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- Collaborative project -

D6.3
Demonstration of data mining tools with full database

WP 6 – Change detection from Data mining & validation

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Lead beneficiary for this deliverable: University College London (UCL)

Last editor: Jan-Peter Muller

Contributors: Panagiotis Sidiropoulos (UCL-MSSL), L. Fanara (DLR), J.-R. Kim (UoS)

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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
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1.0	30.3.17	Jan-Peter Muller	Final edits

Executive Summary

This deliverable summarises the processing demonstration of data mining tools that was conducted within the project, using as an input the full database that was processed during iMars. The relevant data were processed offline and individually, using three automatic change detection algorithms, developed by UCL, DRL and UoS, respectively. The change detection results are demonstrated both within the project, at international conferences and in the iMars public outreach event that was held on 14-Mar-2017 at the UCL Institute of Education in central London.

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Key word list

Change detection, dynamic Mars features, slope streaks, impact craters, aeolian features, active gullies, dune migration, block falls, classifiers.

Definitions and acronyms

Acronyms	**Definitions**
UCL	University College London
DLR	Deutsche Zentrum für Luft- und Raumfahrt
UoS	University of Seoul
NASA	National Aeronautics and Space Administration
JPL	Jet Propulsion Laboratory
EPSC	European Planetary Science Congress
ISPRS	International Society for Photogrammetry and Remote Sensing
EGU	European Geosciences Union
WG	Working Group
SPICE	Spacecraft Planet Instrument C-Matrix Events
CK	Camera-Matrix Kernel
SPK	Spacecraft Position Kernel
HRSC	High-Resolution Stereo Camera
CTX	Context Camera
HiRISE	High-Resolution Imaging Science Experiment
MOC-NA	Mars Orbital Camera – Narrow Angle
THEMIS-VIS	Thermal Emission Imaging System – Visual
MRO	Mars Reconnaissance Orbiter
DTM	Digital Terrain Model
SIFT	Scale Invariant Feature Transform
SVM	Support Vector Machine
DB	Database

1. Introduction

1.1 General context

This deliverable concludes the work that was done within the iMars project related to the automatic detection of surface changes on Mars. The processing systems and results are summarised in this short report. Processing was conducted using three independent pipelines, developed by UCL, DRL and UoS, respectively. The input data, i.e. high-resolution images and DTMs processed using the techniques developed in WP2 and WP4 Workpackages, were processed offline and independently by each partner and are presented after being demonstrated, in international conferences and in outreach activities that were organised as part of WP8 activities. Moreover, part of the results of the change detection processing has been released to UNOTT so as to populate their change detection pairs for use within the WP7 crowdsourcing experiment.

The employed pipelines can be summarised as follows:

- A generic automatic change detection approach, developed and implemented by UCL, that focuses on a batch-mode automatic detection of surface changes on Mars. This pipeline (thoroughly described in deliverables D6.1 and D6.2) was designed to be context-free, i.e. to detect semantically meaningful changes regardless of the specific type of change. The inputs for this processing pipeline are images, co-registered and orthorectified to HRSC baseline using the ACRO pipeline developed by UCL within the project (see D4.4 short report). As a result, the resolution limitations of the aforementioned HRSC imagery, excluded HiRISE imagery from the co-registered datasets, thus limiting the change detection input to imagery acquired by CTX, HRSC, THEMIS-VIS and MOC-NA instruments with IFOV≥1.5m.
- A change detection method, developed and implemented by UoS, that focuses on the automatic detection of changes related to dune migration, using as an input HiRISE images that are co-registered and orthorectified to a CTX baseline. This technique demonstrated the use of sub-pixel accuracy co-registration and orthorectification to detect motion patterns at very fine scales that may reach less than 1 metre.
- A change detection method, developed and implemented by DLR, that focuses on the automatic detection of changes related to North Pole mass movements (block falls), using as inputs HiRISE images that are co-registered and orthorectified to a HiRISE baseline. This technique was the second method used to detect fine-scale changes observable only at HiRISE resolutions, this time related to the tracking of the motion of small objects.

1.2 Deliverable objectives

The techniques developed have demonstrated the potential of planetary surface automatic change detection pipelines, thus generating a new family of tools that can assist the understanding of planetary surface dynamic processes. Apart from their clear technological contribution, these techniques have already assisted in the discovery of unreported instances of Mars surface changes, which can be used to augment the catalogues of current day Mars surface activity.

