MRD 121, 119, 576, 183a, 116- Global and Site-specific Single-band Mosaics

Global and site-specific panchromatic image mosaics derived from PolyCam will be the highest-resolution maps of Bennu available from the OSIRIS-REx instrument payload, and will therefore serve as the base maps for other higher-level thematic maps and long-term science products. Although mosaics can be derived from either PolyCam or MapCam (using the panchromatic filter), the global and site-specific products discussed in this description are intended to be generated from PolyCam.

In planetary image processing, uncontrolled image mosaics are developed by georegistering images using geometry provided by predicted or reconstructed SPICE kernels and a reference ellipsoid or a shape model. Using a high resolution and accurate shape model ensures that the ground sample distance (GSD) is correctly prescribed to individual pixels. Geo-registered images can then be aligned, according to SPICE kernel geometry, to the mosaic. Uncontrolled mosaics make good “quick look” products, but may not be suitable for mission critical planning.

All image mosaics used to derive higher-level OSIRIS-REx data products are controlled. To control the mosaic, a tie-point network is established among the images, using human generated or automated feature-matching. The mosaic can also be tied directly to the “ground” (i.e. the shape model or terrain model). When a robust control network has been defined, the set of images is bundle adjusted (the camera position and pointing of each image is solved to minimize tie-point mismatch within the network) and the geometry is updated. Using updated geometry, images are photometrically corrected to predefined illumination conditions to remove photometric effects and minimize the presence of seams. Mosaics are created by first projecting individual images to a common map projection (common spatial resolution) before mosaicking them together.During the reprojection, individual frames are transformed using the updated geometry (solved-for during the bundle adjustment process) and a shape model (for removal of topographic distortions). The final step consists in stacking the reprojected images according to their desired placement. The selection of mosaic pixels can be based on other user-defined parameters, such as resolution, photometric angles or average values of data number (DN).

Special considerations must be made when mosaicking images of the surface of an irregular body. If the reference ellipsoid used to characterize the shape of the irregular body deviates too significantly from the true shape, the images in the mosaic will show strong distortions. To avoid this issue, a 3D shape model of the irregular body should be used instead of a reference ellipsoid. In particular, ISIS3 supports the NAIF digital shape kernel (DSK) 3D model format. Eventually the image processing working group will be able export mosaics as a point cloud in x, y, z to remove the distortions caused by using a standard map projection.

Overview

Relevant ICD Data Products:

Global Controlled Image Mosaic (IP-4)

Local Controlled Image Mosaics (IP-9)

Global Photmetrically Corrected Image Mosaics (IP-27)

Local Photometrically Corrected Image Mosaics (IP-28)

What is the Data Type?

Image Mosaics

What MRD does this data product satisfy or contribute to satisfying?

MRD 121: OSIRIS-REx shall image > 80% of the surface of Bennu with < 21cm spatial resolution (4-pixel criterion), once at 10am local time and once at 2pm local time, to produce a global mosaic, stereo images, mosaics of hazards and regions of interest, and image sequences of the asteroid surface.

MRD 119: OSIRIS-REx shall, for > 80% of a 2-sigma TAG delivery error ellipse around at least the prime sampling site, map the surface in a panchromatic filter at <25 cm resolution and map the ECAS b-v color index, v-x color index, and the relative depth of the 0.7-micron absorption feature with an accuracy of < 2% in regions where the signal-to-noise ratio is >100 at a spatial resolution < 50 cm.

MRD 576: OSIRIS-REx shall collect OCAMS panchromatic data with < 5cm spatial resolution over 100% of a 3σ TAG error ellipse around each of up to 12 candidate sampling sites from the 1km-radius Safe Home Orbit at ranges between 600 m and 1000 m. Range is the distance from the spacecraft to the observed location on the surface of Bennu.

MRD 183a: The Ground System shall produce the following data products on a global scale and for each candidate sample site in support of site selection during the encounter with Bennu: a. Safety Maps, b. Deliverability Maps, c. Sample-ability Maps, d. Science Value Maps

MRD 116: OSIRIS-REx shall, for > 80% of a 2-sigma TAG delivery error ellipse around at least 2 candidate sampling sites map the areal distribution and determine the particle size-frequency distribution of regolith grains < 2-cm in longest dimension.

What observations are required to provide the input data needed to make the data product?

