HIRISE DIGITAL TERRAIN MODELS: UPDATES AND ADVANCES S. Sutton[1], R. Heyd[1], A. Fennema[1], A. S. McEwen[1], R. L. Kirk[2], E. Howington-Kraus[2], A. Espinoza[1], and the HiRISE Team. [1]Lunar and Planetary Laboratory, University of Arizona, (1541 E. University Blvd. Tucson, AZ 85721 USA ssutton@pirl.lpl.arizona.edu), [2]U.S. Geological Survey Astrogeology Science Center (Flagstaff, Arizona, USA)

Introduction: The High Resolution Imaging Science Experiment (HiRISE) camera [1], operating on the Mars Reconnaissance Orbiter (MRO) [2] since 2006, has acquired over 4200 stereo pairs to date. Digital Terrain Models (DTMs) generated from HiRISE stereo pairs are regularly released to the Planetary Data System (PDS). As of April, 2015, 235 DTMs are available via the PDS, and also at http://hirise.lpl.arizona.edu/dtm. We present recent and upcoming updates and advances to the HiRISE DTM data set.

Stereo Targeting: HiRISE acquires stereo image pairs by rolling the spacecraft off-nadir for one or both images. Each image is acquired on different orbits. Stereo targeting procedures have been refined over the mission to minimize lighting differences between images. For targets that are susceptible to rapid surface changes (i.e. frost, aeolian changes, etc.), great effort is made to acquire each half of the stereo pair as close in time as possible. Imaging geometry considerations such as look angles and convergence angle are also optimized based on the target topography and the available observing opportunities.

Prioritization and Release Schedule: DTM requests are prioritized internally by the HiRISE team. The two primary producing instutions are the University of Arizona and the USGS Astrogeology Science Center Photogrammetry group. Requests are generally either for research or for landing site assessment. Research requests by HiRISE team members are given priority, followed by external requests if resources allow. Landing site DTMs are generally funded through other programs and are produced according to the schedule for that mission/program.

DTMs from other institutions. Many other instutions are now producing high quality HiRISE DTMs thanks to the well-documented training and tools made available to the community primarily through the Photogrammetry facility at the USGS Astrogeology Science Center in Flagstaff, Arizona [3]. The consistency of procedures and documentation makes it possible to PDS archive HiRISE DTMs produced at other institutions, provided they meet quality standards. Please email the corresponding author for details about what is required to archive HiRISE DTMs in the PDS.

Release to the PDS. Preparation of DTM and related files in standard PDS formats is done at the HiRISE Operations Center (HiROC) at the University of Arizona [4]. DTMs produced for research are typically released to the PDS one year from their completion. DTMs for landing site assessment are released sooner, as requested by those teams. DTMs produced externally and delivered for PDS release may be released on a schedule specified by the producing institution. Updates to the PDS catalog occur monthly, as new projects become available.

Updates to Preprocessing: The significant advancement to HiRISE image preprocessing for DTM production is jitter correction via the HiPrecision subsytem. Other improvements are being tested, such as frequency domain processing that removes subtle electronic noise. These image processing techniques have been shown to improve DTM quality, reducing artifacts and editing time.

HiPrecision. The HiPrecision processing subsytem at HiROC has two branches: HiRISE Jitter-Analyzed CK (HiJACK) and HiNoProj [5]. HiNoProj duplicates the standard preprocessing of HiRISE images for stereo analysis in that it runs the Integrated Software for Imagers and Spectrometers (ISIS) program *noproj* [6] on each CCD image strip to remove optical and camera distortions, placing them in a single mosaicked image in a non-map projected “ideal camera” space. The HiJACK branch performs the same geometric correction, while additionally removing distortions in the images due to spacecraft jitter [7]. The output of HiPrecision is essentially what is needed for the input to HiRISE stereo processing. Requests for these products are being accepted now via email to hidip@pirl.lpl.arizona.edu.

Noise removal. This procedure is currently in testing, but will be incorporated in the HiROC calibration pipeline. It removes subtle regular electronic noise by processing individual CCD channels in the frequency domain. This improves the success of the stereo matching algorithm by minimizing noise patterns that occur at 1 or 2 pixel spacing. This processing will benefit HiRISE image analysis in general.

Method: The primary method for creating HiRISE DTMs as discussed here is based on the ISIS 3/SOCET SET ™ (BAE Systems, Inc.) procedures developed by the USGS Astrogeology Photogrammetry group [8]. This method relies on pre- and post-processing in ISIS. HiRISE images are radiometrically and geometrically calibrated in ISIS. The images are bundle adjusted and triangulated to the Mars Orbiter Laser Altimeter (MOLA) [9] gridded and point data in SOCET SET. New tools are available to automate and improve the registration of HiRISE to MOLA, such as *pc_align* from Ames Stereo Pipeline [10], or *autoTriangulation* from the HiRISE team [11]. After an acceptable fit to MOLA is achieved, the source stereo images are orthorectified. Additional images of the scene may also be orthorectified to the same DTM. The output from SOCET SET is map projected and PDS mapping definitions and labels are applied by ISIS routines.