2. Summary of activities and research findings

2.1 *Generic Automatic Change Detection Processing (UCL)*

2.1.1 Change detection algorithm

The input of the generic change detection algorithm are pairs of overlapping images, that have been co-registered using the automatic co-registration and orthorectification (ACRO) method that has been developed within the iMars project (see D4.4). For each region with ACRO'd high-resolution imagery, a set of overlapping pairs are initially estimated and pruned to discard image pairs with overlapping regions that are smaller than 256 x 256 pixels.

Subsequently, the preliminary set of input pairs is further processed to extract a temporal series of images, thus eliminating pairs of images that are not temporally adjacent and processing only the minimum number of image pairs. This approach is required to optimise the computational resources without missing any change instances since by default any change can be temporally narrowed down to a pair of temporally adjacent images (since, if a change can be found between two images I_1 and I_3 and there is another image I_2 that was taken after I_1 and before I_3 then the change can be found either between I_1 and I_2 or between I_2 and I_3). Temporal ordering is particularly useful in areas that have been mapped multiple times, since it reduces the computational complexity from quadratic $O(N^2)$ to linear $O(N)$, where N is the total number of images mapping the area. A schematic diagram of the UCL change detection pipeline is shown in Figure 1.

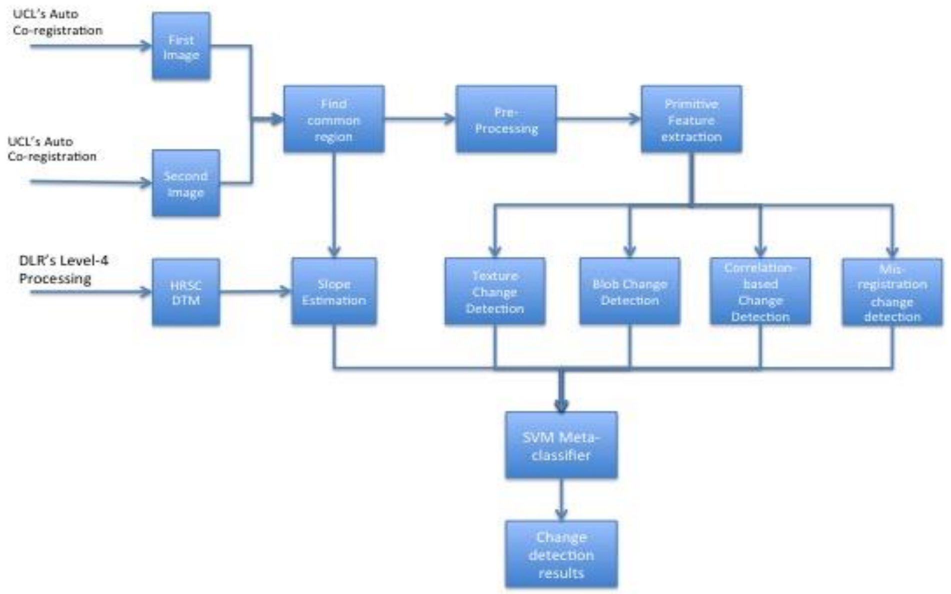

Figure 1. Change detection pipeline (image taken from deliverable D6.2)

Each remaining pair is fed into the change detection pipeline to automatically identify context-free semantically meaningful changes. Apart from the two images, the corresponding HRSC DTM (used during the ACRO pipeline for orthorectification) is also fed in the input, so as to assist in the detection of non-informative changes that are actually caused by differences in the illumination conditions due to changes in the appearance of the surface form different solar elevations and azimuths. Before this step, the input images are initially compared so as to estimate pixels with a significantly different pixel value. Because automatic change detection software can estimate large-size changes or medium-size changes, but not changes that take place in a very limited area, changes that happen in “isolated” pixels are discarded and only change pixels that cover a large area are further taken into account.

