Thermal Emission Imaging System
2001 Mars Odyssey

THEMIS GEOMETRIC PROCESSING USER'S GUIDE

October 1, 2012

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DOCUMENT CHANGE LOG

Date	Description	Sections affected
01/01/06	Initial draft	All
07/15/09	Descriptions of IR products	All
01/01/10	Accumulated updates to instrument & product descriptions Full projection format change to IR-PBT and IR-DCS products	Section 1.3.1, Appx A.4 Sections 2.3, 2.4, 3.1.1, and Appx A.2
07/01/12	Description of VIS DESPECK processing Addition of new peer-reviewed reference	Section 2.5.2, Appx A.5 Section 1.1
10/01/12	Geometry Quality HISTORY object	Appx A.7

CONTENTS

ACRONYMS

ASU	Arizona State University
DCS	DeCorrelation Stretch product
EDR	Experiment Data Record
GEO	Geometrically registered record
IR	Infrared
ISIS	Integrated Software for Imaging Spectrometers
JPL	Jet Propulsion Laboratory
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
PBT	Projected Brightness Temperature record
PDS	Planetary Data System
RDR	Reduced Data Record
ODY	2001 Mars Odyssey
SIS	Software Interface Specification
SPICE	Spacecraft, Planet, Instrument, Camera-matrix, Events
THEMIS	THermal EMission Imaging System
VIS	Visible

1. INTRODUCTION

1.1 Purpose and Contents

The purpose of this document is to provide scientists using the Thermal Emission Imaging System (THEMIS) Visible and Infrared special geometry products with enough information to enable them to read and understand the data products. Topics discussed in this document include an introduction to the ISIS software used to geometrically project the images, a description of the processing algorithm used to generate the images, a description of the data product format, and the contents of available ancillary labels and files.

THEMIS geometry products (IR-GEO and VIS-GEO) are spatially registered, spectral image CUBEs derived from the THEMIS calibrated radiance products (IR-RDR and VIS-RDR). Each image file is accompanied by a detached ASCII label describing the data format, contents, and processing history. THEMIS derived geometry products (IR-PBT and IR-DCS) are spatially registered, image products generated from the IR-GEO products.

For additional information, the user is referred to the following documents available in the THEMIS archive, unless otherwise noted:

1. Calibration Report for the Thermal Emission Imaging System (THEMIS) for the 2001 Mars Odyssey Mission, P.R. Christensen.
2. Mars Odyssey THEMIS: Archive SIS.
3. Mars Odyssey THEMIS: Data Processing User's Guide, P.R. Christensen.
4. Mars Odyssey THEMIS Geometry Processing with ISIS, J. Torson, *internet documentation:* http://isis.astrogeology.usgs.gov/Isis2/isis-bin/themis-processing.cgi.
5. Mars Odyssey THEMIS: Standard Data Products SIS.
6. Overview of ISIS Architecture, *internet documentation:* http://isis.astrogeology.usgs.gov/Isis2/isis-bin/isis_arch.cgi.
7. Planetary Data System Data Standards Reference, October 30, 2002, Version 3.5, JPL D-7669, Part 2.
8. The Thermal Emission Imaging System (THEMIS) for the Mars 2001 Odyssey Mission, P.R. Christensen, et. Al., *Space Science Review*, Vol. 110, pp 85-130, 2004.
9. Edwards, C. S., K. J. Nowicki, P. R. Christensen, J. Hill, N. Gorelick, and K. Murray (2011), Mosaicking of global planetary image datasets: 1. Techniques and data processing for Thermal Emission Imaging System (THEMIS) multi-spectral data, J. Geophys. Res., 116(E10), E10008, doi:10010.11029/12010JE003755.
10. Edwards, C. S., P. R. Christensen, and J. Hill (2011), Mosaicking of global planetary image datasets: 2. Modeling of wind streak thicknesses observed in Thermal Emission Imaging System (THEMIS) daytime and nighttime infrared data, J. Geophys. Res., 116, E10005, doi:10.1029/2011JE003857.

1.2 ISIS Overview

1.2.1 Software and Product Overview

ISIS (Integrated System for Imagers and Spectrometers) is a specialized image processing software package developed by the Astrogeology Program of the United States Geological Survey (USGS, Flagstaff Arizona). The software package includes the standard tools desired for the digital processing of multi-spectral image datasets, as well as instrument specific tools to convert between raw camera geometry and standardized map coordinate systems. Cartographic conversions are made possible by incorporating spacecraft and camera models into the ISIS software. The software and complete documentation is available for download from the ISIS website: http://isis.astrogeology.usgs.gov.

The ISIS software manipulates and stores image data in multi-dimensional qube files, formatted similar to the standard Planetary Data System (PDS) QUBE data object [7]. Each qube file is composed of an ASCII label attached to one or more data objects, such as a HISTORY object and the qube data object. A three-dimensional qube file, with two spatial dimensions and one spectral dimension, is referred to specifically as an ISIS CUBE file. A complete description of ISIS qube files can be found in *Overview of ISIS Architecture* [6].

1.2.2 THEMIS Specific Software Overview

Several essential tools have been developed to allow the ISIS software to process and geometrically project THEMIS standard data products. First, the ISIS software was given the ability to ingest the THEMIS QUBE data products. Although the PDS QUBE and ISIS CUBE formats are similar, they are different enough to require a translation tool. Second, the conversion parameters between the raw raster coordinate systems of the THEMIS cameras and a standardized Mars coordinate system were used to define several specialized projection tools. The projection capability is facilitated with the geometry information in Mars Odyssey SPICE kernels available from NAIF (http://naif.jpl.nasa.gov/naif). All aspects of the ISIS-THEMIS tools are discussed in *Mars Odyssey THEMIS Geometry Processing with ISIS* [4].

1.3 THEMIS Overview

1.3.1 Instrument Overview

The THEMIS instrument is a combined infrared (IR) and visible (VIS) multi-spectral pushbroom imager. The imaging system is comprised of a three-mirror, off-axis, reflecting telescope in a rugged enclosure, a visible/infrared beamsplitter, a silicon focal plane for visible detection, and a microbolometer for infrared detection. The telescope has a 12-cm effective aperture, speed of f/1.6, and co-aligned VIS-IR detector arrays. A major feature of this instrument is the uncooled IR microbolometer array which can be operated at ambient temperature. A small thermal electric (TE) cooler is used to stabilize the detector temperature to ±0.001 K. The calibration flag is the only moving part in the instrument, allowing for thermal calibration and protection of the detectors from unintentional direct Sun illumination when the instrument is not in use.

THEMIS IR images are acquired at selectable image lengths and in combinations of ten selectable bands. The image width is 320 pixels (32 km, based on the nominal 400 km mapping orbit) and the length is variable, in multiples of 256 line increments, with a minimum and maximum image lengths of 272 and 65,296 lines respectively (27.2 km and 6,530 km, based on the nominal mapping orbit). The IR focal plane is covered by ten ~1 µm-bandwidth strip filters (Table 1a), producing ten band images with bands 1 and 2 having the same wavelength range.

THEMIS VIS images are acquired in framelets of size 1024 pixels crosstrack by 192 lines downtrack, for a total image size of 3.734 Mbytes or less. The number of framelets is determined by the number of bands selected (five available, Table 1b) and the spatial resolution selected (three summing modes available). The size of an image is given by:

$$[((1024 * 192) * \#framelets * \#bands) \div summing^2] \leq 3.734 \text{ Mbytes}$$

For example, if spatial summing is not applied (summing=1), either a single-band, 19-framelet (65.6 km) image or a 5-band 3-framelet (10.3 km) image can be collected. Each VIS image collected is stored in the THEMIS internal buffer and must be transferred to the spacecraft computer before a subsequent image can be acquired. VIS images may be compressed with one of two available compression algorithms before storage on the spacecraft computer.

VIS images can be acquired simultaneously with IR images, but the spacecraft can only transfer data from one of the two THEMIS imagers at a time. The IR imager transfers data as it is being collected, while the VIS images are stored within an internal THEMIS buffer for later transfer to the spacecraft computer. Before storage of IR images on the spacecraft, one or more data reduction techniques may be selected. The time-delay integration (TDI) algorithm may be applied to improve the signal-to-noise ratio of each pixel by co-adding 16 independent measurements of each point on the ground. Lossless data compression may be applied to the image by the hardware Rice algorithm chip.

Tables 1a&b: THEMIS available bands

INFRARED BANDS		
Band Numbers	Center (µm)	FWHM (µm)
IR-1	6.78	1.01
IR-2	6.78	1.01
IR-3	7.93	1.09
IR-4	8.56	1.16
IR-5	9.35	1.20
IR-6	10.21	1.10
IR-7	11.04	1.19
IR-8	11.79	1.07
IR-9	12.57	0.81
IR-10	14.88	0.87

VISIBLE BANDS		
Band Numbers	Center (µm)	FWHM (µm)
V-1	0.425	0.049
V-2	0.540	0.051
V-3	0.654	0.053
V-4	0.749	0.053
V-5	0.860	0.045

The IR and VIS cameras share the instrument optics and housing, but have independent power and data interfaces to the spacecraft. In Spring 2006, a software patch was loaded into the spacecraft memory to apply spatial summing to IR images before downlink; use of this patch decreases the effective bandwidth of the IR camera, and allows for the collection of additional IR images. Final data stream formatting for both the IR and VIS data is performed by the spacecraft processor. Further information about onboard processing is available in the THEMIS *Space Science Review* paper [8].

1.3.2 Data Products Overview

THEMIS standard data products include experimental, reduced, and calibrated data files. The experimental and reduced products (VIS-EDR, IR-EDR, VIS-RDR, and IR-RDR) are spectral image QUBEs containing one layer per each visible or infrared band collected. The calibrated products (VIS-ABR and IR-BTR) are one band IMAGE files produced from the reduced data products. A detailed description of the format and content for each of the standard data products is provided in the *THEMIS Standard Data Products SIS* [5].

The THM-RDR data products are uncompressed, binary, band-sequential QUBEs of 16-bit integer data. The image width is fixed (320 pixels for IR, 1024 pixels for VIS), but the length varies proportional to the duration of the observation. Calibration algorithms used to generate each THM-RDR are described in the *THEMIS Data Processing User's Guide* [3] and each execution adds an entry in the cumulative HISTORY object contained in the ASCII header of the QUBE. The THM-RDR QUBE images are not spatially registered, and bands (layers) within a single image can be out of registration with each other by up to 10 lines and/or columns.

The THEMIS geometric data products will be generated by the staff at the ASU Mars Space Flight Facility and be distributed in conjunction with their standard data product counterparts. Geometric projection of the IR-RDR and VIS-RDR standard data products may be augmented with additional manipulation of the images, which may invalidate the calibrated radiance values inherited from the source RDR product. Geometric data products will be stored as one projection per image in a multispectral ISIS CUBE file. All processing performed on the GEO cube will be recorded in the HISTORY object of the detached PDS label.

THEMIS derived geometric data products (IR-PBT and IR-DCS) are generated by additional processing of the IR-GEO products. The IR-PBT products are one band IMAGE files, which conform to the same format standards as the IR-BTR products. The IR-DCS products are stored as simple PNG image products, similar to the PDS standard BROWSE images.

2. GEOMETRIC PROCESSING

2.1 THEMIS to ISIS

In order to generate the geometric projections from the calibrated radiance images, the THEMIS RDR.QUBE format must be modified so that it can be ingested into the standard ISIS projection software. The ISIS *THM2ISIS* tool is used to convert the PDS formatted IR-RDR or VIS-RDR image into an LEV-CUBE image that can be manipulated by subsequent ISIS software tools. At this time the label is initialized with geometric parameters, but the data values and image dimensions remain fundamentally unchanged.

