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- Collaborative project -

D4.3
Completion of HiRISE DTMs and ORIs

WP 4 – Global DTM/ORI production & validation

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Executive Summary

In this report, we summarize the two automated DTM processing chains from UCL and UoS that both contributed to DTM production of several key sites. The HiRISE processing set-ups at UCL-MSSL's imaging cluster is introduced along with the system developed independently at the UoS. A summary of processing results and examples are given.

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1. Introduction

1.1 Background and Context

To track surface changes whether manually or automatically using data mining on Mars, it is important to be able to process data from different sensors. This involves addressing issues of processing extremely large datasets with different image resolution, lighting conditions, coverage and locational accuracy. The goal of the iMars project is to be able to maximize the exploitation of the available planetary datasets to enable improved understanding of the geology and geomorphology of the Martian surface through the generation of high quality Digital Terrain Models (DTM) and corresponding terrain-corrected images, OrthoRectified Images (ORI), using data from different NASA instruments co-registering these to a global set of accurately areo-referenced HRSC DTMs and ORIs to enable change detection. The camera with the highest resolution of up to 25cm flying around Mars is the NASA HiRISE instrument (McEwen et al., 2007) onboard the NASA MRO (Mars Reconnaissance orbiter). It has been acquiring imagery of the Martian surface since 2006.

The HiRISE camera is designed to acquire very detailed orbital images of Mars. HiRISE uses 14 CCDs including 10 red channels, 2 blue-green channels, and 2 NIR channels. The nominal maximum size of the red images is about 20,000 x 126,000 pixels and 4,000 x 126,000 pixels for the narrower B-G and NIR bands. To facilitate the mapping of landing sites, HiRISE produces stereo pairs of images from which the topography can be measured to an accuracy of 0.25 metres up to a grid-spacing of 0.75m.

In iMars, UCL developed a fully automated multi-resolution DTM processing chain, called the Co-registration ASP-Gotcha Optimised (CASP-GO), based on the open source NASA Ames Stereo Pipeline (ASP) (Moratto et al., 2010 and Broxton et al., 2008), tie-point based multi-resolution image co-registration (Sidiropoulos & Muller, 2015), and Gotcha (Shin & Muller, 2012) sub-pixel refinement method. The implemented system guarantees global geo-referencing compliance with respect to High Resolution Stereo Colour imaging (HRSC), and hence to the Mars Orbiter Laser Altimeter (MOLA), providing refined stereo matching completeness and accuracy from the ASP normalised cross-correlation. In parallel, UoS re-implemented an in-house DTM pipeline into a more scientifically oriented form focusing on geodetic control and point density, which are essential properties for geological/geomorphological analyses.

UCL and UoS have processed HiRISE DTMs for the 3 landing site regions used initially for testing each of the DTM production systems and later for the validation as well as a variety of areas of special scientific interest. By the time of writing up this report, a total number of 441 identified HiRISE stereo pairs that have 5 or more repeat coverage are being processing using the Amazon® Web Service (AWS) cloud computing resource.

1.2 Deliverable objectives

This report summarizes the UCL and UoS HiRISE DTM processing chain and processing results for several key sites of interest.

2. UCL HiRISE DTM Processing

2.1 The NASA ASP & UCL CASP-GO Systems

The NASA Ames Stereo Pipeline (ASP) is a suite of automated geodesy and stereo-photogrammetry tools designed for processing planetary imagery captured from orbiting and landed robotic explorers on other planets or Earth. It was designed to process stereo imagery captured by NASA and commercial spacecraft and produce cartographic products including digital elevation models (DEMs), ortho-rectified imagery, and 3D models (Moratto et al., 2010).

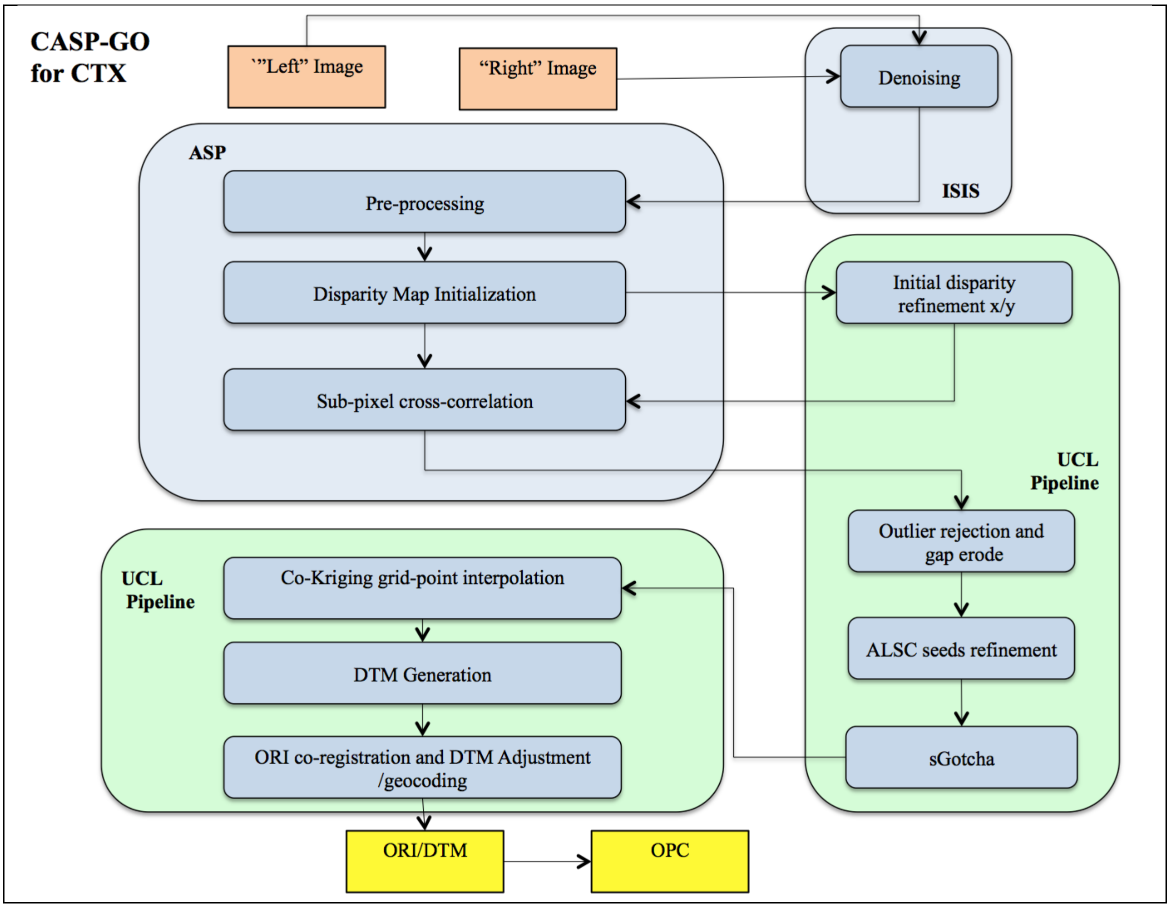
The original ASP pipeline was investigated in the early stages of the iMars project and is reported within D1.2. A quality assessment of the processed results were made by comparing the output DTMs with those produced from the BAE Socet System (SS) and the UoS pipeline applied to the same regions on Mars. For this purpose, input HiRISE stereo images of the three most observed sites on MER and MSL were chosen. The average and standard deviation of the differences between the HRSC, and ASP, SS, and UoS DTMs for the HiRISE instrument was −13.3 ± 19.7m, +4.2±19.7m and +2.3 ± 37.2m respectively. The large dispersion of the differences is due to a smaller number of features for the smaller area covered by the HiRISE instrument. We also found a quilting artefact with the ASP processing chain caused by the initial integer based cross-correlation, failing matching areas for texture-less places. On the other hand, the ASP processing chain showed very good software integration and batch processing potential, but were considered to need significant improvement in global consistency, completeness and robustness.