PolyCam images acquired during the Baseball Diamond of Detailed Survey for the global panchromatic mosaic.

PolyCam images acquired during Orbital B for the 12 site-specific mosaics at 5 cm resolution.

PolyCam and MapCam (panchromatic) images acquired during Reconnaissance for the 2 site-specific mosaics at 2 cm resolution.

What is the spectral and/or spatial resolution of this data product?

The required spatial resolution is ≤ 21 cm for the global panchromatic mosaic from Detailed Survey (MRD 121) for > 80% of the surface of Bennu.

The required spatial resolution is ≤ 5 cm for the 12 site-specific panchromatic mosaics from Orbital B (MRD 576) for 100% of a 3σ TAG error ellipse.

The required spatial resolution < 2 cm for the 2 site-specific panchromatic mosaics from Reconnaissance for > 80% of a 2-sigma TAG delivery error ellipse.

When in the DRM are the observations that make the data product scheduled to be taken?

Detailed Survey during Baseball Diamond

Orbital B

Reconnaissance

How long does it take to produce the data product?

An uncontrolled mosaic can typically be generated within a few hours to a day. A large (1000+ images) controlled mosaic may take several weeks to one month to generate, depending on the quality of the input SPICE kernels, shape model, and whether or not tie-points are being generated by-hand or using automated techniques.

Is this product used for sample site selection, science value, or long term science?

This product will be used for sample site selection, science value, and long-term science.

Observation Requirements

Observation requirements are described in terms of the image-to-image geometry and the photometric angles under which images are acquired.

Emission:

Nadir or low-emission angles are ideal. The maximum allowable emission able for images is 30 degrees. This will ensure high quality mosaics and to avoid foreshortening/loss of spatial scale.

Incidence:

Ideally, there should be two observations: one set at ~0 degrees incidence and another between 30-45 degrees. This would allow for an albedo-only map, and well as a map with visible but not overwhelming topographic relief or obscuring shadows. At larger incidence angles shadows will obscure terrain. For example, 60-degrees incidence gives 1.7-meters of shadow for a meter-tall post (on a flat surface).

Phase:

Image should not be acquired at 0 degrees phase, to avoid the opposition effect, and should not be acquired at high phase to avoid long shadows. Phase angles 15 – 60 degrees are good.

Image Overlap and Blur:

At least 20% overlap between individual images both along and across track is required. Ideally image overlap should be between 30-40%. Image overlap should be sufficient to tie images together with multiple features. Images should be acquired at slew rates which do not permit more than 1 pixel of blur, at most.

Data Product Structure and Organization

What is the structure of the data product (e.g. FITS file with 4 extensions)?

ISIS3 Cubes for internal Science Team processing and for the PDS archive.

Data Format Descriptions

Header information (metadata) included with data product:

At a minimum the following information will be associated with each panchromatic mosaic map. The "Data_Set_ID" keyword will point to a file list that includes all images, SPICE kernels, and the shape model used to support the generation of this product.

/* Identification Information */

DATA_SET_ID = "OSIRIS-REx_B_OCAMS_CRMOS_0001_V1.0"

DATA_SET_NAME = "OSIRIS-REx CAMERA SUITE GLOBAL PANCHROMATIC MOSAIC V1.0"

PRODUCER_INSTITUTION_NAME = "UNIVERSITY OF ARIZONA"

PRODUCER_ID = "UA"

PRODUCER_FULL_NAME = “LUCILLE LE CORRE"

PRODUCT_ID = = "DTbcd_LLLLLL_NNNN_RRRRRR_NNNN_Vnn"

PRODUCT_VERSION_ID = "V1.0"

INSTRUMENT_HOST_NAME = "Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer "

INSTRUMENT_HOST_ID = “OSIRIS-REx”

INSTRUMENT_NAME = “OSIRIS-REx CAMERA SUITE”

INSTRUMENT_ID= “OCAMS”

TARGET_NAME = “BENNU”

SOURCE_PRODUCT_ID = (XSP_LLLLLL_NNNN, XSP_RRRRRR_NNNN)

RATIONALE_DESC = "Brief descriptive text "

SOFTWARE_NAME = “ISIS3.4.11”

OBJECT = IMAGE_MAP_PROJECTION

DATA_SET_MAP_PROJECTION = “TEMPLATE.MAP”

