THE SEARCH FOR ACTIVE MARSQUAKES USING SUBPIXEL COREGISTRATION AND CORRELATION: FIRST RESULTS AND BEST PRACTICES.
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Introduction: The ESA ExoMars Trace Gas Orbiter (TGO) [1] and NASA InSight [2] missions are both focused on detecting and monitoring active surface processes on Mars. Although these missions have different overall goals, they both demonstrate that understanding the present is key to understanding the past. In the case of TGO, although the main goal of the mission is to study the martian atmosphere, the Colour and Stereo Surface Imaging System (CaSSIS; [3]) instrument will help investigate the location and nature of any possible active sources for trace gases from orbit. One of the primary science goals of the InSight mission to Mars is to measure the magnitude, rate and geographical distribution of internal seismic activity, through the Seismic Experiment for Interior Structure (SEIS) instrument [4].

In this study we use COSI-Corr [5] with HiRISE images of a likely young fault system on Mars to (1) develop best practice techniques for identifying Marsquakes, (2) search for surface changes due to co-seismic displacements, and (3) predict the likelihood of future detection with different imaging instruments.

Data and Methods: We used 8 overlapping HiRISE [6] images, provided in the HiPRECISION form [7], in our study covering a time period of about 8 Earth years, with which we also made 4 stereo Digital Terrain Models (DTMs) using standard methods [8]. We used COSI-Corr to coregister, orthorectify and correlate each image using similar methods to previous studies of aeolian processes on Mars [e.g. 9, 10].

Study Region - Cerberus Fossae: Our choice of general study region was guided by geology and image availability. We narrowed our choice of region by concentrating on areas of Cerberus Fossae found to have peaks in boulder size-frequency distribution, attributed to ground shaking during geologically-recent Marsquakes [11].

Regional Setting. The main study region is part of the central Cerberus Fossae fault system, centered around 9.9°N, 157.8°E (Fig. 1). Cerberus Fossae is a single system at this location, approximately 1 – 1.5 km wide and 600 m deep. There is a smaller (up to ~100 m wide and 30 m deep) isolated fault to the north that is orthogonal to the main system, in addition to a 10 km long linear feature interpreted as a poorly-developed fault, that is about 40 km north of and parallel to the main system.

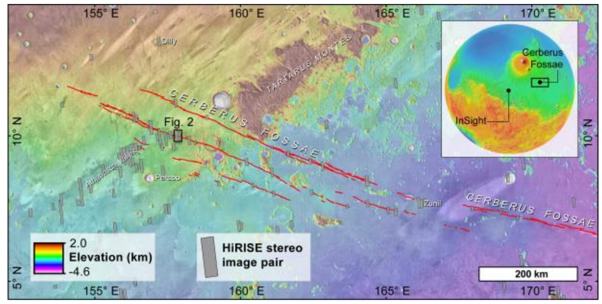

Figure 1. *Global and regional context of the study area. Inset shows the location of Cerberus Fossae in relation to the InSight landing site. Main image shows the fault trace (red line) of the Cerberus Fossae system. Base image is a colorized MOLA image overlain a THEMIS daytime IR image. Location of the main study area (Fig. 2) is shown by the black box, and HiRISE stereo pairs by the grey boxes.*

Local Setting. We concentrate some of our effort on a region (Fig. 2) than showed the best evidence of possible co-seismic deformation and optimal imaging conditions for the approach taken. This local study area is focused on an amphitheater-headed valley, approximately 650 x 900 m in size and up to 300 m in depth, which branches off from the main Cerberus valley in a SSE direction.

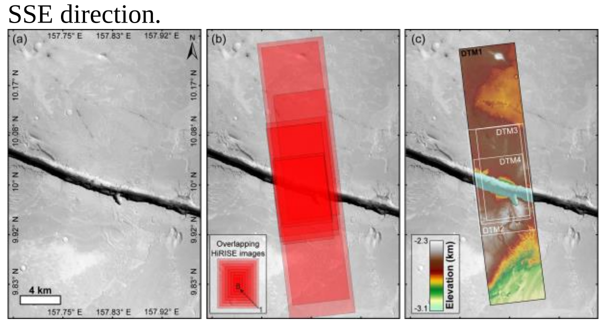

Figure 2. *Local context and image footprints of the local study area. (a) CTX image (G12_022809_1900_6m) orthorectified by a stereo CTX DTM showing the study area of Cerberus Fossae. (b) Footprints of the 8 overlapping HiRISE images used in this study. (c) Location of the stereo HiRISE DTMs generated for this study. DTM1 is used throughout.*

Results: Given that this was the first attempt to use COSI-Corr to detect active co-seismic deformation on Mars, we explored a number of approaches, including (1) whether the use of HiPRECISION data is necessary, (2) the choice of correlation sliding window size in COSI-Corr, (3) the use of low-pass filters after correlation, and (4) whether nearby RSL activity supports co-seismic displacement. However, here we concentrate on the results of a local case study example.