In iMars, UCL decided to further develop the open source ASP pipeline and extended/modified several key components to specifically address issues found from the first experimental products, in order to develop a more optimal processing chain, called CASP-GO (Co-registered ASP – Gotcha Optimised), to provide co-registered geo-spatial coordinates w.r.t HRSC (and MOLA) data, improved DTM completeness, reduced DTM artefacts, and improved DTM accuracy. Apart from the ASP pre-processing, cross-correlation matching, triangulation, and DTM/ORI generation, five additional workflows are introduced to further improve the ASP results. These included (a) a fast Maximum likelihood sub-pixel refinement method to build a floating-point initial disparity map; (b) an outlier rejection and erosion scheme to define and eliminate mismatches; (c) an ALSC and region growing (Gotcha) area-based image matching system to provide refinement of integer level pixel acuity and densification method to refine the disparity value and match un-matched and/or mis-matched area; (d) co-kriging grid-point interpolation to generate the final DTM as well as height uncertainties for each DTM point; (e) ORI co-registration w.r.t. HRSC. The original CASP-GO auto-DTM processing chain is introduced in D4.2.

2.2 CASP-GO DTM Processing Chain for HiRISE

HiRISE images are 10 to 15 times larger than the CTX images (see further details in D4.2) and contain much richer fine scale features at 25cm that may vary between stereo images. The HiRISE EDR products also contain systematic noise such as strip noise and gain variations. Based on the results from the experimental sites of MER-A, MER-B and MSL, several modifications were made to the original ASP DTM processing chain in order to produce optimised results for HiRISE images.

A flow diagram of the original CASP-GO processing chain and its variation for HiRISE processing is shown in Figure 1.



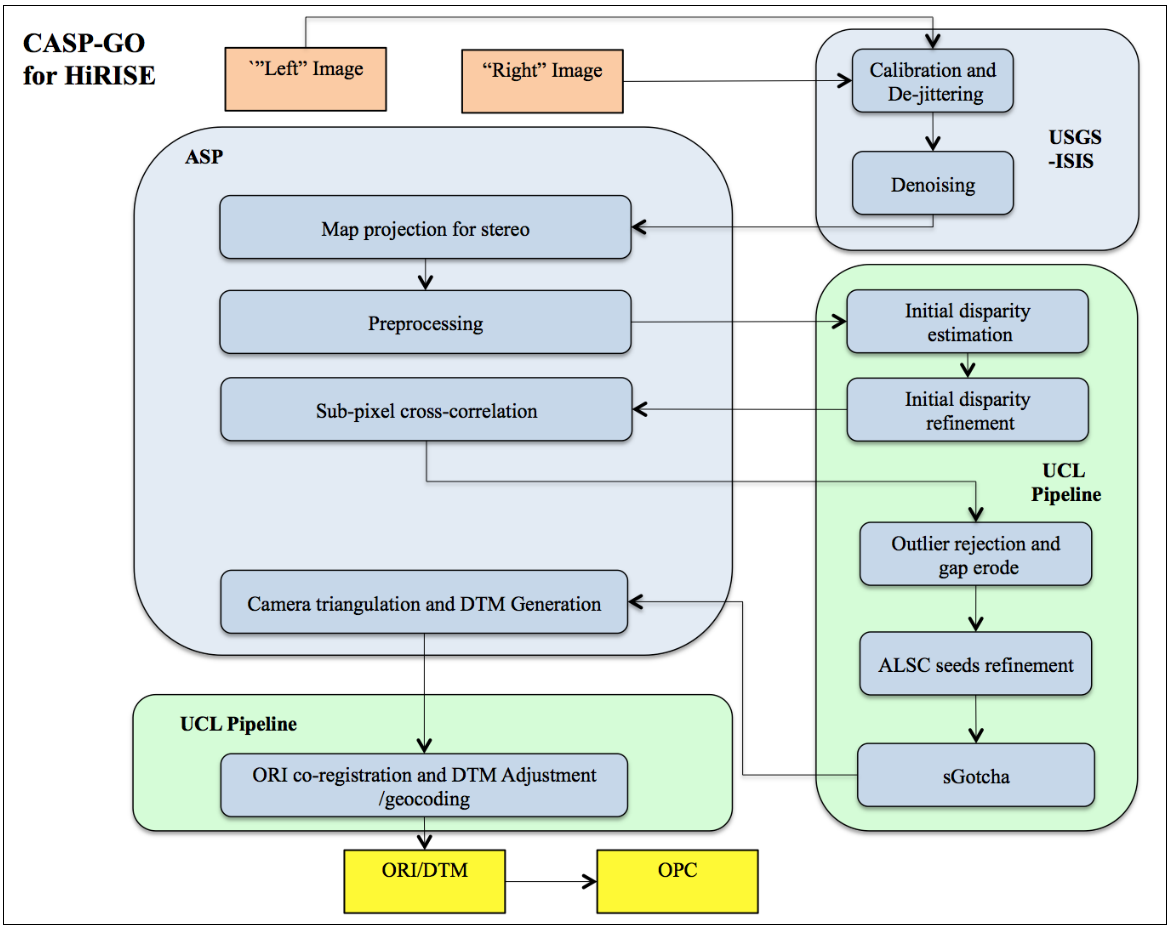


Figure 1: Flow diagram of the original CASP-GO auto-DTM processing chain and its variation for HiRISE processing.

Firstly, pre-processing is required for HiRISE images using routines from the USGS-ISIS processing suite. One important difference between HiRISE and CTX is that HiRISE is composed of multiple linear CCDs that are arranged side by side with some vertical offsets (see McEwen et al., 2007 for further details). These offsets mean that the CCDs view the same terrain at a slightly different time and angle. The USGS-ISIS pre-processing steps includes the standard USGS-ISIS pipeline for HiRISE CCD radiometric de-calibration, stitching, SPICE kernel initialisation, and a de-jittering process. This is followed by a sequence of USGS-ISIS de-stripping and Kuwahara denoise filters (https://isis.astrogeology.usgs.gov).

Secondly, we found that the raw feature extraction algorithms from ASP are not accurate enough without further refinement, especially for image pairs that contain large topographic variations. This always leads to abnormal epipolar-rectification transformations. In this case we used the ASP's map projection to stereo function, which is an ASP wrapper based on USGS-ISIS functions, to remove the large disparity differences between HiRISE images and leave only a small disparity for estimation of initial disparity maps. Note that with USGS-ISIS formatted inputs, one can always work backwards through a map-projection when applying a camera model, so the geometric integrity of input images will not be sacrificed if you apply map-projection first.

Thirdly, we used an absolute difference based initial disparity estimation method to calculate the integer based on a coarser scale. This directly compares the map-projected and x/y disparity minimised stereo images to generate a smoother initial disparity map with less mis-matches than the ASP's normalised cross-correlation based approach. This step is still followed by the fast Maximum Likelihood refinement approach to generate sub-pixel level initial disparity map.

Finally, a less strict outlier rejection and erosion scheme is used and the co-kriging steps have become optional for HiRISE images due to the very big image and very lengthy processing time.

