REVISION OF THE MARS CONTROL NET AND GLOBAL DIGITAL IMAGE MOSAIC. R. Kirk, K. Becker, D. Cook, T. Hare, E. Howington-Kraus, C. Isbell, E. Lee, T. Rosanova, L. Soderblom, T. Sucharski, K. Thompson[1], M. Davies, T. Colvin[2], T. Parker[3]. [1]U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, Arizona, 86001 USA, rkirk@flagmail.wr.usgs.gov, [2]RAND, 1700 Main St., Santa Monica, CA, 90406, [3]JPL, 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]. This Mars mosaicked digital image model (MDIM) incorporated roughly 4600 Viking Orbiter images. The global mosaic, at a scale of 1/256 degree or ~231 m/pixel, was widely distributed on 6 CD-ROMs produced in 1991. As the highest resolution global map of Mars, the MDIM is vital for both scientific studies and planning of current and future missions. Unfortunately, it has significant shortcomings, particularly in the accuracy of geodetic control (i.e., the accuracy of feature positions). Geodetic accuracy is a particular concern for mission planning, which involves targeting of observations and navigation of landers to specific ground points.

The process by which the existing MDIM was controlled is too complex to explain in detail, but two key problem areas can be summarized. First, the MDIM inherited from an early version of the RAND 2D control net [2] a definition of the prime meridian that has been superseded, resulting in a systematic longitudinal offset of 10-15 km between the mosaic and newer control nets [3]. This longitude error propagated into a USGS 3D geodetic calculation [4] in which low-resolution but oblique Viking Orbiter images were used in an attempt to derive three-dimensional control (i.e., heights as well as horizontal coordinates of points). This net, and hence the MDIM, has significant errors [5] both because of the low resolution of the images and because of unreliability of supplementary information used [6]. Since the MDIM was produced, considerable progress has been made in refining the 2D RAND control net [3], in refining elevations [6,7], and in reanalyzing the 3D net [5]. Further useful inputs can be expected from the Mars Global Surveyor mission. We are therefore undertaking the production of revised and improved global mosaics of Mars.

Revision of the MDIM by the USGS is part of a significant team effort by members of the Mars Surveyor Program Geodesy and Cartography Working Group (MSGCWG) with expertise in geodesy, cartography, photogrammetry, spacecraft ephemerides and navigation, and analysis of datasets for Mars gravity, altimetry, and image data. Principal products of this joint effort will include a new unified control net for Mars, revised SPICE data for existing and new datasets, global digital image models (DIMs), digital topographic models (DTMs), and derived maps, and higher resolution special mosaics and maps of MED program landing sites. Our current and planned activities in this project are described below.

Mars Geodetic Control Networks: Revision of the geodetic control network is the foundation for future cartography and will be carried out in a series of steps, building to a final, optimal solution but with significantly improved versions delivered for cartographic use in the interim. As a first step, adopting the latest generation of the RAND network (which is widely used by the Mars missions) for future mosaics will constitute a significant advance; for the first time in over two decades the community will be working with a single, unified control net.

We are collaborating intensively with M. Davies to further refine the RAND net. The 4581 MDIM images, plus 644 images in the RAND net but not the MDIM, have been recovered from archive in radiometrically calibrated form and translated to ISIS format. A subset of image point measurements that were lost have been remeasured, and the point coordinates have been transmitted to RAND, allowing these images to be incorporated into the control network. The earlier RAND net consists of intersecting strips of images along meridians and parallels; inclusion of the MDIM images, which are of comparable resolution, fills in the gaps between these strips and solidifies the net [8]. Along with the point measurements, USGS is supplying reseau measurements (for camera distortion corrections) and a consistent set of ephemeris times, spacecraft vectors, etc.

Existing nearest-pixel point and reseau measurements will soon be refined to subpixel accuracy. This will be achieved quickly and efficiently by automatic image matching based on a correlation technique; the ISIS automatic image-matching algorithm has been improved to greatly increase the speed and precision of subpixel image matches. "Generic" square reseau templates used in the old software are being replaced by individual templates for each reseau (some of which are irregularly shaped because of detritus on the vidicon face) generated by aligning and averaging data from multiple images, a simple form of "superresolution" [9]. The nearest-pixel measurements were incorporated into the control-net analysis as they were delivered, allowing RAND to identify gross errors or mismeasurements for us to rectify. Incorporation of the more precise measurements into the net should therefore be straightforward and rapid. We anticipate that a satisfactory control solution will be obtained by early summer, 1999.

We are also assisting RAND by supplying higher resolution images, point measurements, and ties to lander images for the VL-1, VL-2, and Pathfinder landing sites. At present, it appears that the long-accepted VL-1 identification [10] is incorrect [5], but based on a reanalysis of the lander images with "superresolution" techniques [11] we have high confidence in a new candidate site. An identification of the VL-2 site based on the same technique is less certain [12]; we are comparing it and several proposed alternatives [13] for consistency with the control net as tied to the VL-1 and Pathfinder sites [14].

