GLOBAL DIGITAL IMAGE MOSAICS OF MARS: ASSESSMENT OF GEODETIC ACCURACY. R. L. Kirk, B. A. Archinal, and E. M. Lee[1], M. E. Davies and T. R. Colvin[2], and T. C. Duxbury[3], [1]U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001 (rkirk@usgs.gov), [2]RAND, 1700 Main St., Santa Monica, CA 90406, [3]Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena, CA 91109.

Introduction: In the late 1980s, the USGS, Flagstaff, produced the first in what would become a series of very large, global digital image mosaics of solar system bodies [1, 2]. This Mars mosaicked digital image model (MDIM), incorporating roughly 4600 Viking Orbiter images at a scale of 1/256 degree or ~231 m/pixel, was widely distributed on CD-ROM and, as the highest resolution global map of Mars, was heavily used for both scientific studies and planning of current and future missions. Unfortunately, it was discovered to have significant shortcomings, particularly in the area of geodetic control, both in the local registration of adjacent images and in absolute positional accuracy. We have therefore undertaken the process of replacing the original mosaic with new versions that are successively improved in geodetic accuracy (and also cosmetic quality) [3, 4]. An initial revision of the mosaic has been completed in late 2000 and is available online through the PDS Map-a-Planet website [5] at http://pdsmaps.wr.usgs.gov/maps.html. Production of a second revised mosaic with additional refinements to the control (summarized below) is underway. It is thus worthwhile to attempt to compare the absolute and relative (image-to-image) geodetic accuracy of the first and second generation mosaics and attempt to derive lessons for the control of future mosaics.

Approaches to Geodetic Control: The process by which the original MDIM (hereafter MDIM 1) was controlled was complex [2, 3, 4]. The most important features are 1) that control for the mosaic was based on a global network of ~1 km/pixel images with off-nadir viewing [6]; 2) that this net was tied to what is now known to be an erroneous identification of the Viking 1 landing site [7, 8]; and 3) that the MDIM images were in fact tied to an unrectified mosaic of the control net images, introducing substantial parallax errors. A secondary adjustment of the MDIM images served to reduce the mismatches at image seams but could not improve the absolute accuracy. The misidentification of the Viking site does not directly cause errors in the map coordinates of MDIM 1 (since the longitude system was defined by placing the crater Airy-0 on the prime meridian) but does introduce an error in conversion of other observations from inertial space to map coordinates through the rotational parameter W_0 [9]. It also undoubtedly added to the general confusion over the longitude discrepancies between various geodetic/cartographic products, some of which must simply have been the natural result of errors in the various control networks propagating into W_0.

Our revised mosaic was based instead on the evolving RAND global control network [9, 10], which incorporates mostly higher resolution (200–300 m/pixel) images. The typically less oblique viewing in these images, a liability if one attempts to determine elevations as part of the photogrammetric bundle-block adjustment of the control network, becomes an advantage if good elevation estimates are available from another source such as the Mars Orbiter Laser Altimeter (MOLA [11]). Many of the Viking images in the MDIM were already part of the RAND network; measurements linking the remainder of the images in the mosaic to one another were transferred from USGS to RAND and incorporated in subsequent adjustment calculations. In addition, an increasing fraction of the control points had their elevations constrained by nearby MOLA observations as these became available. The first revised mosaic (MDIM 2.0) was based on an unpublished control solution from November, 1999 that was similar to the solution described in [10] and had MOLA elevations for about 2/3 of points. Because the mosaic was not orthorectified, a secondary adjustment was performed to place the images at the correct latitude-longitude coordinates (determined from the primary adjustment) when projected onto the reference ellipsoid. This procedure amounts to an image-by-image rectification in that it removes parallax errors between but not within images.

Qualitative Assessments of Accuracy: The stated accuracy of the control network on which MDIM 1 was based is 5 km [6]. The documentation supplied with the mosaic itself states that mismatches of 5 km (~20 pixels) between adjacent images are present in some places but are rare. Comparison of feature positions in MDIM 1 with other datasets before and during the Mars Global Surveyor mission provided additional information about geodetic errors in the mosaic. For example, a comparison with the RAND network [9] showed both a mean difference in longitude on the order of 10–15 km (~0.2°) and regional differences on the order of 2_5 km (M. Malin, personal communication, 1996). Later comparison of the MDIM with MOLA data confirmed these differences (unsurprising, since the longitude system in which the MOLA data were presented was based on the W_0 value from [9]).

Our (admittedly unsystematic) examination of MDIM 2.0 as it was produced indicates that image-to-image mismatches in excess of a pixel (231 m) are quite rare. Where they do occur, they are often the result of local parallax, e.g., images of Valles Marineris may match at the rim but not on the floor. The RMS accuracy of the near-contemporary control solution [10] is 10 µm, equivalent to 0.9 pixel. Since the control net error applies only to the control points, for which the elevations are specified, it does not include the local parallax errors seen in the mosaic.