2.3 HiRISE processing set-up

At UCL-MSSL, we have mirrored the HRSC, CTX, HiRISE PDS data volumes from JPL in a local shared storage system in order to speed up the production process with an option such that if data is unreachable it can be read from the original source again at JPL. At UCL-MSSL, the developed software is installed in a shared directory, which is accessible from 14 Linux processing blades (10 with 16 cores and 48GB RAM; 4 with 24 cores and 96GB RAM). Jobs are controlled via a local desktop machine and distributed to the 14 processing blades with multiple sessions of multi-threaded processing. Processed results are stored in several 1TB RAID storage disk partitions and logged back to the local controlling desktop. Failed jobs can be examined through detailed log files and in the future can be reprocessed automatically with different processing parameters. However, with processing pressure from the large number of CTX DTMs for MC11 and UCL ACRO production processing, only very few HiRISE sites with great scientific interest were processed.

In the meantime, UCL was successful with a free access award to $30,000 computing resources from the AWS® Cloud computing. UCL worked on the virtual machine set-up, software integration, and test processing at AWS® cloud computing since early 2017 and started batch processing of 441 HiRISE stereo pairs from late March.

3. UoS HiRISE DTM Processing

Although the original UoS stereo processor was designed for the mass production of CTX and HiRISE DTMs, UoS re-implemented the software into a more scientifically oriented form focusing on geodetic control and point density, which are essential properties for geological/geomorphological analyses. Together with the UoS stereo software and manual parameter setting, CTX/HiRISE DTMs over scientifically interested areas have been processed and delivered. Such efforts aim to accomplish quality scientific research outcomes over specific areas/features using processed DTMs. The target areas, processed outputs and further applications for scientific purposes are described in the following.

Geodetic control and 3D point density are essential properties for geological/geomorphological analyses such as fluvial channel interpretation, numerical simulation and structural geology studies. Therefore the pre-implemented UoS WP1 stereo processor (Figure 2) was re-organised for the processing of ortho/DTMs with more emphasis on geodetic control and point density rather than mass production efficiency. Especially image matching stage and sensor model were integrated with the manual iteration stage for such purposes.

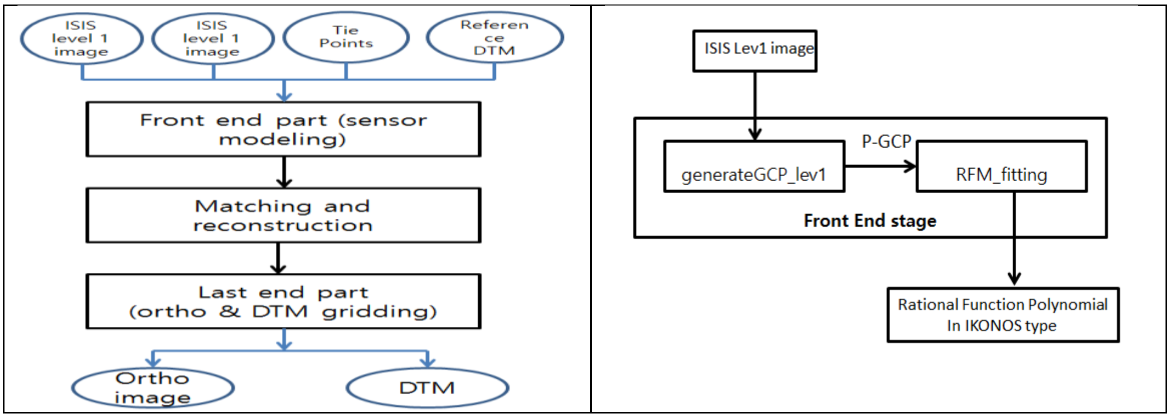
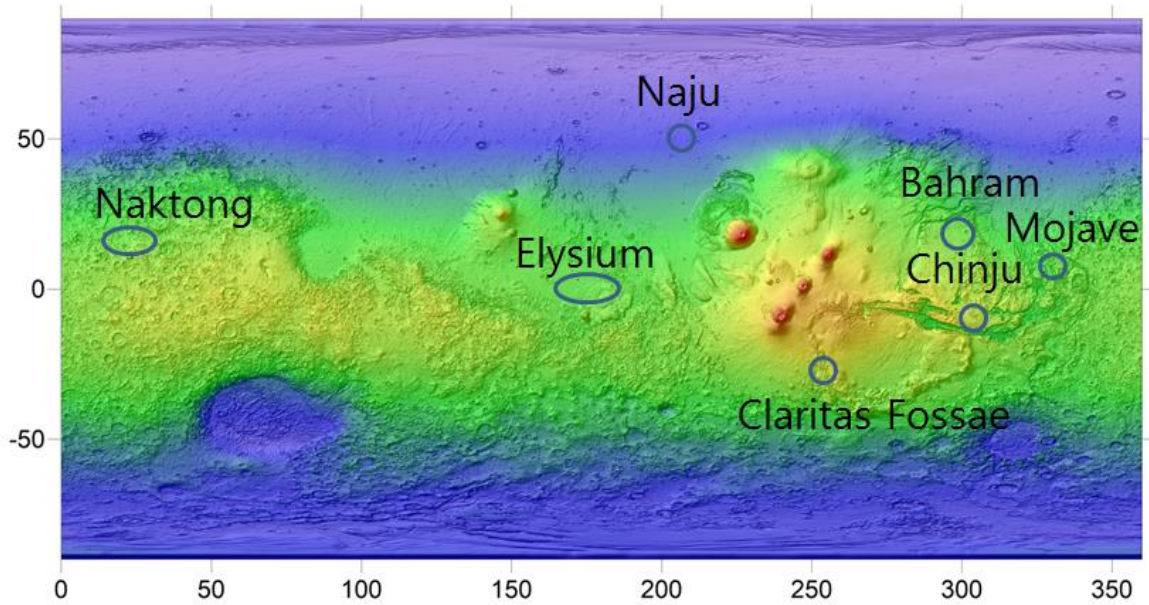


Figure 2: Outlines of UoS stereo processor (left) and sensor modelling part.

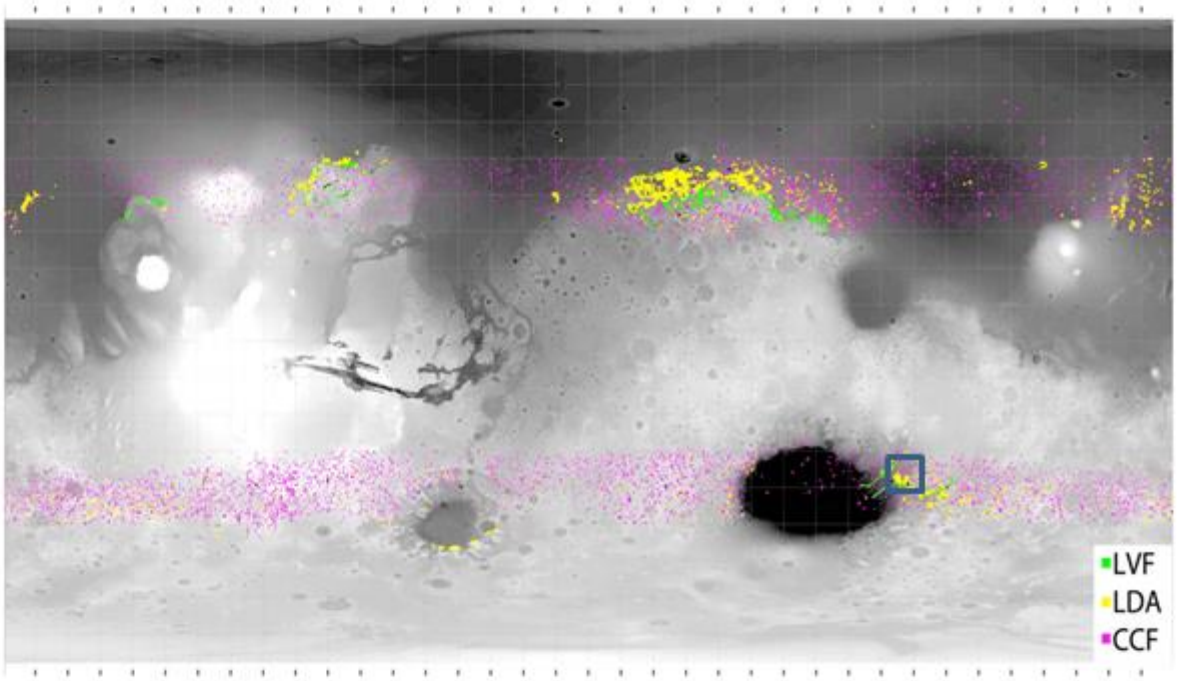
Target areas for the application of UoS stereo processors were established for two types of terrain on Mars:

