Planetary Orbital Mosaicking and Mapping (POMM)

POMM User Guide

Version 1.0

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Prepared for:

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Table 1: Document Terminology

AFIDS	Automated Fusion of Image Data System
AMMOS	Advanced Multi-Mission Operations System; Managed by MGSS
CTX	MRO Context Camera
EquiRectangular	A Geographic Projection with Latitude and Longitudes meeting at right angles
ESA	European Space Agency
FFT	Fast Fourier Transform
GDAL	Geospatial Data Abstraction Library
Georeference	Image Metadata describing the geographic position of image pixels
GEOCAL	Generic geometric calibration library initially developed by the MISR Team.
GeoTIFF	A georeferenced version of the TIFF (Tagged Image File Format) image format
GLAS/GFM	Generic Linear Array System / Generic Frame camera Model
HIRISE	MRO High Resolution Imaging Science Experiment
HRSC	ESA Mars Express High Resolution Stereo Camera
IDS	Instrument Data Systems
ISIS	USGS Integrated Software for Imagers and Spectrometers
JPL	Jet Propulsion Laboratory
LRO	Lunar Reconnaissance Orbiter
MDIM	Mars Digital Image Mosaic
MEX	ESA Mars Express Mission
MIPL	Multi-mission Image Processing Laboratory
MOLA	Mars Orbiter Laser Altimeter (elevation measurements)
MRO	Mars Reconnaissance Orbiter
NAC	LRO Narrow Angle Camera
NASA	National Aeronautics and Space Administration
NEST	AFIDS planetary co-registration software (also Mars_Nest)
NITF	National Image Transmission Format
PDS	Planetary Data System
POMM	Planetary Orbital Mosaicking and Mapping
RSM	Replacement Sensor Model
SPICE	NASA's Navigation and Ancillary Information Facility (NAIF) observation geometry information system
USGS	United States Geological Survey
VICAR	Video Image Communication And Retrieval
WAC	LRO Wide Angle Camera

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1 POMM Overview

1.1 About POMM

Planetary Orbital Mosaicking and Mapping (POMM) is a set of workstation tools supporting the automation of planetary orbital mosaicking and mapping requirements. POMM is designed to provide the planetary scientist, student, and enthusiast with easy-to-use tools that perform basic functions necessary for most satellite mapping and analysis studies. These capabilities include:

1) The ability to co-register (stack) multiple images over the same location for time series analysis;
2) Mosaic multiple adjacent images to create large-area base map coverages and regional overviews; and
3) Create map-projected orbital satellite images from selected sensors and bands provided in raw PDS format.

POMM (v1) supports the co-registration and mosaicking of (existing) single-band map-projected orbital images of Mars, Earth, and the Earth's Moon (excluding polar areas). However, if *map-projected* images are not available, POMM can create them from their raw/EDR PDS format for the following mission sensors:

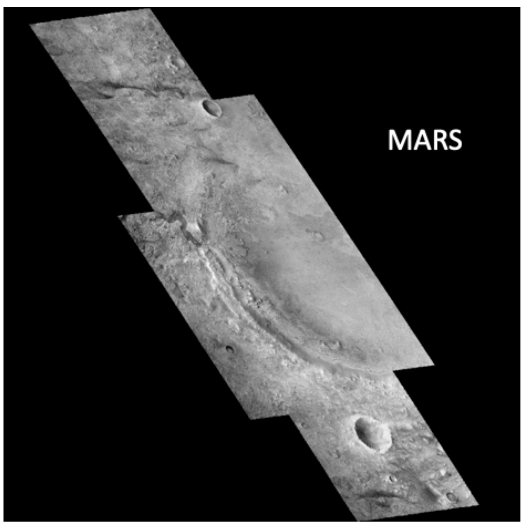
- Mars Reconnaissance Orbiter (MRO) Context Camera (CTX);
- MRO High Resolution Imaging Science Experiment (HiRISE) Red-band;
- Mars Express (MEX) High Resolution Stereo Camera (HRSC) "level-2" format;
- Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (NAC "LE/RE" format); and
- LRO Wide Angle Camera (WAC "CC" format) COLOR VIS bands

POMM was funded by the Advanced Multi-Mission Operations System (AMMOS) which supports NASA robotic missions with tools for planetary exploration, including Earth and space science. Available AMMOS tools are described in the online AMMOS catalog. AMMOS is managed by the Multi-Mission Ground Systems (MGSS), a division of the NASA Interplanetary Network Directorate. The purpose of this document is to describe the operational concept and design of the Planetary Orbital Mosaicking and Mapping (POMM) tool kit, including its components, parameters, capabilities, use cases, and planetary mission applications.

1.2 Mosaicking Orbital Map Images

This toolkit mosaics two or more adjacent map-projected images. The inputs can be from different satellite sensors and resolutions (e.g., CTX and HRSC) as long as they are map-projected, overlap, and have similar brightness histograms. There is no specific limit to the number of input images to mosaic, but specifying a very large mosaic should be considered relative to available cpu performance and disk space resources. All input images (or links) must be in one directory. Accepted map/georeferenced file formats include: .tif (geotiff); .jp2 (jpeg2000); .img (PDS); and .vic (vicarGT). POMM employs automated mosaicking techniques for near-seamless geometric edge matching, brightness feathering and block adjustment between and across images. 100% overlapping images will not be “blended” in the output mosaic, but co-registered and output as separate image files. Disconnected images (“islands”) will not be matched or feathered with neighboring images, and can significantly expand the size of the mosaic. Mosaic output products include:

*prefix*_mosaic.tif – Output multi-image mosaic.
*prefix_1st_input_filename.*tif – First image in mosaic space; Not edge matched.
*prefix_2nd_input_filename.*tif – Second image in mosaic space; Not edge matched.
etc.
*prefix*_mosaic_log.csv. – POMM/VICAR/AFIDS processing log (text).
*prefix*_mosaic_receipt.csv – POMM receipt (summary) text file.



Jezero Crater *Sinusoidal* Projection
Three Image Mosaic

Dominican Republic *Lat/Lon* Projection
Two Image Mosaic

Figure 1-1. Example of POMM Orbital Mosaics.

1.3 Co-Registering Orbital Map Images

This tool is used to co-register and stack time-series satellite images that may have large offsets (100+ meters) relative to each other. The inputs can be from different satellite sensors and resolutions (e.g., CTX and HRSC) as long as they are map-projected (from the same planet) and have a large overlap. The software co-registers the “Second” map image to the “Reference/ Master” map image. The Reference image should be similar or lower resolution than the Second image. With the default option (1), the two registered images are output to the dimensions and projection of the Reference image. With option 2, both (master and secondary images) are trimmed to the size of the secondary image (with added padding). A gridded tiepoint file is output, but is relative to the master image and an “intermediate” projected version of the second image (also output). The tiepoint file (csv/text format) contains six columns: Latitude, Longitude, Reference Image Line, Reference Image Sample, Second Image Line, and Second Image Sample. Note that the quality of the co-registration will be limited by the quality of the original map projections (and their elevation models in high terrain areas). Accepted georeferenced input file formats include: .tif (geotiff); .jp2 (jpeg2000); .img (PDS); and .vic (vicarGT). Co-registration outputs include:

*prefix*_ref_reg.tif – Co-registered Referenced/Master image.
*prefix*_sec_reg.tif – Co-registered Secondary image.
*prefix*_sec_intermediate.tif – Intermediate scaled Secondary image (unregistered).
*prefix*_tiepoints_6col.csv – Gridded tiepoint file between the Master and Intermediate.
*prefix*_log.csv – POMM/VICAR/AFIDS processing log (text).
*prefix*_receipt.csv – POMM receipt (summary) text file.

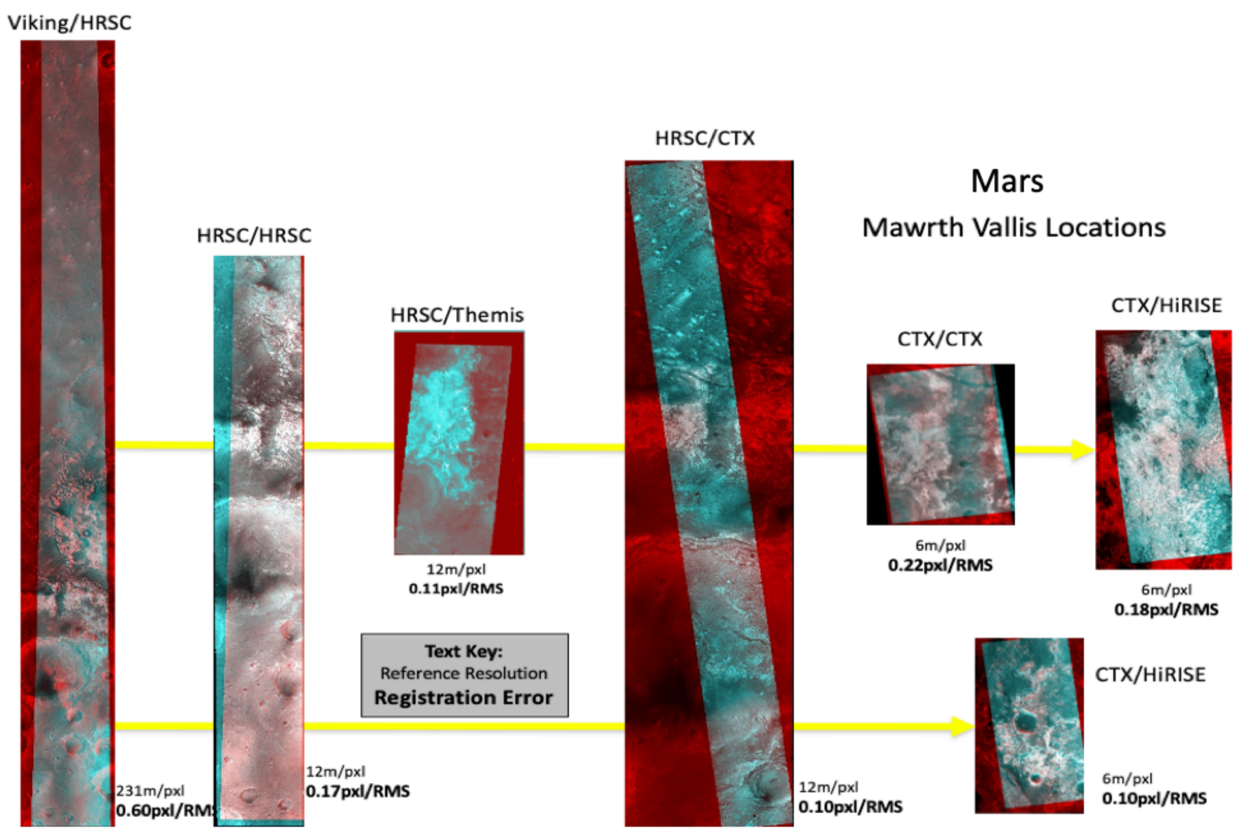


Figure 1-2. Example of POMM Co-Registration/Stacking of Orbital Map Images.

1.4 MAP PROJECTING RAW PDS ORBITAL IMAGES

Use this POMM tool to map project raw/EDR images in PDS format when existing map projected images are not available. Currently supported mission sensors include:

Mars:

- MRO CTX (Context Camera)
- MRO HiRISE (High Resolution Imaging Science Experiment) – Red band
- MEX HRSC (High Resolution Stereo Camera) – nd2 format.

Luna/Moon:

- LRO NAC (Narrow Angle Camera) – "LE/RE" Uncalibrated PDS format
- LRO WAC (Wide Angle Camera) – "CC" Calibrated format; COLOR VIS Bands 1-5

POMM uses the GLAS/RSM (Replacement Sensor Model) camera model for geometric map projection, and ISIS software for radiometric calibration. An optional high-resolution DEM model may be provided for terrain correction or a standard global DEM model (provided) used by default. Three output map projection choices are available. Note that NAIF SPICE kernels are required for ephemeris processing and are automatically downloaded as needed except for MEX/HRSC, which requires a manual download (instructions provided). Map projection outputs include:

*prefix*_map.tif – Map-projected output image.
*prefix*_log.csv – POMM/VICAR/AFIDS processing log (text).
*prefix*_receipt.csv – POMM receipt (summary) text file.

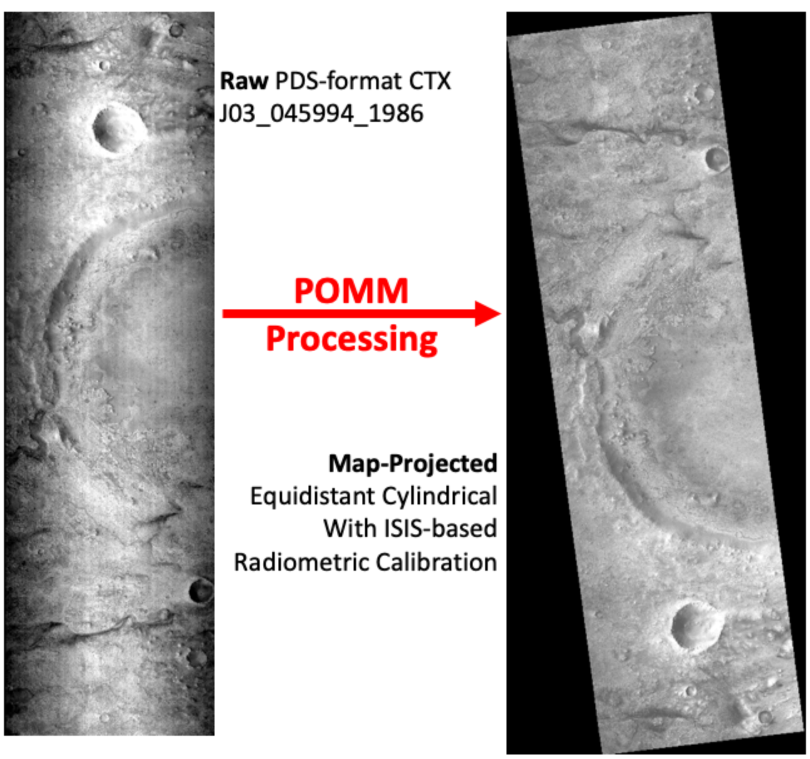


Figure 1-3. Example of Map Projecting a Mars CTX image.