When necessary, the default behavior of *THM2ISIS* can be modified for an image. The most common change is the selection of the kernels which define the orientation of the spacecraft during the acquisition of each image; the kernels used are specified in the ISIS_GEOMETRY object. The PDS2ISIS and LEVINIT HISTORY objects are generated during *THM2ISIS* processing.

2.2 Infrared GEO Products

The generation of infrared projected images (IR-GEO) includes multiple processing steps. First, a post-calibration filter is applied to the infrared calibrated radiance images (IR-RDR). Next, these modified radiance images are ingested into ISIS (Section 2.1) and the geometric projection products are completed by projecting the image into standard Mars coordinates. Finally, additional image processing is applied to complete the process.

These IR-GEO products contain geometrically registered and atmospherically corrected calibrated radiance, making them ideal for use in surface studies and for use with other projected Mars datasets. For these purposes, two derived products may be generated from the geometric projection with further processing: a projected brightness temperature product (IR-PBT), and a decorrelation stretch product (IR-DCS). Parameters of each process, applied by default or request, are recorded in the label of the final product as "keyword = values" pairs (see section 3.3); some significant label entries are highlighted throughout this section using [ ].

2.2.1 THMIRMC

The ISIS *THMIRMC* tool is used to project the ISIS formatted modified IR-RDR data into a geometrically registered image cube. This tool translates the radiance values into the desired map projection by applying a bilinear interpolation algorithm [DNINTERP = "BILINEAR", GEOM object], which incorporates the values of the four pixels closest to each mapped position. The spatial transformation is performed following the projection parameters defined for each image based on the conditions shown in Table 2.2.

Table 2.2: IR-GEO Map parameters

Map Parameter	Value	Application Conditions
kmres	0.1 km/pix	SPATIAL_SUMMING = 1
lonsys	180	CENTER_LONGITUDE < 2 or CENTER_LONGITUDE > 358
	360	2 < CENTER_LONGITUDE < 358
mappars	SINU:lon,OCENTRIC (where lon = default center longitude)	-70 < LATITUDE < 70
	POLA:+90,0	LATITUDE > 60
	POLA:-90,0	LATITUDE < -60

Unless otherwise noted, the infrared geometry product generated by these parameters is identified IooooonnnGGG.CUB.gz (see Section 3.1), where the value of "GGG" is the projection abbreviation.

2.2.2 Additional Processing

Additional image processing may be applied to the IR-GEO image cube either before or after the ISIS projection steps. Each process described in this section generates a HISTORY object in the detached PDS label (see Section 3.4.3), as shown in Appendix A.5.

The *UDDW* (Undrift and Dewobble) filter is applied to the IR-RDR QUBE before the image is projected, and is designed to correct for time-dependent signal offsets which are highly correlated in the original image coordinates. It removes undesirable data value fluctuations resulting from changes in the temperature of the IR detector array during image collection. This filter alters the calibrated radiance values of bands 1 - 9 (where available), but does not change the radiance values of band 10.

The *RECTIFY* algorithm is applied to the projected infrared image to minimize the null space around the image and to prepare the data for additional processing. The image data is first rotated to align the top line of the projected image with the horizontal edge (x axis) of the image frame; then each image line is shifted left to align with the vertical edge (y axis) of the image frame. This process may result in spatial distortions that are reversible using the parameters provided in the *RECTIFY* HISTORY object and the *RECONSTITUTE* algorithm.

The *DEPLAID* algorithm applies a specialized, high-pass filter to projected and rectified infrared radiance images. These filters attempt to remove the effects of both column and row correlated, band independent noise that would otherwise dominate a decorrelation stretch image. The noise originates from voltage fluctuations in the THEMIS instrument during image collection; this noise is minimized, but not completely removed, during the IR-RDR calibration *DESTRIPE* process (see *THEMIS: Data Processing User's Guide* [3]). Validation of the results of this algorithm confirm that the average spectra from a 50 x 50 pixel sample area remains unchanged.

The *ARADCOR* (Automated RADiance CORrection) algorithm attempts to remove the atmospheric radiance component from the projected and filtered infrared image. The correction value is based on multiple 50 x 50 pixel samples identified throughout the image which meet several temperature and quality criteria.

2.3 Infrared PBT Products

Projected Brightness Temperature (PBT) images are available as the projected equivalent product of the standard IR-BTR images. To generate an IR-PBT product, the brightness temperature algorithm described in *THEMIS: Data Processing User's Guide* [3], Section 2.2.11 is applied to the projected and rectified IR-GEO product. Then the resulting image is restored to the full projection dimensions using the *RECONSTITUTE* algorithm for ease of viewing. The IR-PBT products are available as standard PDS IMGAGE objects, almost identical to the IR-BTR products; the only differences being that several of the important parameters from the IR-GEO History objects are available as keywords in the IR-PBT label (see Appendix A.2).

2.4 Infrared DCS Products

The decorrelation stretch (DCS) method maximizes the differences between bands in order to highlight the compositional information in the image. THEMIS IR-DCS products provide a quick preview of the potential compositional variation available in an infrared image. They are generated from the IR-GEO images with an average surface temperature greater than 220 K and a minimum of eight bands (bands 3-10 required).

To generate an IR-DCS image, two final noise filters are applied to all available bands, then the DCS algorithm is applied, and the results are saved as a simple image (PNG format). First, any residual uncorrelated noise is removed by applying the *DESTREAK* and *WHITE_NOISE* algorithms. These filters are useful for reducing the anomalous noise in the qualitative DCS image, but are not appropriate for application on a quantitative radiance product. Next, three bands of the radiance image are selected for decorrelation and displayed in color as variations of red, green, and blue. The THEMIS IR-DCS images are executed on three standard RGB band combinations: bands 6, 4, and 2; bands 8, 7, and 5; and bands 9, 6, and 4. The results are made available individually in full projection dimensions (using *RECONSTITUTE*), and also available combined together side-by-side in rectified dimensions with a brightness temperature image for contrast (see Section 3.1).

2.5 Visible GEO Products

After the visible calibrated radiance images (VIS-RDR) are ingested into ISIS (Section 2.1), the geometric projection products are completed by projecting the image into standard Mars coordinates, and then applying any additional image processing. Parameters of each process, applied by default or request, are recorded in the label of the final projected image as "keyword = values" pairs (see section 3.3); some significant label entries are highlighted throughout this section using [ ].

2.5.1 THMVISMC

The ISIS *THMVISMC* tool is used to project the ISIS formatted VIS-RDR data into a geometrically registered image cube. The spatial transformation is performed following the parameters defined for each image. Individual visible framelets are projected independently then mosaicked together per band, with the overlapping pixels taking the value of the downtrack framelets [TOP = "YES"]. Calibrated radiance values are translated into the desired map projection by applying a bilinear interpolation algorithm [DNINTERP = "BILINEAR", GEOM object], which incorporates the values of the four pixels closest to each mapped position.

The map parameters used to project each visible image are determined by the conditions shown in Table 2.3. Unless otherwise noted, the visible geometry product generated by these parameters is identified VooooonnnLOC.CUB (see Section 3.1), where the abbreviation "LOC" recognizes that this is a local-latitude appropriate projection.

Table 2.5: VIS-GEO Local map parameters

Map Parameter	Value	Application Conditions
kmres	0.018 km/pix	SPATIAL_SUMMING = 1
	0.036 km/pix	SPATIAL_SUMMING = 2
	0.072 km/pix	SPATIAL_SUMMING = 4
lonsys	180	CENTER_LONGITUDE < 2 or CENTER_LONGITUDE > 358
	360	2 < CENTER_LONGITUDE < 358
mappars	SINU:lon,OCENTRIC (where lon = default center longitude)	-60 < LATITUDE < 60
	POLA:+90,lon (where lon = meridian longitude)	LATITUDE > 60
	POLA:-90,lon (where lon = meridian longitude)	LATITUDE < -60

2.5.2 Additional Processing

Additional image processing may be applied to the VIS-GEO projected image cube. Each process described in this section generates a HISTORY object in the detached PDS label (see Section 3.4.3), as shown in Appendix A.5.

The *DESPECKLE* process is a cosmetic correction applied to selected VIS-RDR QUBEs before the image is projected. On occasion, temporary radiation disruptions in the camera electronics produce anomalously bright or dark pixels scattered throughout the image. The distribution and intensity of this pixel "speckling" varies between each radiation event, but the corrupt pixels are usually concentrated either along the framelet edges, or within the more saturated areas of the image. This algorithm identifies the corrupt pixels based on an image specific DN threshold [THRESHOLD_VALUE = #], and then replaces it with a value matching the average of the surrounding valid pixels. This process alters the calibrated radiance values of the selected pixels in the corrected bands.

The *COFF* (Cosmetically Optimized Flat-Field) process is applied to maintain the overall radiance level of each framelet in the VIS-GEO image. This is accomplished by removing an optimized flat-field from each framelet before the *THMVISMC* projection. When applied, all source VIS-RDR radiance values are significantly modified.

The *FEATHER* process is applied to cosmetically enhance the discontinuities along the overlapping framelet boundaries of a projected visible image. This cosmetic filter is applied in concert with the *THMVISMC* projection of the visible framelets of each band, before they are mosaicked together into the final cube file. Because of the nature of this algorithm, all values in the resulting projected image may have been significantly modified from the source VIS-RDR calibrated radiance values.

3. GEOMETRIC PRODUCT SPECIFICATIONS

3.1 Geometry Product Naming and Identification

3.1.1 Naming Conventions

Each THEMIS geometry image product is named using the THEMIS standard data product naming convention, which follows the pattern "AooooonnnGGG.EXT". As established in the standard documentation, the PRODUCT_ID pattern is defined as

A	is a 1-letter description of the type of image collected; [V = visible image; I = infrared image]
ooooo	is a 5-digit mission orbit number when the image was collected; [01000 = mapping orbit number example]
nnn	is a 3-digit image sequence number indicating the order that images were collected each orbit; [001 = first image collected in the xxxxx orbit]

The suffix-extension "GGG.EXT" value identifies the geometry product type and the file format standards (see Section 3.3). The combinations used with the THEMIS geometry products are

D###.PNG	identifies a single, full projection IR-DCS browse image, where the numeric value lists the IR bands represented in red, green, and blue respectively
DCS.PNG	identifies a multiple panel IR-DCS browse image, composed of the following side-by-side, rectified images: D875, D964, D642 (if available), and brightness temperature
LOC.CUB	identifies the VIS-GEO data product: a local-latitude appropriate projection, stored in a multi-spectral ISIS image cube
LOC.LBL	identifies the PDS detached label file for a VIS-GEO data product
PBT.IMG	identifies the IR-PBT data product; both data and label information are available in this file
POL.CUB	identifies an IR-GEO data product: a polar projection, stored in a multi-spectral ISIS image cube
POL.LBL	identifies the PDS detached label file for an IR-GEO data product
SNU.CUB	identifies an IR-GEO data product: a sinusoidal projection, stored in a multi-spectral ISIS image cube
SNU.LBL	identifies the PDS detached label file for an IR-GEO data product

3.1.2 Revision Conventions

As with the THEMIS standard data products, a revision to the geometry product after the initial public release may be warranted. At that time, the PRODUCT_VERSION_ID keyword in the product label will be incremented, an ERRATA_ID will be established, and the change made will be documented. The ERRATA_ID will take the form ODTxx_rrrr_v.v, where xx is the image and dataset abbreviation, rrrr is the original RELEASE_ID number, and v.v is the PRODUCT_VERSION_ID value. Each revision will be documented in the label HISTORY object, the ERRATA.TXT and the appropriate release catalog (ODTIGREL.CAT or ODTIVGREL.CAT), and by modifying records as necessary in the indexes (INDEX_ODTxx, THMIDX_IR, or THMIDX_VIS). See Appendix A.3 for label keyword definitions and the *THEMIS Archive SIS* [2] for document specifications.