MAP_PROJECTION_TYPE = "EQUIRECTANGULAR"

ROJECTION_LATITUDE_TYPE= PLANETOCENTRIC

A_AXIS_RADIUS = nnnn.nn <M>

B_AXIS_RADIUS = nnnn.nn <M>

C_AXIS_RADIUS = nnnn.nn <M>

COORDINATE_SYSTEM_NAME = PLANETOCENTRIC

POSITIVE_LONGITUDE_DIRECTION = EAST

KEYWORD_LATITUDE_TYPE = PLANETOCENTRIC

CENTER_LATITUDE = nn.0 <DEG>

CENTER_LONGITUDE = nnn.nn <DEG>

LINE_FIRST_PIXEL = 1

LINE_LAST_PIXEL = nnnnn

SAMPLE_FIRST_PIXEL = 1

SAMPLE_LAST_PIXEL = nnn

MAP_PROJECTION_ROTATION = nnn.nn <DEG>

MAP_RESOLUTION = nnnnnn.nnnnnnnn <PIX/DEG>

MAP_SCALE = n.nnnnnnnnnnnn <METERS/PIXEL>

MAXIMUM_LATITUDE = nnn.nnnnnnnn <DEG>

MINIMUM_LATITUDE = nnn.nnnnnnnn <DEG>

LINE_PROJECTION_OFFSET = nnnnnnnn.n <PIXEL>

SAMPLE_PROJECTION_OFFSET = nnnnnnnn.n <PIXEL>

EASTERNMOST_LONGITUDE = nnn.nnnnnnnn <DEG>

WESTERNMOST_LONGITUDE = nnn.nnnnnnnn <DEG>

END_OBJECT = IMAGE_MAP_PROJECTION

OBJECT = VIEWING_PARAMETERS

NORTH_AZIMUTH = nnn.nnnnnn <DEG>

PHASE_ANGLE = nnn.nnnnnn <DEG>

PHOTO_MODEL = “LOMMEL-SEELIGER”

END_OBJECT = VIEWING_PARAMETERS

END

Data Product Generation

By whom is the product generated?

The product will be generated using an ISIS3 pipeline developed by Lucille Le Corre with input from the IPWG lead and USGS. In operations, another member of the IPWG may oversee the generation of single band mosaics (panchromatic and 860 nm).

What are the input products needed to produce the product?

The following data are needed to create panchromatic mosaics:

-L2 Calibrated PolyCam and MapCam panchromatic images in units of I/F

-SPICE kernels

-Bennu shape or terrain model (i.e. DSK)

-Photometric model

Are there format expectations for the input products?

All input images will need to conform to the OCAMS SIS for Level 2 products.

The asteroid shape model will need to be in DSK format or a terrain model in ISIS3 cube format.

The photometric model will need to conform to the RADF SIS

What algorithms are used to generate products?

All algorithms used to create panchromatic mosaics are implemented in the ISIS3 software developed by the USGS. The names of individual ISIS3 algorithms are italicized in the below description.

All OCAMS images brought into ISIS3 use the OCAMS image import function and camera model, ocams2isis, which translates important keywords in the image FITS header with ISIS3 variables and associates the image with the OSIRIS-REx SPICE kernels, geometric correction, and converts the files into an ISIS3 image cube. Geometry from the SPICE kernels and Bennu shape model are then calculated across the entire image using spiceinit with a user specified shape model in either ISIS3 DEM cube or DSK format.

Images can be map projected (cam2map) and mosaicked according to their initial SPICE kernel geometry to create an uncontrolled mosaics (automos).

Bundle adjustment (jigsaw)is the photogrammetric algorithm used to control images prior to mosaicking. The process is described as follows: Camera models implemented in ISIS3 define a relationship between ground and image, and include the camera system's intrinsic parameters (calibrated focal length, pixel pitch, geometric distortion models, etc.). Initial estimates of image extrinsic parameters are gathered from spacecraft trajectory and pointing data, available from SPICE kernels. Users will generate tie points between overlapping images by-hand or using automated image-matching techniques. A tie point is a point that has ground coordinates that are not known, but is visually recognizable in the overlap between images. Prior to bundle adjustment, initial ground coordinates of tie points are generated by intersection with an available shape model, such as a sphere, ellipsoid, or digital shape kernel (DSK) [Edmundson et al.]. During bundle adjustment the estimates of the extrinsic camera parameters and the 3D position of common points of features are refined, updated, and exported as smithed SPICE kernels. The elements of the cost function optimized during this process are derived from the corresponding features in the images. Because the extrinsic camera parameters are refined on a per image basis, it is important to recognize that it is only feasible to bundle adjust individual images to produce mosaics. It does not make sense to bundle adjust multiple mosaics that are no longer associated with geometry of individual frames, but instead represent the averaged geometries for a group of frames. There are multiple ways to accomplish this series of steps in ISIS3. The data flow section illustrates the complex data processing that can take place when creating controlled mosaics.