How have feature positions changed in the revised mosaic? We calculated the latitude-longitude coordinates of the centers of the ~4600 images, first with the orientation data used to produce MDIM 1 and then with those from MDIM 2.0. Figure 1 shows a vector plot comparing the results. Eight low-resolution images (used to fill small gaps in the mosaic) have moved substantially (15 to 62 km) in a different direction from their neighbors. Apart from these exceptions, the median displacement is about 4 km and the RMS is 5 km., and the motions are highly correlated over distances of hundreds to thousands of kilometers. Indeed, the predominant pattern is global, a northward shift that is likely related to the hemispheric dichotomy in elevation and the improved elevation constraints on the new control solution. The average longitude change of 0.113° (6.7 km at the equator) has been subtracted from the vectors in Fig. 1 for clarity. This large average change results from the local change near Airy-0 being mapped into the remainder of the control points when that feature is placed at zero longitude as required. Large changes in the mean longitude of all points other than Airy-0 (and hence large changes in W_0) seem to be the rule.

Figure 2 shows a similar vector plot comparing the positions of image centers based on an (unpublished) 2000 control solution in which nearly all points have MOLA elevations to the 1999 solution used in MDIM 2.0. The vectors are exaggerated 5x relative to Fig. 1. The mean longitude shift is 0.041° (2.4 km) and the median displacement excluding this longitude shift is 0.9 km. The pattern of displacements is, if anything, even smoother than in Fig. 1, with a dominant component that is hemispheric in scale. The stability of the RAND/USGS control network as data are added provides a clue to its accuracy. Thus, Fig. 2 suggests (though it does not prove) that, now that MOLA elevations are available for 100% of the control points, the remaining errors in the net can be described as a combination of (a) local random errors caused by errors in the image measurements, hence on the order of 1 pixel (~200 m) or less; and (b) long to hemispheric-wavelength errors that are probably ≤1 km.

Absolute Accuracy—Comparison with MOLA: The MOLA global altimetric dataset provides us with an opportunity to test the above assertions about the remaining errors in the control network and mosaics, as well as providing a very helpful constraint on future products [12]. Least-squares adjustment of the MOLA ground tracks based on a comparison of the 24 million crossings has produced a global dataset that is internally consistent with a horizontal accuracy of ~100 m [13]. It is not possible to define absolute longitudes in terms of this dataset, because Airy-0, which is only 500 m in diameter, has not yet been observed. Nevertheless, the rigidity of the MOLA dataset allows us to compare positions of points all over Mars to high accuracy. We are initiating an effort to compare

MDIM 2.0 data, in small regions every 15° of latitude and 30° of longitude, to shaded-relief "images" of the corresponding areas derived from the MOLA data. Such a comparison will allow us to determine the magnitude of positional errors in MDIM 2.0 and—unless, contrary to our expectations, it is less than the spacing of our samples—the typical distance over which these errors vary. We further plan to incorporate feature matches between Viking images MOLA data in our future control calculations. This will provide a subset of control points all three of whose coordinates are constrained by MOLA, and should result in planetwide control accuracy on the order of 100 m. The comparison of MDIM 2.0 with MOLA is the first step toward determining the density of such ties that will be needed to achieve the desired accuracy in MDIM 2.1.

We hope to present the results of this comparison in our poster.

References: [1] U.S. Geological Survey, compiler, 1991, Mission to Mars: Digital Image Maps, PDS Volumes USA_NASA_PDS_VO_2001 through VO_2007 (CD-ROM). [2] Batson, R. M., and E. M. Eliason, 1991, , *Photogram. Eng. & Remote Sens., 61*, 1499–1507. [3] Kirk, R. L., et al., 1999, Mars DIM:, *LPS XXX*, 1849. [4] Kirk, R. L., et al., 2000, LPS XXXI, ??. [5] Garcia, P. A., et al., this conference. [6] Wu., S. S. C., and F. Schafer, 1984, *Tech. Papers of the 50th Annual Meeting of the ASPRS, 2,* 445–463. [7] Parker, T. J., and R. L. Kirk, 1999, *5th International Conf. on Mars*, 6124. [8] Zeitler, W., and J. Oberst, 1999, *J. Geophys. Res.*, 104, 8935. [9] Davies, M. E., et al., 1992, *Celest. Mech. Dyn. Astron., 63*, 127. [10] Davies, M. E., et al., 1999, *Eos Trans. AGU (suppl.), 80,* F615. [11] Smith, D. E., et al., 1999, *Science, 284*, 1495. [12] Duxbury, T. W., et al, 1999, *5th International Conf. on Mars*, 6040. [13] Neumann, G.A., et al., 2001, *J. Geophys. Res.,* submitted.