2 POMM Design and Requirements

2.1 Introduction

The initial POMM proposal called for developing an automated planetary mosaicking tool that would relieve scientists and enthusiasts from the burdensome task of preparing extensive base maps before they could begin their planetary research. Once funded, a number of requirements were identified that quickly shaped the design of the POMM Toolkit. These requirements are identified in the JPL "IDS-AFIDS SRD" (System Requirements Document, DOC-001615), but the key design drivers are discussed below in Section 2.2.

2.2 Requirements

2.2.1 The Mosaicking Design Should Be Extensible To Other Planets And Moons

The first key requirement is that the software must be sufficiently generic that it can be easily adapted to a variety of other planets and moons with minimal parameter and projection changes. To accomplish this, the planet/moon must be relatively circular or spherical in shape and of moderate-to-large size, as opposed to angular or elongated. This precludes asteroids and other small objects and worlds with complicated projection characteristics. Thus, the requirement for the software to work across a variety of planets and moons also requires that the input orbital images be Map Projected. This eliminates the need for special POMM mosaicking code to adapt and map project each individual Mission Sensor, and instead relies upon the various planetary science missions to produce map projection products. As the various orbital missions may also have spectral band products of varying resolution and geographic coverage, mosaicking is currently limited to single-bands.

As implemented, the expected map projection georeference must be compatible with the GeoTIFF Geokey standard, which is widely used in the planetary community. To simplify the use of the Geokey standard, POMM has a special VICAR GDAL-compatible plug-in that will convert most external georeferenced formats (e.g., jpeg2000; ENVI) to the internal "VicarGT" format which uses the GeoTIFF Geokeys.

2.2.2 The Mosaicking Design Should Maximize Software Reuse

JPL has a long history of developing orbital mosaicking software for specific missions. One such package was the AFIDS Mosaicking (AFIDS-MOS) toolset, developed by Dr. Albert Zobrist in the early 2000s. This automated package was modified a number of times to support a variety of Earth orbital missions including Landsat, ASTER, Ikonos, Quickbird, WorldView, and other NASA and commercial Earth missions. Over time, the AFIDS-MOS software was used to produce a number of high-quality Earth mosaics supporting various NASA and JPL missions. In particular, the global Landsat 7 Earth mosaic created in 2004 by Dr. Zobrist with support from Dr. Nevin Bryant and Mr. Richard Fretz, is still used in the early 2020s as an orthobase for ECOSTRESS, EMIT, MAIA, and other JPL missions. The key features of AFIDS-MOS include:

1) Automated geometric (xy) scene edge alignment/matching, and

2) Automated brightness (z-value) block adjustment and scene edge matching/feathering. The combination of mosaicking features and history of software reuse made AFIDS-MOS a good software baseline for POMM.

Reuse of the automated AFIDS-MOS software introduced a number of POMM design constraints. The most important of these is that input orbital images must be re-projected to a common gridded coordinate system such as Latitude/Longitude or UTM. This enables the creation of internal projection-tagged grids (for each input orbital image) containing xy edge matching and z-brightness values that can then be merged to create adjustment values and subsequent correction grids between overlapping image areas. While this approach works well across equatorial and mid-latitudes, it does not support polar regions. While there are work-arounds for the polar case, these will need to be addressed in future versions of POMM.

2.3 POMM/AFIDS Design Heritage

Implementation of the POMM mosaicking capability soon revealed the need for:

1) A co-registration/stacking tool to improve relative map projection displacements due to spacecraft timing and ephemeris differences, and
2) An ability to map project key orbital imagery if existing projected imagery were not readily available for the user's specific area-of-interest. POMM relies on existing AFIDS co-registration and map-projection tools and designs to provide these capabilities.

2.3.1 Earth Orbital Image Co-Registration

The VicarGT georeferenced image file format is the foundation of the AFIDS design, which in turn, relies upon the JPL GEOCAL geometric calibration library. The AFIDS concept assumes that images to be co-registered are *map-projected images with an embedded map georeference*. Existing georeferenced map image formats like GeoTIFF, ENVI, JPEG2000, and others can be converted by GDAL into vicarGT format for AFIDS use. The AFIDS software uses the map image's georeference to initially setup the matching alignment between two images, then applies FFTs (Fast Fourier Transforms) to nail down the co-registration. This permits the process to be fully automated. The core program is "gtpwarp," but there are 10 "gt" projection and map warping programs that support various automated co-registration situations with Earth map projections.

2.3.2 Planetary Orbital Image Co-Registration

For the planetary community, the equivalent design is the AFIDS/GEOCAL program "mars_nest." Despite its name, the program is not specific to Mars, and works for Earth and Moon/Luna as well. The core of this software is a modified "gtpwarp" with GEOCAL-provided map projection support. The code also includes known map projection corrections (e.g., HiRISE), verification of image overlap, resampling, and image registration accuracy assessment. The Mars_Nest algorithm is diagrammed in Figure 2-1 below.

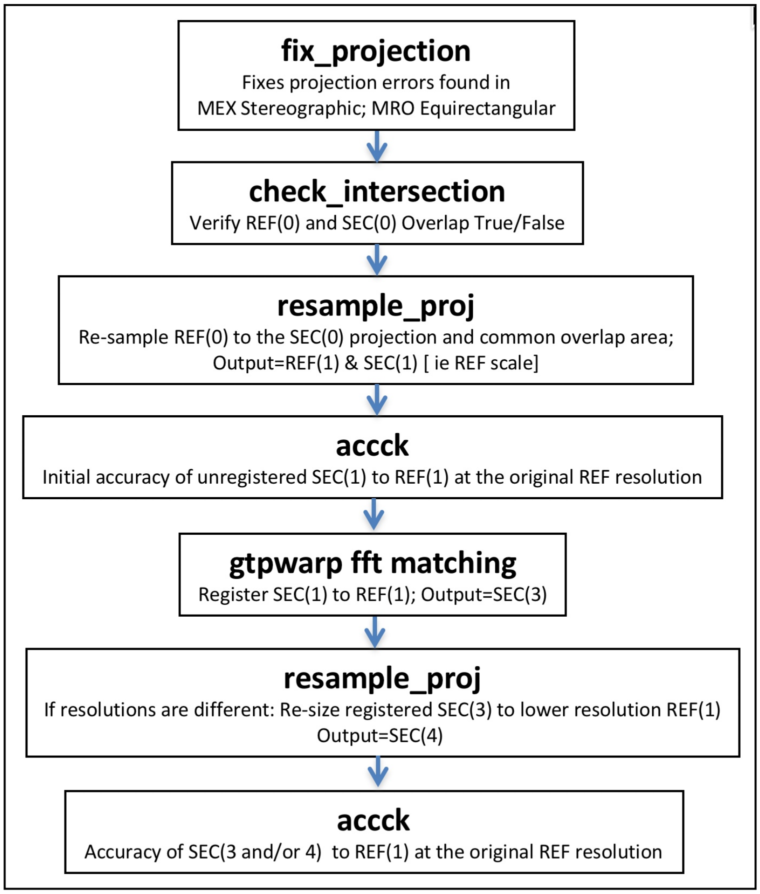


Figure 2-1. AFIDS Planetary Co-Registration Algorithm Design.

2.3.3 Earth Orbital Image Mapping

In the early years of the US Earth mapping program, most satellite imagery was only available in a basic pixel-image swath format. Today most imagery such as Landsat-8/9 and Sentinel-2AB are provided as terrain-corrected ortho-map images with a high degree of positional accuracy. These products are ready-made for AFIDS/GEOCAL co-registration after a simple “gdal_translate” conversion from their native GeoTIFF or JPEG2000 formats to VicarGT format. However, a few of the high-resolution commercial imaging products such as the Maxar “Worldview,” “Geoeye,” “Ikonos,” and “Quickbird” imaging systems are not terrain-corrected or mapped, but come with “RPCs” or an “RSM” camera model replacement that can be used to produce a map-image product. The AFIDS/GEOCAL software for map-rectifying these images are “rpcwarp” and “rpc2grid” which despite their “rpc” name, also handle the RSM (Section 2.3.4). AFIDS can create RPCs as well as providing over 25 RPC-support programs for various applications. A number of older programs are also available to support the “logging” of legacy image formats and manual tiepoint collection.

2.3.4 Planetary Orbital Image Mapping

While a large number of "mapped" orbital planetary images currently exist, the number of new raw images is also increasing. Unfortunately, most of the existing mapped imagery are based solely on ephemeris and pointing data and so tend not to align to ground position or to each other. In a recent Mars landing site test case, 38 HIRISE images were found to have an average offset of 120 meters North-South and 200 meters East-West. The solution for this problem is the Replacement Sensor Model (RSM) that is a generic replacement for the original physical camera model, and offers a standardized approach for adding ground correction information. Figure 2-2 provides an overview of replacement camera model designs.

A Camera Model defines the relationship between an Imaging system's focal plane (FPA) and the ground.

- The better the model, the more accurate the image can be mapped to correct ground coordinates, and better utilize elevation and platform ephemeris information for error correction.
- The conventional approach uses **RPC**s (Rational Polynominal Coefficients) as a replacement for the Physical Model.
  - Utilizes a 3^{rd} order ground-to-image polynomial with 80 coefficients to model the entire image.
  - Works best for Frame Cameras and specific Pushbroom Sensors.
  - Includes 2 Error Terms (Circular and Random errors).
- The current standard is the **RSM** (Replacement Sensor Model):
  - Utilizes a 5^{th} order ground-to-image RPC polynomial, or optionally use a Correspondence Grid.
  - Supports a separate Adjustment function for correcting polynomials.
  - Provides an Error Covariance for each Adjustment function. Supports 36 Error Terms.
  - Can use ancillary camera metadata (e.g., timing, sun angle, trajectory).
- The latest advancement is the **GLAS/GFM** (Generic Linear Array System / Generic Frame-Camera Model):
  - Incorporates RSM and RPC camera model design components.
  - Integrates multiple imaging planes (CCDs) as one image (RSM treats CCDs as separate images).
  - Models projection from FPA-to-ground (rather than ground-to-FPA as with RSM), which supports turbulent airborne imagery with overlapping image planes.

Figure 2-2. Replacement Camera Model Designs.

AFIDS software supports the "RSM" and "GLAS/GFM" replacement sensor camera models for Mars CTX, HRSC, HIRISE, and Luna/Moon NAC and WAC instruments. There are currently four AFIDS programs involved with converting the raw "PDS" orbital image to Mars map projection: "pomm_generate_model" combines the SPICE kernel and navigation data with PDS metadata to create the initial RSM or GLAS/GFM model. The program "rsm_project" then uses digital elevation data (DEM Terrain) to map project the model and output a GeoTIFF image as desired. However, the key AFIDS advantage is the next step in which the program "rsm_tiepoint" automatically finds tiepoints with a supplied orthobase or existing map image, and supplies them to the program "rsm_improve" to correct/update the RSM (or GLAS/GFM) model to match the provided map datum. The updated RSM/GLAS camera model can be stored with the raw PDS image for archive, or map-projected using the "rsm_project" program. The process is diagrammed in Figure 2-3.