1) Area oriented targets over Naktong valley, Chinju crater, Naju crater
2) Feature oriented target areas such as Lobate Debris Apron (LDA) over Euripus Mons, fluvial channel over Baharm and Elysium, tectonic features around Claritas Fossae, Inter-crater features over Elysium, Mojave and Jazero (see Figure 3).

It should be noted that the geodetic controls over the target area follows the hierarchical approaches described by Kim and Muller (2009). In this approach, HRSC are employed as the base DTM/ortho image for geodetic controls of the CTX base image. Then HIRISE stereo is controlled using the stereo-derived CTX DTM/ortho image. However, HRSC to HIRISE control is sometimes carefully conducted in the case where there is no CTX stereo coverage such as the Claritas Fossae target area.



Target area locations for HiRISE DTM processing using the UoS stereo processor



Target areas over Euripus Mons and the locations of LDA structures (Levy et al., 2014)

Figure 3: Target areas for the applications of the UoS stereo processor.

To this end, all possible CTX/HIRISE DTMs and ortho images over the UoS test areas were processed and delivered to FUB for display on the iMars webGIS. Over some areas, the validation of geodetic control using MOLA track profiles was also conducted (see D 4.5)

4. Summary of Processing Results and Research Findings

The first HiRISE DTM processing at UCL-MSSL was focused on the 3 rover sites, i.e. MER-A, MER-B and MSL. A series of re-processing for the most difficult (noisy) MER-B site were achieved in parallel with CASP-GO pipeline development and refinement. Figure 4 shows the HiRISE ORI with colour-coded heights from MER-A, MER-B and MSL. A table showing the results of a comparison of the HiRISE DTM heights and corresponding CTX DTM heights are shown in Table 1 derived by DLR. The shaded DTMs show that the overall qualities of the product are reasonably good. Height artefacts related to CCD borders and blunder points are evident over terrain with smooth or small-scale relief. Colour coded heights show no gross systematic effects like large-scale tilting of the surface model. The statistics show good agreement with the corresponding CTX DTMs.

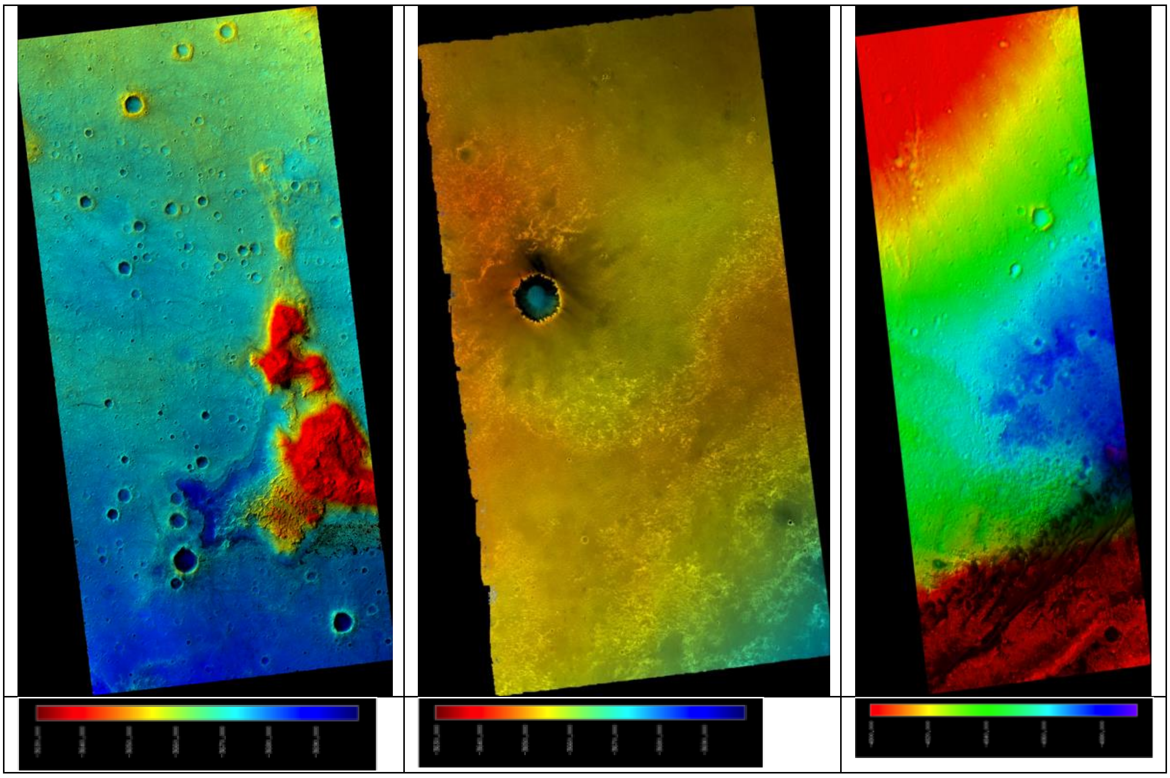


Figure 4: ORIs with colourised DTM heights for MER-A (left), MER-B (middle), MSL (right) final processing results.

	CTX DTM	HiRISE DTM	CTX – HiRISE DTM
Number of Elements:	53,853,617	53,853,617	53,853,137
Minimum [m]:	-1941.49	-2189.98	-31.6903
Maximum [m]:	-1860.42	-1851.54	321.232
Height range [m]:	81.07	338.44	352.9223
Average DN Value [m]:	-1883.53	-1883.57	0.0467466
Standard Deviation [m]:	10.3173	11.4009	7.74501
	CTX DTM	**HiRISE DTM**	**CTX – HiRISE DTM**
Number of Elements:	88,182,234	88,182,234	88,182,234
Minimum [m]:	-3710.41	-3699.29	-118.201
Maximum [m]:	-3608.78	-3578.45	8.14648
Height range [m]:	101.63	120.84	126.34748
Average DN Value [m]:	-3688.85	-3669.31	-19.5391
Standard Deviation [m]:	14.0781	14.0563	5.85132
	CTX DTM	**HiRISE DTM**	**CTX – HiRISE DTM**
Number of Elements:	141,207,925	141,207,925	141,201,637
Minimum [m]:	-4,888.08	-4,891.41	-37.4331
Maximum [m]:	-4,509.07	-4,486.92	90.8442
Height range [m]:	379.01	404.49	128.2773
Average DN Value [m]:	-4,813.33	-4,812.86	-0.464134
Standard Deviation [m]:	61.2551	64.6398	5.00121

Table 1: Statistics for the MER-A, MER-B and MSL HiRISE DTMs in comparison with corresponding CTX DTMs taken from D4.5.