The next step of the algorithm is to discard pixel differences that are caused by different illumination (e.g. shadows). The corresponding patches are ignored from further processing, while the rest of the (candidate) patches are fed into a deep learning module that can detect four different types of changes. Note that the detectable “types” of changes are defined according to their low-level image content which only loosely correspond to semantically defined types of changes. The four modules are as follows:

- blob detection, which detect changes that appear like homogenous blobs present only in one patch of the pair
- texture detection, which detect changes that appear like small-sized changes in the patch texture
- global detection, which detect global changes between the two patches
- motion detection, which detect cases in which a small feature has moved between the two patches

Each module is a supervised learning classifier that produces a “confidence level” score, i.e. a value between 0 and 1 that models the probability of a change of a certain type is present. These intermediate scores are further combined (using a second-layer classifier). The final result for each patch is a score, which is compared with a threshold to declare a change. Finally, the detected changes are expanded so as to cover a 512 x 512 region, so as to provide context on the identified dynamic feature. More information about the developed algorithm can be found in deliverables D6.1 and D6.2.

2.1.2 Results

The aforementioned algorithm has been extensively used to detect changes on the imagery that was co-registered and orthorectified within the project, as part of WP4. The change detection results that were acquired using the algorithm of the previous sub-section are as follows:

- 3,365 changes on image pairs from randomly selected image pairs from MC11-E, MC11-W, as well as regions-of-interest all over Mars, a dataset that was also internally released so as to form the input to the WP7 crowdsourcing experiment
- 465 changes from the same datasets that were further manually annotated, generating 270 true positive and 195 false positive results. The implied change detection performance (58.06%) provides a first evaluation of the change detection performance, while a more thorough evaluation will be eventually

conducted with the help of planetary scientists and the citizen science inputs. Note that while this score doesn't seem impressive it still defines the state-of-the-art, since it is the first time that such an algorithm has ever been developed for Mars. Moreover, it is believed in discussions with colleagues that an automatic tool that generates three semantically meaningful change examples per five detected change instances is still be very useful for planetary scientists.

- 3,512 changes that were detected by the available high-resolution imagery of the MC11-E half-quadrangle. Note that 527 of them were duplicates with the first set of experiments, therefore they need to be excluded from the overall number of changes. However, the fact that the algorithm produces duplicates signifies that the results are reproducible, i.e. the stochastic stages of the followed algorithm don't cause irreproducibility in the algorithm output, a feature that should be carefully designed in any algorithm that employs stochastic stages.
- 4,764 changes that were detected from the available high-resolution imagery of the MC11-W half-quadrangle, 1,089 of which were duplicates with the first set of experiments and should be excluded from the total change estimation.

Overall, the change detection runs estimated 10,490 in an area that is 5.5% of the Martian overall surface. Taking into account the preliminary true positive rate of 58.06% and extrapolating to the total size of Mars, this would mean more than **110 thousand** instances of change, could be detected in all the imagery acquired by CTX, HRSC, THEMIS-VIS and MOC-NA instruments.

This number confirms the main hypothesis of the project, i.e. that the frequency and distribution of Mars surface changes is so large that any "manual" analysis of image pairs to track dynamic features is obsolete due to the data-intensive Mars exploration of the last two decades, and that Mars surface science would greatly benefit from the development of automatic change detection techniques that would assist planetary scientists in their effort by flagging the most "promising" to include dynamic feature regions. Moreover, it becomes apparent that a thorough examination of 110,000 changes would require a significant amount of time from the planetary science community. Some examples of automatically detected changes are shown in Figures 2-5.

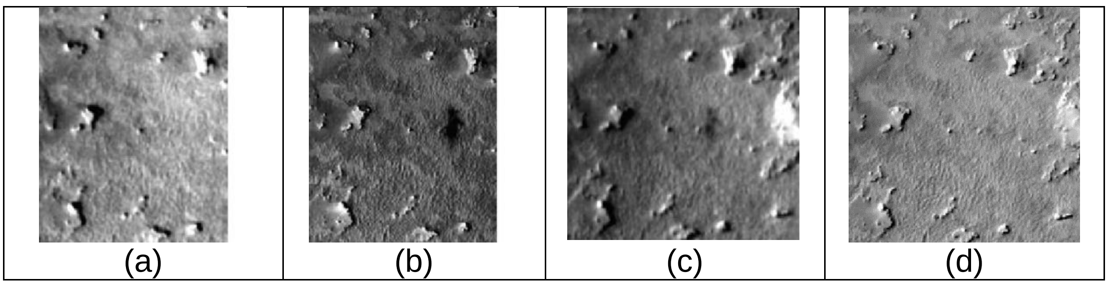

Figure 2. A new impact crater that was automatically detected in MC11-E half-quadrangle. Images (a) and (c) are THEMIS-VIS while images (b) and (d) are CTX images. The automatic change detection pipeline achieved to detect the pairwise change in all pairs (i.e. (a)-(b), (b)-(c) and (c)-(d)), thus successfully tracking the whole process of the impact crater formation. Image (a), which is the last image before the impact, is from 2005 while image (b), which is the first image after the impact, is from 2007. This is a new discovery, not reported in the literature, which becomes more important if it is taken into account that the impact happened only 190 km from Opportunity rover.

