Global Controlled Mosaic of Mercury from MESSENGER Orbital Images. Kris J. Becker[1], Lynn A. Weller[1], Kenneth L. Edmundson[1], Tammy L. Becker[1], Mark S. Robinson[2], Andrew C. Enns[2], and Sean C. Solomon[3], [1]Astrogeology Science Center, United States Geological Survey, Flagstaff, AZ 86001 (kbecker@usgs.gov); [2]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85281; [3]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015.

Introduction: The MESSENGER spacecraft entered orbit around Mercury in March 2011. Since then, the Mercury Dual Imaging System (MDIS) has steadily acquired images from the monochrome narrow-angle camera (NAC) and the multispectral wide-angle camera (WAC). With these images, the U.S. Geological Survey (USGS) is constructing a global, controlled monochrome base map of the planet using the Integrated Software for Imagers and Spectrometers (ISIS3) [1].

Although the characterization of the MESSENGER spacecraft navigation and attitude data has proven to be reliable to date, an element of uncertainty in these parameters is unavoidable. This uncertainty leads to registration offsets between images in the base map. To minimize these errors, images are controlled using a least-squares bundle adjustment that provides refined spacecraft attitude and/or position parameters plus triangulated ground coordinates (latitude, longitude, and radius) of image tie points. Adjusted image parameters facilitate base map creation, and the resulting ground-point coordinates are used in the production of a digital elevation model (DEM). Interpolation of radius values between points results in a continuously sampled, global DEM of the surface of Mercury that will be used to create a high-quality WAC color base map.

Here we present the results of this ongoing effort.

Control Process: The global mosaic was created from images acquired from a few days after orbit insertion (DOY 095) to 15 November 2011 (DOY 319). Of the 24,507 images collected from the monochrome base map campaign, we selected images with a pixel scale greater than 50 m and emission angles less than 65° at the central pixel. These constraints are designed to result in a uniform map suitable for morphologic interpretation. After down-selection, 21,498 images were included in the control network.

Images are typically registered (or tied) to one another through the measurement of common features (tie points) between them. This registration can be done manually or with automated methods. Here, using ISIS3, a moderately dense grid of ground points were generated and then projected into the images, resulting in approximate image measurement locations. These measurements were then refined to sub-pixel accuracy via image matching techniques. Finally, as mentioned above, the bundle adjustment yielded updated spacecraft position and pointing and ground-point coordinates. Bundle adjustment results on MDIS monochrome images are summarized below and further described elsewhere [2].

MDIS Monochrome Control: The current state of the control network for the MDIS monochrome campaign consists of 21,498 NAC and WAC G-filter images. The images range from 88°S to 87°N latitude and from 0°E to 360°E longitude. MESSENGER had not completely imaged the surface as of DOY 319. There are 263,762 points with 1,857,334 measures. For the bundle adjustment, pointing angles were constrained to ±0.2°, and all points were constrained by ±10 km in radius. After the adjustment, the average root mean squared (RMS) error in sample and line is 0.21 and 0.24 pixels. The RMS error of triangulated ground point coordinate uncertainties in latitude, longitude, and radius are 51, 107, and 276 m, respectively. The resulting point cloud distribution is shown in **Figure 1**. The viewing parameters of each image were updated, and the base map mosaic was created.

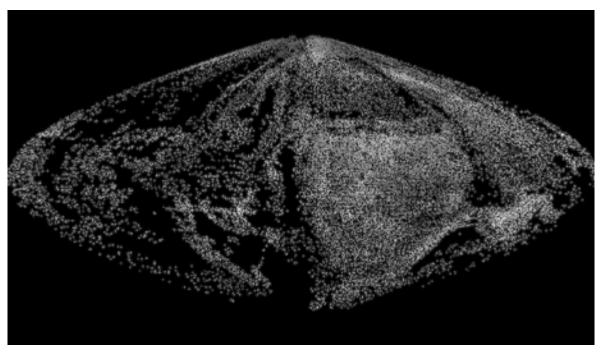

Figure 1. Point cloud distribution after bundle adjustment. There are 263,762 control points in a sinusoidal equal-area projection at 16 pixels/degree.

Mosaic Tiling Scheme: There are many images in the control network that overlap multiple images, each with its own particular lighting and viewing parameters. The current mosaic was designed to emphasize morphological features. The tiling scheme is based on a specialized equation that determines the best viewing conditions. Resolution and phase, incidence, and emission angles are combined in an equation that results in the order in which the images are placed on the map. The value to minimize (*index*), placed at the top of the stacking order, is defined by the equation:

$$\text{index} = 1.25 * f(\text{incidence}) + f(\text{resolution}) + 0.1 * f(\text{phase}) - 0.1 * f(\text{emission})$$

where

$$f(incidence) = \begin{cases} 1.0 - 0.01 * ABS(77 - incidence), & ABS(incidence) < 77° \\ 1000.0, & ABS(incidence) \geq 77° \end{cases}$$

$$f(resolution) = \begin{cases} 10 + \left(\frac{resolution + 800m/p}{800m/p}\right), & resolution < 190m/p \\ 1.25 - \left(\frac{resolution}{800m/p}\right), & resolution \geq 190m/p \end{cases}$$

$$f(phase) = phase/180°$$

$$f(emission) = emission/90°$$

The list of images included in the base map is sorted from smallest to largest *index* value. Images are then laid in the mosaic in the determined order, and subsequent images in the list are visible only in areas where no previous data exist (**Figure 2**).