Following on from the 3 rover sites, UCL has produced DTMs for several scientific sites of interest including a candidate Mars2020 landing site and a separate candidate site in the Eberswalde Crater (Figure 5a). An example of HiRISE products over the Swiss Cheese terrain HiRISE DTM is shown in Figure 5b.

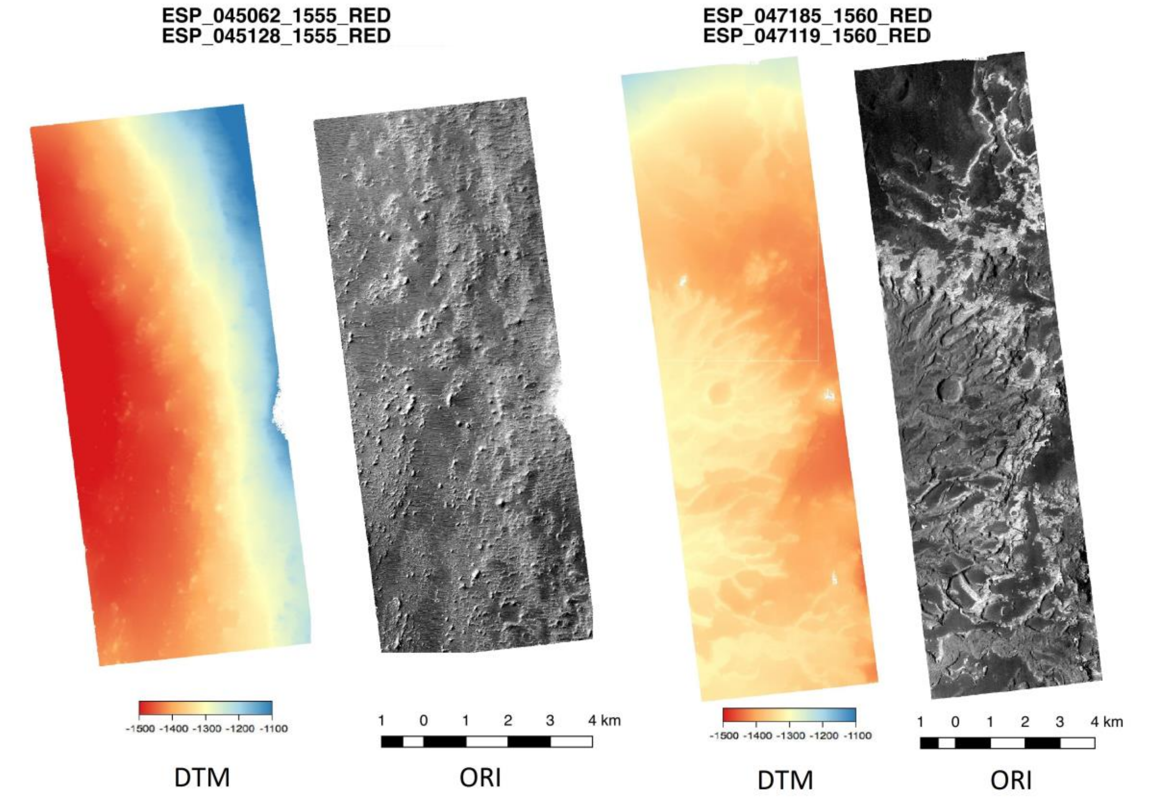


Figure 5a: Colourised DTMs and ORIs of the Mars2020 landing sites and a candidate site inside the Eberswalde Crater for the 2020 mission.

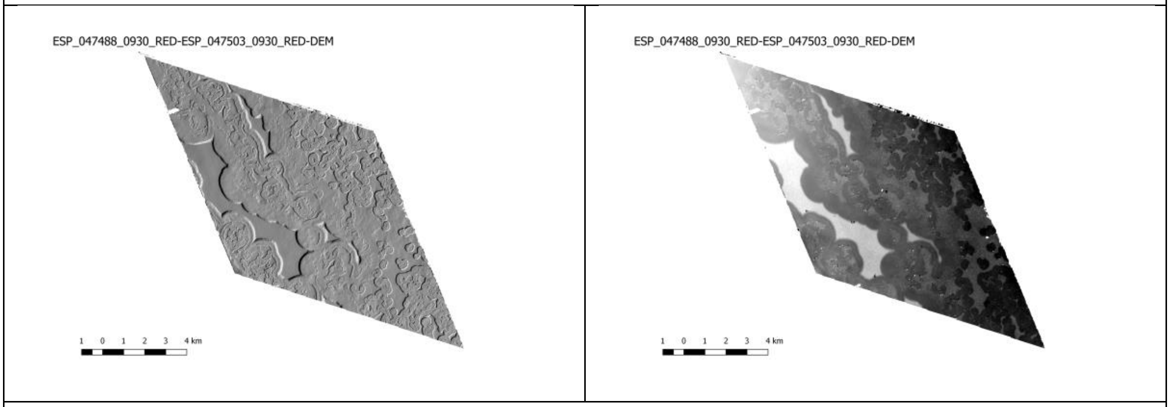
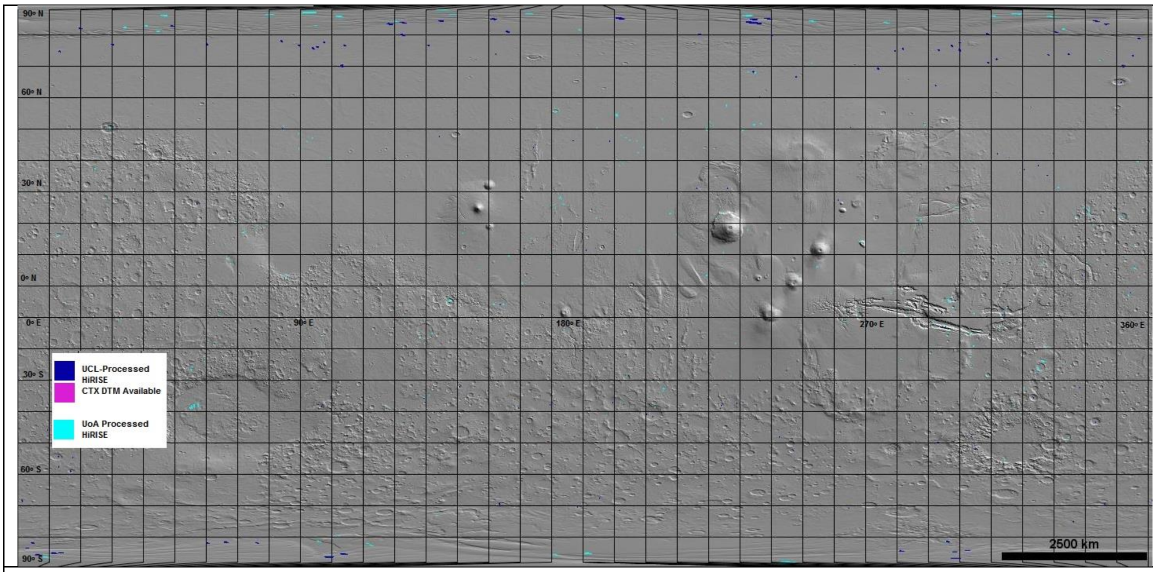
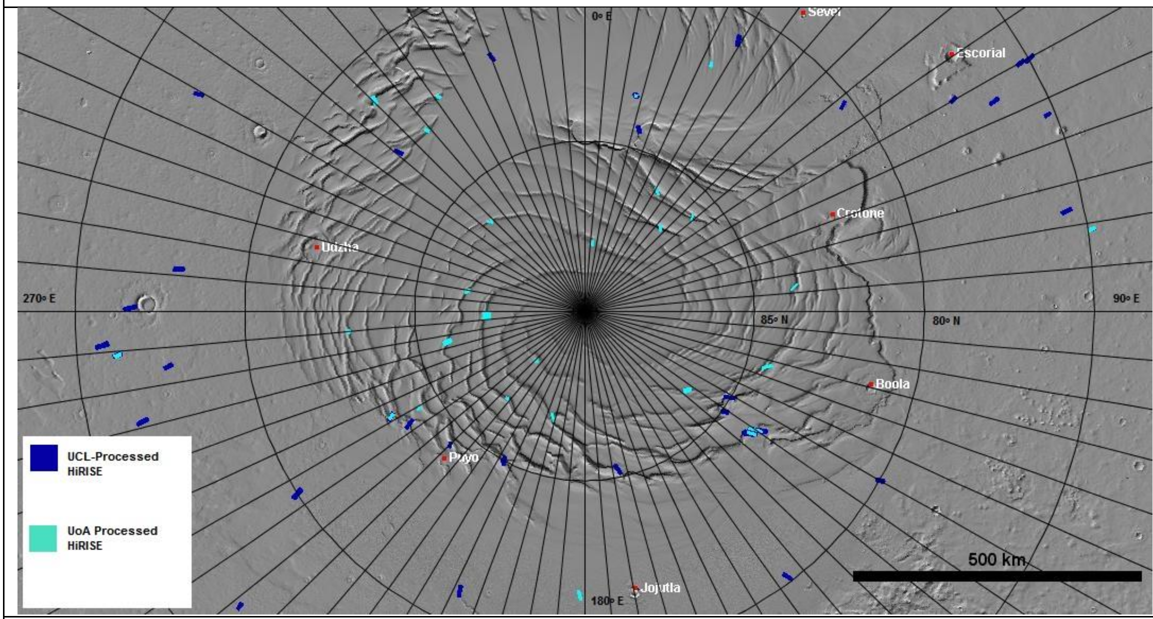