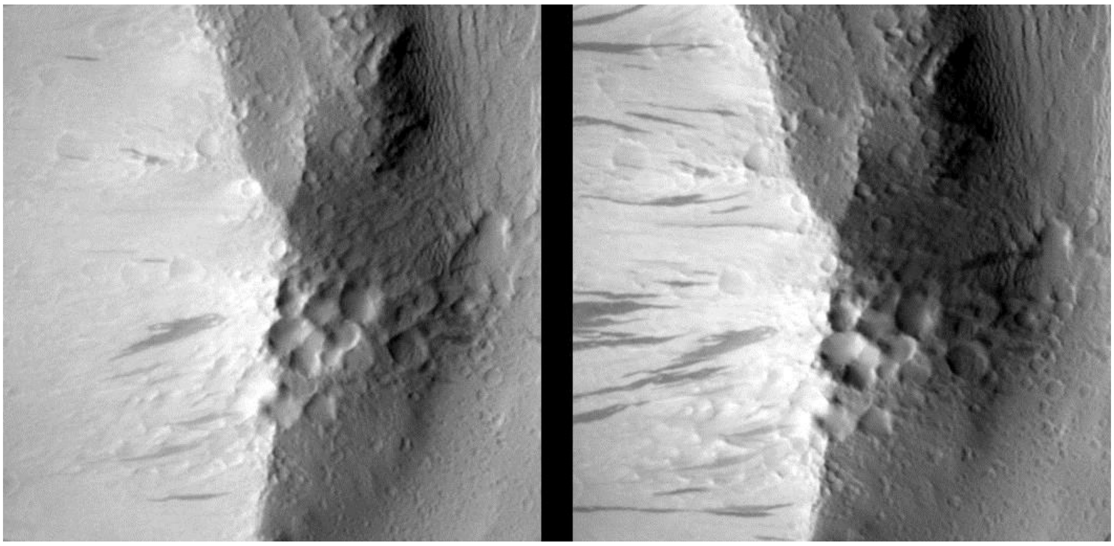

Figure 3. New slope streaks in Olympus Mons Aureole.

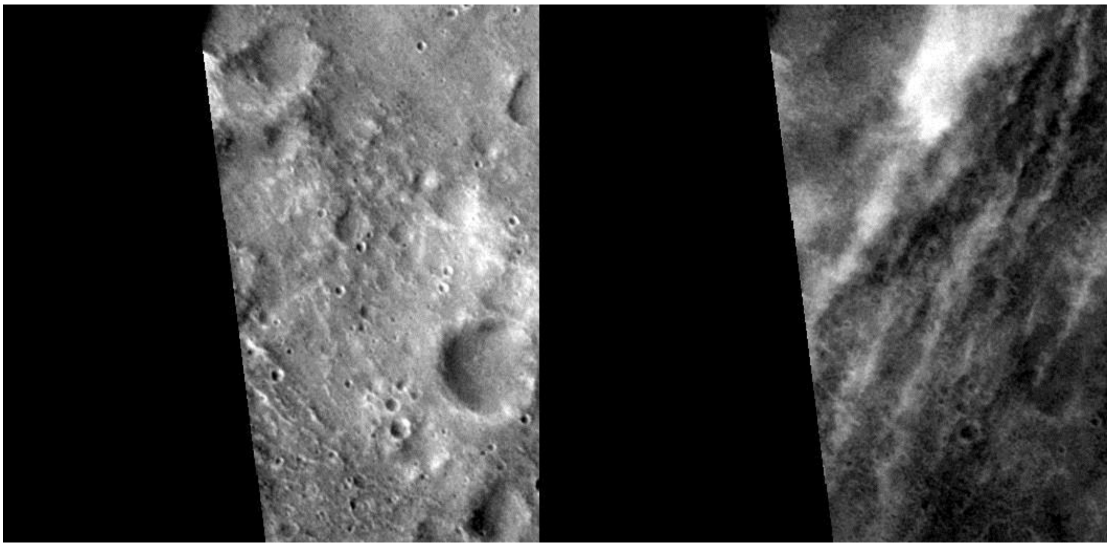

Figure 4. Dust storm in MC11-E.

