IMAGE-TO-IMAGE REGISTRATION FOR A CTX MOSAIC OF MARS AT THE GLOBAL SCALE: ESTIMATIONS OF OFFSET IN MRO CTX IMAGE POINTING.

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Introduction: At the global scale, our knowledge of the panchromatic appearance of Mars (~5-6 m/px with Mars Reconnaissance Orbiter Context Camera data [1]) is significantly greater than our knowledge of its shape (interpolated at 463 m/px with Mars Global Surveyor Mars Orbiter Laser Altimeter data [2]) and gravity field [3-4]. This disparity manifests in absolute uncertainty of where specific features below the resolution of MOLA are in coordinate space, and thus targeted stereo topography is necessary for higher-fidelity knowledge of specific sites, especially for in-situ science [5]. At a more practical level for implementation of a global CTX mosaic [6], this resolution disparity manifests in relative uncertainty in that high-resolution images do not always register well *with each other.* Measurements and observations inherit the error to their placement based on predictive spacecraft positioning and instrument pointing alone.

We measured the range of positional misregistration of CTX images to each other at the global scale as part of our effort to generate a semi-controlled CTX mosaic of Mars rendered at 5 m/px. These values provide estimates of absolute/relative position uncertainty for SPICE kernel-derived CTX image placements, as well as an error metric for the "beta01" version of the CTX global mosaic that we have already released [6], which focused on non-destructive blending of orbits without correcting for misregistrations.

Methods: The mosaicking workflow semi-controls CTX data between 88°S and 88°N. The workflow's automated registration of two orbits was deemed successful if three tie-points could be generated, all with sub-pixel residuals (though typically dozens/hundreds of points were generated). A manual registration required two confident tie-points in different portions of the overlap that did not require sub-pixel residuals, as the inability to achieve sub-pixel registration is one reason it likely failed automatic registration. The resulting network produced an optimized linear shift with minimized errors that is sufficient for construction of this version of the CTX mosaic, while offsets due to local factors (steep topography, variable spacecraft motion during acquisition, etc.) are retained. All shifts and errors were measured in a locally accurate equidistant projection.

ERROR orbits. MRO CTX orbits that are incomplete due to missing packets during transmission are tagged "ERROR" (instead of "OK") in their DATA_QUALITY_DESC field. While these products are missing rows, the transmitted data are typically of nominal quality with the critical exception of their location: separate segments of ERROR data are not necessarily positioned accurately relative to each other, and are thus internally inconsistent (Fig. 1). We treated each segment of ERROR data separately but the shift required to register them to other CTX images includes the misalignment due to transmission dropouts, not simply the error due to camera pointing. We calculated their required shift separately (Fig. 2).

Results: We successfully registered 96,331 CTX images and image segments to overlapping CTX data. Some were registered to multiple images separately, such that we created 159,821 unique image-to-image matches (Fig. 2), recording the distance of the required shift and the residuals for all control points. 11,024 of these matches required manual registration. 8,273 of the 159,821 total matches included an ERROR image segment as the translated or reference image.

We found that 99.90% (n = 151,399) of OK orbits require less than one MOLA pixel shift (463 m) to register with overlapping data. ERROR orbit segments are nearly as likely (99.13%, n = 8,201) to be within one MOLA pixel. Mean translation required for OK orbits is 98.61 m with a standard deviation of 77.75 m. 95% of OK image-to-image registrations require less than a 249.78 m linear shift, and 95% of registrations that include at least one ERROR image segment require less than a 272 m shift.

Our largest recorded translations of OK orbits (~ 850 m) occur at 88°N and 88°S, where images included in our study overlap with the 2° of latitude at the poles where MOLA data are not available for effective orthorectification, so this distortion propagates into our analysis region. Only one non-polar match of OK orbits exceeded 700 m (Translate orbit: D22_035751_1387, Reference orbit: J10_048819_1381). The largest shift of an error segment was 58.47 km (P07_003807_1713), while all other ERROR shifts were < 1 km.

Discussion: Our quantitative assessment of CTX image-to-image registration is consistent with our qualitative analysis of CTX data and the feedback we have received from our technology demonstration version of the global CTX mosaic (“beta01”) [6], which did not perform any corrections for image misregistrations. Misalignments within “beta01” have been recognized for small features (< 50 m), but we have not encountered any errors at 1-km-scale. At the global scale, alignment of CTX images to each other can be trusted with close to 100% confidence at the sub-MOLA-pixel level (<463 m), even when including ERROR orbits.