Figure 5b: An example of a processed HiRISE ORI (left) and DTM for Swiss Cheese terrain in the South Polar region.

Meanwhile, a large number of HiRISE DTMs is being processed in the AWS® cloud computing VMs. These contain 441 stereo pairs for the areas that have 5 or more repeat HiRISE observations. This is still on-going due to the large computing resource required and limitations from the free AWS® credit. Once they are completed, the 441 HiRISE DTMs will be integrated into the iMars webGIS together with the existing UoA processed HiRISE DTMs. The global coverage of the UCL HiRISE DTMs that are being processed and the UoA HiRISE DTMs are shown in Figure 6.



Global coverage of UCL HiRISE DTMs and UoA HiRISE DTMs in Equirectangular projection system.



North pole.

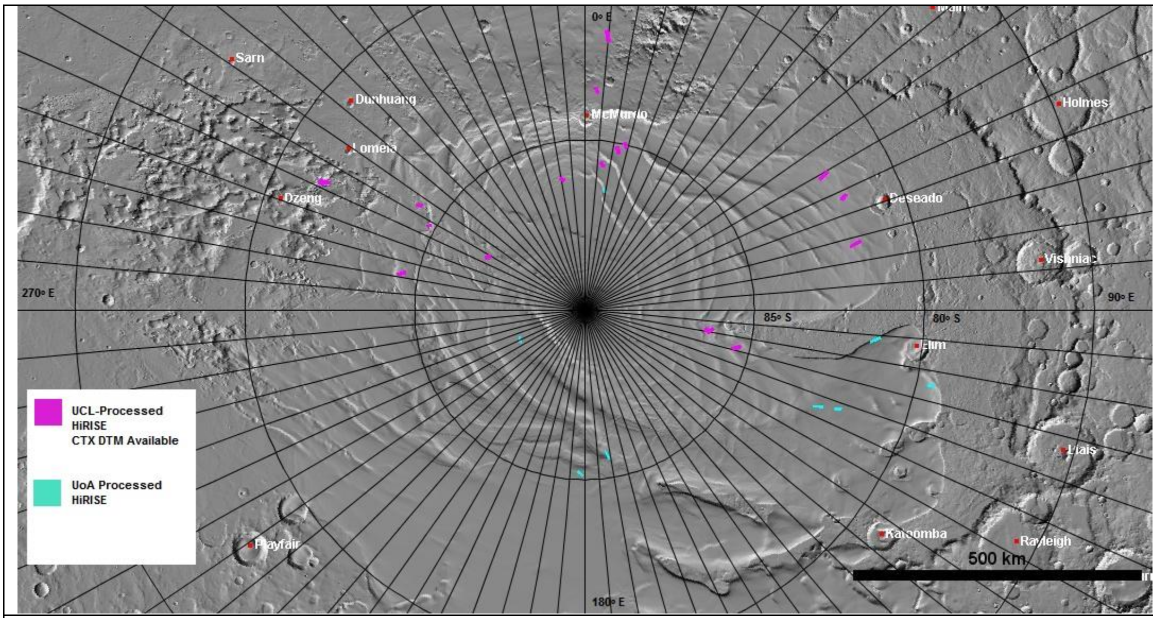


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Figure 6: Global coverage of the UCL HiRISE DTMs that are being processed and the existing UoA HiRISE DTMs.

In parallel, the UoS processed DTMs are displayed as follows. Figure 7 shows all the topographic datasets of CTX and HIRISE generated by the UoS stereo processors over the Euripus Mons LDA showing these are well co-registered. For this area, DTM strips with a spatial resolution of 18 m from 3 different CTX stereo pairs were extracted and a better seamless DTM mosaic was constructed. Then a HIRISE stereo DTM was established using this CTX stereo base. Figure 8 shows the HiRISE and their CTX base DTM over Claritas Fossae graven and the channel over Bahram Valles. It should be noted that Figure 9 shows significant jitter effects (Kirk et al., 2008) for the stereo DTM construction. The spatial patterns of the jitter effects are obvious especially over the flat topography of the target area.