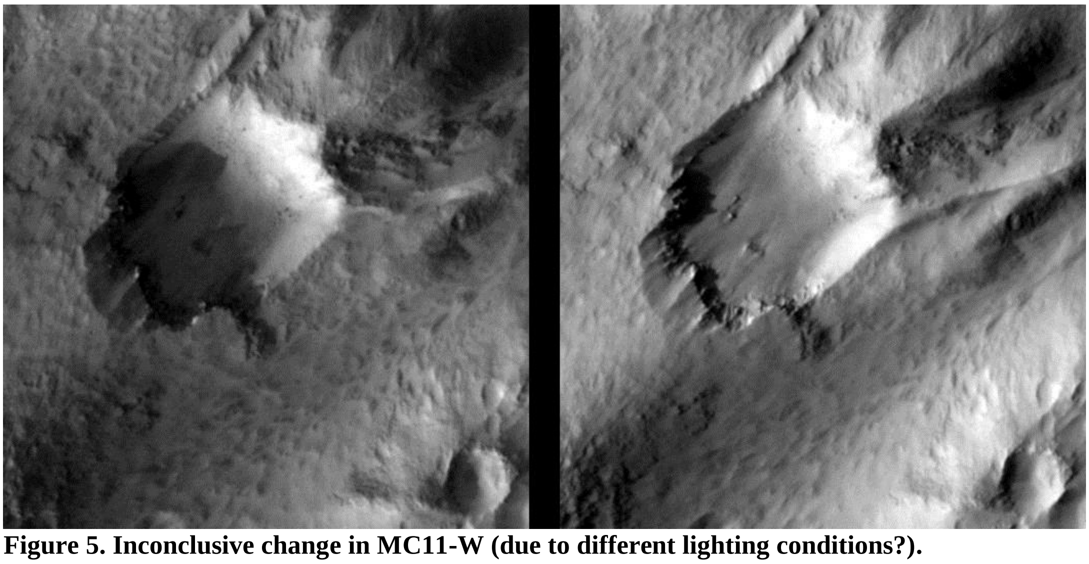

Figure 5. Inconclusive change in MC11-W (due to different lighting conditions?).

2.2 Automatic Dune Migration Detection Processing (UoS)

At the present time, debate continues regarding the migration speeds of Martian dune fields and their correlation with atmospheric circulation. However, precisely measuring the spatial translation of Martian dunes is not feasible due to the technical difficulties introduced by the estimated small migrations and the large error in radiometric/geometric image control. Therefore, UoS developed a generic procedure to precisely measure the migration of dune fields with HIRISE employing a high-accuracy photogrammetric processor and sub-pixel image correlator. The processor was designed to trace estimated dune migration, albeit slight, over the Martian surface by 1) the introduction of very high resolution orthorectified images and stereo analysis based on hierarchical geodetic control for better initial point settings; 2) the removal of positional error through a sensor model refinement with a non-rigorous bundle block adjustment, which makes possible the co-alignment of all images in a time series; and 3) improved sub-pixel co-registration algorithms using optical flow with a refinement stage conducted on a pyramidal grid processor and a blunder classifier. The established algorithms have been tested using high-resolution HIRISE images over a large number of Martian dune fields covering the whole Mars Global Dune Database.

2.2.1 Technical backgrounds and test areas

The main technical barrier for dune migration measurement is the accuracy associated with the photogrammetric issue. The sensor orientation parameters of HiRISE images, based on the SPICE CK and SPC kernel needs to be improved to attain precise co-registration. However, the available rigorous photogrammetric adjustment doesn't work with the ideal sensor model used for HIRISE images. Moreover, the chance for base topography reconstruction for ortho-rectification is limited, because the target topography itself is continuously migrating (see Figure 6). In addition, the other technical issues which should be addressed are as follows:

1) Temporal lags between the image acquisitions and the surface migrations
2) Reliability of the manual/automated measurements over texture-less topography
3) Target image resolution and the feasibility of sub-pixel accuracy measurements
4) Radiometric changes in the target surfaces

The primary technical challenge of this work is the photogrammetric error control over multiple high resolution images without proper ground truth and a precise sensor model. Based on previous studies and the availability of CTX and HRSC overlapping coverage, the following target areas and images were chosen (see Figure 7):
(1) Kaiser crater : As a typical barchan dune, active bedform and Co2 gullies activities were noted in HiRISE imagery. The best HiRISE time series exist for the dune migration measurements.
(2) Proctor crater : appears to be partially activated by the wind regime consisting of three opposing winds (Fenton et al. 2005). Recent computational fluid dynamic simulation by Jackson et al. (2015) provided a good comparison data set.
(3) Wirtz crater : A bimodal dunes studied by Parteli and Herrmann (2007) and Parteli, et al. (2009).

