\text{-}LonP)}$$

$$\mathbf{y = 2\cdot R\cdot TAN(Pi/4+Lat/2)\cdot COS(Lon\text{-}LonP)}$$

Where LonP is the central longitude, LatP is the latitude of true scale and is always 90 or -90, and R is the polar radius of the Moon, or 1,737.4 km [19].

The spherical inverse formulas for Lat and Lon from X and Y position in the image array are:

$$\mathbf{Lat = ARCSIN[COS(C) \cdot SIN(LatP)+y \cdot SIN(C) \cdot COS(LatP)/P]}$$

North Polar Stereographic:

$$\mathbf{Lon = LonP + ARCTAN[x/(-y)]}$$

South Polar Stereographic:

$$\mathbf{Lon = LonP + ARCTAN[x/y]}$$

where:

$$\mathbf{P = SQRT(x^2 + y^2)}$$
$$\mathbf{C = 2 \cdot ARCTAN(P/2*R)}$$

recall:

$$\mathbf{x = (Sample\text{-}S_0\text{-}1) \cdot Scale}$$
$$\mathbf{y = (1\text{-}L_0\text{-}Line) \cdot Scale}$$

The keywords corresponding to the equation parameters for the Polar Stereographic projection are located in the IMAGE_MAP_PROJECTION object found in the PDS labels. The keywords for each equation parameter are shown above.

Orthographic Projection

The Orthographic projection is based on the formula for a sphere. To eliminate confusion in the IMAGE_MAP_PROJECTION object we have set all three values, A_AXIS_RADIUS, B_AXIS_RADIUS, and C_AXIS_RADIUS to the same number, which is R below.

The Orthographic projection [9] is a perspective azimuthal projection. It is not very useful for measurements with severe distortion near the edges in both area and shape, but it is commonly used for pictorial representations. In continuous form, the equations relating map coordinates (x, y) to geographic coordinates (Lat, Lon) are:

$$\mathbf{x = R\ COS(Lon)\ SIN(Lon - LonP)}$$
$$\mathbf{y = R[COS(LatP)SIN(Lat) - SIN(LatP)COS(Lat)COS(Lon\text{-}LonP)}$$

where LonP is the center longitude of the map projection, LatP is the center latitude of the projection, and R the radius of the body. For the Moon R is assumed to be 1,737.4 km [19].

The inverse formulas for Lat and Lon from x and y position in the projection are:

Lat = ARCSIN[COS(c)SIN(LatP) + (y SIN(c)COS(LatP/ρ)]

If LatP is not ±90°:

Lon = LonP + ARCTAN[x SIN(c)/(ρ COS(LatP)COS(c) – y SIN(LonP)SIN(c)]

If LatP is 90°:

Lon = LonP + ARCTAN[x/-y]

If LatP is -90°:

Lon = LonP + ARCTAN(x/y)

Where:

$\rho = SQRT(x^2 + y^2)$

$c = 2ARCTAN(\rho/2R)$

recall:

$x = (Sample-S_0)\cdot Scale$

$y = (-L_0-Line)\cdot Scale$

The keywords corresponding to the equation parameters for the Orthographic projection are located in the IMAGE_MAP_PROJECTION object found in the PDS labels. The keywords for each equation parameter are shown above.