COMMUNITY TOOLS FOR CARTOGRAPHIC AND PHOTOGRAMMETRIC PROCESSING OF MARS EXPRESS HRSC IMAGES. R. L. Kirk[1], E. Howington-Kraus[1], K. Edmundson[1], B. Redding[1], D. Galuszka[1], T. Hare[1], K. Gwinner[2], [1]Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff AZ 86001 (rkirk@usgs.gov), [2]German Aerospace Center (DLR) Institute of Planetary Research, Rutherfordstraße 2, D-12489 Berlin, Germany.

Introduction: The High Resolution Stereo Camera (HRSC) on the Mars Express orbiter [1] is a multi-line pushbroom scanner that can obtain stereo and color coverage of targets in a single overpass, with pixel scales as small as 12.5 m at periapsis. Since commencing operations in 2004 it has imaged >77% of Mars at 20 m/pixel or better. The instrument team uses the Video Image Communication and Retrieval (VICAR) software to produce and archive a range of data products from uncalibrated and radiometrically calibrated images to controlled digital topographic models (DTMs) and orthoimages and regional mosaics of DTM and orthophoto data [2-4]. Alternatives to this highly effective standard processing pipeline are nevertheless of interest to researchers who do not have access to the full VICAR suite and may wish to make topographic products or perform other (e.g., spectrophotometric) analyses prior to the release of the highest level products. We have therefore developed software to ingest HRSC images and model their geometry in the USGS Integrated Software for Imagers and Spectrometers (ISIS; isis.astrogeology.usgs.gov), which can be used for data preparation, geodetic control, and analysis, and the commercial photogrammetric software SOCET SET (® BAE Systems; [5]) which can be used for independent production of DTMs and orthoimages. This abstract presents the completion of development and testing that took place in stages spanning more than a decade.

Relation to Past Work: The initial implementation of this capability [6] utilized the then-current ISIS2 system [7] and the generic pushbroom sensor model of SOCET SET, and was described in the DTM comparison of independent photogrammetric processing by different elements of the HRSC team [8]. A major drawback of this prototype was that neither software system then allowed for pushbroom images in which the exposure time changes from line to line. Except at periapsis, HRSC makes such timing changes every few hundred lines to accommodate changes of altitude and velocity in its elliptical orbit. As a result, it was necessary to split observations into blocks of constant exposure time, greatly increasing the effort needed to control the images and collect DTMs.

Here, we describe a substantially improved HRSC processing capability that incorporates sensor models with varying line timing in the current ISIS3 system [9] and SOCET SET. This enormously reduces the work effort for processing most images and eliminates the artifacts that arose from segmenting them. In addition, the software takes advantage of the continuously evolving capabilities of ISIS and the improved image matching module NGATE (Next Generation Automatic Terrain Extraction, incorporating area and feature based algorithms, multi-image and multi-direction matching) of SOCET SET [10], thus greatly reducing the need for manual editing of DTM errors. These advances were reported in [11]. We have also developed a procedure for geodetically controlling the images to Mars Orbiter Laser Altimeter (MOLA) data by registering a preliminary stereo topographic model to MOLA by using the point cloud alignment (*pc_align*) function of the NASA Ames Stereo Pipeline (ASP; [12]). This effectively converts inter-image tiepoints into ground control points in the MOLA coordinate system. The result is improved absolute accuracy and a significant reduction in work effort relative to manual measurement of ground control. *The ISIS and ASP software used are freely available; SOCET SET, is a commercial product.* In 2017 we ported our SOCET SET HRSC sensor model to the Community Sensor Model standard (CSM; [13, 14]) utilized by the successor photogrammetric system SOCET GXP that is currently offered by BAE. This model is currently being tested and will be open-sourced early in 2018.

Demonstration and Testing: We illustrate current processing capabilities with three examples, described in more detail in [15]. The first two sites are from the DTM comparison [8]. Candor Chasma (h1235_0001) was a near-periapse observation with constant exposure time that could be processed relatively easily at that time. We show qualitative and quantitative improvements in DTM resolution and precision as well as greatly reduced need for manual editing, and illustrate some of the photometric applications possible in ISIS. At the Nanedi Valles site we are now able to process all 3 long-arc orbits (h0894_0000, h0905_0000 and h0927_0000) without segmenting the images (Fig. 1). Finally, processing image set h4235_0001, which covers the landing site of the Mars Science Laboratory (MSL) rover and its rugged science target of Aeolis Mons in Gale crater, provides a rare opportunity to evaluate DTM resolution and precision because extensive High Resolution Imaging Science Experiment (HiRISE) DTMs are available [16]. The HiRISE products have ~50x smaller pixel scale so that discrepancies can mostly be attributed to HRSC. We compare the HRSC DTMs to increasingly smoothed versions of the HiRISE DTM to find the best match and evaluate its vertical error (Fig. 2).

