

HIGH RESOLUTION REGIONAL DIGITAL TERRAIN MODELS AND DERIVED PRODUCTS FROM MESSENGER MDIS NAC IMAGES. M. R. Henriksen¹, M. R. Manheim¹, K. J. Becker², E. Howington-Kraus³, and M. S. Robinson¹. ¹School of Earth and Space Exploration, Arizona State University, 1100 S Cady, Tempe AZ 85287 – (mhenriksen@ser.asu.edu), ²Astrogeology Science Center, United States Geological Survey, 2255 N Gemini Dr., Flagstaff AZ 86001, ³Retired

Introduction: One of the primary objectives of the Mercury Dual Imaging System (MDIS) is to acquire high-resolution images of key surface features [1]. Although (MDIS) was not designed as a stereo camera, stereo pairs are acquired from two orbits, with the camera pointing off-nadir for at least one orbit. This abstract describes the production of regional MDIS Narrow Angle Camera (NAC) Digital Terrain Models (DTMs) produced by the ASU and USGS teams, using a combination of the Integrated Software for Imagers and Spectrometers (ISIS) [2] and SOCET SET by BAE Systems [3].

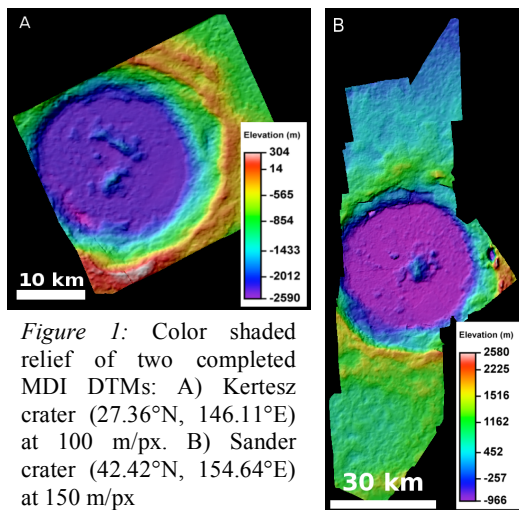


Figure 1: Color shaded relief of two completed MDI DTMs: A) Kertes crater (27.36°N, 146.11°E) at 100 m/px. B) Sander crater (42.42°N, 154.64°E) at 150 m/px

Data Sources: The DTMs are extracted from NAC images and Mercury Laser Altimeter (MLA) tracks are used as a geodetic reference frame for the DTMs to improve accuracy [4]. Wide Angle Camera (WAC) images are used to bridge gaps in coverage or for control when no MLA tracks cover the NAC DTMs.

Mercury Dual Imaging System. The NAC is a 1.5° field-of-view (FOV) off-axis reflector, which is co-aligned with the WAC, a four element refractor with a 10.5° FOV. Each camera has an identical 1,024 x 1,024 charge couple device detector [1].

Mercury Laser Altimeter. Altimetry obtained from the Mercury Laser Altimeter (MLA) is used to increase the absolute accuracy of NAC DTMs. MLA is a time-of-flight altimeter that measures the shape of Mercury by using pulse detection and pulse edge timing to precisely determine the range from the spacecraft to the surface [4]. MLA data is only available only for lati-

tudes between 90°N and 18°S due to MESSENGER's highly elliptical orbit, with periaapsis at high northern latitudes. MLA measurements have a radial precision of < 1 m and a radial accuracy of < 20 m with respect to Mercury's center of mass [5].

Methodology: Stereo image selection is accomplished via a 2-step query of a MDIS image database that first identifies images with favorable illumination conditions (incidence, emission, and phase angles) and pixel scale, and then selects images which form acceptable stereo pairs, with good pixel scale ratios, parallax/height ratios, illumination compatibility, and image overlap [6]. Because of the highly elliptical orbit, NAC images used for DTM production range in resolution from 5 m to 50 m pixel scale. The amount of overlap and the actual footprint of the DTMs are affected by the topography and acquisition parameters such as center latitude, center longitude, and slew angles, with optimal convergence angle between 20° and 30°.

To produce DTMs of key regions of interest, ISIS is used to ingest images, to perform radiometric calibration, and to export the images (8-bit raw files and 16-bit TIFFs) in formats compatible with SOCET SET 5.6.0, along with associated spacecraft position and pointing information [2,3].

Images are then imported into SOCET SET, where all overlapping images are linked together with tie points and then bundle-adjusted. The NAC images are then manually controlled directly to shapefiles of the MLA tracks. If the sparsity of MLA points prevents direct control, WAC images are controlled to MLA instead. The NAC images are then tightly controlled to the WAC images in order to indirectly improve their geodetic accuracy.

Once a bundle adjustment solution has been achieved with an overall RMS of < 0.5 pixels and all residuals < 1.0 pixel, 16-bit TIFF images are imported and the solution information is transferred. The Next Generation Automatic Terrain Extraction (NGATE) program in SOCET SET is used to create a DTM at 3 times the pixel scale of the largest pixel scale image in a stereo pair, with typical ground sampling distances between 80 m and 150 m. After editing the DTM for artifacts, the final version is used to create 16-bit orthophotos in which distortion due to camera obliquity and terrain relief is removed.

Error Analysis: DTMs are subject to both qualitative and quantitative error analysis. Contour intervals created from the DTMs are compared to the images in stereo to confirm a close match with the terrain. The overlapping stereo pairs are also compared to the available MLA data to ensure that there is no tilt present in the DTM, and that the tracks closely align with the images in stereo. Quantitative metrics are also reported for precision and accuracy (Table 1).