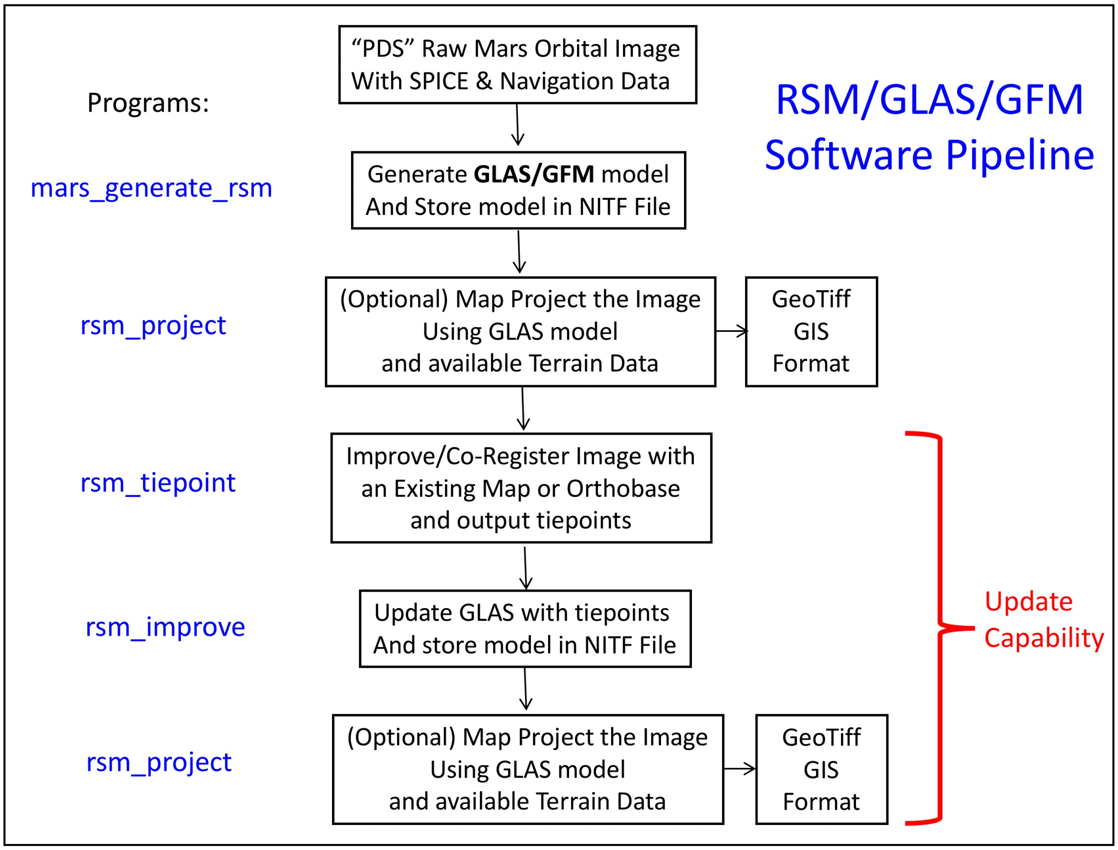


Figure 2-3. AFIDS/GEOCAL Replacement Sensor Camera Model Pipeline.

3 POMM User Guide

3.1 Introduction

POMM is provided with a menu-based user interface for the occasional user, but can also be run directly from the vicar command line by the experienced user. Both interfaces perform the same essential function of building a "user parameter file" (UPF) and submitting that UPF text file (via a POMM batch script) for vicar execution. The menus guide the process of filling out the UPF file by providing Help/Example information (via menu buttons), whereas the non-menu user must fill out the UPF file directly, correctly, and launch the vicar script manually. Note that the menus described herein may evolve over time.

3.2 Launching POMM

At the VICAR prompt, type: (See Section 5.4.1 for Sourcing/Starting VICAR)

pomm-ui.py

to display the initial POMM dialog box and POMM Toolkit:

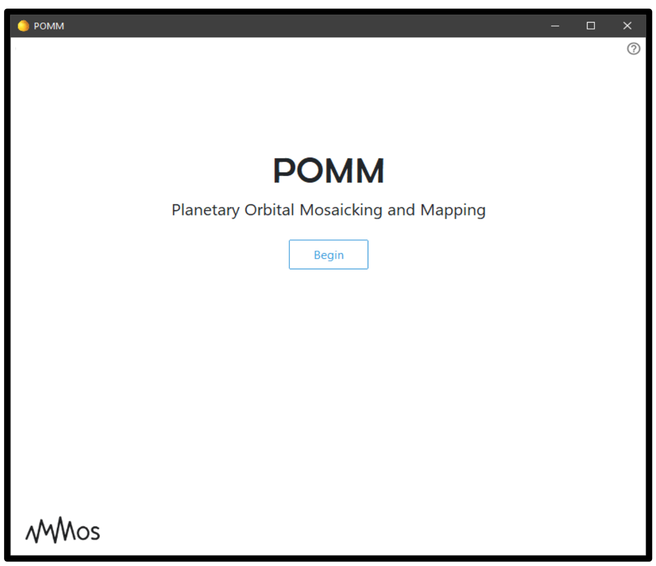


Figure 3-1: POMM Launch Dialog Box.

POMM locks your current Linux terminal window, so open a second window to access and view temporary files and products (in the default output "finalmos" directory).

A "Home" icon can be found in the upper left corner (except Figure 3-1) along with a "Help" icon in the upper right corner. Use the "Home" button to quickly return to this page from other menu pages, and use the "Help" button to learn about the current POMM menu options:

 Home  Help

Click the "Begin" button to enter the POMM menu environment.

3.2.1 Planet Selection Menu

Click your planet or moon of interest. Then press “Continue” to proceed.

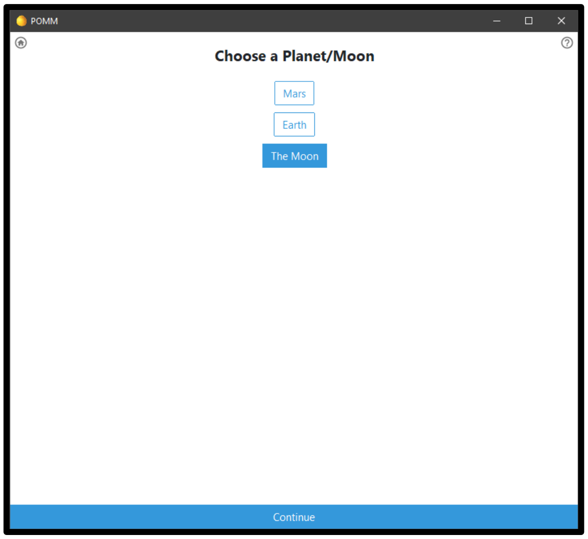


Figure 3-2: Planet/Moon Selection Dialog Box.

Choose one planet/moon for your study case. Planet-specific mosaicking and mapping software has been developed and tested for Mars, Earth, and the Earth’s Moon/Luna, and partially installed for future Ceres and Europa applications. The POMM mapping software assumes a hard-body spherical world and is currently incompatible with irregular-shaped and small bodies (e.g., asteroids). Future support for gas planets is problematic given the motion associated with their surface expression.

3.2.2 Tool Kit Operations Menu

Click/Select the POMM application tool you want to perform:

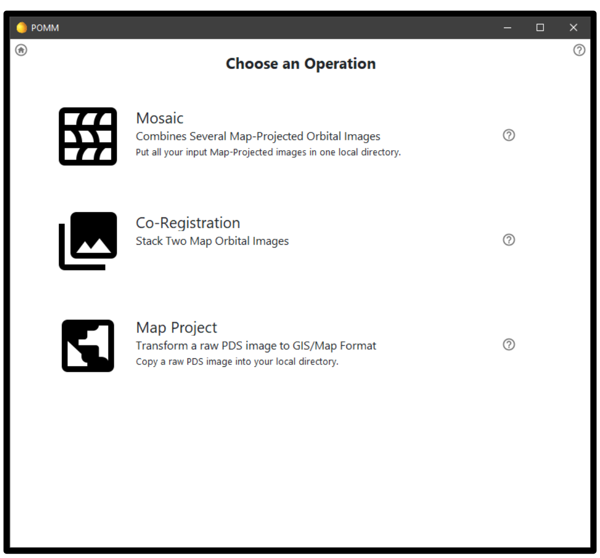


Figure 3-3: POMM Application Tool Selection Box.

Mosaic…

This option mosaics two or more adjacent map-projected images. The inputs can be from different satellite sensors and resolutions (e.g., CTX and HRSC) as long as they are map-projected, overlap, and have similar brightness histograms. There is no specific limit to the number of input images to mosaic, but specifying a very large mosaic should be considered relative to available cpu performance and disk space resources. All input images (or links) must be in one directory. Directory path and filenames must follow standard Linux filename conventions (e.g., no blanks or special characters). Accepted map/georeferenced file formats include 8bit and 16bit: .tif (geotiff); .jp2 (jpeg2000); .img (PDS); and .vic (vicarGT). 100% overlapping images will not be "blended" in the output mosaic, but co-registered and output as separate image files. Polar mosaicking is not currently supported.

Co-Registration…

This option adjusts the geometry of a secondary image to align with the first (master reference) image. Use this tool to co-register and stack time series satellite images that may have offsets (200+ meters) relative to each other. The inputs can be from different satellite sensors and resolutions (e.g., CTX and HRSC) as long as they are map-projected and have a large overlap. The secondary image can be matched to dimensions of the master image (Option 1), or both (master and secondary images) trimmed to the size of the secondary image (with padding; Option 2). A tiepoint file is output, but is relative to the master image and an intermediate projected version of the second image (also output). Note that the quality of the co-registration will be limited by the quality of the original map projections (and their elevation models in high terrain areas). The input images (or links) must be in one local directory. Directory path and filenames should must follow standard Linux filename conventions (e.g., no blanks or special characters). Accepted georeferenced file formats include 8bit and 16bit: .tif (geotiff); .jp2 (jpeg2000); .img (PDS); and .vic (vicarGT). Polar co-registration is not currently supported.

Map-Projection…

Use this tool to map project a raw/EDR image in PDS format when existing map projected images are not available. Currently supported images include:

Mars:

- MRO CTX (Context Camera)
- MRO HiRISE (HIgh Resolution Imaging Science Experiment) – Red band
- MEX HRSC (High Resolution Stereo Camera) – nd2 format.

Luna/Moon:

- LRO NAC (Narrow Angle Camera) – "LE/RE" Uncalibrated PDS format
- LRO WAC (Wide Angle Camera) – "CC" Calibrated PDS format; COLOR VIS Bands 1-5

POMM uses the GLAS/RSM (Replacement Sensor Model) camera model for geometric map projection, and ISIS software for radiometric calibration. An optional high-resolution DEM model may be provided for terrain correction or a standard global DEM model used by default. Five output map projection choices are available. Note that NAIF SPICE kernels are required for ephemeris processing and are automatically downloaded as needed (except for MEX/HRSC, which were pre-loaded by POMM). Polar map projection is not currently supported.

3.3 Mosaicking Menu Options

POMM Mosaicking parameters are solicited via two menus. Click the “Continue” button when all parameters have been entered.

3.3.1 Mosaicking Menu 1

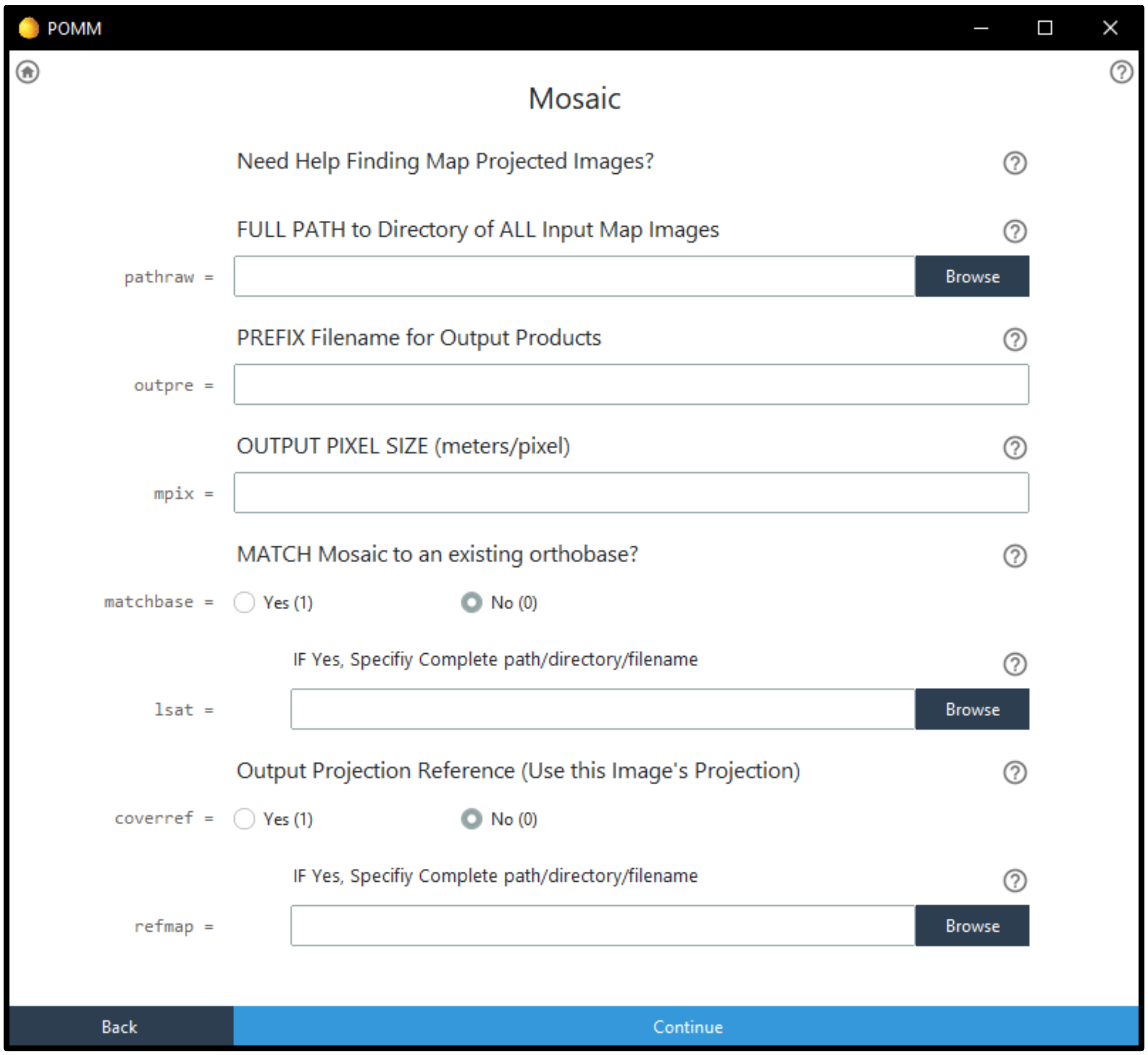


Figure 3-4: POMM Mosaicking Parameter Entry Menu 1.