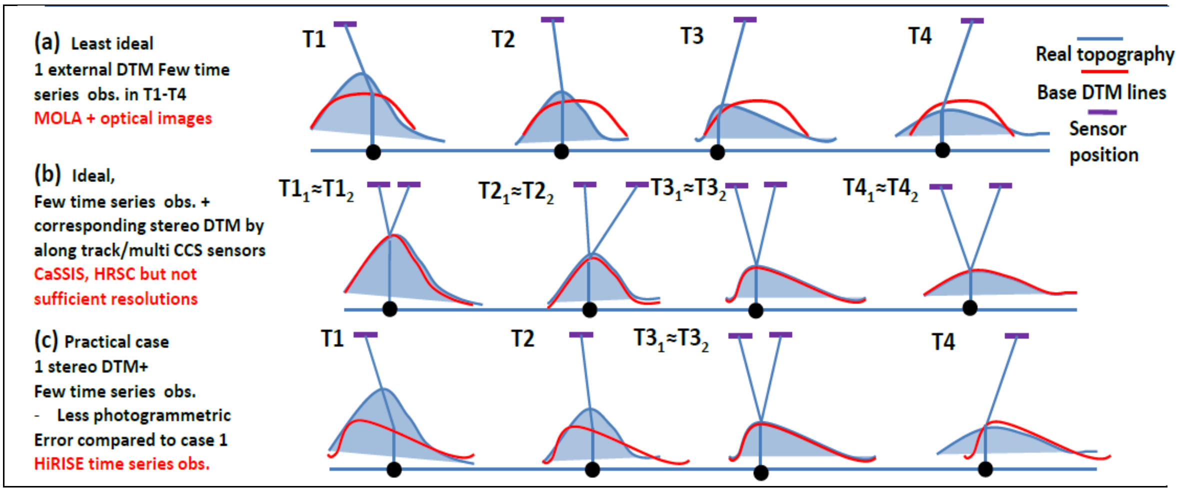

Figure 6: Observation scenarios of Martian dune by in-orbital images.