3.2 Standards Used in Generating Geometry Products

3.2.1 PDS Standards & Data Processing Level

The THEMIS GEO CUBE products are similar to Planetary Data System QUBE data product in file format and label structure, however, they are not intended to meet all of the standards specified in the PDS Standards Reference [7]. The detached label associated with each image CUBE does comply with Planetary Data System standards for file labels. The THEMIS geometric products are NASA processing Level 2 images, derived from the THM-RDR products (Level-1A) and adjusted for instrument location, pointing, and sampling.

3.2.2 Time Standards

All time stamps stored in the GEO label are extracted from the source THM-RDR image; a full description of the time standards used with THEMIS data products is available in the *THEMIS Standard Data Products SIS* [5], Section 2.3.4.

The time stamp (SPACECRAFT_CLOCK_START_COUNT) stored with each geometry product is the value of the spacecraft clock at the time of data acquisition of the leading edge of the first detector in the array (filter 1), even if filter 1 is not downlinked. For visible images, this time is calculated from the UNCORRECTED_SCLK_START_COUNT and may differ by as much as 4 seconds, depending on which bands are acquired in the observation. The stop time stamp, SPACECRAFT_CLOCK_STOP_COUNT, is calculated from the sum of the UNCORRECTED_SCLK_START_COUNT and IMAGE_DURATION. Depending on which bands are acquired in a visible image, the difference of the start and stop time stamps may not be equivalent to IMAGE_DURATION.

3.2.3 Coordinate Systems

All geometric values are based on Mars IAU 2000 areocentric model with east positive longitude. The geographic map projection for each data product is identified in the MAP_PROJECTION_TYPE keyword (see Appendices A.1-3) in both labels and defined in detail in the ISIS attached cube label.

ISIS requires the precise geometric locations of the Odyssey spacecraft, THEMIS camera, and Mars in order to correctly project each image. This information is referenced from the Mars Odyssey SPICE kernels published by the navigation team (http://naif.jpl.nasa.gov/naif), and the kernels actually used are recorded in the label of the ISIS CUBE. The Planet and Instrument kernels are static, and only the current version is used. The Spacecraft and Camera-matrix kernels are time dependant, constructed from measurements made by the spacecraft; the kernel corresponding to the image acquisition time is used. The camera-matrix kernels contain intermittent time gaps which occasionally overlap with the imaging times; when this happens, a substitute kernel is used which assumes a known and fixed camera-matrix geometry.

3.2.4 Compression Standards

Due to the potential for large file sizes, many THEMIS GEO products are routinely compressed using the GZIP utility. The ".gz" extension on any product filename (see Section 3.1.3 above) indicates that the gzip compression has been applied. For more information, or to download this free software, visit http://www.gzip.org.

3.3 Image Formats

The THEMIS geometry images maintain the ISIS CUBE format of the software from which they were generated [6]. Each CUBE is composed of an ASCII label attached to a core of uncompressed, binary, band-sequential qubes of scaled, 16-bit integer data.

Like the unprojected equivalent IR-BTR images, the THEMIS IR-PBT images are PDS standard IMAGE objects. See Section 2.3.3 of the *THEMIS Standard Data Products SIS* [5] for a description of this THEMIS file format.

3.3.1 ISIS CUBE Data Object

The CUBE core is an array of sample values in three dimensions: two spatial dimensions (samples and lines) and one spectral dimension (bands), as shown conceptually in Figure 1a. Additional information may be stored in "suffix" planes (back, side, or bottom) as shown in Figure 1b. This format allows each CUBE to be simultaneously a set of images (at different wavelengths) of the same target area, and also a multi-point spectrum at each spatially registered pixel in the target area. The spectral dimension of each THM-GEO cube is identical to the source THM-RDR image, but the spatial dimensions are expanded to accommodate the projected data.

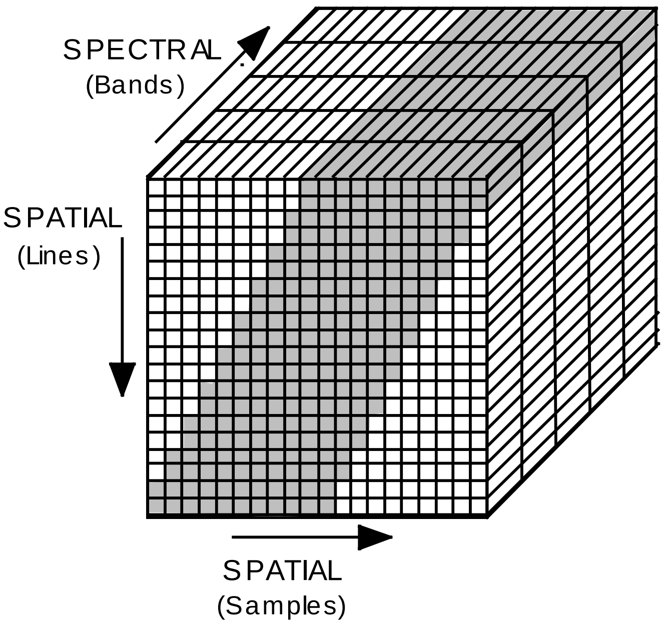

Figure 1a: ISIS CUBE core structure with projected data pixels shown in gray

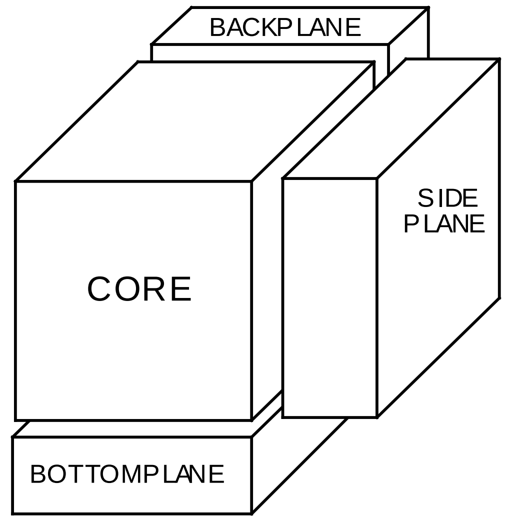

Figure 1b. Exploded view of ISIS CUBE

The data format of the THM-GEO CUBE is similar to the source THM-RDR QUBE, and both are stored as floating point values, scaled into 16-bit integers. To recover the floating point values, apply the following function to each data value per band (x_i)

$$y = m * x + b$$

where m is the CORE_MULTIPLIER value and b is the CORE_BASE value, given in the CUBE label.

Missing image pixels and padding around the image data to square up the spatial dimensions are set to the CORE_NULL value. The total count of missing lines in an IR-GEO image is stored in the MISSING_SCAN_LINES keyword of the detached label.

3.3.2 ISIS CUBE Label Object

The CUBE object has an attached label containing pertinent observation information, and header data objects (Figure 2). A "keyword=value" text format, similar to the structure of the PDS Object Definition Language (ODL), define the CUBE structure, the CORE and suffix parameters, the geographic projection parameters, and the ISIS History. See the *Overview of ISIS Architecture* [7] for examples of the elements in this label.

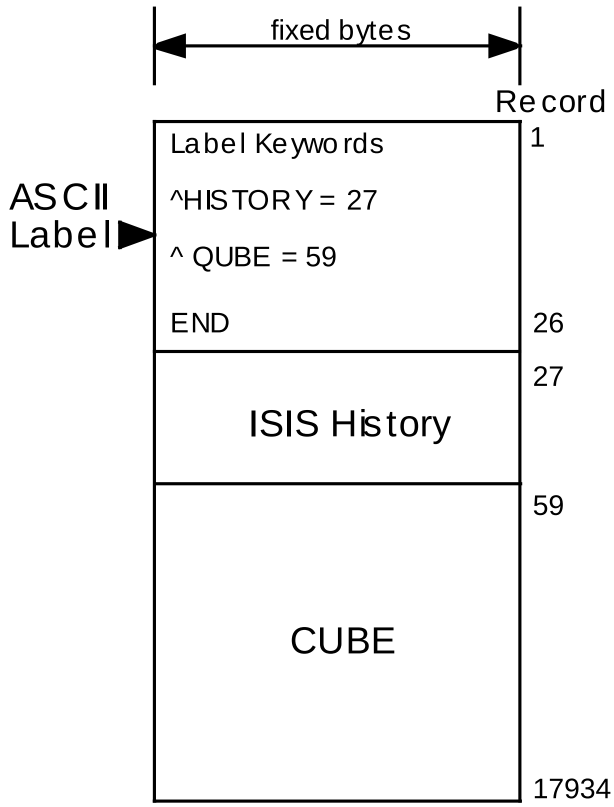

Figure 2: Example of a ISIS CUBE: attached label, header data object, and image data

3.4 GEO Label Format

A PDS label describes the structure, content, and observation specifications of the data. It is a discrete ASCII text available with each image file. Information in the label is stored in a "keyword=value" text format and structured in the Object Definition Language (ODL) of PDS. Example labels are shown in Appendices A.1-A.2; individual keyword items are defined in Appendices A.3.

3.4.1 File Identification and Structure Label

The first lines of the label are the file identification keywords and associated values. Next are the file structure keywords, which define the number and size of records in the associated ISIS CUBE data file. The pointer keywords define the filename and start byte of the HISTORY (in the PDS label) and the header and image data objects in the ISIS CUBE file. Finally, "identification data elements" define parameters of the mission, spacecraft, instrument team, and data stream. See Appendix A.3 for a detailed description of these keywords.

3.4.2 QUBE Object Label

The QUBE object keywords are organized by the following sub-structure descriptions:

QUBE structure	- parameters of the multidimensional array (image)
CORE description	- parameters of the array elements (pixels)
Observation parameters	- operational modes of the instrument for this image
Band-bins	- parameters of the layers (bands) in the array

See Appendix A.3 for a detailed description of the keywords used in the QUBE label.

3.4.3 HISTORY Object

A cumulative HISTORY object is available in each geometry label. The HISTORY object structure keywords define the size and format of the data object stored later in the label. The HISTORY object itself is a structured series of text entries identifying all previous computer manipulations of the data in the file; the format is not intended to be compliant with PDS-ODL standards. HISTORY entries may include identification of source data, processes performed, processing parameters, and dates and times of processing. See Appendix A.5 for a detailed description of the entries and keywords used with THM-GEO HISTORY objects.

3.5 Data Product Archive

The special geometry data products will be generated and validated at the ASU Mars Space Flight Facility. The size of individual geometry products depends on several factors: image type (VIS vs. IR), length of an image, number of bands in the image, and map projection. Within these parameters, most VIS-GEO images will be a factor of 1-4 larger than the source VIS-RDR. Validation will be conducted using the latest, best-effort algorithms available.

Standard data products will be archived and released following the agreement outlined in the *THEMIS Archive SIS* [2]. Starting in January 2006, the special geometry data products will be released concurrent with their source THM-RDR images; geometry products for previously released THM-RDR images will be added to the archive as available. Due to the large volume of data products expected from the mission, physical copies will be made for PDS long-term archive purposes only. All other data distribution will be facilitated through an online THEMIS data archive service, maintained by the ASU Mars Space Flight Facility.

4. APPLICABLE SOFTWARE

The THEMIS team uses the software tools DAVINCI and ISIS to generate, display, and analyze the THM-RDR and THM-GEO images. DAVINCI is a data analysis package for working with multispectral images. DAVINCI is distributed by ASU and is available at http://davinici.asu.edu/software. ISIS is an image processing package produced by USGS - Flagstaff and is available at http://isis.astrogeology.usgs.gov.

Since THEMIS images are stored and labeled using a standard and known structure, any tool that can be taught to understand that structure should be able to view them.

A. APPENDICIES

Appendices A.1-3 contain example labels from THEMIS IR-GEO, THEMIS IR-PBT, and VIS-GEO, with definitions of individual label keywords given in Appendix A.4. “Valid values” for each item are shown in [ ] at end of each description, as appropriate. Appendix A.5 contains definitions for the basic HISTORY keywords and example geometric HISTORY objects. Appendix A.6 contains geometric parameter fields available in the THEMIS indexes. Appendix A.7 describes the geometric quality assessment and associated HISTORY object.

