MRO CTX STEREO IMAGE PROCESSING AND PRELIMINARY DEM QUALITY ASSESSMENT.

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Introduction: The Mars Reconnaissance Orbiter (MRO) Context Camera (CTX) [1] acquires ~6 m/px image data with maximum dimensions of ~30x300 km. As of Jan 1, 2011, CTX has acquired ~36700 images, covering >63% of the martian surface monoscopically and >20% with repeat coverage. Many of these images were acquired off-nadir with roll angles up to ±30°. We generate and filter cumulative lists of CTX image intersections to identify stereopairs on a weekly basis. Approximately ~12000 "valid" stereopairs can be formed from existing images, covering 5% of the surface between 80°S to 80°N. Several locations (e.g., monitoring sites, past/future landing sites) have been imaged >100 times with CTX, yielding hundreds of stereopairs for a range of acquisition geometries and imaging conditions. Here, we describe ongoing efforts to process and characterize the quality/accuracy of CTX anaglyphs and digital elevation models (DEMs).

Anaglyph Generation: Mars Global Surveyor Mars Orbiter Laser Altimeter (MOLA) statistics for each pair intersection area are computed from 128 px/deg gridded data. Right and left CTX images are calibrated, mapped (on a flat surface corresponding to the mean elevation of the intersection area), clipped, and stretched. Finally, an RGB image with the left image in the R channel and the right image in the GB channels is produced.

DEM Generation: A "divide-and-conquer" approach is used to split longer CTX images into smaller, overlapping segments. Segments are calibrated and mapped with a sinusoidal projection on an upsampled, smoothed version of the MOLA 128 px/deg grid. Backplanes of the original X and Y sensor pixel locations are generated during mapping. The NASA Ames Stereo Pipeline (ASP) correlator [2-5] is utilized to generate X and Y disparity maps. Custom triangulation software uses the disparity maps and pixel location backplanes to produce an output grid via inverse bilinear interpolation. Final steps involve mosaicing completed segments, adjusting elevations to the MOLA areoid [6], and generating additional products (shaded-relief maps, orthoimages, etc). A quantitative measure of correlation success is provided by ASP "good-pixel" maps.

Processing time is dependent on image intersection area, choice of sub-pixel refinement (SPR) method, correlator kernel/window size, and overall pair quality. Average processing time for "high-quality" DEM generation using the ASP Bayes Expectation-Maximization (EM) affine adaptive SPR [7] is roughly 10x that required for "draft" DEM generation using the ASP parabolic SPR option.

Valid Pair Geometry: Opportunities for stereopair acquisition are evaluated based on several criteria: spacecraft roll limits, emission angle difference (convergence angle), symmetry, temporal separation (L_s difference), and target priority. Ideal pair geometry differs for anaglyph and DEM generation. Both products are scientifically useful, as anaglyphs provide continuous, qualitative stereo information at native resolution, and DEMs provide quantitative information, but often at a reduced resolution with artifacts and/or gaps.

Multiple coincident anaglyphs (>10 pairs) for a range of available pair geometries (convergence angle range ~0-60°) were analyzed for 10 locations displaying different MOLA relief values (range 0-6 km). An inverse relationship exists between ideal convergence angle and relief: greater convergence angles are required for targets displaying low relief. In general, convergence angles between ~10-20° produce the best CTX anaglyphs; higher angles can cause viewer discomfort, particularly for areas with high relief.

Ideal DEM stereopair geometry involves larger convergence angles. Pixel displacements for a given feature increase with emission angle, while pointing/mapping errors remain constant, resulting in reduced vertical error during triangulation.

We presently use the following criteria to satisfy both anaglyph and DEM requirements:

Minimum convergence angle*	8-12°
Maximum convergence angle*,†	25-40°
Maximum L_s difference‡	30-60°
Minimum intersection dimensions	5x30 km

*Dependent on surface relief.
†Only relevant for anaglyph production.
‡Dependent on latitude.

Preliminary DEM Analysis: High-quality DEMs were generated for ~1180 valid pairs that satisfy ~750 CTX stereo observation targets. An additional ~800 pairs were generated to provide context for the four candidate MSL landing sites (Figure 1). Validated MOLA shot data were extracted for the area covered by each uncorrected CTX DEM (for ~1180 pairs, mean n_{shots} ~7240, 1-σ ~6260). Differences between the CTX DEMs and MOLA shots were computed based on the assumption that MOLA shot locations/elevations represent actual topography.

Correlation success rates are high (>90%) for the full range of convergence angles (Figure 2). DEM ab-

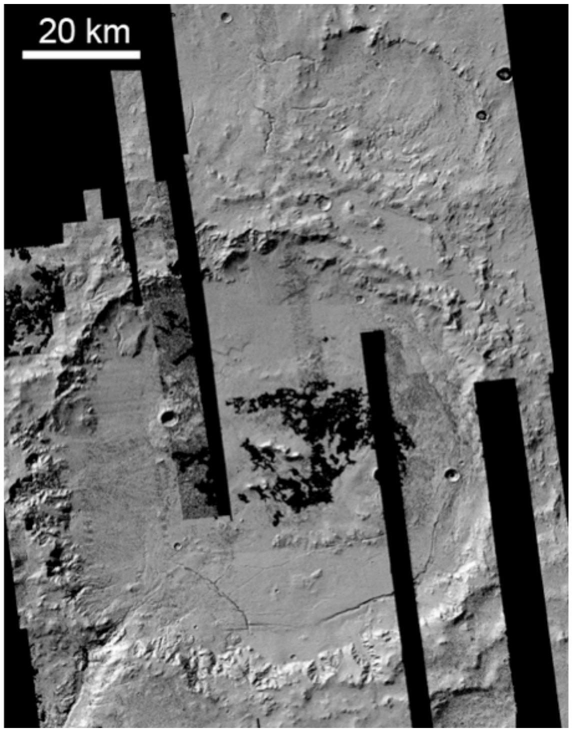

Figure 1: Unsupervised mosaic of shaded relief maps for Holden/Eberswalde as of Sept 2010.

solute accuracy appears to improve with increased convergence angle, although the number of high convergence angle pairs (>35°) is limited (Figure 2).