Accuracy and Precision: Horizontal precision is 1 or 2 m, depending on the summing mode of the source stereo images (25 cm or 50 cm pixel scale, respectively). Horizontal and vertical accuracy are determined by best fit to MOLA shot points. Due to the large difference between the spatial resolutions of these two data sets, absolute horizontal accuracy is only as good as that of MOLA. Vertical accuracy is reported in the README text file, when available. This is measured by the average and standard deviation of differences between the terrain model and the MOLA shot elevations. Vertical precision can be estimated with knowledge of the stereo images' pixel scale, the triangulation RMS error and the convergence angle between the stereo pair [12]. This value will be calculated and reported in the README file in future releases. Other factors can locally affect the quality and accuracy within a DTM, such as dusty or bland areas, jitter, image noise, or shadows [13]. The Figure of Merit (FOM) map is generated to classify the correlation values reported from SOCET SET into a product that provides the user a guide to the quality of the DTM at each post (**Fig. 1**).

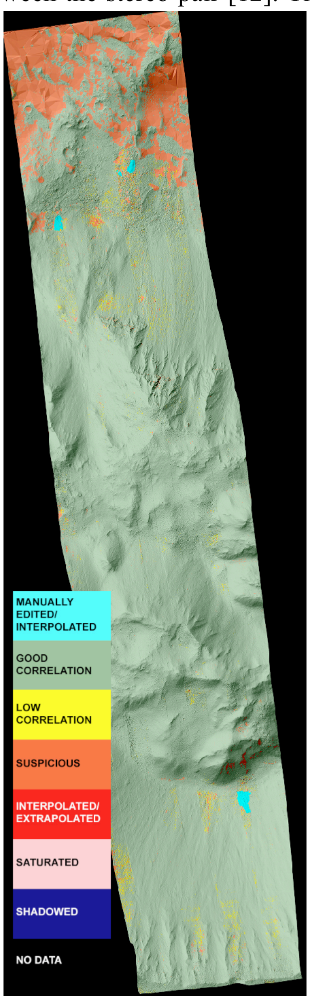

Figure 1. FOM map showing areas where low stereo correlation led to interpolation artifacts (orange), good correlation (green), and manually edited areas (turquoise).

Products: The products released to the PDS are in two categories: Standard and Extras. The standard products are the DTM in a 32-bit raster format (.IMG) with an embedded label, and the orthoimages as 8-bit JPEG-2000 (.JP2) images with detached PDS labels (.LBL). Extras are reduced resolution browse images (.jpg) in annotated and non-annotated versions. Cartographic definitions match the HiRISE Reduced Data Records (RDRs) as much as possible to maintain consistency with the HiRISE catalog.

DTM. Terrain is extracted at 1 m or 2 m post, or grid spacing. In most cases, one stereo pair is used per DTM. Contiguous adjacent stereo pairs can be used to produce regional DTMs. However, in the PDS, each pair is released individually with its corresponding orthoimages. At this time, it is up to the end user to mosaic these products. The HiRISE team may make mosaicked products available in the future. Information about images used in a single solution is contained in the README file.

Orthoimages. Orthoimages are generated at the source pixel scale (25 cm or 50 cm) as well as at the corresponding DTM scale. Color orthoimages are also generated, when available (HiRISE has a narrow central swath of 3-band color in Near-IR, visible red and blue-green). Additional images acquired over a target can be orthorectified by tying them to the existing stereo pair for a DTM. This allows for highly accurate change detection studies to be performed.

Extras. Browse images of the DTM are produced as grayscale, shaded relief, and colorized altimetry. Browse versions of the orthoimages are also available. The FOM map is produced as a color-coded map draped over a shaded relief image (.JP2), with a separate legend. The README text file contains basic information about the project, as well as an explantion of the naming convention and possible artifacts.

Conclusion: HiRISE DTMs are valuable data or geologic research, landing site hazard assessment, and visualization. Although there have been many improvements and refinements to the procedures used to create them over the years, they are still difficult to generate, requiring a great deal of operator skill and computational resources. The HiRISE team strives to communicate information about these DTMs, and new tools available for their creation and analysis, to the community, to enhance the science return from these products.

References: [1] McEwen, A.S. et al. (2007) *JGR* 112(E05S02). [2] Zurek, R. W. and Smrekar, S. E. (2007) *JGR*, 112(E05S01). [3] Kirk, R. L., Howington-Kraus, E., Rosiek, M. R. (2009) *LPSC XL*, #1414. [4] Mattson, S. et al. (2011) *LPSC XLII*, #1558. [5] Mattson, S. et al. (2012) *EPSC*, v. 7, 481. [6]http://isis.astrogeology.usgs.gov/Application/presentation/Tabbed/noproj/noproj.html [7] Mattson, S. et al. (2009) *EPSCI,* v. 4, 604. [8] Kirk, R. et al. (2008) *JGR-Planets*, 113(E00A24). [9] Smith D. et al. (2001) *JGR-Planets 106(E10),* 23, 689-23,722. A74. [10] Beyer, R. et al. (2014) *LPSC XLV*, #2902. [11] Kilgallon, A. et al. (2015) *LPSC XLVI*, #2373. [12] Kirk, R. L. et al. (2003) *JGR*, 108:8088. [13] Sutton, S. et al. (2015) *LPSC XLVI*, #3010.