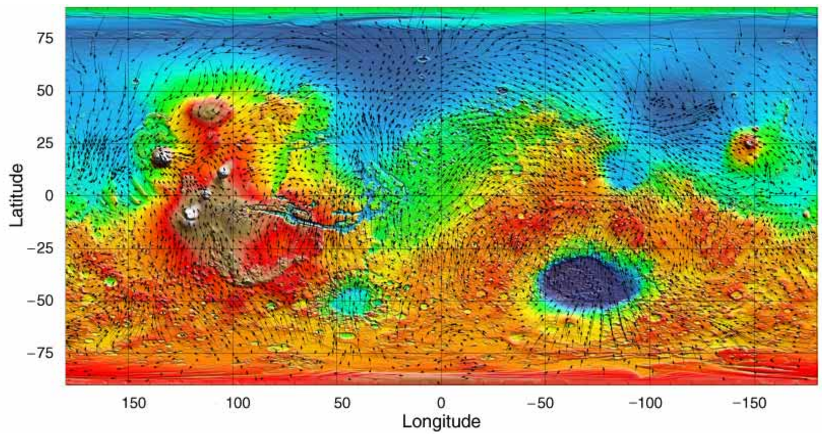

Figure 1. Displacement of features resulting from recently completed revision of Viking mosaic of Mars (MDIM). Base is MOLA shaded relief with elevation color. Vectors show positions of ~4600 image centers in 2000 MDIM 2.0 relative to 1991 MDIM 1. Mean longitude shift of 0.113° has been subtracted. Vectors show displacement in km (not degrees) and are scaled to the map grid in degrees, i.e., a 1-km displacement is the same length as 1° on the grid. Exaggeration is thus ~60x.

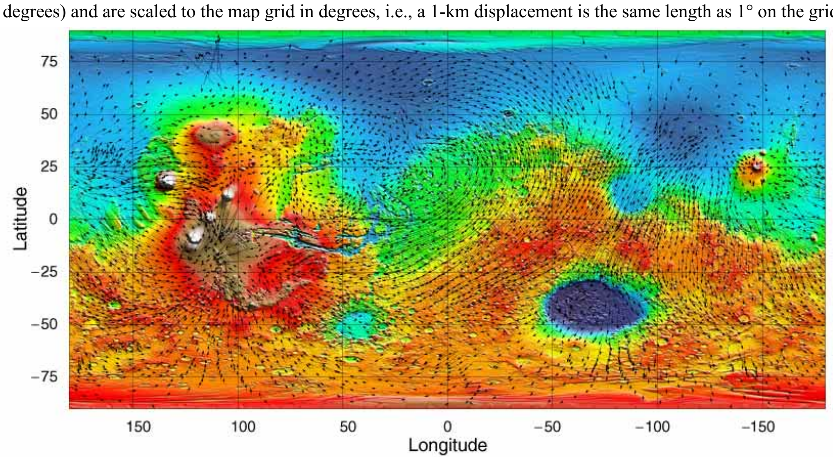

Figure 2. Displacement of features resulting from completion of effort to constrain all control points with MOLA-derived elevations. Vectors show image center positions in unpublished 2000 control net relative to MDIM 2.0. Exaggeration is 5x greater than in Fig. 1.

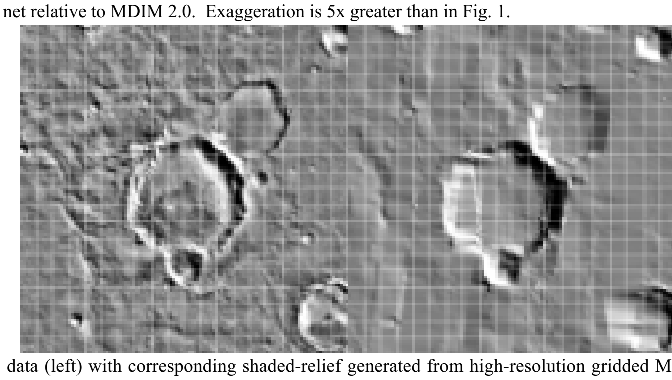

Figure 3. Comparison of MDIM 2.0 data (left) with corresponding shaded-relief generated from high-resolution gridded MOLA data (right) prepared in common coordinate system. A 2°x2° region centered on Airy-0 is shown in Sinusoidal projection at 256 pixels/degree (~231 m/pixel) scale of MDIM. Grid interval is 0.1° (~6 km); local positional difference of ~2.5 km in longitude, 1 km in latitude is visible. Comparison of datasets like these at intervals around planet will be used to assess MDIM 2.0 positional errors and provide additional control for MDIM 2.1.