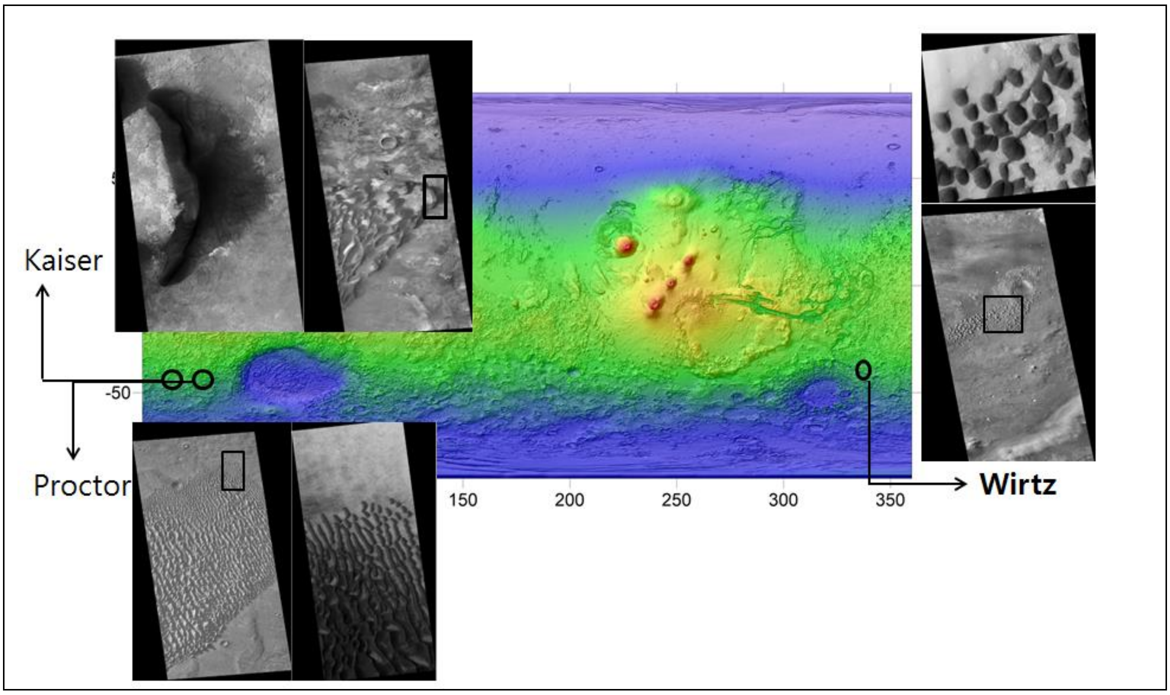

Figure 7: Test areas for the application of the dune migration algorithms.

2.2.2 Data processing and algorithms

To address the photogrammetric issues, UoS employ a conversion routine for the non-rigorous sensor model of individual HIRISE images and the space resection by high order polynomial adjustment. On the other hand, ground control points are taken from the established stereo DTM, thus images are co-aligned over the base DTM. Conventional pixel tracking methods using image warping don't make reliable measurements over the target images likely due to the absence of high precision sub pixel registration ability and the algorithm failures over dark and monotonous dune textures. Thus in-house algorithms were established on the technical bases as

1) Coarse-to-Fine pyramidal detection scheme employing the image warping with an affine transformation
2) Scale-invariant feature transform (SIFT) was introduced to define the target points for tracing.

3) Adaptive Least Squares correlation was employed to refine registration and to calculate registration costs.
4) Only reliable registration with sufficient matching cost value were delivered to the next pyramidal stage

The processing system is illustrated in Figure 8.

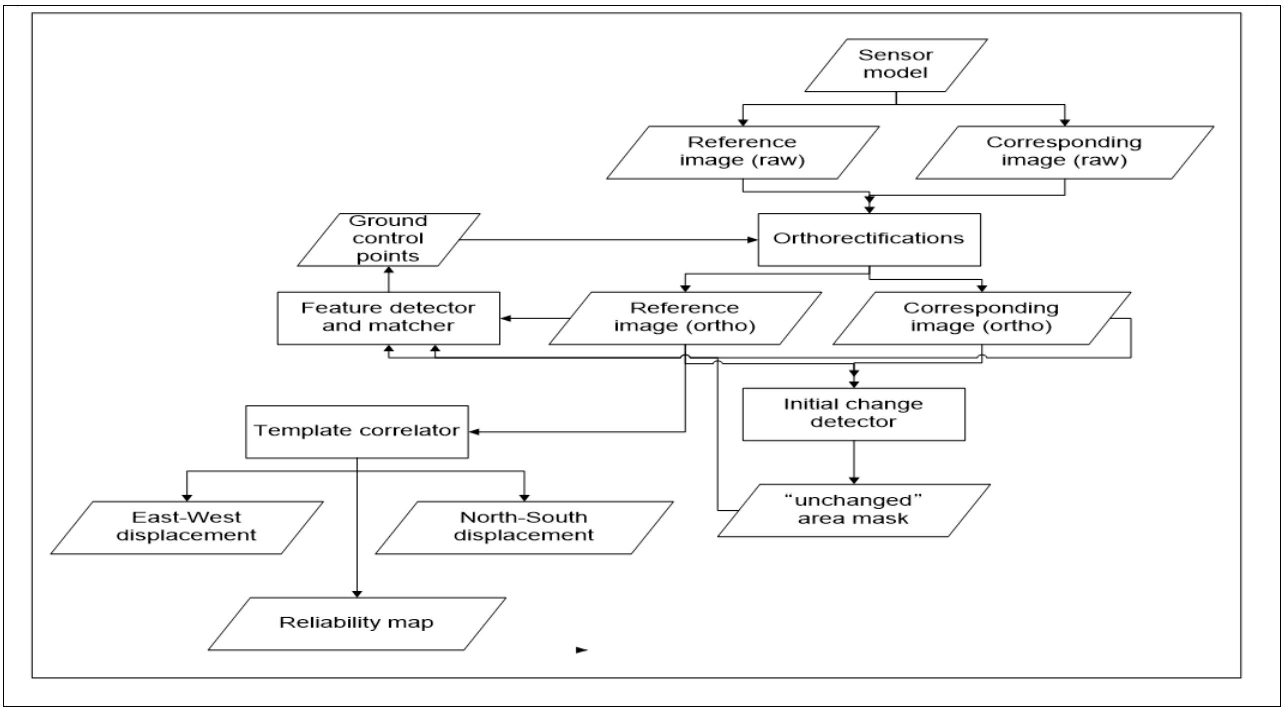

Figure 8: Implemented algorithms for the observation of dune migration.