Once frames have updated geometry, a photometric correction can be applied using the photometric angles determined by the geometry refinement.

The final step in the mosaicking process consists of stacking the individual image frames according to pixel priority, using the automos algorithms in ISIS3. The "priority" parameter will determine how input pixels are combined with the output mosaic. The selection of input pixels can be based on resolution, photometric angles, averaging schemes, etc. The final mosaic will be generated in a standard cartographic projection, such as equirectangular or polar stereographic.

References:

Edmundson et al. "Jigsaw: The Isis3 Bundle Adjustment For Extraterrestrial Photogrammetry" SPRS Annals of the

Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume I-4, 2012

What calibration data are used to generate products?

PolyCam and MapCam L2 images are used to create this product. These products will be radiometrically calibrated by the OCAMS pipeline prior to use by the IPWG. In ISIS3, the products will be geometrically corrected using the PolyCam and MapCam camera models. Images will be photometrically corrected to predefined illumination conditions in ISIS3 using the parameters of the photometric model generated by Co-I Dr. Beth Clark and her team.

Has a specific Science Team Member been assigned to produce this product?

Creating the panchromatic ISIS3 mosaicking pipeline has been assigned to Dr. Lucille Le Corre. In operations, a different member of the IPWG may be responsible for generating the mosaics for each phase of the mission where they are required.

Will multiple versions of the product be generated?

We will regenerate this product each time a new shape model is released and/or each time a new photometrical model is released.