Help Mosaicking… [Upper Right Menu Corner]

This option mosaics two or more adjacent map-projected images. The inputs can be from different satellite sensors and resolutions (e.g., CTX and HRSC) as long as they are map-projected, overlap, and have similar brightness histograms. There is no specific limit to the number of input images to mosaic, but specifying a very large mosaic should be considered relative to available cpu performance and disk space resources. All input images (or links) must be in one directory. Accepted map/ georeferenced file formats include: .tif (geotiff); .jp2 (jpeg2000); .img (PDS); and .vic (vicarGT). POMM employs automated mosaicking techniques for near-seamless geometric edge matching, brightness feathering and block adjustment between and across images. 100% overlapping images will not be "blended" in the output mosaic, but co-registered and output as separate image files. Disconnected images ("islands") will not be matched or feathered with neighboring images, and can significantly expand the size of the mosaic. Polar mosaicking is not currently supported. Mosaic outputs include:

*prefix*_mosaic.tif – Output multi-image mosaic.
*prefix_1st_input_filename.*tif – First image in mosaic space; Not edge matched.
*prefix_2nd_input_filename.*tif – Second image in mosaic space; Not edge matched.
etc.
*prefix*_mosaic_log.csv. – POMM/VICAR/AFIDS processing log (text).
*prefix*_mosaic_receipt.csv – POMM receipt (summary) text file.

Need HELP Finding PDS Images for Projection?...

Click the Help/Question button for tips on where to find map projected orbital imagery for mosaicking. The discussion can also be found in Section 4.2 of this document.

FULL PATH to Directory of ALL Input Map Images…

Browse to, or enter the path to a local Linux directory containing ALL input images.

Example: /data/myfiles/mars_ctx/maps

The path must be a complete (full/absolute/canonical) specification through the file system. The directory path must be less than 121 characters and the directory must contain ALL (and ***only***) the input map-projected images (or links) to be mosaicked. Individual filenames should not exceed 54 characters and should follow standard Linux filename conventions (e.g., no blanks or special characters). Acceptable georeferenced file formats include: .tif (geotiff); .jp2 (jpeg2000); .img (PDS); and .vic (vicarGT).

PREFIX Filename for Output Products (<30 characters)…

Output filenames will start with this supplied description/prefix.

Example: ctx_hrsc_siteA

The prefix should not exceed 30 characters and should follow standard Linux filename conventions (e.g., no blanks or special characters). "_mosaic.tif" text is attached after the prefix. Example: ctx_hrsc_siteA_mosaic.tif.

OUTPUT Pixel Size (meters/pixel)…

The output mosaic is resampled to the specified pixel resolution (meters).

Example: 6.0

Generally, this should be the lowest resolution of all the input images to avoid uneven image quality. Increasing the resolution can *dramatically* increase the output mosaic size and processing time, and may produce unsatisfactory results. Typical pixel scales for CTX are 5.5 to 6.5 meters. HRSC scales are typically 12.0 or 12.5 pixels, although some HRSC collections may be 20, 50, or 100 meters. HiRISE mosaicks are typically 0.25 to 2.0m/pxl (with 1.0m/pxl a good balance between processing time and image quality).

MATCH Mosaic to an existing orthobase?...

Click the **Yes** box to co-register the mosaic to an *existing map-projected mosaic or orthobase*. The output mosaic will then assume the pixel resolution, map projection, and dimensions of the supplied map base. This option is useful for aligning spectral band mosaics and stacking multiple mosaics.

If the **Yes** box is clicked, Browse to, or enter the complete (full/absolute/canonical) path and filename of the map-projected “match” image. If the **No** box is clicked, the path/filename entry box is ignored.

Example: /data/mywork/mosaics/mars/ctx_siteA_mosaic.tif

Output Projection Reference…

Click the **Yes** box to apply the map-projection of an *existing image* to the output mosaic. The output mosaic will assume the map projection, but not the resolution or dimensions, of the supplied map base. This option is useful for maintaining a common map-projection across image datasets.

If the **Yes** box is clicked, Browse to, or enter the complete (full/absolute/canonical) path and filename of the map-projected reference image. If the **No** box is clicked, the path/filename entry box is ignored, and the default Latitude-Longitude projection is used.

Example: /data/mywork/mars/maps/ctx_B04_011266_2065_map.tif

3.3.2 MOSAICKING MENU 2

Mosaicking solicitation Menu 2. Click the "Continue" button when all parameters have been entered.

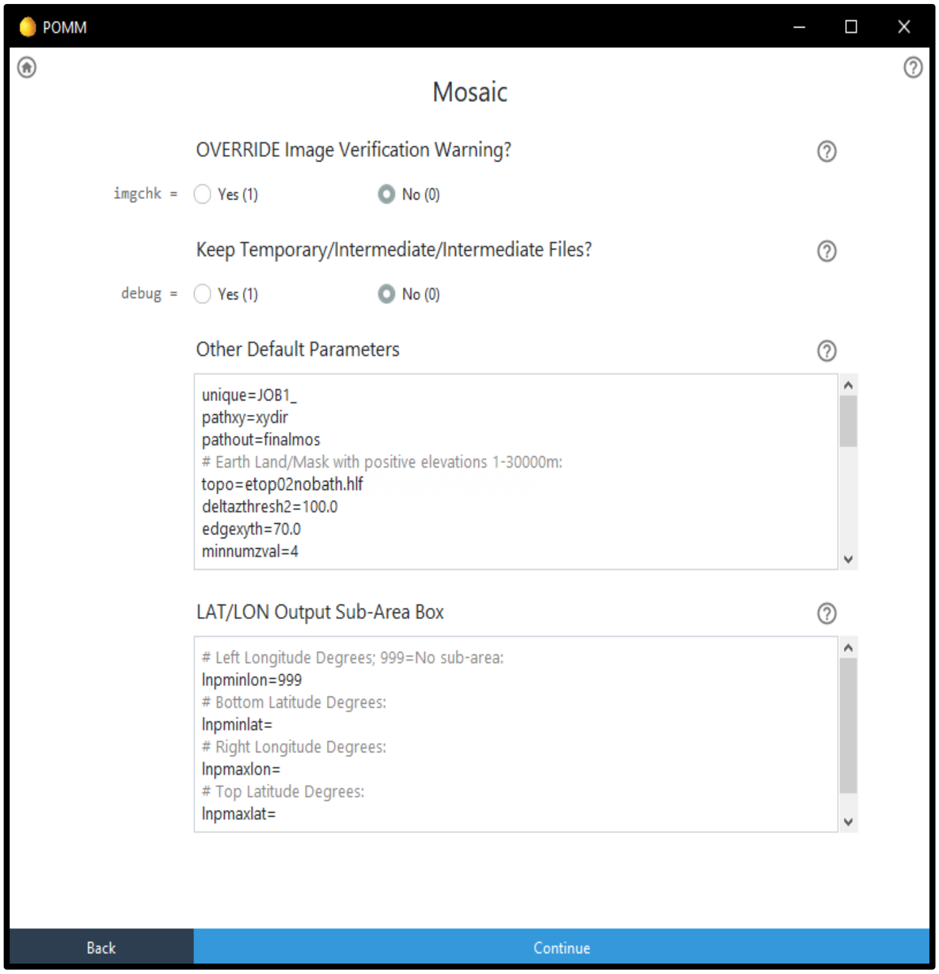


Figure 3-5: POMM Mosaicking Parameter Entry Menu 2.

OVERRIDE Image Verification Warning?...

All input images are checked for a variety of simple issues. If a problem is found, the processing is halted with a warning message. Errors such as "files-not-found" and "unsupported file format" must obviously be corrected immediately, but a difference between 8 or 16-bit format might be fine if their histograms are similar. In that case, click the **Yes** box to override the Image Check and continue processing. The default is **No**, don't override, and stop processing if an issue is detected.

KEEP Temporary/Intermediate Files?...

A large number of temporary working files are produced during the preparation of a POMM mosaic, and written to the local work directory. The default (**No**) deletes these files at the completion of the mosaic. Select **Yes** to keep the temporary files.

OTHER Default Parameters…

These are default POMM processing parameters that have been optimized for Mars, Moon, and Earth mosaicking. In general, they should not be changed without an understanding of their function.

LAT/LON Output Sub-Area Box…

The default value (999) creates an output mosaic with boundaries defined by the outer edges of (all) the input orbital images. These four parameters are used to define an exact Latitude and Longitude boundary (for the output mosaic) which may be larger or smaller than the actual input image coverage. The parameters specify the top and bottom latitudes, and the left and right longitudes. Image pixels (if any) outside the lat/lon boundaries are removed. This will produce data gaps if (optionally) matching to a larger existing orthobase. Examples:

inpminlon=999 (default; acquire lat/lon dimensions from input orbital images)
OR
inpminlon=76.3 (Minimum Longitude; must be in degree units)
inpminlat=17.6 (Minimum Latitude; must be in degree units)
inpmaxlon=78.3 (Maximum Longitude; must be in degree units)
inpmaxlat=19.6 (Minimum Latitude; must be in degree units)

Click the "Continue" button when all parameters have been entered.

3.3.3 MOSAICKING RUN BOX

Upon clicking the "Continue" button in Mosaicking Menu 2 (Figure 3-5), your entered parameters are summarized as shown in the Figure 3-6 below. Use the "Home" button to change and re-enter parameters, then click the "Run" button to launch the POMM Mosaicking task. The Process Log will display in the Running box as a progress and success indicator. Upon completion, click the "Close Application" button to exit POMM. This will return control of your Linux terminal window to you, and the POMM output products will be in the (default) "finalmos" directory, or whichever name you chose as the "pathout" directory.

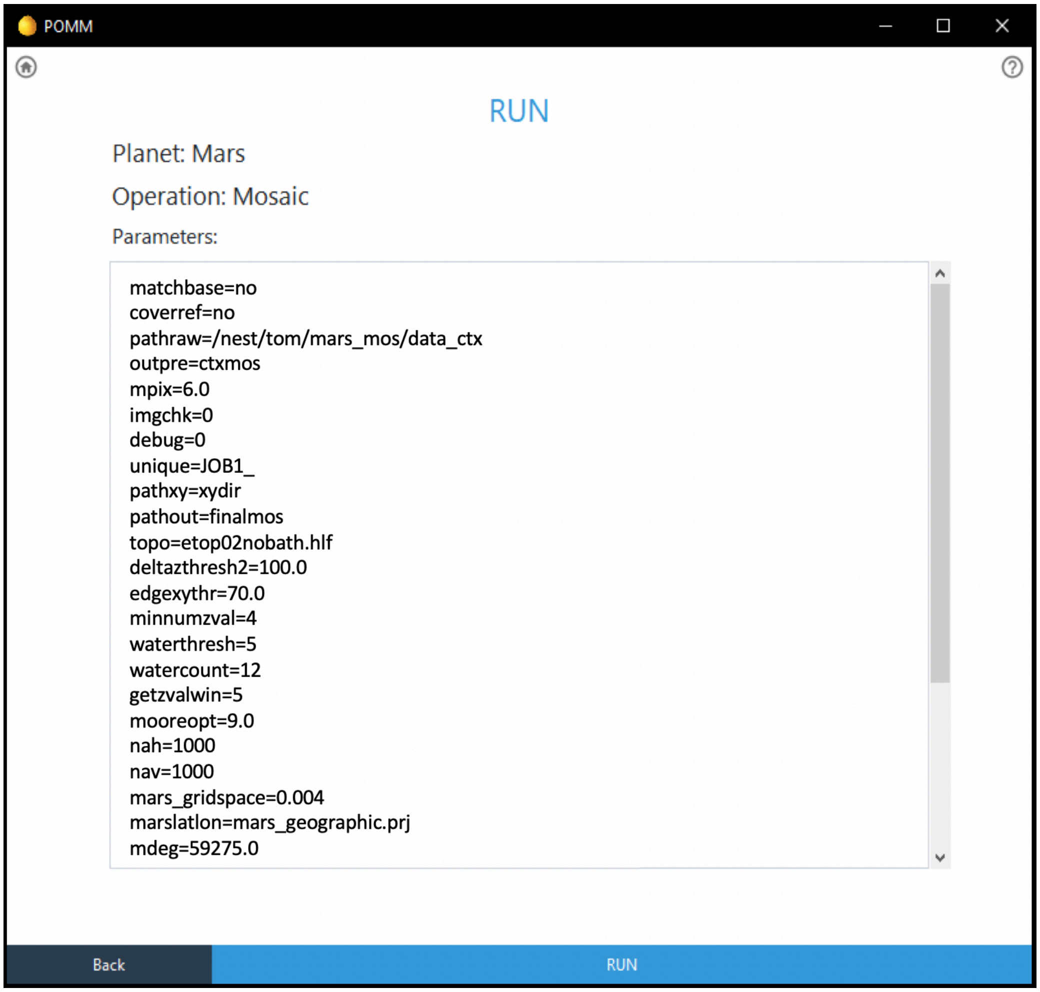


Figure 3-6: POMM Mosaicking Parameter Summary and Run Box.