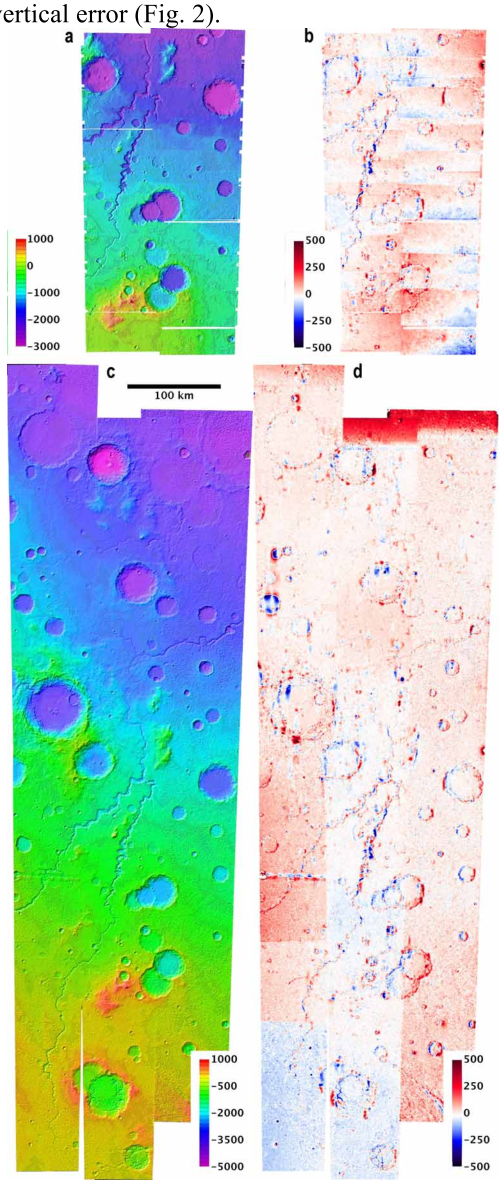

Figure 1. Nanedi comparison area. (a) Color shaded relief of area mapped in 2006. (b) Difference of 2006 DTM from MOLA, showing artifacts related to the segmentation of the images by exposure time. (c) DTM covering the full longitude extent of 3 orbits. (d) Difference between current DTM and MOLA. Mean and RMS error relative to MOLA points (excluding the areas with strong end effects) are -0.5 and 44 m.

We find that the vertical precision of HRSC DTMs is comparable to the pixel scale but the horizontal resolution is 15-30 image pixels, (350-700 m) depending on processing. This is significantly coarser than the lower limit of 3-5 pixels based on the minimum size for image patches to be matched. Misalignment of the DTMs is a possible explanation (the "truth" DTM must be smoothed to hide the misalignment as well as to match the resolution of the HRSC DTM) but simulations in which we smooth and displace the HiRISE data indicate that very large misalignments (tens of pixels) would be required; the observed misregistration is no more than a few pixels (Fig. 3). We are presently investigating how other measures of DTM resolution (cf. [8]) compare to those based on the HiRISE data.

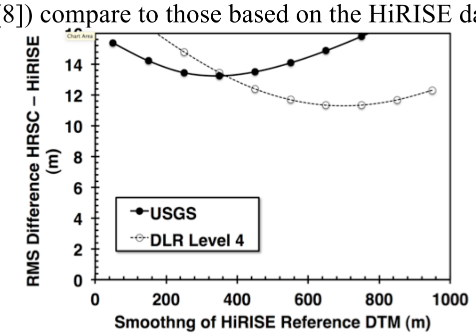

Figure 2. Standard deviation of the difference between USGS and HRSC Team Level 4 DTMs for rugged terrain on Aeolis Mons. Error level for the products is similar when evaluated at 350 m (~15 image pixels) smoothing, suggesting they simply make different trades between resolution and precision.

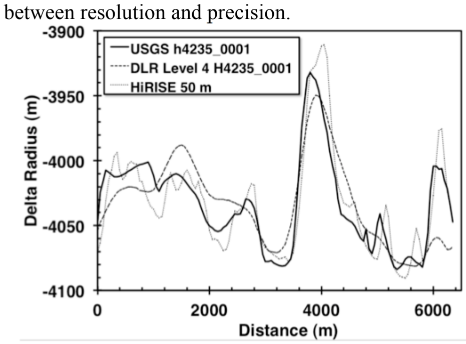

Figure 3. Sample profiles in Gale crater illustrating the differences in resolution between USGS and standard HRSC Team DTMs and the HiRISE DTM (downsampled from 1 m to 50 m per post).

Stereo DTMs registered to MOLA altimetry by surface fitting typically deviate by 10 m or less in mean elevation. Estimates of the RMS deviation are strongly influenced by the sparse sampling of the altimetry, but range from <50 m in flat areas to ~100 m in rugged areas.

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