Relative Linear Error. Precision is calculated by the SOCET SET Software as relative error at a 90% confidence level, meaning 90% of elevation measurements will be equal to or less than the reported value. Vertical precision is reported as relative linear error and is expected to be less than the ground sampling distance (GSD) of the DTM (~ 0.5 to 2.0 times the GSD of the images in the stereo pair) [3]. The horizontal precision of the DTM is reported to be equal to the GSD of the DTM, as the GSD is consistently greater than the circular error reported by SOCET SET.

Offsets from MLA. Positional accuracy is evaluated by comparing DTM elevations with MLA data. Wherever MLA tracks directly cross the DTM, the mean, median, and standard deviation of the offsets are evaluated (Fig. 2). However, due to the highly elliptical orbit of MESSENGER and the sparse MLA coverage, these calculations are not always possible. In this case,

offsets are reported from the WAC DTMs used to control the NAC DTMs. Special care is taken to ensure that the difference in elevation between the NAC and WAC DTMs is <10 m. With the range accuracy of MLA better than 20 m, we would like the measured differences between the DTMs and MLA tracks to have similar values. However, as both our error analysis and DTM processing methods are still being refined, these levels of accuracy are currently challenging to obtain.

Table 1: Error Analysis for Completed Regions

	Sander	Catullus*	Kertesz*
Pixel Scale (m)	150	85	100
Mean Offset (m)	9.89	-313.9	157.9
Median Offset (m)	12.32	-306.1	151.9
Standard Deviation (m)	39.11	190.3	189.8
Vertical Precision (m)	101.3	83.7	99.74

* Values as compared to overlapping 1 km pixel scale WAC DTMs

PDS Products and Derived Products: In addition to the DTM in PDS IMG format, several derived products are provided. A confidence map and orthophotos of each image in the stereo pair are available at both the pixel scale of the DTM and at the largest native pixel scale from the stereo pair. A terrain shaded relief map, a color shaded relief map, a slope map, and corresponding legends are also provided at the pixel scale of the DTM in the EXTRAS directory of the PDS in GeoTIFF format, as well as a 32-bit GeoTIFF of the DTM. These derived GeoTIFF products were created using the Geospatial Data Abstraction Library (GDAL) [7].

Production and Future Work: Three sites consisting of ~40 stereo pairs are currently complete: Sander crater, Kertesz crater and the central peak of Catullus crater. The MESSENGER project plans to release over 60 stereo pairs in at least 6 regions as part of the MESSENGER DTM PDS Archive. Future work also involves including the higher resolution, higher precision DLR global DTM product to improve accuracy and resolve issues with sparse data at lower latitudes.

References: [1] Hawkin, S. E., et al. (2007) *Space Sci Rev*, 131, 247–338. [2] Anderson, J.A., et al. (2004) *LPSC XXXV*, Abstract #2039. [3] Burns, K. N., et al. (2012) *IS-PRS XXII*, v. XXXIX-B4-483 [4] Cavanaugh, J. F., et al. (2007) *Space Sci Rev.*, 131, 451. [5] Zuber, M. T., et al. (2012) *Science*, 316, 217. [6] Becker K. J. et al. (2015) *LPS XLVI*, Abstract #2703. [7] Warmerdam, F. (2008) *Open Source Approaches in Spatial Data Handling*, pp. 87-108.

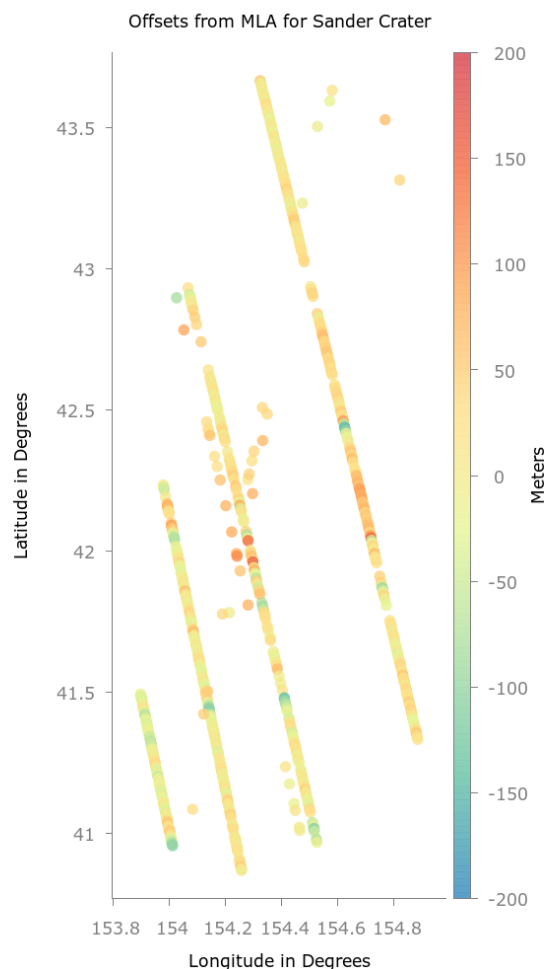


Figure 2: Plot showing the difference between MLA tracks and the Sander crater regional DTM (42.42°N, 154.64°E). This DTM mosaic consists of 36 stereo pairs and has a pixel scale of 150 m.