To manually run the POMM VICAR/AFIDS Mosaic script at the Linux/VICAR Command Line, use your text editor to create the User Parameter File (UPF) containing all required parameters. The contents of an example UPF are shown below. The parameters can be in any order.

```
planet=mars
matchbase=no
coverref=no
pathraw=/nest/tom/mars_mos/data_ctx
outpre=ctxmos
mpix=6.0
imgchk=0
debug=0
unique=JOB1_
pathxy=xydir
pathout=finalmos
topo=etop02nobath.hlf
deltazthresh2=100.0
edgexythr=70.0
minnumzval=4
waterthresh=5
watercount=12
getzvalwin=5
mooreopt=9.0
nah=1000
```

```
nav=1000
mars_gridspace=0.004
marslatlon=mars_geographic.prj
mdeg=59275.0
earth_gridspace=0.004
earthlatlon=earth_geographic.prj
edeg=108000.0
luna_gridspace=0.004
lunalatlon=luna_geographic.prj
ldeg=30322.2
inpminlon=999
inpminlat=999
inpmaxlon=999
inpmaxlat=999
```

The upf filename must consist of two parts: 1) A user-defined prefix, and 2) A hard-wired suffix. For example, if the prefix were “my_mosaic,” the complete and proper UPF filename would be:

my_mosaic_params.upf (where “_params.upf” is required text)

The VICAR/AFIDS Linux command to launch the POMM mosaick task is:

```
vicarb “runtop_pom my_mosaic” >& xxlog.log &
```

where:

“vicarb” is required
the parentheses are required as shown above
the “_params.upf” is NOT specified (the software assumes it is there)
the “>&” or “>” is required
“xxlog.log” is required (this is a temporary log file that is later parsed)
the trailing “&” is required (to submit the job into the background queue)

For those running the POMM at the command line, the following Linux command will display the contents of the xxlog.log file in real-time for progress monitoring:

tail -f xxlog.log

3.4 CO-REGISTRATION/STACKING MENU OPTIONS

POMM Co-Registration parameters are solicited from a single Menu. Click the "Continue" button when all parameters have been entered to display a parameter summary.

3.4.1 CO-REGISTRATION/STACKING MENU

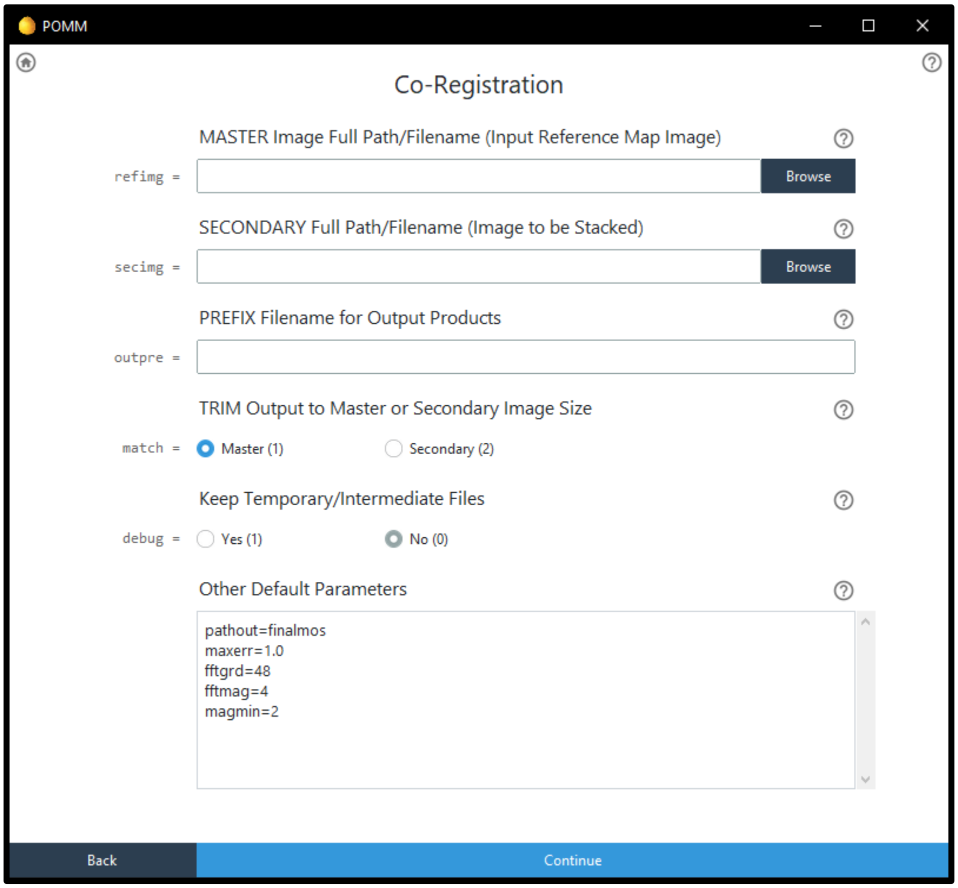


Figure 3-7: POMM Co-Registration/Stacking Parameter Entry Menu.

Help Co-Registration... [Upper Right Menu Corner]

Use this tool to co-register and stack time series satellite images that may have large offsets (100+ meters) relative to each other. The inputs can be from different satellite sensors and resolutions (e.g., CTX and HRSC) as long as they are map-projected (from the same planet) and have a large overlap. The software co-registers the "Second" map image to the "Reference/ Master" map image. The Reference image should be similar or lower resolution than the Second image. With the default option (1), the two registered images are output to the dimensions and projection of the Reference image. With option 2, both (master and secondary images) are trimmed to the size of the secondary image (with added padding). A gridded tiepoint file is output, but is relative to the master image and an "intermediate" projected version of the second image (also output). The tiepoint file (csv/text format) contains six columns: Latitude, Longitude, Reference Image Line, Reference Image Sample, Second Image

Line, and Second Image Sample. Note that the quality of the co-registration will be limited by the quality of the original map projections (and their elevation models in high terrain areas). The two input images (or links) must be in one local directory. Accepted georeferenced input file formats include: .tif (geotiff); .jp2 (jpeg2000); .img (PDS); and .vic (vicarGT). Polar co-registration is not currently supported. Co-registration outputs include:

*prefix*_ref_reg.tif – Co-registered Referenced/Master image.
*prefix*_sec_reg.tif – Co-registered Secondary image.
*prefix*_sec_intermediate.tif – Intermediate scaled Secondary image (unregistered).
*prefix*_tiepoints_6col.csv – Gridded tiepoint file between the Master and Intermediate.
*prefix*_log.csv – POMM/VICAR/AFIDS processing log (text).
*prefix*_receipt.csv – POMM receipt (summary) text file.

MASTER Image Full Path/Filename (Input Reference Map Image)…

Browse to, or enter the path/filename containing the map-projected Master/Reference image.

Example: /data/myfiles/mars/pre-reg/h5270_0000.nd4.50.jp2

The path must be a complete (full/absolute/canonical) specification through the file system. The Directory path/filename must be less than 99 characters and follow standard Linux filename conventions (e.g., no blanks or special characters). Acceptable georeferenced file formats include: .tif (geotiff); .jp2 (jpeg2000); .img (PDS); and .vic (vicarGT).

SECONDARY Full Path/Filename (Image to be Stacked)…

Browse to, or enter the path/filename containing the map-projected Secondary image to-be-co-registered to the Master image.

Example: /data/myfiles/mars/pre-reg/ctx_F05_037752_2008.tif

The path must be a complete (full/absolute/canonical) specification through the file system. The Directory path/filename must be less than 99 characters and follow standard Linux filename conventions (e.g., no blanks or special characters). Acceptable georeferenced file formats include: .tif (geotiff); .jp2 (jpeg2000); .img (PDS); and .vic (vicarGT).

PREFIX Filename for Output Products (<30 characters)…

Output filenames will start with this supplied description/prefix.

Example: hrsc_ctx_siteB

The prefix should not exceed 30 characters and must follow standard Linux filename conventions (e.g., no blanks or special characters). The output products will have appended (file-defining) text. For example:

*hrsc_ctx_siteB*_ref_reg.tif (registered master)
*hrsc_ctx_siteB*_sec_reg.tif (registered secondary)

*hrsc_ctx_siteB*_sec_intermediate.tif (registered intermediate)

TRIM Output to Master or Secondary Image Size…

With the default option (1), the two registered images are output to the dimensions and projection of the Reference image. With option 2, both (master and secondary images) are trimmed to the size of the secondary image (with added padding).

KEEP Temporary/Intermediate Files?...

A large number of temporary working files are produced during the co-registration process, and written to the local work directory. The default (**No**) deletes those files at the completion of the mosaic. Select **Yes** to keep the temporary files.

OTHER Default Parameters…

These are default POMM co-registration parameters that have been found to provide a balance between speed and accuracy. However, if better accuracy is required, the "fftgrd" parameter can be increased to a maximum of 64. In general, these parameters should not be changed without an understanding of their function.

3.4.2 Co-Registration Run Box

Upon clicking the "Continue" button in the Co-Registration Menu (Figure 3-7), your entered parameters are summarized as shown in the Figure 3-8 below. Use the "Home" button to change and re-enter parameters, then click the "Run" button to launch the POMM Co-Registration task. The Process Log will display in the Running box as a progress and success indicator. Upon completion, click the "Close Application" button to exit POMM. This will return control of your Linux terminal window to you, and the POMM output products will be in the (default) "finalmos" directory, or whichever name you chose as the "pathout" directory.

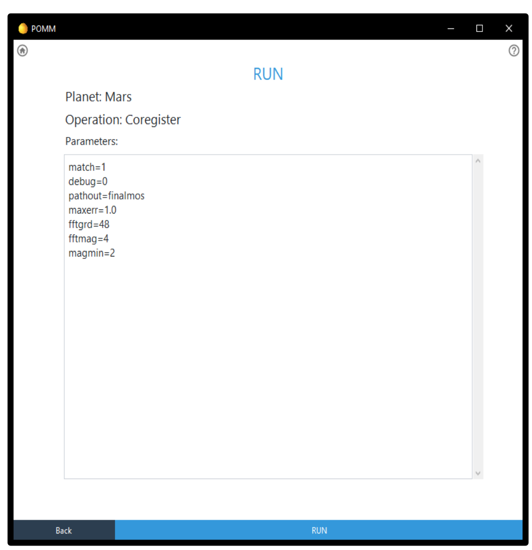


Figure 3-8: POMM Co-Registration/Stacking Parameter Summary and Run Box.

To manually run the POMM VICAR/AFIDS Co-Registration script at the Linux/VICAR Command Line, use your text editor to create the User Parameter File (UPF) containing all required parameters. The contents of an example UPF are shown below. The parameters can be in any order.

```
refimg=/data/mars/hrsc/map/h5270_0000.nd4.50.jp2
secimg=/data/mars/ctx/map/rectF05_037752_2008.tif
outpre=nest_coreg
match=1
debug=0
pathout=finalmos
maxerr=1.0
fftgrd=48
fftmag=4
magmin=2
```

The upf filename must consist of two parts: 1) A user-defined prefix, and 2) A hard-wired suffix. For example, if the prefix were “my_stackjob,” the complete and proper UPF filename would be:

my_stackjob_params.upf (where “_params.upf” is required text)

The VICAR/AFIDS Linux command to launch the POMM co-registration task is:

```
vicarb “runtop_nest my_stackjob” >& xxlog.log &
```

where:

“vicarb” is required
the parentheses are required as shown above
the “_params.upf” text is NOT specified (the software assumes it is there)
the “>&” or “>” is required
“xxlog.log” is required (this is a temporary log file that is later parsed)
the trailing “&” is required (to submit the job into the background queue)

For those running the POMM at the command line, the following Linux command will display the contents of the xxlog.log file in real-time for progress monitoring:

tail -f xxlog.log

3.5 Map Projection Menu Options

POMM map projection parameters are solicited from two Menus. Click the “Continue” button after all parameters have been entered to display a parameter summary and the “Run” button.