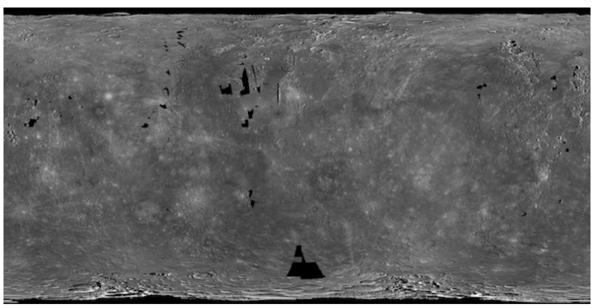

Figure 2. Global controlled MDIS monochrome mosaic at 200 m/pixel, centered at 180° longitude.

DEM Construction: The latitude, longitude, and radius points were plotted in ArcGIS with a reference radius of 2440 km (a figure different from the IAU-approved value) currently adopted by the MESSENGER team. **Figure 3** shows the distribution of elevations on Mercury's surface. Areas with no data

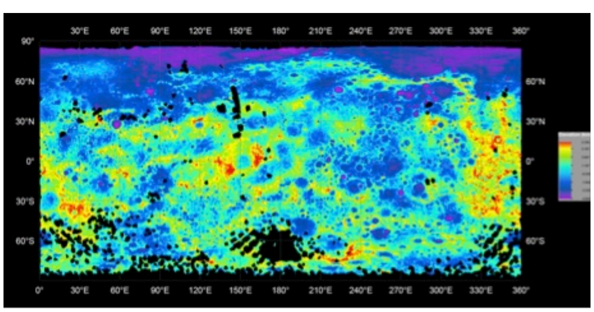

Figure 3. Global DEM of Mercury derived from the bundle adjustment process (simple cylindrical projection, 16 pixels/degree, centered at 180° longitude). Sparse point cloud from Figure 1 was interpolated to a continuously sampled global map.

are present where the maximum range of interpolation exceeds 2.5 km between points. **Figure 4** shows a histogram of the elevation point cloud. The average and median elevation is -371.1 and -356.9 m, respectively. From these results, the minimum and maximum elevations are -4,866.9 and 5,812.8 m, respectively, and the average and median radius of Mercury is approximately 2439.6 km. This value compares well with Mariner-10-based estimate of Fjeldbo et al. [3] of 2439.5 ± 1 km and the IAU value of 2439.7 km.

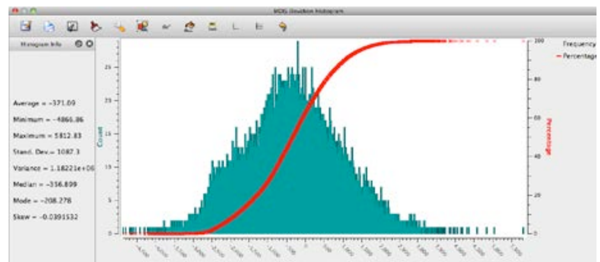

Figure 4. Histogram of DEM point cloud (no spatial interpolation) computed from Figure 1.

Future Plans: The USGS will use the DEM and base map for the construction of a registered color (WAC) map of high spatial integrity essential for reliable scientific interpretation of the color data. With time, higher-resolution laser altimetry and stereo-based DEMs will become available and will be used to refine the global map products.

Ongoing improvements to the base map will be made as new images from MDIS become available, providing continuity in resolution, illumination, and viewing conditions. Additional bundle adjustments will further improve spacecraft attitude. The results from these bundle adjustments will ultimately be provided to users in the form of a new, *smithed* (derived) CK SPICE [4] kernel (C-matrix subsystem dealing with orientation of spacecraft and rotating structures on the spacecraft), replacing the original *reconstructed* kernel (typically provided by the mission navigation team). The determination of updated attitude parameters for every image acquired by MDIS is a primary goal of the USGS.

References: [1] Anderson, J. A., et al. (2004) *LPS, 35*, abstract 2039. [2] Edmundson, K. L., et al. (2011) GSA *Abstracts with Programs 43*, paper 100-6, p. 267. [3] Fjeldbo, G., et al. (1976), *Icarus, 29*, 439-444. [4] Acton, C. H. (1966) *Planet. Space Sci. 44*, 65-70.