Our measurements of sub-MOLA pointing accuracy of CTX images relative to each other indicates that the absolute pointing of CTX is comparable in precision. Absolute uncertainties at the 1-km scale, like those reported for ~5% of CTX images at southern high-latitudes [7], should manifest in our study at the > 1-km scale for an image-to-image match. The lack of offsets at this scale shows that uncorrected OK CTX orbits can typically be trusted to be accurate at the sub-MOLA pixel level.

References: [1] Malin M. C. et al. (2007) *JGR,* 112*,* E05S04. [2] Smith, D. E. et al. (2001) *JGR,* 106*,* 23,689-23,722. [3] Lemoine, F. G. et al. (2001) *JGR*, 106, 23,359-23,376. [4] Konopliv, A. S. et al. (2016) *Icarus*, 274, 253-260. [5] Tao, Y. et al. (2016) *Icarus*, 280, 139-157. [6] Dickson, J. L. et al. (2018) *LPSC*, 49, 2480. [7] Robbins, S. J. et al. (2020) Earth & Space Sci., 7(10), 10.1029/2019EA 001054

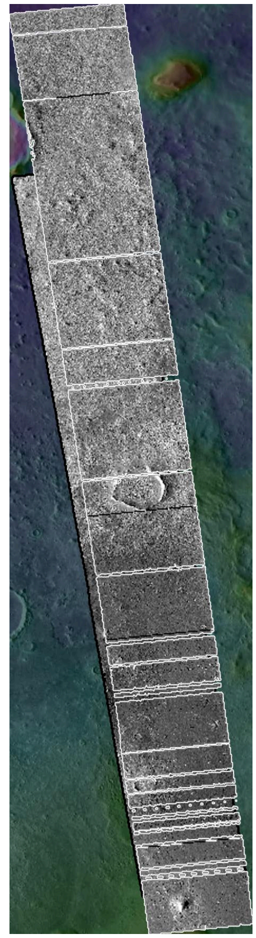

Figure 1. An ERROR orbit (F05_037683_2213) over an OK orbit (B19_017007_2209). We registered individual segments (white outlines) to overlapping data separately, producing distinct translations for segments of the same CTX image.

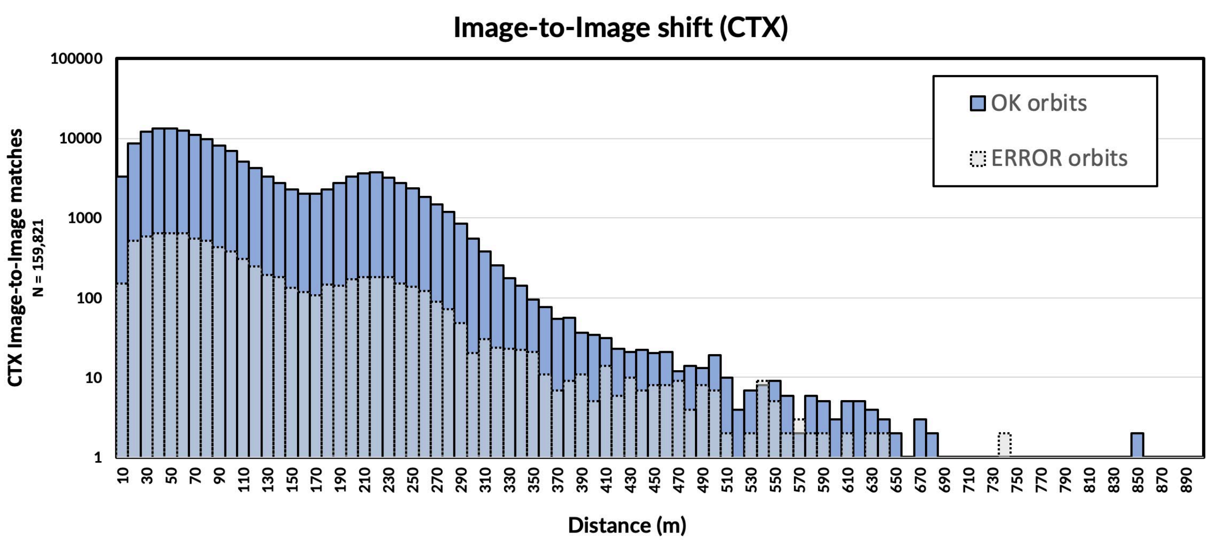

Figure 2. Distribution of linear shifts required for successful image-to-image registration of CTX images across Mars. One ERROR match that required a 58.47 km shift omitted for clarity (Translate orbit: P07_003807_1713_XN_08S166W, Reference orbit: F19_043181_1723_XN_07S166W).