Further improvements of the martian control net will involve MGS data. Control points will be assigned elevations based on MOLA data as the latter become available. In addition, T. Duxbury (JPL) has demonstrated that he can identify points (e.g., bottom centers of craters) in the MDIM whose 3D inertial coordinates are known from MOLA, and he will expand this activity. USGS will then transfer these points from the old MDIM to individual VO images and supply the image coordinates of the points to RAND. This will truly open a new era in martian geodesy/cartography because these will be the first genuine ground control points known in inertial space (apart from the three landing sites). As MOC wide angle images from the global geodesy campaign become available, M. Malin (MSSS) and S. Synnott (JPL) will measure points on these and plan to construct a purely MOC-derived geodetic net. We will assist in comparing the RAND/VO and MOC nets for consistency and in merging them into a final, joint control. Comparison of mosaics of VO data tied to the various nets will be an important part of this process.

The output of each of these control net calculations will consist of estimated ground coordinates of a globally distributed set of points, plus revised camera pointing parameters (SPICE) for the images used (including all MDIM images), any pixel in any one of which can potentially be used as a geodetic tie for other, regional datasets.

Global Image Mosaics: In parallel with the refined geodetic networks, at least three successively improved global mosaics will be produced and made available online and in limited distribution on CD-R disks as they are produced. Referring to the existing mosaic [1] as "MDIM 1.0," we plan to produce MDIM 2.0 in mid calendar-year 1999. This mosaic will use the same VO images as version 1.0, but will be based on the updated RAND control network. The MSGCWG has recommended that production of the new mosaic should be delayed until the dimensions for a new reference figure of Mars based on MOLA data from the global mapping phase are available in the summer of 1999. This brief delay will avoid production of a mosaic that would almost immediately be obsolete and will not greatly inconvenience most users. We have already produced a mosaic of the Mars Polar Lander (MPL) landing zone from the MDIM images based on partially updated control (i.e., a RAND net solution that includes USGS image measurements in the landing zone but does not yet incorporate all our new measurements) [15]. Although it will soon be superseded by MDIM 2.0 (with very slight coordinate shifts due to further refinement of the net and use of the new reference figure), this mosaic is significantly more accurate than MDIM 1.0 and was therefore produced to aid the MPL team in their time-critical selection of a landing point.

The PICS software used to produce MDIM 1.0 has been ported to our newer ISIS system, with significant improvements in several areas being finalized at present. The software to be used for MDIM 2.0 incorporates the following advances.

- Subpixel measurement of image points and reseau centers.
- Redesigned software for handling image points to allow measurement of each point on an arbitrary number of images ($\geq$2) in order to maximize the amount and redundancy of information fed into the geodetic solution.
- Revised photometric modeling/correction incorporating a first-order atmospheric scattering model [16] and realistic surface scattering [17], significantly improving the cosmetic appearance of the mosaics by improving the equalization of feature contrasts in images obtained under widely varying illumination conditions.
- Use of 16-bit rather than 8-bit format throughout processing to avoid loss of low-contrast details, and use of more sophisticated spatial filters to remove noise while better preserving image details will each improve the cosmetic quality of the final mosaic. This is a significant issue because an important use of the MDIM is for targeting MOC observations and many subtle but interesting features are reportedly difficult to see in MDIM 1.0.

Further revision of the control network based on incorporation of MOLA data and MOC data (and/or a MOC-derived geodetic solution) will lead to the production of a MDIM 2.1 in 2000. The VO images will again be used, with the cosmetic processing improvements described above.

Finally, in 2001 we expect to produce MDIM 3.0, a global mosaic of MOC wide angle images with resolutions comparable to the VO images used in MDIMs 1.0–2.1. The resolution (1/256 degree or ~231 m/pixel) and format of the mosaic will be the same as earlier versions. The software needed for radiometric correction and geometric projection of MOC images is currently under development. Geodetic control will be based on the final solution derived from MOC and MOLA data.

Other Cartographic Products: We plan to produce additional cartographic products in response to the needs of the Mars missions and the community of researchers. The following types of products can be identified as being of interest. Under the first category, an interim mosaic of the MPL landing site has already been produced. A topographic map of the landing site will be made later in 1999.