A.1 Example Label: IR-GEO

An example IR-GEO label is shown below:

```
PDS_VERSION_ID = PDS3

/* File Identification and Structure */
RECORD_TYPE = "FIXED_LENGTH"
RECORD_BYTES =  512
FILE_RECORDS =  8922

/* Pointers to Data Objects */
^HISTORY = 3480 <BYTES>
^HEADER = ("I31099044SNU.CUB")
^QUBE = ("I31099044SNU.CUB", 67 )

/* Identification Data Elements */
MISSION_NAME = "2001 MARS ODYSSEY"
INSTRUMENT_HOST_NAME = "2001 MARS ODYSSEY"
INSTRUMENT_NAME = "THERMAL EMISSION IMAGING SYSTEM"
INSTRUMENT_ID = "THEMIS"
DETECTOR_ID = "IR"
MISSION_PHASE_NAME = "EXTENDED-3"
SPACECRAFT_ORIENTATION_DESC = (PITCH, ROLL, YAW)
SPACECRAFT_ORIENTATION = (0, 0, 0)
SPACECRAFT_POINTING_MODE = "NADIR"
^SPACECRAFT_POINTING_MODE_DESC = "ODY_ORIENT_POINT.TXT"
TARGET_NAME = "MARS"
PRODUCT_ID = "I31099044SNU"
PRODUCER_ID = "ODY_THM_TEAM"
DATA_SET_ID = "ODY-M-THM-5-IRGEO-V1.0"
PRODUCT_CREATION_TIME =  2009-03-25T17:41:41
PRODUCT_VERSION_ID = "1.0"
SOURCE_PRODUCT_VERSION_ID = "1.0"
RELEASE_ID = "0028"
START_TIME = 2008-12-18T00:44:50.791
STOP_TIME = 2008-12-18T00:44:59.858
SPACECRAFT_CLOCK_START_COUNT = "914028697.153"
```

```
SPACECRAFT_CLOCK_STOP_COUNT = "914028706.170"
START_TIME_ET = 282833156.000
STOP_TIME_ET = 282833165.000
ORBIT_NUMBER = 31099

/* History Object Structure */
OBJECT = HISTORY
   BYTES = 7615
   HISTORY_TYPE = CUSTOM
   INTERCHANGE_FORMAT = ASCII
END_OBJECT = HISTORY

OBJECT = QUBE

   /* QUBE Structure */
   AXES = 3
   AXIS_NAME = (SAMPLE, LINE, BAND)

   /* Core Description */
   CORE_ITEMS =  (352,321,10)
   CORE_NAME = "CALIBRATED_SPECTRAL_RADIANCE"
   CORE_ITEM_BYTES =  4
   CORE_ITEM_TYPE = PC_REAL
   CORE_BASE = 0.000000e+00
   CORE_MULTIPLIER = 1.000000e+00
   CORE_UNIT = "WATT*CM**-2*SR**-1*UM**-1"
   CORE_NULL = -32768
   CORE_VALID_MINIMUM = -32752
   CORE_LOW_REPR_SATURATION = -32767
   CORE_LOW_INSTR_SATURATION = -32766
   CORE_HIGH_REPR_SATURATION = -32765
   CORE_HIGH_INSTR_SATURATION = -32764

   /* Suffix Description */
   SUFFIX_ITEMS =  (1,0,0)
   SUFFIX_BYTES =  4
   SAMPLE_SUFFIX_NAME = RECTIFY_LEFTEDGE
   SAMPLE_SUFFIX_ITEM_BYTES = 4
   SAMPLE_SUFFIX_ITEM_TYPE = LSB_INTEGER
   SAMPLE_SUFFIX_BASE = 0.000000
   SAMPLE_SUFFIX_MULTIPLIER = 1.000000
   SAMPLE_SUFFIX_VALID_MINIMUM = 16#FF7FFFFA#
   SAMPLE_SUFFIX_NULL = 16#FF7FFFFB#
   SAMPLE_SUFFIX_LOW_REPR_SAT = 16#FF7FFFFC#
   SAMPLE_SUFFIX_LOW_INSTR_SAT = 16#FF7FFFFD#
   SAMPLE_SUFFIX_HIGH_REPR_SAT = 16#FF7FFFFF#
```

```
    SAMPLE_SUFFIX_HIGH_INSTR_SAT = 16#FF7FFFFE#

    /* Observation Parameters */
    FLIGHT_SOFTWARE_VERSION_ID = "1.00"
    COMMAND_SEQUENCE_NUMBER = 31099
    IMAGE_ID = 44
    DESCRIPTION = "35 deg day atmos"
    INST_CMPRS_RATIO = 2.72
    UNCORRECTED_SCLK_START_COUNT = "914028697.153"
    IMAGE_DURATION = 9.067
    GAIN_NUMBER = 16
    OFFSET_NUMBER = 2
    TIME_DELAY_INTEGRATION_FLAG = "ENABLED"
    RICE_FLAG = "ENABLED"
    SPATIAL_SUMMING = 1
    PARTIAL_SUM_LINES = "N/A"
    MISSING_SCAN_LINES = 0
    MD5_CHECKSUM = "ed9c27074865056d8d5f1edcfb2737a8"

    /* Band Bins */
    GROUP = BAND_BIN
      BAND_BIN_FILTER_NUMBER = (1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
      BAND_BIN_BAND_NUMBER = (1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
      BAND_BIN_CENTER = (6.78, 6.78, 7.93, 8.56, 9.35, 10.21, 11.04,
                    11.79, 12.57, 14.88)
      BAND_BIN_WIDTH = (1.01, 1.01, 1.09, 1.16, 1.20, 1.10, 1.19,
                    1.07, 0.81, 0.87)
      BAND_BIN_UNIT = "MICROMETER"
    END_GROUP = BAND_BIN
  END_OBJECT = QUBE

  END
```

A.2 Example Label: IR-PBT

An example IR-PBT label is shown below:

```
  PDS_VERSION_ID = PDS3
  FILE_NAME = "I33413035PBT.IMG"
  RECORD_TYPE = "FIXED_LENGTH"
  RECORD_BYTES = 419
  FILE_RECORDS = 336
  LABEL_RECORDS = 6
  ^IMAGE = 7

  MISSION_NAME = "2001 MARS ODYSSEY"
  INSTRUMENT_HOST_NAME = "2001 MARS ODYSSEY"
```

```
INSTRUMENT_NAME = "THERMAL EMISSION IMAGING SYSTEM"
INSTRUMENT_ID = "THEMIS"
DETECTOR_ID = "IR"
MISSION_PHASE_NAME = "EXTENDED-3"
SPACECRAFT_ORIENTATION_DESC = (PITCH, ROLL, YAW)
SPACECRAFT_ORIENTATION = (0,-20,0)
SPACECRAFT_POINTING_MODE = "HGA_MITIGATION_R-20"
^SPACECRAFT_POINTING_MODE_DESC = "ODY_ORIENT_POINT.TXT"
TARGET_NAME = "MARS"
PRODUCT_ID = "I33413035PBT"
PRODUCER_ID = "ODY_THM_TEAM"
DATA_SET_ID = "ODY-M-THM-5-IRPBT-V1.0"
PRODUCT_CREATION_TIME = 2009-07-07T20:28:08
PRODUCT_VERSION_ID = "1.0"
SOURCE_PRODUCT_VERSION_ID = "1.0"
RELEASE_ID = "0028"
START_TIME = 2009-06-26T13:39:06.870
STOP_TIME = 2009-06-26T13:39:15.936
SPACECRAFT_CLOCK_START_COUNT = "930491180.025"
SPACECRAFT_CLOCK_STOP_COUNT = "930491189.042"
START_TIME_ET = 299295613.1
STOP_TIME_ET = 299295622.1
UNCORRECTED_SCLK_START_COUNT = "930491180.025"
IMAGE_DURATION = 9.067
ORBIT_NUMBER = 33413

BAND_NUMBER = 9
BAND_CENTER = 12.57 <MICROMETERS>
SPATIAL_SUMMING = 1

GEOMETRY_SOURCE_DESC = "Reconstructed"
PDS2ISIS_VERSION = "2004-05-28"
GEOM_VERSION = "2004-06-17"
CUBEIT_VERSION = "2004-06-17"
LONGITUDE_SYSTEM = 360
MINIMUM_LATITUDE = 70.3685
MAXIMUM_LATITUDE = 70.905
CENTER_LONGITUDE = 55
WESTERNMOST_LONGITUDE = 53.408
EASTERNMOST_LONGITUDE = 55.5926
MAP_RESOLUTION = 592.747
MAP_SCALE = 0.1
MAP_PROJECTION_TYPE = "SINUSOIDAL"
PROJECTION_LATITUDE_TYPE = "PLANETOCENTRIC"
LINE_PROJECTION_OFFSET = -42028.5
SAMPLE_PROJECTION_OFFSET = -317.5
```

```
ASU_PROCESSES = "PROJECT; RECTIFY; RECONSTITUTE"
MINIMUM_BRIGHTNESS_TEMPERATURE = 152.701
MAXIMUM_BRIGHTNESS_TEMPERATURE = 163.601

OBJECT = IMAGE
   LINES = 330
   LINE_SAMPLES = 419
   SAMPLE_TYPE = UNSIGNED_INTEGER
   SAMPLE_BITS = 8
   SAMPLE_NAME = "BRIGHTNESS_TEMPERATURE"
   SAMPLE_UNIT = K
   NULL_CONSTANT = 0
   OFFSET = 152.701
   SCALING_FACTOR = 0.042744
   MD5_CHECKSUM = "dea37efdfefd89e7195171bf33c3dbc5"
END_OBJECT = IMAGE
END
```