Our focus in searching for evidence of active co-seismic deformation was concentrated on a single area and signal that was most similar to that of a terrestrial earthquake. The main pattern that we used to identify such a feature was an area with apparent displacement that was approximately equal in magnitude, but opposite in direction, either side of a linear feature that could be a fault.

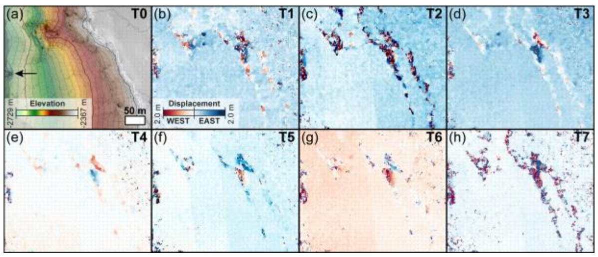

Figure 3. *Example of local displacement results. (a) Stereo DTM1 overlain on a hillshade image. Black arrow shows the location of a small DTM blunder. (b) – (h) East-west component of the correlation for images T1 to T7 respectively.*

The case study area lies on steep south-west facing slopes that run down from relatively flat plains. Correlation results from images T1 and T2 are relatively noisy, but images T3 and T4 show near identical results up to 1 – 2 m west displacement near the top of the slope and up to 1 – 2 m of east displacement lower down the slope. Images T5 and T6 show almost identical displacement results but with the directions reversed. Image T7 is again too noisy to interpret with confidence. No other displacement signals in any image in this local area demonstrated such a distinct and consistent, albeit reversing, signature.

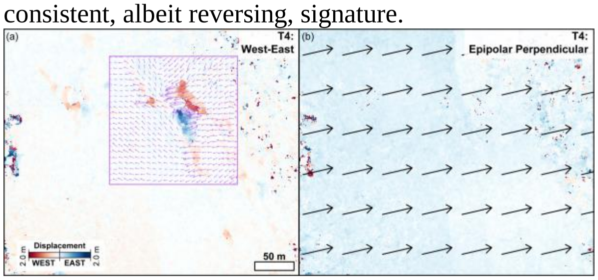

Figure 4. *Epipolar perpendicular displacement. (a) West-east component of the T4 correlation. Purple arrows show the displacement direction and magnitude of this result. (b) Reprojection of the displacement map in (a) into the epipolar perpendicular plane. Black arrows show the direction of this plane across the image, which are parallel due to the consistent use of pushbroom detector images before and after the putative event. Any possible Marsquake signal is eliminated in this projection.*

As none of the images in the time series are nadir looking, we expect parallax difference between images if topography is not entirely corrected during orthorectification. Following Reprojection into the epipolar perpendicular plane, which should contain no residual topographic information [12], we see no displacements that can confidently be attributed to co-seismic deformation. Therefore, rather importantly, removing the effect of topography also removes any putative signal of a Marsquake, thus making it unlikely that we have observed active deformation due to a seismic event.

Conclusions: It is evident that unless suitable post-processing techniques are developed, the use of jitter-corrected images significantly improves the correlation results. Investigation of the correlation parameters highlighted the different scale of image noise and possible changes in the resultant displacement maps, which can be improved with the use of a low-pass filter post-processing. Together with the use of jitter-corrected images, this filtering can effectively remove almost all instrument artefacts from the final correlation data. Overall, we saw no strong evidence for co-seismic displacement in our study region during the time period of the observations. One candidate signal had the appearance of typical terrestrial earthquake displacement, with an apparent west-east displacement of 1-2 m, possibly twice in opposite directions, over a length-scale of about 50 m. This signal was present, albeit with different noise levels, in all of the images in the time series. However, we dismissed this signal as evidence of co-seismic deformation, and through the use of an epipolar perpendicular projection, instead interpreted this signal to be the result of the incomplete correction of topography during the coregistration stage. Ancillary observations of RSL activity in the surrounding fault system, which could be triggered by stochastic seismic events, do not obviously support the observation of a seismic event. Although RSL activity that does not match previous seasonal observations elsewhere requires further explanation. Nonetheless, our study offers a best practice approach in searching for active Marsquakes with orbital images, which can be used to complement and independently verify in situ observations by the InSight lander.

References: [1] Vago J. et al. (2015) *Solar System Res.*, *49*, 518-528. [2] Banerdt W.B. et al. (2013) *LPSC 44*, #1915. [3] Thomas N. et al. (2016) *LPSC 47*, #1306. [4] Dandonneau P.A. et al. (2013), *LPSC 44*, #2006. [5] LePrince S. et al. (2007) *IEEE Trans.*, 45, 1529-1558. [6] McEwen A.S. et al. (2007) *JGR*, 112, E05S02. [7] Mattson S. et al. (2012) *EPSC* 7, #481. [8] Kirk R.L. et al. (2008) *JGR*, 113, E00A24. [9] Bridges N.T. et al. (2012) *Nature*,485, 339-342. [10] Ayoub F. et al. (2014) *Nature Comms.*, 5, 5096. [11] Roberts G.P. et al. (2012) *JGR*, 117, E02009. [12] Hollingsworth J. et al. (2014) *JGR*, 117, B11407.