Elevation Corrections: As a first-order correction, a constant offset is applied to all CTX DEM elevations based on the median value of elevation differences (Figure 2B). However, residual offsets of ~10-30 m are still present between overlapping DEMs. Subtracting an interpolated grid (natural neighbor or radial basis function) of elevation differences offers improved results for areas with sufficient MOLA shot density.

Limitations & Artifacts: DEM artifacts, data gaps, and some elevation errors arise from 1) poor image quality/SNR (related to illumination, atmospheric clarity, etc.) 2) surfaces lacking high-frequency variations (e.g., dark dunes, north polar residual cap), 3) temporal changes in surface albedo/features (e.g., seasonal frost, wind streaks, shadows, dust storms, clouds, etc.), 4) steep surfaces displaying extreme foreshortening at high roll angles (e.g., crater walls), and 5) pointing errors. Pitch errors of ~0.001° in the reconstructed NAIF SPICE CK data ("jitter" [8,9]) can result in along-track "washboarding" artifacts with ~10-50 m relief. We are testing options for automatic removal of artifacts/gaps using filters and inpainting techniques.

Future Work: An effort to generate full-resolution "draft" DEMs for all ~12000 valid CTX stereopairs is underway. These will eventually be replaced by "high-quality" DEMs. We hope to distribute these products along with a more detailed analysis of quality and accuracy in the coming year.

References: [1] Malin M.C. et al. (2007) *JGR*, 115. [2] Edwards L.J. and M.J. Broxton (2006), *Space 2006*, AIAA 2006-7435. [3] Edwards L.J. and M.J. Broxton (2008) *LPS XXXIX*, Abstract #2489. [4] M.J. Broxton and Edwards L.J. (2008) *LPS XXXIX*, Abstract #2419. [5] Broxton M.J. et al. (2010) http://ti.arc.nasa.gov/m/project/ngt/asp_book_1.0.1.pdf. [6] Smith D.E. et al. (2001) *JGR*, 106. [7] Segal A.V. et al. (2009) http://www.stanford.edu/~avsegal/resources/papers/subpixel_refinement.pdf. [8] Mattson S. et al. (2009) *EPSC 4*, EPSC2009-604-1. [9] McEwen A. et al. (2010) *Icarus*, 205.

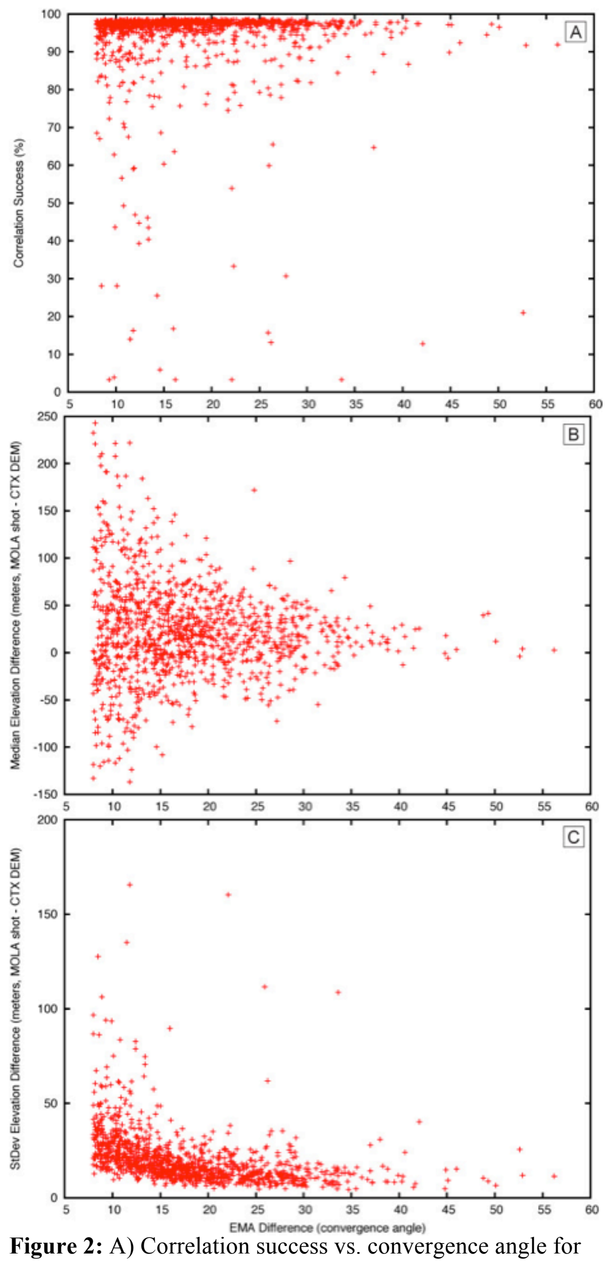

Figure 2: A) Correlation success vs. convergence angle for ~1180 high-quality CTX DEMs. B) Median value of differences between MOLA shot and CTX DEM elevations for each DEM. C) Standard deviation of elevation differences for each DEM.