A.3 Example Label: VIS-GEO

An example VIS-GEO label is shown below:

```
PDS_VERSION_ID = PDS3

/* File Identification and Structure */
RECORD_TYPE = "FIXED_LENGTH"
RECORD_BYTES =  512
FILE_RECORDS =  17934

/* Pointers to Data Objects */
^HISTORY = 4131 <BYTES>
^HEADER = ("V01001004.loc.cub")
^QUBE = ("V01001004.loc.cub", 59 )

/* Identification Data Elements */
MISSION_NAME = “2001 MARS ODYSSEY”
INSTRUMENT_HOST_NAME  = “2001 MARS ODYSSEY”
INSTRUMENT_NAME  = “THERMAL EMISSION IMAGING SYSTEM”
INSTRUMENT_ID  = “THEMIS”
DETECTOR_ID = “VIS”
MISSION_PHASE_NAME = “MAPPING”
SPACECRAFT_ORIENTATION_DESC = (PITCH, ROLL, YAW)
SPACECRAFT_ORIENTATION = (0, 0, 0)
SPACECRAFT_POINTING_MODE = "NADIR"
^SPACECRAFT_POINTING_MODE_DESC = "ODY_ORIENT_POINT.TXT"
```

```
TARGET_NAME = “MARS”
PRODUCT_ID = “V01001004LOC”
DATA_SET_ID = "ODY-M-THM-5-VISGEO-V1.0"
PRODUCT_CREATION_TIME =  2004-12-07T13:28:26
PRODUCT_VERSION_ID = "1.0"
SOURCE_PRODUCT_VERSION_ID = "1.5"
RELEASE_ID = "0011"
START_TIME = 2002-03-06T22:46:31.259
STOP_TIME = 2002-03-06T22:46:50.259
SPACECRAFT_CLOCK_START_COUNT = "699922043.000"
SPACECRAFT_CLOCK_STOP_COUNT = "699922062.000"
START_TIME_ET = 68726855.445
STOP_TIME_ET = 68726874.444
ORBIT_NUMBER = 01001

/* History Object Structure */
OBJECT = HISTORY
   BYTES = 5126
   HISTORY_TYPE = CUSTOM
   INTERCHANGE_FORMAT = ASCII
END_OBJECT = HISTORY

OBJECT = QUBE

   /* QUBE Structure */
   AXES = 3
   AXIS_NAME = (SAMPLE, LINE, BAND)

   /* Core Description */
   CORE_ITEMS =  (1415,3234,1)
   CORE_NAME = "CALIBRATED_SPECTRAL_RADIANCE"
   CORE_ITEM_BYTES = 2
   CORE_ITEM_TYPE = LSB_INTEGER
   CORE_BASE = 4.302270e-03
   CORE_MULTIPLIER = 3.629682e-08
   CORE_UNIT = "WATT*CM**-2*SR**-1*UM**-1"
   CORE_NULL = -32768
   CORE_VALID_MINIMUM = -32752
   CORE_LOW_INSTR_SATURATION = -32766
   CORE_LOW_REPR_SATURATION = -32767
   CORE_HIGH_INSTR_SATURATION = -32765
   CORE_HIGH_REPR_SATURATION = -32764

   /* Observation Parameters */
   FLIGHT_SOFTWARE_VERSION_ID = “1.00”
   COMMAND_SEQUENCE_NUMBER = 1001
```

```
    IMAGE_ID = 4
    DESCRIPTION = "Example VIS image"
    INST_CMPRS_RATIO = 1.96
    UNCORRECTED_START_SCLK_COUNT = "699922045.000"
    IMAGE_DURATION = 19.000
    INST_CMPRS_NAME = "PREDICTIVE"
    FOCAL_PLANE_TEMPERATURE = 1.05
    EXPOSURE_DURATION = 4.000
    INTERFRAME_DELAY = 1.000
    SPATIAL_SUMMING = 1
    MD5_CHECKSUM = "5d0ee743130781de5fbd73d5a7cb98ef"

    /*Band Bins */
    GROUP = BAND_BIN
        BAND_BIN_FILTER_NUMBER = (2, 5, 3, 4, 1)
        BAND_BIN_ BAND_NUMBER = (1, 2, 3, 4, 5)
        BAND_BIN_CENTER = (0.425, 0.540, 0.654, 0.749, 0.860)
        BAND_BIN_WIDTH = ( 0.049, 0.051, 0.053, 0.053, 0.045 )
        BAND_BIN_UNIT = "MICROMETER"
    END_GROUP = BAND_BIN

END_OBJECT = QUBE

END
```

A.4 Label Keyword Descriptions

FILE AND DATA IDENTIFICATION ELEMENTS

PDS_VERSION_ID
: PDS version number for the label format. [PDS3]

RECORD_TYPE
: Style of records in this label file. [“FIXED_LENGTH”]

RECORD_BYTES
: Number of bytes per record in ISIS CUBE file.

FILE_RECORDS
: Number of records in ISIS CUBE file, including labels and data.

Pointer to HISTORY
: Start byte location of HISTORY object in this detached THM-GEO label; units given in < >.

Pointer to HEADER
: Filename and start byte location of the ISIS CUBE label object; byte =1 is implied if no byte location is given.

Pointer to IMAGE
: Start byte location of the image data object.

Pointer to QUBE
: Filename and start byte location of the ISIS CUBE data object.

MISSION_NAME
: Name of the mission including the THEMIS instrument. [“2001 MARS ODYSSEY”]

INSTRUMENT_HOST_NAME
: Name of the host spacecraft for the THEMIS instrument. [“2001 MARS ODYSSEY”]

INSTRUMENT_NAME
: Proper name of the instrument. [“THERMAL EMISSION IMAGING SYSTEM”]

INSTRUMENT_ID
: Abbreviated name of instrument used to collect this image. [“THEMIS”]

DETECTOR_ID
: Abbreviated name of camera used to collect this image. [“IR” or “VIS”]

MISSION_PHASE_NAME
: Mission phase during which this image was collected. [“MAPPING”, “EXTENDED-1”]

SPACECRAFT_ORIENTATION_DESC
: Description of rotation axis corresponding to values of SPACECRAFT_ORIENTATION keyword. [(PITCH,ROLL,YAW)]

SPACECRAFT_ORIENTATION
: Odyssey orientation during which this image was collected; described as a angle (in degrees) of rotation away from nadir around the three axes spacecraft frame of reference;

see given in SPACECRAFT_POINTING_MODE_DESC value for more information. [(#,#,#)]

SPACECRAFT_POINTING_MODE
Description of the Odyssey pointing mode during which this image was collected; see text given in SPACECRAFT_POINTING_MODE_DESC value for definitions of valid modes.

^SPACECRAFT_POINTING_MODE_DESC
Pointer to text file describing valid Odyssey orientation values and pointing modes; text file is in the DOCUMENT directory. [“ODY_ORIENT_POINT.TXT”]

TARGET_NAME
The name of the target observed in the image. [“MARS”]

PRODUCT_ID
Unique identifier for this THM-GEO image. [“Aooooonnnggg”]

PRODUCER_ID
Identity of the producer of this dataset. [“ODY_THM_TEAM”]

DATA_SET_ID
Unique alphanumeric identifier of this dataset. [“ODY-M-THM-5-IRGEO-V1.0”, “ODY-M-THM-5-VISGEO-V1.0”]

PRODUCT_CREATION_TIME
Time of creation of this QUBE on the ground (in UTC). [yyyy-mm-ddThh:mm:ss]

PRODUCT_VERSION_ID
Version identification of this THM-GEO image.

SOURCE_PRODUCT_VERSION_ID
Version identification of the THM-RDR QUBE from which this product was derived.

RELEASE_ID
Identification of the original public release of this THM-GEO image.

START_TIME
The time of data acquisition of the leading edge of the detector array (filter 1), even if filter 1 is not downlinked; the difference of STOP_TIME minus START_TIME may not be equivalent to IMAGE_DURATION. Value given in spacecraft event time (SCET), UTC format. [yyyy-mm-ddThh:mm:ss.fff]

STOP_TIME
The time of the end of data acquisition calculated from the sum of the UNCORRECTED_SCLK_START_COUNT and IMAGE_DURATION; given in spacecraft event time (SCET), UTC format. [yyyy-mm-ddThh:mm:ss.fff]

SPACECRAFT_CLOCK_START_COUNT
The value of the spacecraft clock at the time of data acquisition of the leading edge of the detector array (filter 1), even if filter 1 is not downlinked; the difference of SPACECRAFT_CLOCK_STOP_COUNT minus SPACECRAFT_CLOCK_START_COUNT may not be equivalent to IMAGE_DURATION. Value given in seconds.

SPACECRAFT_CLOCK_STOP_COUNT

The time on the spacecraft clock at the end of data acquisition (in seconds) calculated from the sum of the UNCORRECTED_SCLK_START_COUNT and IMAGE_DURATION.

START_TIME_ET

The time of data acquisition of the leading edge of the detector array (filter 1), even if filter 1 is not downlinked; the difference of STOP_TIME_ET minus START_TIME_ET may not be equivalent to IMAGE_DURATION. Value given in spacecraft event time (SCET), ET format.

STOP_TIME_ET

The time of the end of data acquisition calculated from the sum of the UNCORRECTED_SCLK_START_COUNT and IMAGE_DURATION; given in spacecraft event time (SCET), ET format.

ORBIT_NUMBER

Spacecraft orbit during which this image was observed.

HISTORY STRUCTURE

See Appendix A.5

QUBE STRUCTURE & CORE DESCRIPTION

AXES

Number of dimensions (axes) of the QUBE. [3]

AXIS_NAME

Names of axes in physical storage order. [(SAMPLE, LINE, BAND)]

CORE_ITEMS

The length of each of the three axes of the core in pixels.

CORE_NAME

Name of the data value stored in core of ISIS CUBE. [“CALIBRATED_SPECTRAL_RADIANCE”]

CORE_ITEM_BYTES

Core element size in bytes. [2]

CORE_ITEM_TYPE

Core element type. [MSB_INTEGER]

CORE_BASE

The offset value of the stored data; the CORE_BASE value is added to the scaled data (see CORE_MULTIPLIER) to reproduce the true data.

CORE_MULTIPLIER

The constant value by which the stored data is multiplied to produce the scaled data; the CORE_BASE value is added to the scaled data to reproduce the true data.

CORE_UNIT

Unit of the value stored in the core of QUBE. [“WATT*CM**-2*SR**-1*UM**-1”]

CORE_NULL
Value assigned to missing data and padding of projected image.

CORE_VALID_MINIMUM
Value of the minimum valid core data in an RDR QUBE.

CORE_LOW_REPR_SATURATION
Value of representation saturation at the low end in an RDR QUBE.

CORE_LOW_INSTR_SATURATION
Value of instrument saturation at the low end in an RDR QUBE.

CORE_HIGH_REPR_SATURATION
Value of representation saturation at the high end in an RDR QUBE.

CORE_HIGH_INSTR_SATURATION
Value of instrument saturation at the high end in an RDR QUBE.

SUFFIX DESCRIPTION (IR-GEO QUBEs only)

SUFFIX_ITEMS
The dimensions of available suffix planes following the order given in AXIS_NAME keyword. [(1, 1, 0)]

SUFFIX_BYTES
The allocation in bytes of each suffix plane defined. [4]

*AXIS*_SUFFIX_NAME
Name of "axis" suffix plane, where "axis" can be either SAMPLE or LINE in IRRDR QUBEs. [HORIZONAL_DESTRIPE (for SAMPLE suffix planes) or VERTICAL_DESTRIPE (for LINE suffix planes)]

*AXIS*_SUFFIX_ITEM_BYTES
Size of "axis" suffix plane elements in bytes, where "axis" can be either SAMPLE or LINE in IRRDR QUBEs. [2]

*AXIS*_SUFFIX_ITEM_TYPE
"Axis" suffix plane element type, where "axis" can be either SAMPLE or LINE in IRRDR QUBEs. [LSB_INTEGER]

*AXIS*_SUFFIX_BASE
Base value of "axis" suffix plane item scaling, where "axis" can be either SAMPLE or LINE in IRRDR QUBEs.

*AXIS*_SUFFIX_MULTIPLIER
Multiplier for "axis" suffix plane item scaling, where "axis" can be either SAMPLE or LINE in IRRDR QUBEs.

*AXIS*_SUFFIX _VALID_MINIMUM
Value of the minimum valid "axis" suffix plane data, where "axis" can be either SAMPLE or LINE in IRRDR QUBEs. [16#FF7FFFFA#]

*AXIS*_SUFFIX _NULL
Value assigned to "invalid" or missing data in an "axis" suffix plane, where "axis" can be either SAMPLE or LINE in IRRDR QUBEs. [16#FF7FFFFB#]

*AXIS*_SUFFIX _LOW_REPR_SATURATION
Value of representation saturation at the low end in an "axis" suffix plane, where "axis" can be either SAMPLE or LINE in IRRDR QUBEs. [16#FF7FFFFC#]

*AXIS*_SUFFIX _LOW_INSTR_SATURATION
Value of instrument saturation at the low end in an "axis" suffix plane, where "axis" can be either SAMPLE or LINE in IRRDR QUBEs. [16#FF7FFFFD#]

*AXIS*_SUFFIX _HIGH_REPR_SATURATION
Value of representation saturation at the high end in an "axis" suffix plane, where "axis" can be either SAMPLE or LINE in IRRDR QUBEs. [16#FF7FFFFF#]

*AXIS*_SUFFIX _HIGH_INSTR_SATURATION
Value of instrument saturation at the high end in an "axis" suffix plane, where "axis" can be either SAMPLE or LINE in IRRDR QUBEs. [16#FF7FFFFE#]

OBSERVATION PARAMETERS

FLIGHT_SOFTWARE_VERSION_ID
Indicates version of instrument flight software used to acquire image. ["1.00"]

COMMAND_SEQUENCE_NUMBER
Numeric identifier for the sequence of commands sent to the spacecraft which include this image.