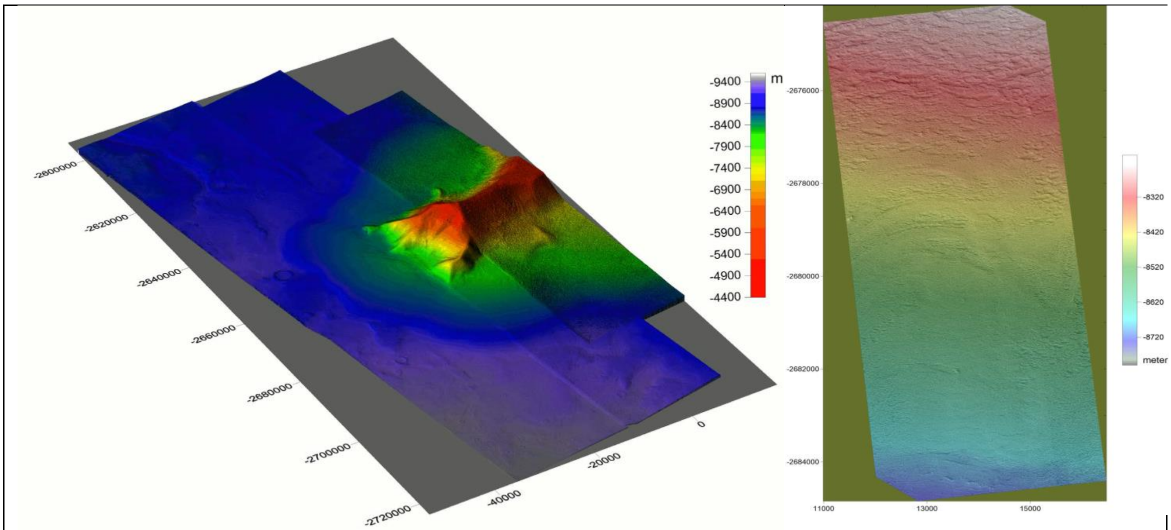

Figure 7: CTX stereo mosaic over Euripus Mons and established HIRISE DTM by base CTX control.

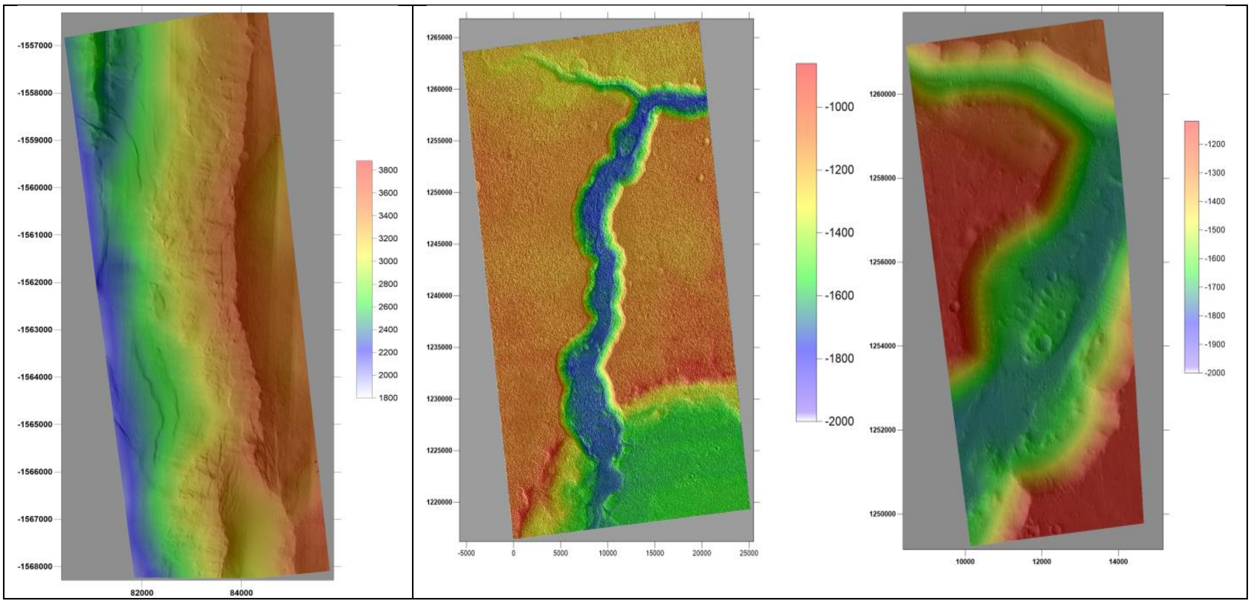

Figure 8: HIRISE DTMs over Claritas Fossae (left) and CTX/HIRISE DTMs over Bahram Valles.

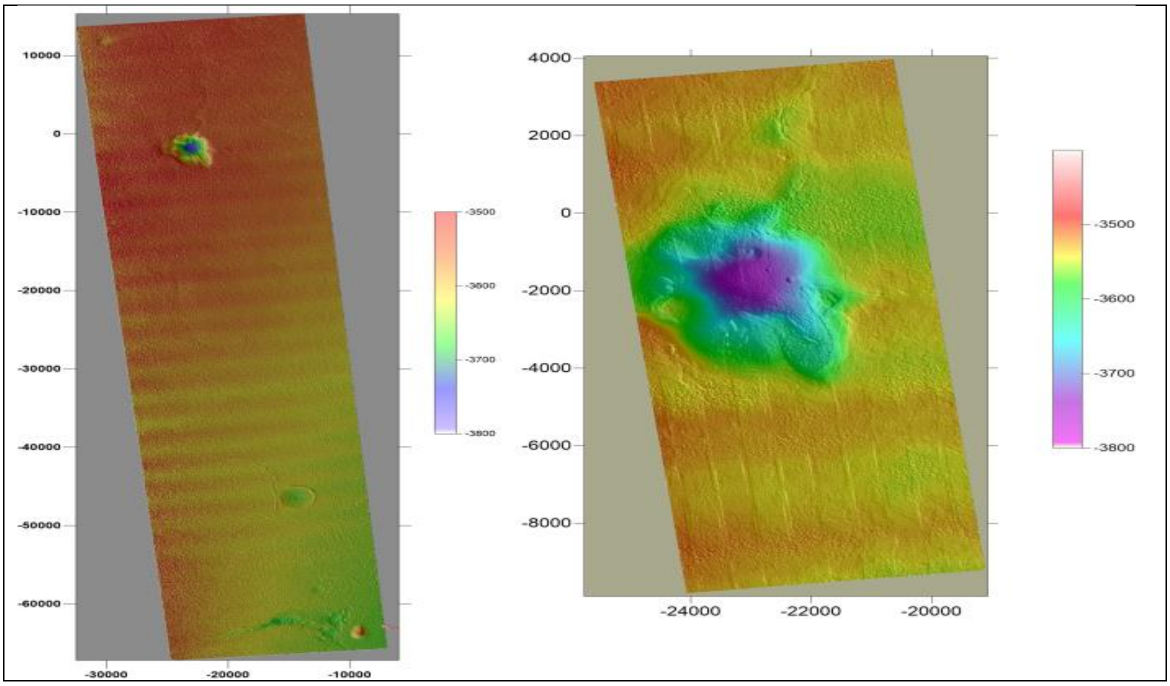

Figure 9: CTX and HiRISE DTMs over the Elysium target area. Note the obvious jitter effect over both CTX (left) as well as HIRISE.

Except for the cases that represent poor stereo baselines and jitter effects, the products demonstrated high qualities, which can be applied to scientific research. Thus studies employing these processed DTMS are actively ongoing and will be continued after the project.

For instance, the HIRISE DTM in Claritas Fossae was employed to conduct a structural analysis together with commercial interpretation software (Figure 10). The hydrodynamic/hydrological analysis over the fluvial channel is a very interesting scientific application of a Martian stereo DTM as shown by Kim et al. (2014). Thus, CTX and HIRISE DTMs over Bahram Valles (Figure 11) are currently investigated employing 2D hydrodynamic modelling and manual measurement.

Combining SHARAD profiles, the multi-underlying sub-surfaces in Euripus Mons were detected (Figure 12). The residual height discontinuities in the southern part of the topographic model will be improved in the future to conduct numerical simulation of rock and debris transport.