3.5.1 Map Projection Menu 1

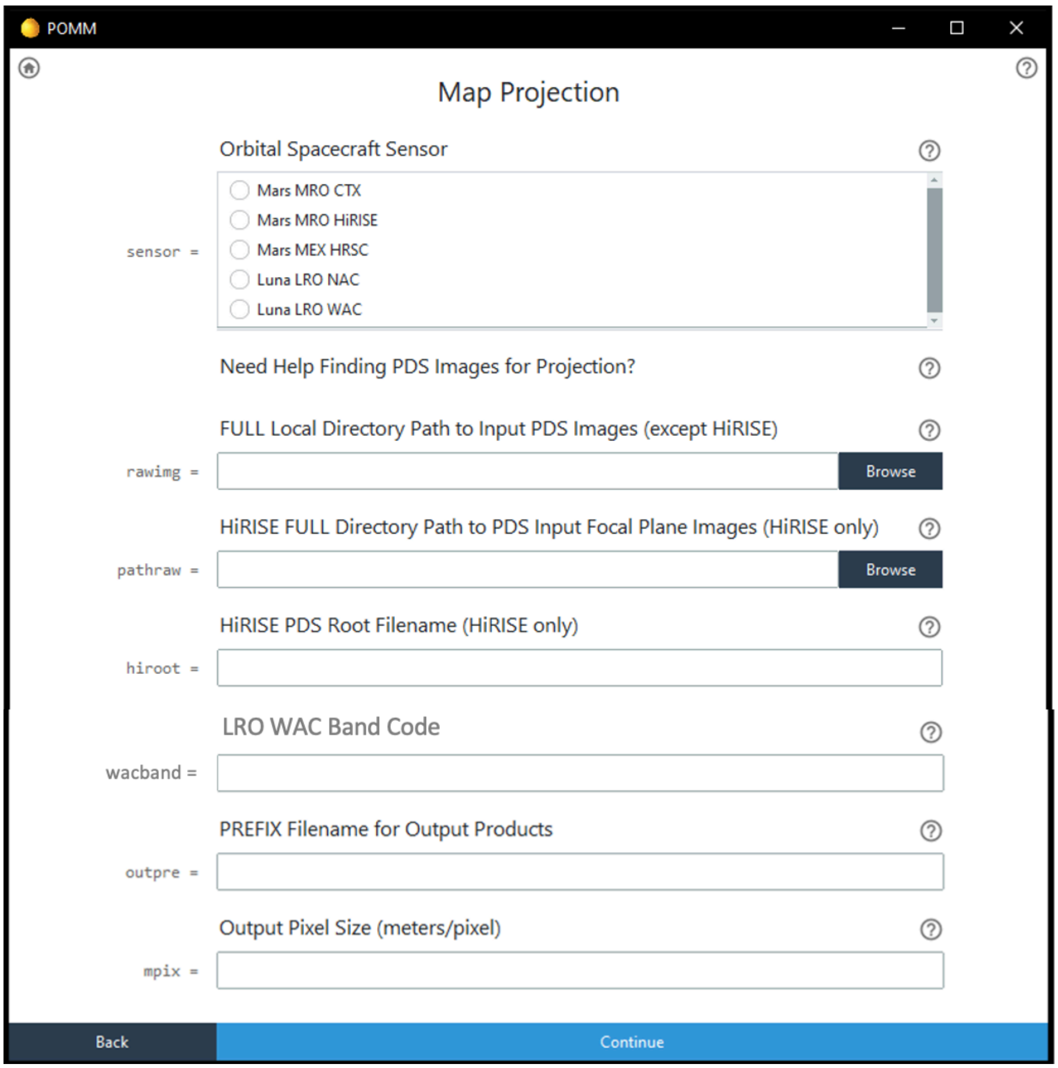


Figure 3-9: POMM Map Projection Parameter Entry Menu Box 1.

Help Map-Projection… [Upper Right Menu Corner]

Use this tool to map project raw/EDR/CDR images in PDS format when existing map projected images are not available. Currently supported mission sensors include:

Mars:

- MRO CTX (Context Camera)
- MRO HiRISE (HIgh Resolution Imaging Science Experiment) – Red band
- MEX HRSC (High Resolution Stereo Camera) – nd2 format.

Luna/Moon:

- LRO NAC (Narrow Angle Camera "LE/RE" Uncalibrated format)
- LRO WAC (Wide Angle Camera "CC" Calibrated format) – COLOR VIS Bands 1-5

POMM does not provide specific Earth map projection support because the most common Earth orbital missions (Landsat 7/8/9; Sentinel 2A/B) are already available in map-projected GIS product formats.

POMM uses the GLAS/RSM (Replacement Sensor Model) camera model for geometric map projection, and ISIS software for radiometric calibration. An optional high-resolution DEM model may be provided for terrain correction or a standard global DEM model (provided) used by default. Three output map projection choices are available. Note that NAIF SPICE kernels are required for ephemeris processing and the base files are pre-loaded by POMM. However, specific sensor image kernels are automatically downloaded as needed using the ISIS "spiceinit" tool, therefore requiring an active internet connection. Polar map projection is not currently supported. Map projection outputs include:

*prefix*_map.tif – Map-projected output image.
*prefix*_log.csv – POMM/VICAR/AFIDS processing log (text).
*prefix*_receipt.csv – POMM receipt (summary) text file.

SELECT Orbital Spacecraft Sensor…

Choose the mission sensor to be converted from raw PDS format to map-projected GeoTiff format. Current POMM (v1) options include:

Mars:
MRO CTX (Context Camera)
MRO HiRISE (High Resolution Imaging Science Experiment) – Red band.
MEX HRSC (High Resolution Stereo Camera) – nd2 format.
Luna/Moon:
LRO NAC (Narrow Angle Camera) – "LE/RE" Uncalibrated format.
LRO WAC (Wide Angle Camera) – "CC" Calibrated format; COLOR VIS Bands 1-5

Need HELP Finding PDS Images for Projection?...

Click the Help/Question button for tips on where to find map projected orbital imagery for mosaicking. The discussion can also be found in Section 4.2 of this document.

FULL Path/Filename to the Input Raw/PDS Image… (except HiRISE)

Browse to, or enter the path/filename containing the raw/EDR PDS image. Examples:

/data/myfiles/mars/raw_pds/B04_011266_2065_XN_26N065W.IMG	[CTX]
/data/myfiles/mars/raw_pds/h5235_0000_nd2.img	[HRSC]
/data/myfiles/luna/pds/M133513417LE.IMG	[NAC]
/data/myfiles/luna/pds/M1124542975CC.IMG	[WAC]

PDS files use the ".IMG" or ".img" suffix. (Tiff ".tif" and jpeg ".jpg; .jp2" are not valid.) The path must be a complete (full/absolute/canonical) specification through the file system. The combined directory path and filename must be less than 250 characters and follow standard Linux filename conventions (e.g., no blanks or special characters).

HiRISE FULL Directory Path to Input PDS Focal Plane Images…

Browse to, or enter the *path t*o a local Linux *directory* containing the input HiRISE focal plane images. Example path:

/data/myfiles/mars/hirise_pds

Raw PDS HiRISE imagery consists of (up to) 10 focal planes (0-9), each split into two parts (0/1; both parts are required). (Set 9 [the 10th fpa] is usually excluded because of severe degradation.) FPA Set 0 *must always be the starting set*. For example, an input collection might specify Sets 0-3 or 0-8, but a collection of Sets 2-4 would be *invalid*. Only the Red band is currently supported. An example HiRISE input collection for Sets 0-2:

PSP_002387_1985_RED**0**_0.IMG
PSP_002387_1985_RED**0**_1.IMG
PSP_002387_1985_RED**1**_0.IMG
PSP_002387_1985_RED**1**_1.IMG
PSP_002387_1985_RED**2**_0.IMG
PSP_002387_1985_RED**2**_1.IMG

The path must be a complete (full/absolute/canonical) specification through your file system, be less than 250 characters, and follow standard Linux filename conventions.

HiRISE PDS Root Filename…

Enter the root filename for the HiRISE imagery. This name must be *generic* to all the input HiRISE files and should end in "RED". Example:

PSP_002387_1985_RED

POMM will use this filename root (wildcard) to find all the focal plane files. Only the Red band is currently supported (BG and IR are future upgrades). *Leave this field blank* if CTX, HRSC, NAC, or other sensor data are being processed.

WAC “CC” PDS Band Number Code…

Enter the integer Band Number “code” of the input LRO WAC (Wide Angle Camera “CC” format) PDS image to-be-processed. The WAC “CC” PDS file contains “COLOR” mode files from the UV and VIS sensors. Currently only the VIS sensors are supported via “wacband” codes 3-7:

Codes:

1 - UV1 (321 nm) (not supported)
2 - UV2 (360 nm) (not supported)
3 - VIS 1 (415 nm)
4 - VIS 2 (566 nm)
5 - VIS 3 (604 nm)
6 - VIS 4 (643 nm)
7 - VIS 5 (689 nm)

PREFIX Filename for Output Products (<30 characters)…

Output filenames will start with *this* supplied description/prefix.

Example: ctx_B04_011266

The prefix should not exceed 30 characters and must follow standard Linux filename conventions (e.g., no blanks or special characters). The output map product will have “_map.tif” appended as part of the filename. For example: ctx_B04_011266_map.tif

Output Pixel Size (meters/pixel)…

The output map-projected image is resampled to the specified pixel resolution (meters).

Example: 6.0

Typical pixel scales for CTX are 5.5 to 6.5 meters. HRSC scales are typically 12.0 or 12.5 pixels, although some collections may be 20, 50, or 100 meters. HiRISE images are typically 0.25 to 2.0m/pxl (1 meter/pixel provides a good balance of fast processing and reduced artifacts). The LRO NAC (Narrow Angle Camera) resolution should be specified as 0.5m or 1.0m/pxl if subsequent POMM mosaicking is planned (coarser resolutions don’t permit enough pixel overlap). The nominal WAC (Wide Angle Camera) pixel resolution is 95-100m, but can be reduced to 200m or coarser.

Click the “Continue” button with Map Projection Menu 1 is complete.

3.5.2 MAP PROJECTION MENU 2

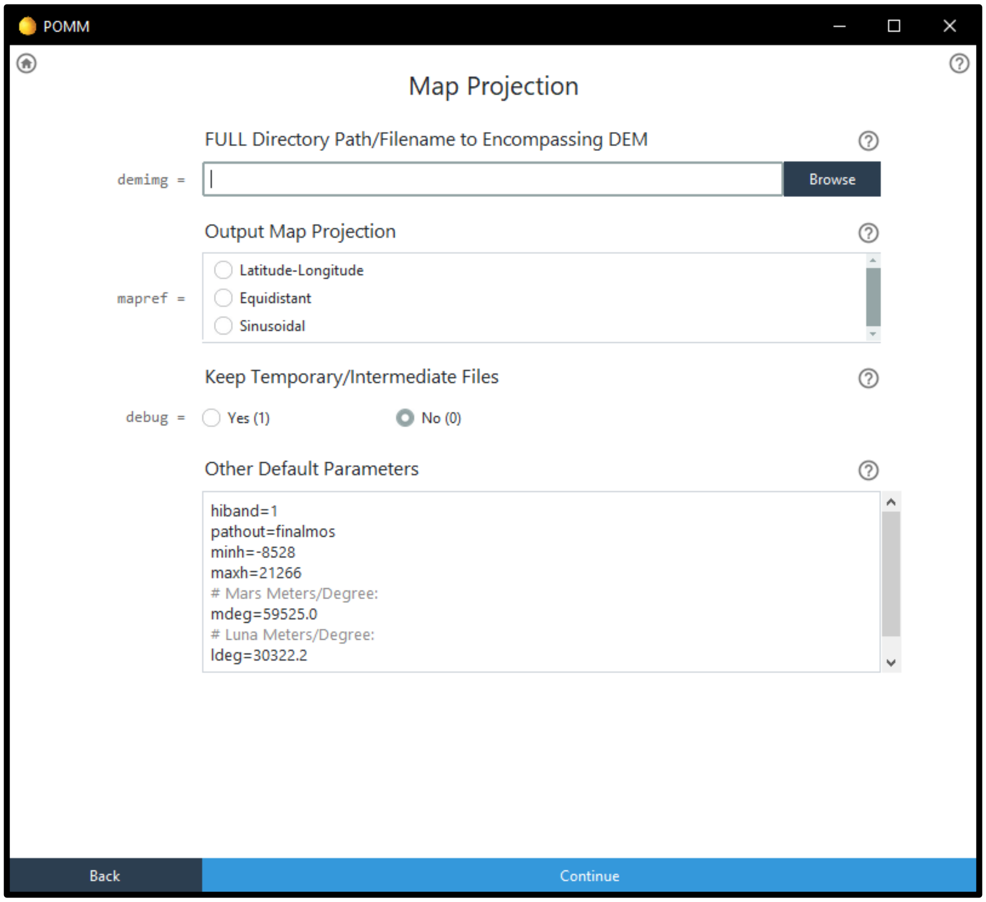


Figure 3-10: POMM Map Projection Parameter Entry Menu Box 2.

FULL Directory Path/Filename to Encompassing DEM…

Browse or enter the path/filename of a DEM fully covering the area of the mosaic. The quality of the DEM significantly affects the quality of the map projection. POMM-provided global DEMs for Mars and the Moon are listed below. User-supplied higher resolution DEMs should produce a better map-projected product. The path for a user-supplied DEM must be a complete (full/absolute/canonical) specification through the file system. For the supplied DEMS, use the linux “printenv” command to identify the DEM path (type “printenv AFIDS_PLANET_DEM” to identify the directory path.

In a Linux terminal window type: printenv AFIDS_PLANET_DEM

Available DEMS: &path/Mars_HRSC_MOLA_BlendedDEM_Global_200mp_v2.tif

&path/Lunar_LRO_LOLAKaguya_DEM_59m_60N60S.vic

&path/luna_dem/Lunar_LRO_LOLA_Global_LDEM_118m_Mar2014.vic

The combined Directory path and filename must be less than 250 characters and follow standard Linux filename conventions (e.g., no blanks or special characters). Acceptable georeferenced DEM formats include: .tif (geotiff); .jp2 (jpeg2000); and .vic (vicarGT).

Output Map Projection…

Select the output map-projection. POMM (v1) choices currently include: Latitude-Longitude, Equidistant, and Sinusoidal.

KEEP Temporary/Intermediate Files?...

A large number of temporary working files are produced during the co-registration process, and are written to the local work directory. The default (**No**) deletes those files at the completion of the mosaic. Select **Yes** to keep the temporary files.