IMAGE_ID
Numeric identifier for this image within the onboard command sequence.

DESCRIPTION
Description of image written by mission planner.

INST_CMPRS_RATIO
The ratio of the size, in bytes, of the uncompressed data file to the compressed data file.

UNCORRECTED_SCLK_START_COUNT
The spacecraft clock value (in seconds) when the instrument was commanded to acquire an observation. This can differ from the SPACECRAFT_CLOCK_START_COUNT (or the other START_TIME keywords) by as much as 4 seconds, depending on which bands are acquired in the image.

IMAGE_DURATION
The length of time (in seconds) required to collect all frames of all bands in the downlinked image.

INST_CMPRS_NAME
The type of compression applied to the VIS data and removed before storage in the image QUBE. ["NONE" or "DCT" or "PREDICTIVE"]

FOCAL_PLANE TEMPERATURE
Temperature in Kelvin of the VIS camera focal plane array at the time of the observation.

EXPOSURE_DURATION
The length of time the VIS detector array is exposed per frame in an image; given in milliseconds.

INTERFRAME_DELAY

The time between successive frames of a VIS image; given in seconds.

SPATIAL_SUMMING

Onboard spatial average of NxN set of pixels, where N is the value of the keyword. SPATIAL_SUMMING = 1 implies that no spatial averaging has been applied to the image. [VIS: 1 or 2 or 4; IR: 1 through 320]

PARTIAL_SUM_LINES

The number of lines in a summed IR image which were produced by averaging less than N lines of the original non-summed image, where N is the value of the SPATIAL_SUMMING keyword. ["N/A" for spatial_summing=1 or integer for spatial_summing > 1]

MISSING_SCAN_LINES

The total number of scan lines missing from an IR image when it was received at Earth.

GAIN_NUMBER

The gain value of the THEMIS IR camera; a multiplicative factor used in the analog to digital conversion.

OFFSET_NUMBER

The offset value of the THEMIS IR camera; the offset value multiplied by a constant voltage is added to the measured voltage in the analog to digital conversion.

TIME_DELAY_INTEGRATION_FLAG

Status of onboard algorithm which applies a temporal average of successive lines in an IR image; when enabled, THEMIS TDI averages 16 detector rows to equal one line in an IR image. ["ENABLED" or "DISABLED"]

MISSING_SCAN_LINES

The total number of scan lines missing from an IR image when it was received at Earth.

MD5_CHECKSUM

A 128-bit checksum identification of the data portion of the QUBE. Corruption of the data QUBE will result in a different value when the MD5 algorithm is reapplied as compared to the value stored in the keyword. An example of the source code applied by ASU is available in SRC/BIN/md5_qube.pl. A complete definition of the MD5 algorithm is available at http://www.ietf.org/rfc/rfc1321.txt. ["fd2781d05bdc0215dc87a0f41035ad77"]

BAND-BINS or BAND INFORMATION

BAND_NUMBER

Identifies from which band in the source RDR this image was derived; see Table 1, Section 2.2 of this document (THM-SDPSIS).

BAND_BIN_FILTER_NUMBER

List of filter numbers corresponding to each layer (band) contained in the image; up to 10 entries possible for IR images and up to 5 entries possible for VIS images. The filter number describes the physical location of the band in the detector array; filter 1 is on the leading edge of the detector array.

BAND_BIN _BAND_NUMBER

List of band numbers corresponding to each layer (band) contained in the image; up to 10 entries possible for IR images and up to 5 entries possible for VIS images. The band number is equivalent to the instrument band number listed in Table 1, Section 2.2 of this document (THM-SDPSIS).

BAND_CENTER

The wavelength value of the band contained in the image; units are given in < > with the value.

BAND_BIN_CENTER

List of wavelength values corresponding to each layer (band) contained in the image; up to 10 entries possible for IR images and up to 5 entries possible for VIS images.

BAND_BIN_WIDTH

Calculated full width, half maximum (in micrometers) for each band listed in the BAND_BIN_ BAND_NUMBER.

BAND_BIN_UNIT

Unit which applies to the values of the BAND_BIN_CENTER keyword. [“MICROMETER”]

IMAGE STRUCTURE & GEOMETRIC PARAMTERS (IMAGEs only)

GEOMETRY_SOURCE_DESC

Description of the geometry kernels used by the ISIS software when generating geometric information for this image. [“Not Available”, “Predicted”, “Reconstructed”, “Nadir pointing assumed”, or “Off Nadir pointing assumed”]

PDS2ISIS_VERSION

Version of ISIS software algorithm PDS2ISIS used during the projection of this image [“yyyy-mm-dd”].

GEOM_VERSION

Version of ISIS software algorithm GEOM used during the projection of this image [“yyyy-mm-dd”].

CUBEIT_VERSION

Version of ISIS software algorithm CUBEIT used during the projection of this image [“yyyy-mm-dd”].

LONGITUDE_SYSTEM

Longitude system standards in place during the projection of this image, where a value of 180 indicates that longitude is measured from 0 to +180 east of the meridian and 0 to -180 west of the meridian; a value of 360 indicates that longitude is measured from 0 to 360 degrees from the meridian in the positive longitude direction.

MINIMUM_LATITUDE

The northernmost latitude on the planet Mars of the image.

MAXIMUM_LATITUDE

The southernmost latitude on the planet Mars of the image.

CENTER_LONGITUDE
Approximate longitude on the planet Mars at the image center.

WESTERNMOST_LONGITUDE
The longitude on the planet Mars at the image western edge.

EASTERNMOST_LONGITUDE
The longitude on the planet Mars at the image eastern edge.

MAP_RESOLUTION
The scale of the image in pixels per degree.

MAP_SCALE
The scale of the image in kilometers per pixel.

MAP_PROJECTION_TYPE
The type of projection applied to this image [“SINUSOIDAL”].

PROJECTION_LATITUDE_TYPE
The type of latitude that is sample in equal increments by successive image lines [“PLANETOCENTRIC”].

LINE_PROJECTION_OFFSET
The line offset value between the map projection origin and the upper left corner of the image.

SAMPLE_PROJECTION_OFFSET
The sample offset value between the map projection origin and the upper left corner of the image.

ASU_PROCESSES
Simple list identifying the ASU processes that have been applied to this image; a more complete description of these processes may be available in the Appendix A.5 examples.

RECTIFY_WIDTH
Parameter of the ASU Rectify process which describes the original width of the projected image.

RECTIFY_ANGLE
Parameter of the ASU Rectify process which describes the amount of rotation required to make the top line of a projected image parallel to the x-axis of the image.

MAXIMUM_BRIGHTNESS_TEMPERATURE
Maximum brightness temperature value measured within the image.

MINIMUM_BRIGHTNESS_TEMPERATURE
Minimum brightness temperature value measured within the image.

LINES
Total number of data pixels along the vertical axis of the image.

LINE_SAMPLES
Total number of data pixels along the horizontal axis of the image.

SAMPLE_TYPE
Data storage representation of a pixel value [UNSIGNED_INTEGER]

SAMPLE_BITS

Stored number of bits in a single pixel value.

SAMPLE_NAME

Identifies the scientific meaning of each pixel value ["BRIGHTNESS_TEMPERATURE"] .

SAMPLE_UNIT

Identifies the scientific unit of each pixel value [K].

NULL_CONSTANT

Numeric value used to represent NULL data.

OFFSET

The offset value of the stored data; the offset value is added to the scaled data to reproduce the true data.

SCALING_FACTOR

The constant value by which the stored data is multiplied to produce the scaled data; the offset value is added to the scaled data to reproduce the true data.

A.5 HISTORY Object Items and Examples

The HISTORY data object is described within the THM-GEO labels by the following keywords:

BYTES
Number of bytes in the HISTORY object.

HISTORY_TYPE
Identifies the software compliance of the HISTORY object format. [CUSTOM]

INTERCHANGE_FORMAT
Identifies the manner in which the HISTORY object data items are stored. [ASCII]

Each program that operates on the data product will generate a new "history entry" and will concatenate the new entry onto the existing HISTORY object. All HISTORY objects follow this basic format, where the values have been replaced with keyword descriptions:

```
GROUP                    = The name of the program that generated the history entry.
    DATE_TIME            = Date and time, in UTC standard format, that the program
                           was executed.  [yyyy-mm-ddThh:mm:ss]
    SOFTWARE_DESC        = Program generated description and execution notes.
    VERSION_ID           = Program version number.
    USER_NAME            = Username and name of computer. ["marvin@mars"]
    USER_NOTE            = User supplied brief description of program; may be blank.
    GROUP                    = Used to delineate the statements specifying the
                               parameters of the program;  will not be present if
                               additional keywords are not required.
                               [PARAMETERS]
        KEYWORD              = Value.
    END_GROUP                = [PARAMETERS]
END_GROUP                = The name of the program that generated the history entry.
END
```

THM-GEO labels contain the cumulative processing history of the observation. The HISTORY objects generated during THEMIS standard data processing (THM-EDR, THM-RDR, THM-BTR, or THM-ABR) are described in Appendix 8 of the *THEMIS Standard Data Products SIS* [5]. Examples of the HISTORY objects added during geometric processing are shown below.

ISIS PROJECTION HISTORY OBJECT

```
  GROUP = ISIS_PROJECTION
    DATE_TIME =  2004-12-07T13:28:26
    SOFTWARE_DESC = "ISIS geometric projection of a THEMIS QUBE.
                    Process includes translation of file formats (PDS2ISIS and
                    LEVINIT); determining the valid core data range (DSK2DSK);
                    geometric transformation of image planes (GEOM); and merging
                    the individual bands back together (MOSAIC and CUBEIT).
                    See header of resulting ISIS cube for more details of projection.

                    The ISIS_COMMAND parameter may also include additional
                    processing steps that are described in other HISTORY groups in
                    this label."
    VERSION_ID =  "2003-07-23T23:51:07-7"
    USER_NAME = "marvin@mars"
    USER_NOTE = ""
    GROUP = PARAMETERS
      GEOMETRY_SOURCE_DESC = "Reconstructed"
      ISIS_COMMAND = "feather.dv V010XXRDR/V01001002RDR.QUB \
                      SINU:315,OCENTRIC 0.018 --"

      PDS2ISIS_VERSION = " 2003-06-17"
      GEOM_VERSION = "1995-06-16"
      MOSAIC_VERSION = " 2003-07-01"

      LONGITUDE_SYSTEM = 360
      MINIMUM_LATITUDE =  -9.0765104
      MAXIMUM_LATITUDE =  -8.0947313
      CENTER_LONGITUDE = 315.0000000
      WESTERNMOST_LONGITUDE = 315.2828979
      EASTERNMOST_LONGITUDE = 315.7157593
      MAP_RESOLUTION = 3293.0387513
      MAP_SCALE = 0.0180000
      MAP_PROJECTION_TYPE = "SINUSOIDAL_EQUAL-AREA"
      PROJECTION_LATITUDE_TYPE = "PLANETOCENTRIC"
      LINE_PROJECTION_OFFSET = 26656.000000
      SAMPLE_PROJECTION_OFFSET = 920.000000
    END_GROUP = PARAMETERS
END_GROUP = ISIS_PROJECTION
```

IR-GEO UDDW HISTORY OBJECT

GROUP = ASU_PROCESS_UDDW
DATE_TIME = 2009-03-25T17:41:41
SOFTWARE_DESC = "The Undrift-Dewobble filter was applied to this THEMIS IR-RDR QUBE to remove data value fluctuations caused by changes in the temperature of the IR detector array. Band 10 values remain unchanged."
VERSION_ID = 1.80
USER_NAME = "thmproc@c145.mars.asu.edu"
END_GROUP = ASU_PROCESS_UDDW