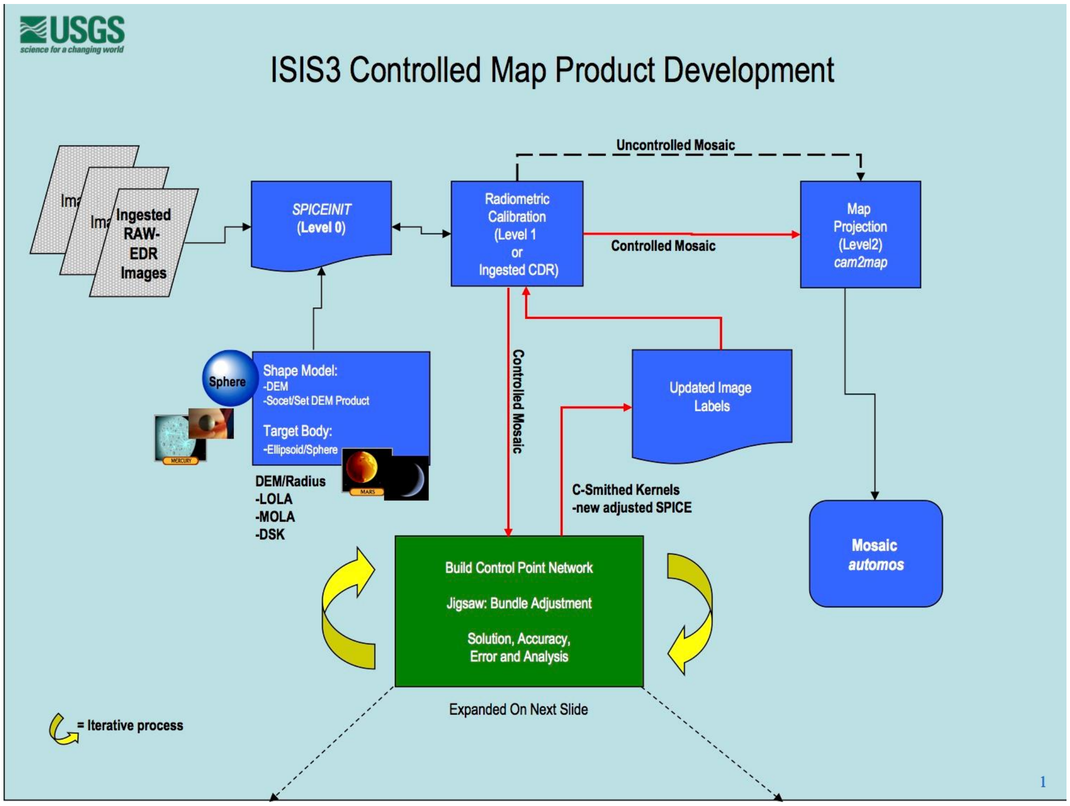
Data Product Validation

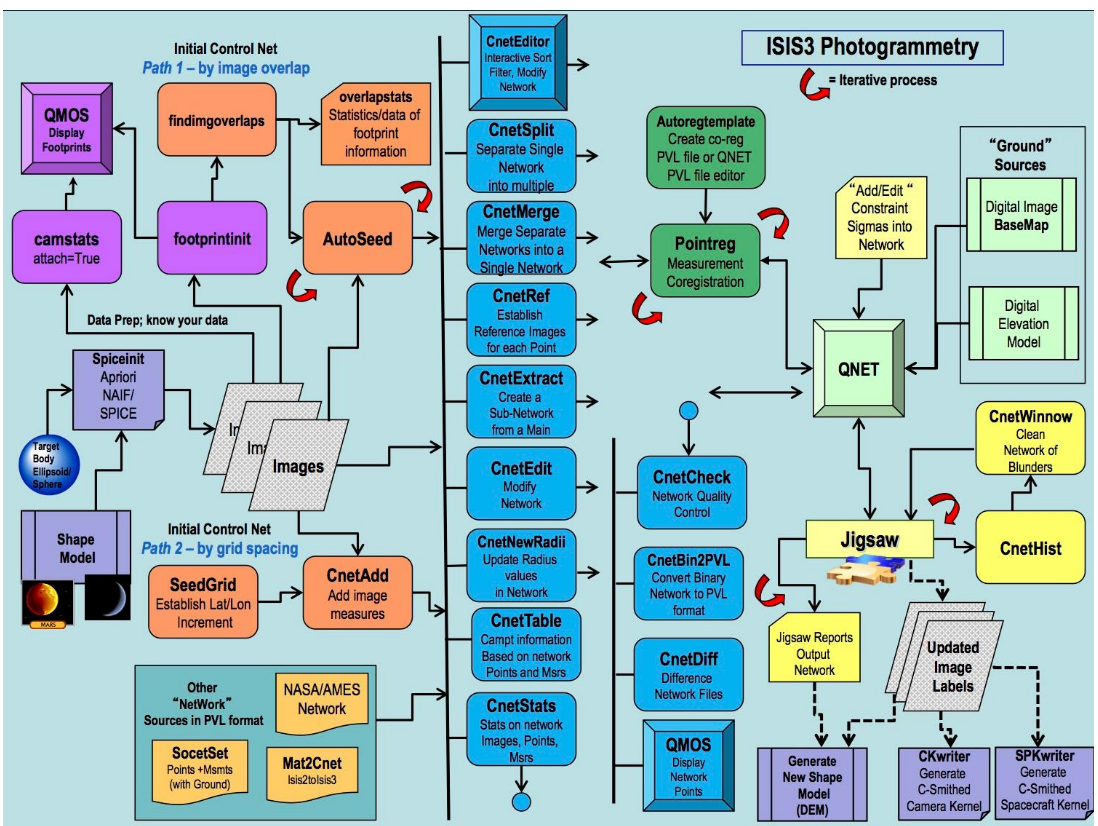
How will the product be validated to ensure contents and formats are correct?

This data product will need to pass an IPWG acceptance test before being delivered to the SPOC. The IPWG acceptance test will ensure that format is correct.

The IPWG lead will review the content of the data product and the data provenance before it is delivered to the SPOC.

Data Flow





Standards used to generate data product

Cartographic Standards

Panchromatic mosaics will be generated in either equirectangular or polar stereographic cartographic projections. The equations describing these projections are included in the Image Processing Software Interface Specification (SIS) document.

Eventually, panchromatic mosaics will be generated in a point cloud format where DN values are associated with x, y, z coordinates rather than values of latitude and longitude.