OTHER Default Parameters…

These default POMM map projection parameters define the number of meters per lat/lon degree on Mars and Luna, the elevation range (max/min) of the DEM (for the AOI), the Red HiRISE band (1), and the output directory name. In general, these parameters should not be changed without a full understanding of their function. The maximum elevation ranges (meters) are:

Mars: -8528 to 21266

Luna: -18257 to 21563

3.5.3 MAP PROJECTION RUN BOX

Upon clicking the “Continue” button in the Map Projection Menu-2 (Figure 3-10), your entered parameters are summarized as shown in the Figure 3-11 below. Use the “Home” button to change and re-enter parameters, then click the “Run” button to launch the POMM Map Projection task. The Process Log will display in the Running box as a progress and success indicator. Upon completion, click the “Close Application” button to exit POMM. This will return control of your Linux terminal window to you, and the POMM output products will be in the (default) “finalmos” directory, or whichever name you chose as the “pathout” directory.

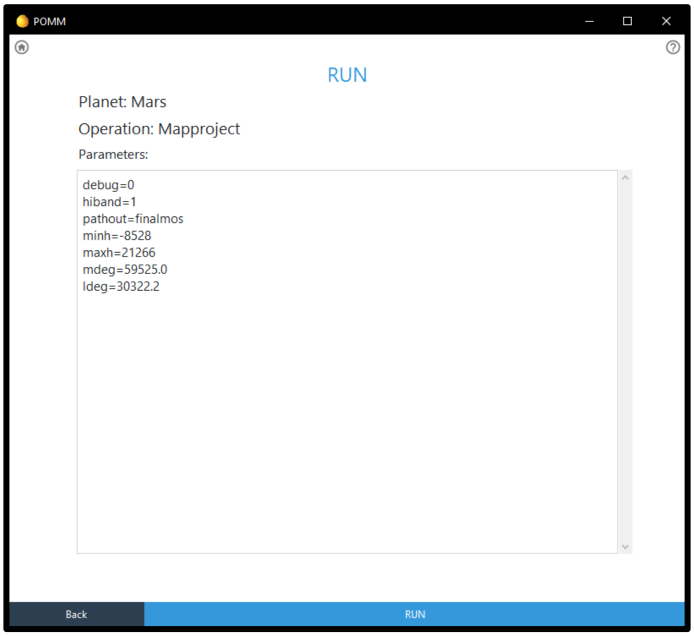


Figure 3-11: POMM Map Projection Parameter Summary and Run Box.

To manually run the POMM VICAR/AFIDS Map Projection script at the Linux/VICAR Command Line, use your text editor to create the User Parameter File (UPF) containing all required parameters. The contents of an example UPF are shown below. The parameters can be in any order.

```
planet=mars
sensor=ctx
rawimg=/data/mars_misc/B04_011266_2065_XN_26N065W.IMG
outpre=ctx_B04_011266_2065
pathraw=
hiroot=
hiband=1
wacband=
mpix=6.0
mapref=mars_proj_latlon.vic
pathout=finalmos
debug=0
minh=-8528
maxh=21266
mdeg=59275.0
ldeg=30322.2
```

The upf filename must consist of two parts: 1) A user-defined prefix, and 2) A hard-wired suffix. For example, if the prefix were “my_mapjob,” the complete and proper UPF filename would be:

my_mapjob_params.upf   (where “_params.upf” is required text)

The VICAR/AFIDS Linux command to launch the POMM mapping task is:

```
vicarb “runtop_map my_mapjob” >& xxlog.log &
```

where:

“vicarb” is required
the parentheses are required as shown above

the “_params.upf” text is NOT specified (the software assumes it is there)
the “>&” or “>” is required
“xxlog.log” is required (this is a temporary log file that is later parsed)
the trailing “&” is required (to submit the job into the background queue)

For those running the POMM at the command line, the following Linux command will display the contents of the xxlog.log file in real-time for progress monitoring:

```
tail -f xxlog.log
```

4 POMM Data Sources

4.1 POMM-Provided Data

POMM comes packaged with global planetary DEM elevation models and map projection reference files. The global DEMs facilitate the creation of map-projected products throughout the Mars and Luna worlds (excluding polar areas). However, their coarse resolution can reduce projection quality. The user should supply their own high resolution DEMs whenever possible. POMM-provided global DEMs are stored in a directory:

<local drive>/PommDelivery/install/pomm_data/planet_dem/

And include:

Mars_HRSC_MOLA_BlendDEM_Global_200mp_v2.hlf
Lunar_LRO_LOLAKaguya_DEM_59m_60N60S.vic
Lunar_LRO_LOLA_Global_LDEM_118m_Mar2014.vic

The map projection references are stored in a directory:

<local drive>/PommDelivery/install/pomm_data/projdef/

And include:

earth_geographic.prj
luna_equidistant.prj
luna_geographic.prj
luna_north_pole_stereographic.prj (future use)
luna_sinusoidal.prj
luna_south_pole_stereographic.prj (future use)
mars_equidistant.prj
mars_geographic.prj
mars_north_pole_stereographic.prj (future use)
mars_sinusoidal.prj
mars_south_pole_stereographic.prj (future use)

4.2 Where To Find Planetary Orbital Map-Projected and Raw Imagery

The Scientist or Planetary Enthusiast POMM user is expected to have their map-projected or raw PDS inputs locally available as an outgrowth of their study or hobby. However, it is useful to review the process and resources available for identifying a Planetary Area-of-Interest (AOI), as well as finding POMM-input raw PDS and mapped orbital imagery.

4.2.1 Finding A Mars Or Luna/Moon Area-of-Interest (AOI)

The following websites can be perused to find interesting areas (AOI) on the Moon or Mars. Be sure to record your AOI's latitude/longitude coordinates and planetary feature name (if available).

- Mars Trek: https://trek.nasa.gov/mars/
- Moon Trek: https://trek.nasa.gov/moon/
- I-Mars GIS: http://i-mars.eu/web-gis/

4.2.2 Find and Download Mars or Luna/Moon Orbital Images

- USGS Pilot: https://pilot.wr.usgs.gov/
  - Interactive Mars and Earth/Moon image locator. Select raw images, view footprints, and download. See Figures 4-1 and 4-2.
- Orbital Data Explorer (PDS Geosciences Node): https://ode.rsl.wustl.edu/
  - Select "Mars Orbital Explorer" to find Mars CTX, HiRISE, and HRSC raw (and HRSC mapped) images, and download. See Figures 4-3 and 4-4.
  - Select "Lunar Orbital Data Explorer" to find Moon NAC and WAC raw and mapped images, and download. See Figures 4-3 and 4-4.
- ESA Planetary Science Archive (PSA): https://archives.esac.esa.int/psa/#!Home%20View
  - Select "Instruments=**HRSC;**" "Processing Level=Level 2;" Location, etc.

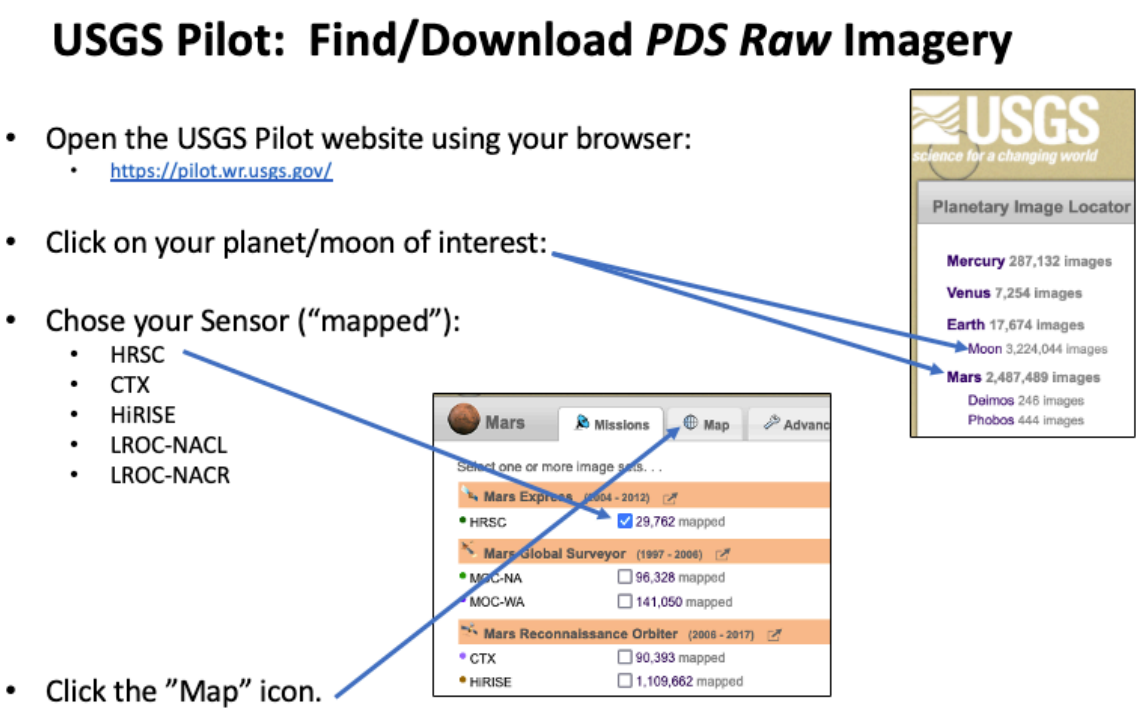
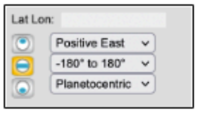
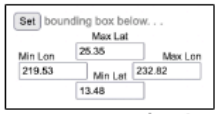


Figure 4-1. "USGS Pilot" Orbital Planetary Data Website.

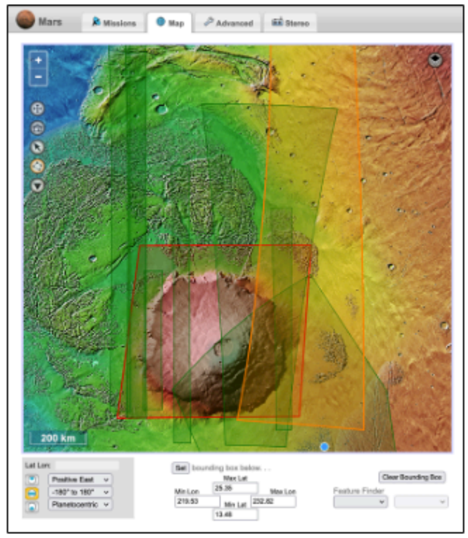
Using USGS Pilot (cont.)

- Zoom and Scroll around the Map until you find your AOI.
- Use the Polygon Tool to define your AOI, or enter your AOI's Lat/Lon coordinates:





- Hoover your cursor over the image icons to see their filenames.
- Click the image icons to display their footprint and overview picture.
  - Image Information Toggle
  - Image Download (See Next Pages)
  - Image Footprint Toggle
  - Image Picture (Click "close" to Close)



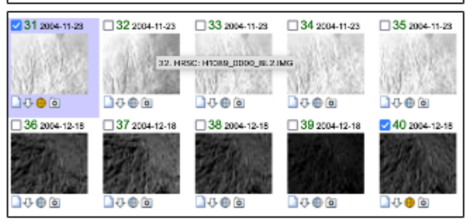
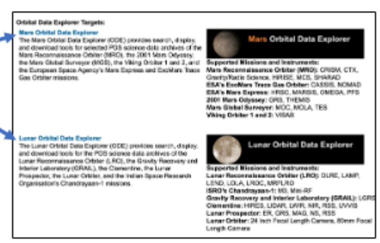


Figure 4-2. Using the "USGS Pilot" Orbital Planetary Data Website.

Orbital Data Explorer: Find/Download PDS Raw and Map-Projected Imagery

- Open the Orbital Data Explorer website using your browser:
  - https://ode.rsl.wustl.edu/
- Click on your Planet/Moon of Interest:
- Select "Map Search", then:
  - Zoom/Scroll the map to your AOI
  - Select the Rectangle or Polygon icon and draw/define your specific image area.
  - Optionally select:
    - Display by Area
    - Feature Layer



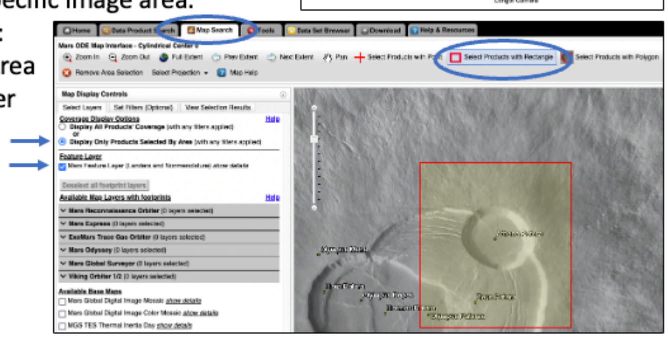


Figure 4-3. "Orbital Data Explorer" (ODE) Planetary Data Website.

Using ODE (cont.)

- To show CTX footprints, Select:
  - **Mars Reconnaissance Orbiter**, then
  - **CTX**, then
  - **Raw and Derived**, then
    - Check the EDR box (for raw PDS files)
    - Mapped RDR images are not available.
  - Click the Yellow box to display available Images.
  - Click an image to display foot-prints, and see download options.
  - Procedure is similar for HiRISE and HRSC.