- Regional mosaics of Viking Orbiter images (and possibly Mariner 9 images, for the south polar region) at higher resolution than the MDIM. VO image resolutions range from ~250 m/pixel globally to <10 m/pixel in limited areas [8]. The new mosaics will be tied to the best geodetic control available at the time of production, greatly improving their usefulness for targeting of orbital observations and landing points over existing medium-to-high resolution mosaics, which are tied to MDIM 1.0.
- High resolution regional DTMs derived by stereogrammetric analysis of VO images. The expected vertical precision (EP) of VO stereo coverage varies widely [8], from 300-1000 m over much of Mars to <10 m in limited areas (e.g., several candidate Viking landing sites). Accuracy of these regional DTMs will be greatly increased over past maps by tying them to MOLA observations. The stereo data, in turn, will significantly improve the (horizontal) spatial resolution achievable in some areas, compared to what MOLA alone provides.
- As MOC narrow angle observations become available, they can be mosaicked into maps with context data derived from VO images. Photogrammetric analysis of MOC narrow angle images paired with suitable VO images may also be possible in some areas of interest.
- Global image coverage of Mars with MOC wide angle images at resolutions <300 m/pixel with strong stereo sidelap is planned as part of the MGS "geodesy campaign." Once accurate SPICE data for these images are calculated as part of the MOC-derived geodetic net, we will be able to perform systematic stereotopographic mapping of part or all of Mars with ~1 km horizontal sampling and 50-100 m EP vertically.

Stereotopographic mapping will be performed with our LH Systems DPW790 digital photogrammetric workstation [18]. We have augmented the SOCET Set software supplied with this system with ISIS/SOCET interface routines for importing and exporting planetary data. Mapping with planetary framing camera images (e.g., VO, Clementine, Mars Pathfinder IMP) has been demonstrated extensively and is now routine. An appropriate sensor model (functional relation between 3D coordinates in object space and image coordinates) is needed for mapping with the MOC scanners. LH Systems offers a "generic" scanner model that can be used with any scanner provided a sufficient density of ground control is available beforehand. We will investigate the merits of using this model or of writing our own sensor model for the MOC cameras with the SOCET Developer's Toolkit.

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); Batson, R. M., and E. M. Eliason, 1991, Digital Maps of Mars, *Photogram. Eng. & Remote Sens., 61*, 1499–1507; [2] Davies, M. E., and F. Y. Katayama, 1983, The 1982 Control Net of Mars, *J. Geophys. Res., 88*, 7403–7404; [3] Davies, M. E., et al., 1992, Geodesy and Cartography, in *Mars*, Univ. of Ariz. Press, 321–342; [4] Wu., S. S. C., and F. Schafer, 1984, *Tech. Papers of the 50th Annual Meeting of the ASPRS, 2*, 445–463; [5] Zeitler, W., and J. Oberst, 1999, The Mars Pathfinder Landing Site and the Viking Control Point Network, *J. Geophys. Res*., 104 (E4), 8935–8942; [6] Smith, D. E., and M. T. Zuber, 1996, The Shape of Mars and the Topographic Signature of the Hemispheric Dichotomy, *Science, 271*, 194–188; [7] Smith, D. E., et al., 1998, Topography of the Northern Hemisphere of Mars from the Mars Orbiter Laser Altimeter, *Science, 279*, 1686–1692; [8] Kirk, R. L., et al., 1999, A Database of Viking Orbiter Image Coverage of Mars for Cartographic and Scientific Use, this conference; [9] Parker, T. J., 1998, "Super Resolution" of the Mars Pathfinder Landing Site by Manual Techniques, In *Lunar Planet. Sci. XXIX*, abstract #1965 (CD-ROM); [10] Morris, E. C., and K. L. Jones, 1980, Viking 1 Lander on the Surface of Mars: Revised Location, *Icarus, 44*, 217–222; [11] Parker, T. J., et al., 1999, Location and Geologic Setting for the Viking 1 Lander, Lunar Planet Sci. XXX, abstract #2040 (CD-ROM); [12] Parker, T. J., et al., 1999, Location and Geologic Setting for the 3 US Mars Landers, this conference; [13] Stooke, P. J., 1998, Locating the Viking 2 Landing Site, In *Lunar Planet. Sci. XXIX*, abstract #1024 (CD-ROM); [14] Davies, M. E., et al., 1999, Status of the RAND-USGS Control Network of Mars, this conference; [15] Kirk, R. L., et al., 1999, Mars DIM: The Next Generation, In *Lunar Planet. Sci. XXX*, abstract #1849 (CD-ROM); [16] Chandrasekhar, S., 1960, *Radiative Transfer*, Dover, 216–219; [17] Hapke, B., 1984, Bidirectional Reflectance Spectroscopy: 3. Correction for Macroscopic roughness, *Icarus, 59*, 41–59; [18] Kirk, R. L., et al., 1999, Digital Photogrammetric Analysis of the IMP Camera Images: Mapping the Pathfinder Landing Site in Three Dimensions, *J. Geophys. Res.*, 104 (E4), 8869–8888.