IR-GEO RECTIFY HISTORY OBJECT

GROUP = ASU_PROCESS_RECTIFY
DATE_TIME = 2008-12-31T2hh:mm:ss
SOFTWARE_DESC = "The Rectify algorithm was applied to this THEMIS IR-GEO cube to minimize null space around the image data and to prepare the data for the Deplaid algorithm. This process may result in spatial distortions that are reversible using the parameters provided."
VERSION_ID = 2005.07
USER_NAME = "thmproc@c145.mars.asu.edu"
USER_NOTE = ""
GROUP = PARAMETERS
WIDTH = 385.000000
ANGLE = 3.084812
END_GROUP = PARAMETERS
END_GROUP = ASU_PROCESS_RECTIFY

IR-GEO DEPLAID HISTORY OBJECT

GROUP = ASU_PROCESS_DEPLAID
DATE_TIME = 2008-12-31T3hh:mm:ss
SOFTWARE_DESC = " Deplaid is a specialized, high-pass filter which was applied to remove row and line radiance spikes from the THEMIS IR-RDR data in this projection. Validation of the resulting spectral image confirms that the average spectra from a 50 x 50 pixel sample area remains unchanged."
VERSION_ID = 2005.07
USER_NAME = "thmproc@c145.mars.asu.edu"
USER_NOTE = ""
END_GROUP = ASU_PROCESS_DEPLAID

IR-GEO Auto-RADCOR HISTORY OBJECT

```
GROUP = ASU_PROCESS_ARADCOR
   DATE_TIME = 2008-12-31T3hh:mm:ss
   SOFTWARE_DESC = "An automated radiance correction algorithm was applied to the
                    THEMIS IR-RDR data in this projection to remove the
                    atmospheric radiance component.  The correction value is based
                    on multiple 50 x 50 pixel samples located throughout the image
                    which meet several temperature and emissivity criteria."
   VERSION_ID = 2005.07
   USER_NAME = "thmproc@c145.mars.asu.edu"
   USER_NOTE = ""
END_GROUP = ASU_PROCESS_DCS
```

VIS-GEO DESPECKLE HISTORY OBJECT

```
GROUP = ASU_PROCESS_DESPECKLE
    DATE_TIME = 2012-07-01Thh:mm:ss
    SOFTWARE_DESC = "The Despeckle filter was applied after calibration of this
                     THEMIS VIS-RDR QUBE.  This cosmetic filter uses the
                     method below to identify anomalously bright (or dark) pixels;
                     all values from the original RDR exceeding the threshold value
                     have been replaced.  The replacement value is calculated by
                     filtering the surrounding good pixels."
    VERSION_ID = 1.0
    USER_NAME = "smith@mars"
    USER_NOTE = ""
    GROUP = PARAMETERS
        METHOD = "STANDARD DEVIATION"
        METHOD_LIMIT = # or ( #, #, #, #, # )
        FILTER = "filter name"
        FILTER_SIZE = #
        THRESHOLD_VALUE = # or ( #, #, #, #, # )
    END_GROUP = PARAMETERS
END_GROUP = ASU_PROCESS_DESPECKLE
```

VIS-GEO COFF HISTORY OBJECT

```
GROUP = ASU_PROCESS_COFF
    DATE_TIME = 2005-08-19T17:00:
    SOFTWARE_DESC = "The radiance values of this THEMIS VIS-RDR QUBE were
                     modified before geometric projection.  This is a cosmetic
                     correction which removes an optimized flat-field from each
                     framelet in the image.  The process maintains the overall
                     radiance level of each framelet at the expense of significantly
                     modifying the source VIS-RDR radiance values"
    VERSION_ID = 2005.07
    USER_NAME = "smith@mars"
    USER_NOTE = ""
    GROUP = PARAMETERS
        FLATFIELD_FILE = "/themis/data/flat_frames12.prof1.fits"
        FLATFIELD_FILE_DATE = 2005-03-16T04:54:55
    END_GROUP = PARAMETERS
END_GROUP = ASU_PROCESS_COFF
```

VIS-GEO FEATHER HISTORY OBJECT

```
GROUP = ASU_PROCESS_FEATHER
    DATE_TIME = 2004-12-07T13:28:26
    SOFTWARE_DESC = "The Feather filter was applied during the geometric projection of
                     this THEMIS VIS-RDR QUBE.  This cosmetic filter blends the
                     data in the overlapping lines between framelets, and, if
                     necessary, ramps brightness differences back towards the start
                     of the framelet.  All values in the resulting cube may have been
                     significantly modified from the source VIS-RDR values."
    VERSION_ID = 2003.11
    USER_NAME = "smith@mars"
    USER_NOTE = ""
END_GROUP = ASU_PROCESS_FEATHER
```

ERRATA HISTORY OBJECT

```
GROUP                   = ERRATA_ODTVG_0001_1_1
    DATE_TIME           = “2005-09-01T00:00:00”
    SOFTWARE_DESC       = “Description of the change which required the regeneration
                          of this product.

                          Associated ERRATA_ID: ODTVR_0001-1.5”
    ERRATA_ID           = “ODTIG-0011-1.1”
    USER_NAME           = “marvin@mars”
    USER_NOTE           = “”
END_GROUP               = ERRATA_ODTVG_0001_1_1
```

A.6 Geometry Indexes

Index files, available in the archive volume INDEX directory (*THEMIS Archive SIS* [2], Section 2.7), contain release information for the THM-GEO products. The INDEX_ODTIG and INDEX_ODTVG files contain one record of release information per geometry data product, including product creation time, version identification, and map projection type. See the appropriate label for a list of all columns and their descriptions.

In addition, selected geometric parameters of each observation are included in the general THEMIS indexes, THMIDX_IR or THMIDX_VIS. The column descriptions for these parameters have been reproduced here; the complete labels (THMIDX_*.LBL) are available in the archive INDEX directory. Note that the column number for each index is given for reference only following the syntax

COLUMN_NUMBER = [thmidx_ir = #, thmidx_vis =#].

All geometry parameter values are calculated using the basic ISIS processing for the first available band in the observation.

```
OBJECT                  =  COLUMN
  NAME                  =  GEOMETRY_SOURCE
  COLUMN_NUMBER         =  [ thmidx_ir = 25, thmidx_vis =19 ]
  DATA_TYPE             =  CHARACTER
  BYTES                 =  1
  DESCRIPTION           =  "Description of the geometry kernels used by the ISIS
                           software when generating the geometry information for
                           this image:
                              P = Predicted using NAIF tools (some parameters
                                  may be unavailable)
                              R = Reconstructed
                              N = Nadir pointing assumed
                              U = Geometry unavailable; parameters filled with
                                  UNKNOWN_CONSTANT"
END_OBJECT              =  COLUMN

OBJECT                  =  COLUMN
  NAME                  =  SAMPLE_RESOLUTION
  COLUMN_NUMBER         =  [ thmidx_ir = 26, thmidx_vis = 20 ]
  DATA_TYPE             =  ASCII_REAL
  BYTES                 =  5
  UNKNOWN_CONSTANT      =  32767
  UNIT                  =  "KM"
  DESCRIPTION           =  "The horizontal size of a pixel at the center of the image
                           as projected onto the surface of the target."
END_OBJECT              =  COLUMN

OBJECT                  =  COLUMN
  NAME                  =  LINE_RESOLUTION
```

```
    COLUMN_NUMBER         = [ thmidx_ir = 27, thmidx_vis = 21 ]
    DATA_TYPE             = ASCII_REAL
    BYTES                 = 5
    UNKNOWN_CONSTANT      = 32767
    UNIT                  = "KM"
    DESCRIPTION           = "The vertical size of a pixel at the center of the image
                            as projected onto the surface of the target."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
    NAME                  = PIXEL_ASPECT_RATIO
    COLUMN_NUMBER         = [ thmidx_ir = 28, thmidx_vis = 22 ]
    DATA_TYPE             = ASCII_REAL
    BYTES                 = 5
    UNKNOWN_CONSTANT      = 32767
    UNIT                  = "DIMENSIONLESS"
    DESCRIPTION           = "Ratio of the height to the width of the projection of the
                            center pixel onto the surface of the target."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
    NAME                  = CENTER_LATITUDE
    COLUMN_NUMBER         = [ thmidx_ir = 29, thmidx_vis = 23 ]
    DATA_TYPE             = ASCII_REAL
    BYTES                 = 7
    UNKNOWN_CONSTANT      = 32767
    UNIT                  = "DEGREE"
    DESCRIPTION           = "Latitude on Mars at the image center."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
    NAME                  = CENTER_LONGITUDE
    COLUMN_NUMBER         = [ thmidx_ir = 30, thmidx_vis = 24 ]
    DATA_TYPE             = ASCII_REAL
    BYTES                 = 7
    UNKNOWN_CONSTANT      = 32767
    UNIT                  = "DEGREE"
    DESCRIPTION           = "Longitude on Mars at the image center using an east
                            positive coordinate system."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
    NAME                  = UPPER_LEFT_LATITUDE
    COLUMN_NUMBER         = [ thmidx_ir = 31, thmidx_vis = 25 ]
    DATA_TYPE             = ASCII_REAL
    BYTES                 = 7
```

```
    UNKNOWN_CONSTANT  =  32767
    UNIT              =  "DEGREE"
    DESCRIPTION       =  "Latitude on Mars at the upper left corner of the
                         image."
END_OBJECT            =  COLUMN

OBJECT                =  COLUMN
    NAME              =  UPPER_LEFT_LONGITUDE
    COLUMN_NUMBER     =  [ thmidx_ir = 32, thmidx_vis = 26 ]
    DATA_TYPE         =  ASCII_REAL
    BYTES             =  7
    UNKNOWN_CONSTANT  =  32767
    UNIT              =  "DEGREE"
    DESCRIPTION       =  "Longitude on Mars at the upper left corner of the
                         image."
END_OBJECT            =  COLUMN

OBJECT                =  COLUMN
    NAME              =  UPPER_RIGHT_LATITUDE
    COLUMN_NUMBER     =  [ thmidx_ir = 33, thmidx_vis = 27 ]
    DATA_TYPE         =  ASCII_REAL
    BYTES             =  7
    UNKNOWN_CONSTANT  =  32767
    UNIT              =  "DEGREE"
    DESCRIPTION       =  "Latitude on Mars at the upper right corner of the
                         image."
END_OBJECT            =  COLUMN

OBJECT                =  COLUMN
    NAME              =  UPPER_RIGHT_LONGITUDE
    COLUMN_NUMBER     =  [ thmidx_ir = 34, thmidx_vis = 28 ]
    DATA_TYPE         =  ASCII_REAL
    BYTES             =  7
    UNKNOWN_CONSTANT  =  32767
    UNIT              =  "DEGREE"
    DESCRIPTION       =  "Longitude on Mars at the upper right corner of the
                         image."
END_OBJECT            =  COLUMN

OBJECT                =  COLUMN
    NAME              =  LOWER_LEFT_LATITUDE
    COLUMN_NUMBER     =  [ thmidx_ir = 35, thmidx_vis = 29 ]
    DATA_TYPE         =  ASCII_REAL
    BYTES             =  7
    UNKNOWN_CONSTANT  =  32767
    UNIT              =  "DEGREE"
```

```
    DESCRIPTION            = "Latitude on Mars at the lower left corner of the
                             image."
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
    NAME                   = LOWER_LEFT_LONGITUDE
    COLUMN_NUMBER          = [ thmidx_ir = 36, thmidx_vis = 30 ]
    DATA_TYPE              = ASCII_REAL
    BYTES                  = 7
    UNKNOWN_CONSTANT       = 32767
    UNIT                   = "DEGREE"
    DESCRIPTION            = "Longitude on Mars at the lower left corner of the
                             image."
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
    NAME                   = LOWER_RIGHT_LATITUDE
    COLUMN_NUMBER          = [ thmidx_ir = 37, thmidx_vis = 31 ]
    DATA_TYPE              = ASCII_REAL
    BYTES                  = 7
    UNKNOWN_CONSTANT       = 32767
    UNIT                   = "DEGREE"
    DESCRIPTION            = "Latitude on Mars at the lower right corner of the
                             image."
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
    NAME                   = LOWER_RIGHT_LONGITUDE
    COLUMN_NUMBER          = [ thmidx_ir = 38, thmidx_vis = 32 ]
    DATA_TYPE              = ASCII_REAL
    BYTES                  = 7
    UNKNOWN_CONSTANT       = 32767
    UNIT                   = "DEGREE"
    DESCRIPTION            = "Longitude on Mars at the lower right corner of the
                             image."
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
    NAME                   = PHASE_ANGLE
    COLUMN_NUMBER          = [ thmidx_ir = 39, thmidx_vis = 33
    DATA_TYPE              = ASCII_REAL
    BYTES                  = 7
    UNKNOWN_CONSTANT       = 32767
    UNIT                   = "DEGREE"
```

```
    DESCRIPTION          = "The angle between the surface-to-Sun vector and the
                           surface-to-THEMIS vector drawn at the center of the
                           image for the time the image was acquired."
END_OBJECT               = COLUMN

OBJECT                   = COLUMN
    NAME                 = INCIDENCE_ANGLE
    COLUMN_NUMBER        = [ thmidx_ir = 40, thmidx_vis = 34 ]
    DATA_TYPE            = ASCII_REAL
    BYTES                = 7
    UNKNOWN_CONSTANT     = 32767
    UNIT                 = "DEGREE"
    DESCRIPTION          = "The angle between the Sun and a 'normal' drawn
                           perpendicular to the surface of the planet at the center
                           of the image for the time the image was acquired.  A
                           value of 0 degrees indicates that the Sun was directly
                           overhead at the time the image was acquired."
END_OBJECT               = COLUMN

OBJECT                   = COLUMN
    NAME                 = EMISSION_ANGLE
    COLUMN_NUMBER        = [ thmidx_ir = 41, thmidx_vis = 35 ]
    DATA_TYPE            = ASCII_REAL
    BYTES                = 6
    UNKNOWN_CONSTANT     = 32767
    UNIT                 = "DEGREE"
    DESCRIPTION          = "The angle between THEMIS and a 'normal' drawn
                           perpendicular to the planet surface at the center of the
                           image.  For nadir observations, this value will be
                           approximately 0 degrees."
END_OBJECT               = COLUMN

OBJECT                   = COLUMN
    NAME                 = NORTH_AZIMUTH
    COLUMN_NUMBER        = [ thmidx_ir = 42, thmidx_vis = 36 ]
    DATA_TYPE            = ASCII_REAL
    BYTES                = 7
    UNKNOWN_CONSTANT     = 32767
    UNIT                 = "DEGREE"
    DESCRIPTION          = "The clockwise angle from an imaginary three o'clock
                           axis to the North polar axis, where the origin of both
                           axes is at the center of the image."
END_OBJECT               = COLUMN

OBJECT                   = COLUMN
    NAME                 = SLANT_DISTANCE
```

```
    COLUMN_NUMBER        =  [ thmidx_ir = 43, thmidx_vis = 37 ]
    DATA_TYPE            =  ASCII_REAL
    BYTES                =  8
    UNKNOWN_CONSTANT     =  32767
    UNIT                 =  "KM"
    DESCRIPTION          =  "A measure of the distance from the spacecraft to the
                            target body at the center of the image;  this value is the
                            spacecraft altitude if the emission angle is 0 degrees."
END_OBJECT               =  COLUMN

OBJECT                   =  COLUMN
    NAME                 =  LOCAL_TIME
    COLUMN_NUMBER        =  [ thmidx_ir = 44, thmidx_vis = 38 ]
    DATA_TYPE            =  CHARACTER
    BYTES                =  6
    UNKNOWN_CONSTANT     =  32767
    UNIT                 =  "HOUR"
    DESCRIPTION          =  "The local time on Mars at the center of the image,
                            given as the division of the Martian day into 24 equal
                            parts; for example, 12.00 represents high noon."
END_OBJECT               =  COLUMN

OBJECT                   =  COLUMN
    NAME                 =  SOLAR_LONGITUDE
    COLUMN_NUMBER        =  [ thmidx_ir = 45, thmidx_vis = 39 ]
    DATA_TYPE            =  ASCII_REAL
    BYTES                =  7
    UNKNOWN_CONSTANT     =  32767
    UNIT                 =  "DEGREE"
    DESCRIPTION          =  "The position of Mars relative to the Sun as measured
                            from the vernal equinox;  also known as heliocentric
                            longitude."
END_OBJECT               =  COLUMN

OBJECT                   =  COLUMN
    NAME                 =  SUB_SOLAR_AZIMUTH
    COLUMN_NUMBER        =  [ thmidx_ir = 46, thmidx_vis = 40 ]
    DATA_TYPE            =  ASCII_REAL
    BYTES                =  7
    UNKNOWN_CONSTANT     =  32767
    UNIT                 =  "DEGREE"
    DESCRIPTION          =  "The clockwise angle from an imaginary three o'clock
                            axis to the Sun at the time the image was acquired,
                            where the origin of both axes is at the center of the
                            image."
END_OBJECT               =  COLUMN
```