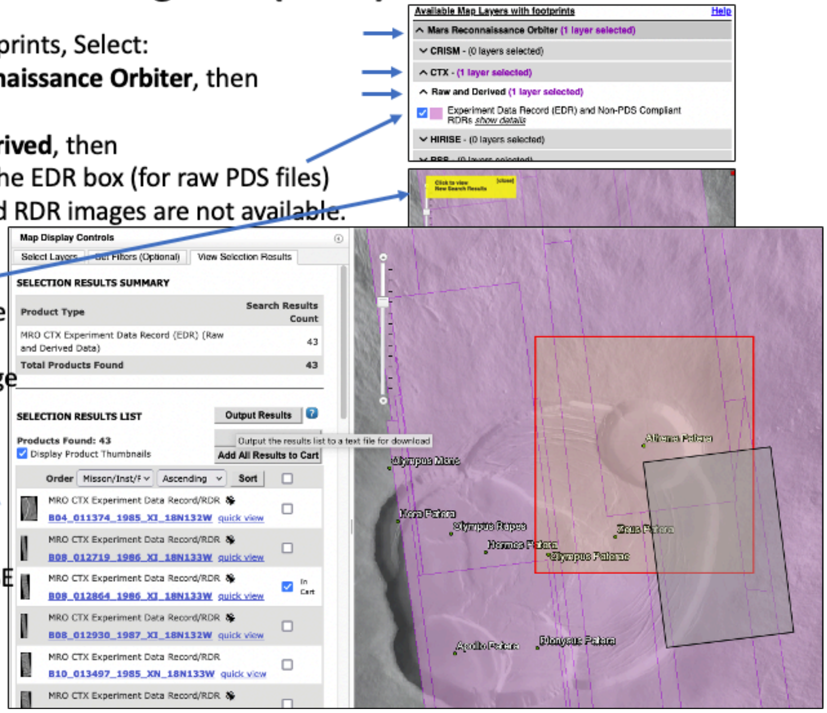


Figure 4-4. Using “Orbital Data Explorer” (ODE) Planetary Data Website.

4.2.3 OTHER MARS ORBITAL IMAGE SOURCES

- HRSC Raw (level-2) Sources: [Can replace “https:” with “ftp:” for download]
  - Circa JAN2023: HRSC level-2 may only be available from the ESA-PSA (Section 4.2.2).
  - https://pds-geosciences.wustl.edu/mex/mex-m-hrsc-3-rdr-v3/mexhrs_1001/data
  - http://i-mars.eu/web-gis/
    - HRSC single-strip footprints
      - Level-3 single-strip images
- HRSC Map-Projected (nd4) Sources:
  - http://www.i-mars.eu/publications/products/dt4_da4_nd4
  - http://i-mars.eu/web-gis/
    - HRSC single-strip footprints
      - Level-4 single-strip images (archive)
      - Level-4 single-strip images (prelim.)
  - https://archives.esac.esa.int/psa/ftp/MARS-EXPRESS/HRSC/
- CTX/HiRISE Raw PDS (Level 0) Images:
  - https://pds-imaging.jpl.nasa.gov/volumes/mro.html. (CTX and HiRISE)
  - https://pds-imaging.jpl.nasa.gov/data/mro/mars_reconnaissance_orbiter/ctx/ (CTX)
- CTX Map-Projected Images:
  - https://archives.esac.esa.int/psa/ftp/Guest-Storage-Facility/UCL-MSSL_iMars_CTX_V1.0/
- HiRISE Map-Projected Images:
  - https://hirise-pds.lpl.arizona.edu/PDS/RDR/

4.2.4 Other Luna/Moon Orbital Image Sources

LROC NAC and WAC PDS Archives:

https://pds.lroc.asu.edu/data/

"The LROC Planetary Data System archive is divided into three sections: Engineering Data Records (EDRs) are images and their associated metadata, Calibrated Data Records (CDRs) are EDRs that have been decompanded and calibrated, and Reduced Data Records (RDRs) that can be made from as few as one image or as many as thousands that are processed and reduced for the purpose of, for example, making a mosaic that combines multiple images of a particular area or feature, or a high-resolution global digital elevation model created with stereo observations. LROC has been releasing data to PDS quarterly since 2009, soon after the project began. In October 2018, EDRs and CDRs were switched to monthly releases while RDRs continue to be released quarterly."

Raw PDS EDR:
https://pds.lroc.asu.edu/data/LRO-L-LROC-2-EDR-V1.0/
Calibrated:
https://pds.lroc.asu.edu/data/LRO-L-LROC-3-CDR-V1.0/
MAP Projected and Derived RDR:
https://pds.lroc.asu.edu/data/LRO-L-LROC-5-RDR-V1.0/

To find metadata for a specific LRO image (as well as view and download it), search the following address:

Given: M1238975774RE

https://wms.lroc.asu.edu/lroc/view_lroc/LRO-L-LROC-2-EDR-V1.0/M1238975774RE

5 AFIDS System Installation and Tutorial

5.1 Introduction

POMM (Planetary Orbital Mosaicking and Mapping) is a collection of scripts that run in the VICAR/AFIDS software environment (Section 5.3). The VICAR/AFIDS/POMM Open Source software environment will initially be provided in a docker/podman container available in early March 2023 at: https://github.com/NASA-AMMOS/AFIDS-POMM/. A full "anaconda" installation is expected to become available in late 2023 at: https://github.com/NASA-AMMOS/VICAR/. Once installed, VICAR/AFIDS contains a variety of image processing and GIS programs that can be scripted and run (separately from POMM). A tutorial for running these programs is provided in Section 5.3.

5.2 POMM Software Installation

AFIDS/POMM docker/podman and anaconda installation instructions will be provided in a separate README file available at the github download site (Section 5.1).

5.3 VICAR/AFIDS Overview

VICAR (Video Image Communication And Retrieval) is a comprehensive image processing system originally developed to support the Nation's unmanned space exploration program. AFIDS (Automated Fusion of Image Data System) is a subset of VICAR focused on the automated co-registration and rectification of NASA Earth observing satellites as well as Commercial imaging systems. AFIDS image geo-referencing capabilities are based on the GeoTiff standard previously developed at JPL, and also relies upon the GEOCAL routines developed in support of the NASA MISR (Multi-angle Imaging SpectoRadiometer) mission. AFIDS also integrates the open source GDAL (Geospatial Data Abstraction Library), NAIF/SPICE camera model and planetary mission sensor kernels, and USGS ISIS3 (Integrated Software for Imagers and Spectrometers; v6).

AFIDS (Automated Fusion of Image Data System) was developed in the early 2000s to support the co-registration, mapping, and mosaicking of orbital imagery in support of the NASA Earth Science Program. However, the origins of AFIDS began in the late 1970s with development of the Image Based Information System (IBIS), the first fully functional raster-based GIS (Geographic Information System). Extensive use of IBIS identified the need for a standardized method for mapped and referenced images, which led in turn to the development at JPL of the "Geo"-TIFF georeferenced image design in the early 1990s (the TIFF format was developed by Aldus, Inc). The design was incorporated in to VICAR as the "geotiff" property label also known as the "vicarGT" raster file format. Beginning in 2015 AMMOS and other Sponsors supported the reuse and extension of AFIDS co-registration and mapping software for planetary applications, initially Mars test cases, but eventually as a platform for any spherical hard-body planet or moon. Currently the AFIDS POMM software supports Earth, Mars, and Moon planetary mosaicking, co-registration of most map-projected orbital imaging sensors, and camera mode-based map projection Mars CTX, HRSC, HIRISE, and Lunar/Moon NAC and WAC orbital sensor imagery.

The AFIDS software environment runs on the Linux Red Hat (or similar) Operating Systems using a Command Line interface. Independent of POMM (which is supplied with a menu gui), VICAR/AFIDS software can be scripted using the built-in TAE (Transportable Applications Executive) or other software wrapping tools such as python and shell script.

VICAR/AFIDS has its own binary file format(s) and does not work natively with other formats like tiff, GeoTIFF, jpeg, png, etc. The native binary formats are referred to as "vicar" and "vicarGT" (with integrated GeoTIFF georeference keys). VICAR recognizes vicar files (and format information) from the file label, not the file's suffix, so the vicar file's suffix can be most anything. VICAR users often use ".img" for 8bit vicar files, ".hlf" for 16bit files, ".ful" for 32bit, and ".rel" floating point vicar files. Sometimes ".vic" is used when vicar files are being exported. Foreign formats can be converted to vicar format using the built-in GDAL tools:

gdal_translate -of VICAR input_image_file.tif output_vicar_file.img

VICAR provides a tool for displaying tiff, native vicar/vicarGT, jpg, pnt, and other formatted files. The primary display program is called "xvd," but it has been wrapped with GDAL and renamed "ctv2" to open non-vicar files. Navigate to the directory where your image of interest is located, and at the Linux prompt (outside of VICAR), enter the program name (ctv2) and the image to be displayed. For example:

```
ctv2
ctv2 <image_pan>
ctv2 <image_red image_grn image_blu>
```

A graphics box will appear for you to select an image to display. Be sure the directory path and filename combined are less than 99 characters.

Inside of VICAR, use the "xvd" program directly:

```
xvd <vicar image>
```

Note that basic "display" functions must be setup on your computer for xvd/ctv2 to work, and the "-Y" option must be used if login was via "Secure Shell," for example: ssh -Y user@cpu.

5.4 VICAR/AFIDS TUTORIAL

5.4.1 SOURCING VICAR/AFIDS

VICAR is launched by activating the "setup_afids_env.csh script." For "tshell" (tsch) users, update your path to the following command and add it to your /home/<user>/.cshrc file:

source /<local path>/PommDelivery/install/afids/setup_afids_env.**csh**

For bash users, add the activation path to your bash_profile:

. /<local path>/PommDelivery/install /setup_afids_env.**sh**   (Note the preceding dot)

The changes to your .cshrc fill will not take effect until a new shell is started (i.e., quit and restart). Alternatively, just source AFIDS manually before you want to use it.

5.4.2 Interactive/Command Line VICAR Tutorial

Launch VICAR by typing **vicar** at the Unix prompt. The system will respond with a Welcome Banner, several messages, and the vicar prompt:

$ VICAR>

To leave/quit VICAR, type **exit**
$ VICAR>**exit**

To execute a Unix command while in VICAR (except for 'ls'), type **ush** and the command:
$ VICAR>**ush cat**

To execute a VICAR application program, type its name and parameters at the command line. For example, VICAR program "gen" is used to generate a test image with the output filename "a", 552 lines (rows), and 818 samples (columns):
$ VICAR>**gen out**=**a nl**=**552 ns**=**818**

To verify the new file, read the file's label with the program "label-list":
$ VICAR>**label-list inp**=**a**   or just: **label-l a**

To print the first 20 lines by 10 samples of image "a" to your screen, use VICAR program "list":
$ VICAR>**list a size**=**(1,1,20,10)**

To display the image on your screen, use the interactive VICAR display program "xvd":
$VICAR>**xvd a**

To identify all the parameters associated with a program, use the tutor mode (below). At the bottom of the tutor screen, type "**help *parameter***" to display information about the parameter (then **exit** to leave the parameter description). The tutor mode can also be used to run the program by filling in the parameter fields with values. Type **exit** to quit tutor mode, or **run** to execute the program (after filling in the parameter values):
$ VICAR>**t gen** (or **tutor gen**)

To determine the function of a particular program, use the help mode (**exit** to quit):
$ VICAR>**h gen** (or **help gen**)

5.4.3 Batch VICAR Tutorial (From Inside the VICAR Environment)

The basic syntax of a VICAR command-line 'procedure' or 'script' is shown below. The VICAR 'procedure' is a text file with the suffix ".pdf" (that predates Adobe Acrobat). The file must have the keywords "procedure", "body", and "end-proc", with some VICAR applications after the 'body' keyword. (The space between 'procedure' and 'body' is reserved for special declaration statements.) An example procedure is:

```
procedure          ![required keyword]
```

```
body                ![required keyword]
gen       a nl=250 ns=255
label-l   a
list      a size=(1,1,20,10)
hist      a
end-proc            ![required keyword]
```

The procedure can be written using any text editor such as **gedit**, **joe** (built-in) or **vi.** Just be sure to end the filename with a ".pdf" (VICAR text-formatted "procedure definition files pre-date Adobe's commercial PDF files.) To run the procedure in real-time, simply type its name at the VICAR prompt.

$ VICAR>**testjob|run**=**batch|**

VICAR uses the exclamation point (!) to identify comment lines in the procedure. This can be useful for adding notes and descriptive text as well as bypassing program calls. The "goto *here*" command is also useful for jumping to different locations in a procedure. Use the "ush" command to run shell commands inside a vicar script.

```
!This is a test
procedure
body
gen      a nl=250 ns=255
!Jump over the label-list program
goto next
label-l  a
next>
hist     a
ush ls
ush pwd
ush gdal_tranlsate –of GTIFF a a.tif
end-proc
```

Note: Any single word could be used in-place of 'next'. The ">" is required.

If a VICAR command-line must continue to a second line, place a plus sign (+) at the end of the first line to tell VICAR to continue to the next line.

5.4.4 Batch VICAR Tutorial (From Outside the VICAR Environment)

VICAR scripts can be run in batch mode directly as shown in the following examples. This is the simplest way to run vicar batch scripts.

```
$vicarb   testjob.pdf
$vicarb   testjob
$vicarb  "testjob  inp=img.hlf  out=product.hlf"
$vicarb  "testjob  img.hlf  product.hlf"
```

Text output from a running vicar script can be captured to a log file, for example:

```
$vicarb   testjob > testjob.log
```

The job can also be submitted for background operation by appending the "&" symbol:

```
$vicarb   testjob > testjob.log &
```