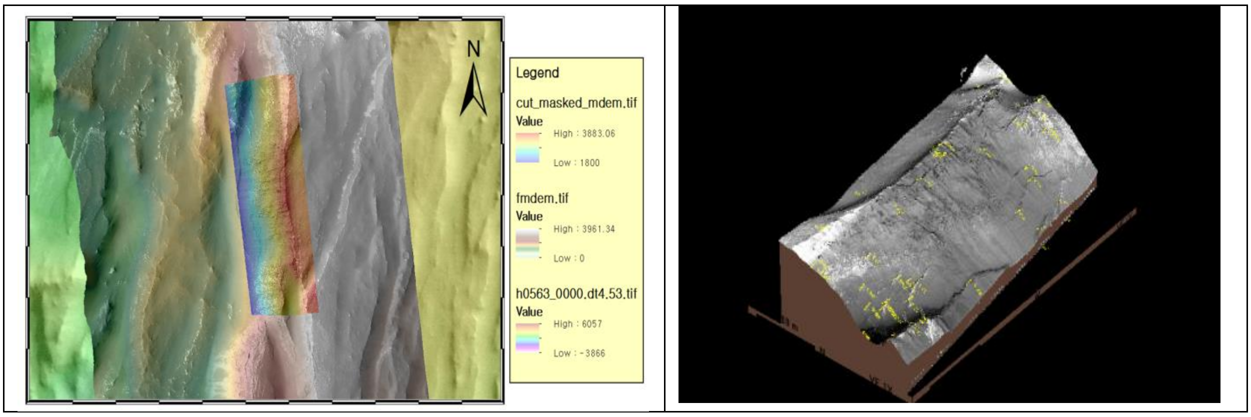

Figure 10: Application to structural analysis.

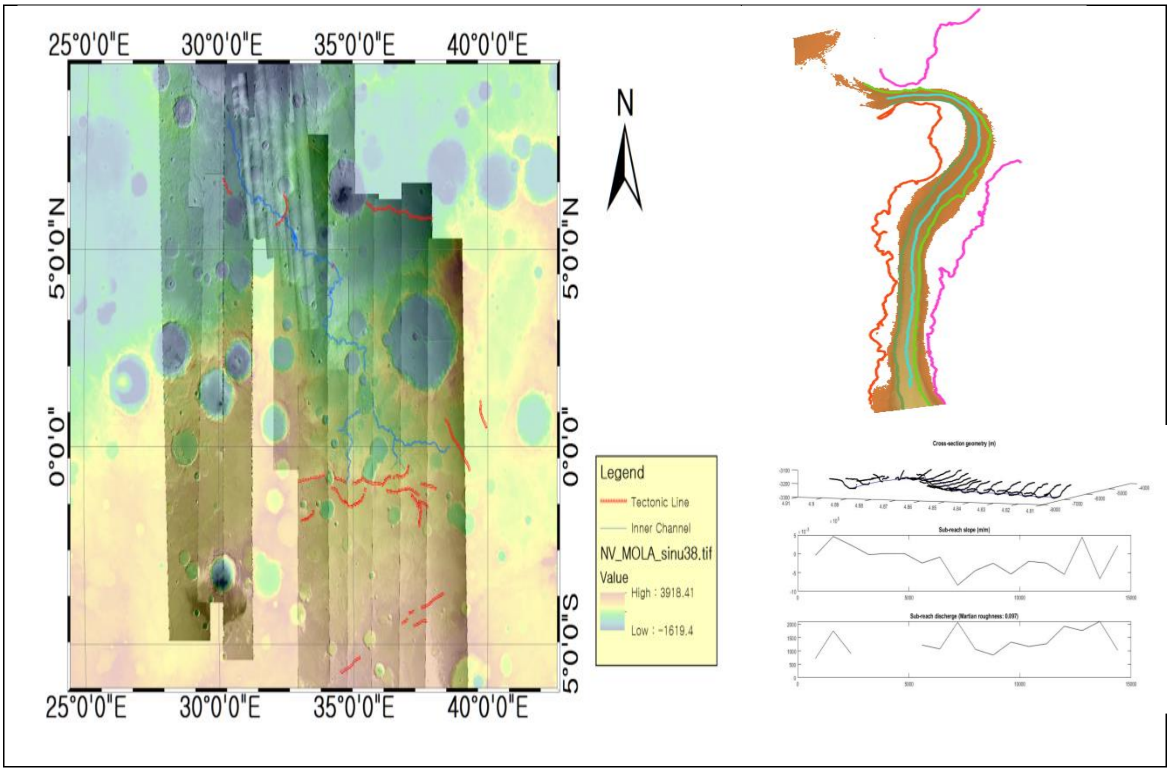

Figure 11: Hydrological/hydrodynamic analysis.

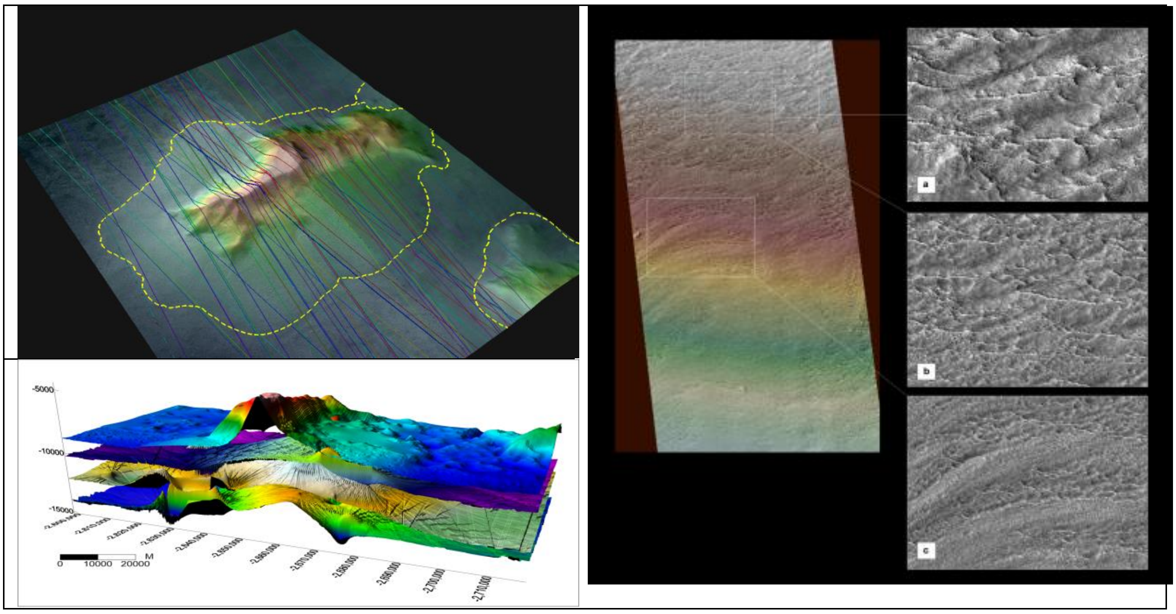

Figure 12: Intercomparison of SHARAD data and morphological analysis over LDA using HIRISE stereo.

5. Conclusions and future steps

In this report, we summarized the two automated DTM processing chains from UCL and UoS that are contributing to several scientifically interesting site studies. The large batch processing of 441 HiRISE DTMs that have repeat observations is still on-going due to limited computing resources. Examples of the processed HiRISE DTMs and global coverage of the HiRISE DTMs that are being processed are given. Once all of the HiRISE DTMs are complete, they will be integrated into the iMars webGIS system by UCL and be available to the scientific community.

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