A.7 Geometric Quality Assesment and HISTORY object

After nearly 10 years in flight, the M01 Odyssey Spacecraft team began to be concerned about end-of-life issues for the Inertia Measurement Unit (IMU) which is the basis for the Gyro based attitude determination mode used since the start of the mission. After weighing all the options, the M01 Odyessy Project and Spacecraft teams decided to switch to All-Stellar based attitude determination. Testing and on-board demos of All-Stellar mode began January 2012; full time operations using All-Stellar mode began March 2012, with returns to Gyro mode as needed. The only affect of this spacecraft operational change to THEMIS images is on the geometric accuracy of the projected image, which will now be documented in a Geometric_Quality HISTORY object (shown below) added to the labels of all RDR and GEO products.

Through extensive validation it has been determined that highly accurate geometric results, as well as very poor geometric results, can be obtained during either GYRO or ALL-STELLAR based attitude determination modes. In reality, the final geometric accuracy of any given THEMIS image is dependent on several parameters, not just the attitude determination mode. The following is a brief description of some of the other parameters that affect the geometric accuracy of any THEMIS image.

Star Camera Mode. Both attitude determination modes depend on solutions from the Star Camera in the attitude control logic; obviously, ALL-STELLAR is more dependent on the results, and therefore, more susceptible to severe Star Camera outages. The Star Camera normally operates in "TRACKING" mode; when an anomaly is encountered, the camera autonomously transitions to "ACQUISTION" mode until a good solution can be made. Brief solution outages (less than 100 seconds) spent in acquisition mode are expected during nominal spacecraft operations and rarely affect geometric accuracy; longer outages can affect geometric accuracy, depending on how far the spacecraft attitude has strayed during the outage.

Spacecraft Attitude Error. Attitude is continuously monitored onboard the Odyssey spacecraft and the various measurements are used in the attitude control algorithms. The spacecraft attitude error is calculated from the difference between the commanded and estimated spacecraft attitude, and quantifies the amount of offset around the each of the three axes of the spacecraft body frame. Typical spacecraft attitude error measurements during GYRO based operations are routinely lower than during ALL-STELLAR based operations, especially around the spacecraft pitch axis.

Angular Momentum Desaturation. Angular Momentum Desaturation (AMD or DESAT) events are requried to maintain spacecraft attitude and stability. Testing early during the Odyessy Mapping Phase of the mission concluded that THEMIS images were relatively insensitive to DESATs during GYRO based operations. However, DESATs executed during ALL-STELLAR based operations are marked by heightened spacecraft attitude error values, especially around the pitch axis.

Data Gaps in Telemetry. Like any other downlinked data product, spacecraft telemetry can contain data gaps. When THEMIS image collection times intersect a gap in the spacecraft telemetry, the status of the various parameters described above will be unknown, and may compromise our ability to predict the cumulated affects on the geometric accuracy. When THEMIS image collection times intersect a gap in the spacecraft trajectory kernels (NAIF CK kernels), the ISIS processing will use an "ASSUMED-NADIR" kernel instead of the reconstructed trajectory kernel. During GYRO based operations, using the "ASSUMED-

NADIR" kernels produce results with accuracy similar to using the "RECONSTRUCTED" kernels. During ALL-STELLAR based operations, geometric accuracy using "ASSUMED-NADIR" is more unpredictable.

Coregistration of Image to Mars Basemap. Validation studies have shown that the only way to reliably know the geometric accuracy of an image is to project the image, use feature coregistration to fit the image to a Mars basemap with acceptable geometric accuracy, and measure any image offset. For images where coregistration is possible and produces acceptable results (ASU_BASEMAP_COREG = YES), a GEOMETRIC_QUALITY_RATING of "GOOD", "OKAY", or "BAD" is reported, corresponding to the amount of pixel offset requried: none, minimal, or significant. For images where coregistration is not possible, the parameters discussed above are used to suggest the final geometric accuracy of the image: a GEOMETRIC_QUALITY_RATING of "NO-ISSUES", "CAUTION", or "WARNING" corresponds to the predicted equivalent of none, minimal, or significant pixel offsets required to accurately locate this image on Mars. Unfortunately, the above parameters are not perfect predictors of geometric accuracy, so the user is forewarned that approximately 78% of the predictions turn out to be true (i.e. when coregistered, an image with a NO-ISSUES prediction results in a GOOD quality rating), and approximately 7% of the predictions turn out to be false (i.e. when coregistered, an image with a WARNING prediction results in a GOOD quality rating).

GEOMETRIC QUALITY HISTORY OBJECT

GROUP = GEOMETRIC_QUALITY
    DATE_TIME = *YYYY-MM-DDTmm:hh:ss*
    SOFTWARE_DESC = "The quality of the projected location of a THEMIS image can be affected by multiple factors, which are summarized here along with the assessed GEOMETRY_QUALITY_RATING. See the GEOMETRY/GEOMETRY.PDF for a full discussion of the individual parameters."
    USER_NAME = "marvin@mars"
    USER_NOTE = ""
    GROUP = PARAMETERS
        [*see parameter keyword list with definitions and valid values below*]
    END_GROUP = PARAMETERS
END_GROUP = GEOMETRIC_QUALITY

GEOEMTRIC QUALITY PARAMETERS

GEOMETRY_SOURCE_DESC

Description of the geometry kernels used by the ISIS software when generating geometric information for this image. ["PREDICTED", "RECONSTRUCTED", or "ASSUMED-NADIR"]

SPACECRAFT_ATTITUDE_DESC

Two part description of the attitude control mode during collection of this image: Attitude Determination mode and Star Camera mode. [(“GYRO” or “ALLSTAR, “TRACKING” or “ACQUISITION”)]

SPACECRAFT_ATTITUDE_ERROR

Maximum spacecraft attitude error during collection of this image; given in degrees as (pitch, roll, yaw) around the spacecraft body frame. [“N/A”, or (#.#, #.#, #.#)]

SPACECRAFT_DESAT_EVENT

Results from testing if this image was collected during an angular momentum desaturation event. [“N/A”, “YES”, or “NO”]

SPACECRAFT_TELEMETRY_GAP

Results from testing if this image coincides with a data gap in the downlinked spacecraft telemetry. [“N/A”, “YES”, or “NO”]

ASU_BASEMAP_COREG

Results from testing for success when attempting to coregister this ISIS projected image against a Mars basemap. The ASSOC_IR value indicates that the IR image collected concurrently with this VIS image was successfully coregistered. [“N/A”, “YES”, “NO”, or “ASSOC_IR”]

GEOMETRIC_QUALITY_RATING

Assessed quality of geometric values when projected using appropriate NAIF kernels and ISIS software. [“N/A”, “GOOD”, “OKAY”, ”BAD”, “NO-ISSUES”, “CAUTION”, “WARNING”]