2.2.3 Results

The detected dune migration speed with the best possible photogrammetric adjustment is very tiny, close to static. Estimated maximum aeolian migration in the test area Kaiser crater (see Figure 9) is less than 1m/Earth year. Although the moving directions of large slip faces coincide with the typical dune migration mechanism (Figure 10), it appears that the observed dune migrations are not genuine but mainly result from photogrammetric errors, if a proper geodetic control is not applied. Illumination changes combining topographic reliefs, seasonal surface conditions occasionally induce "false dune migration" measurements. In the case of the Proctor dune, influenced by bad photogrammetric control is obvious shown in Figure 11 (a) and (c). As shown in Figure 11 (b) and (d), the correctly controlled base images and the migration measurements demonstrated a smaller migration speed than Kaiser and irregular pattern.

The dune migration measurements over Wirtz after applying jitter offset (>0.3 pixel) value estimated from empty space are presented in Figure 12. Any prevailing migrations were not observed and the displacement vectors represent that Wirtz is a static dune field.

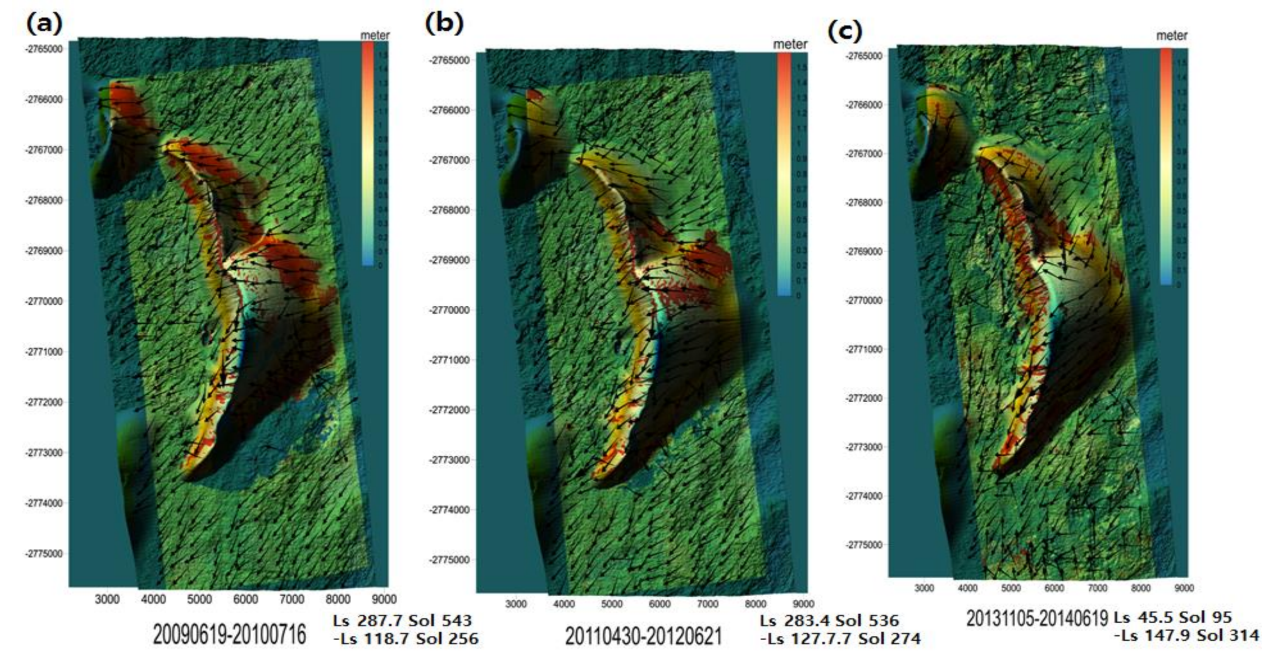

Figure 9: The dune migration detections over Kaiser crater.

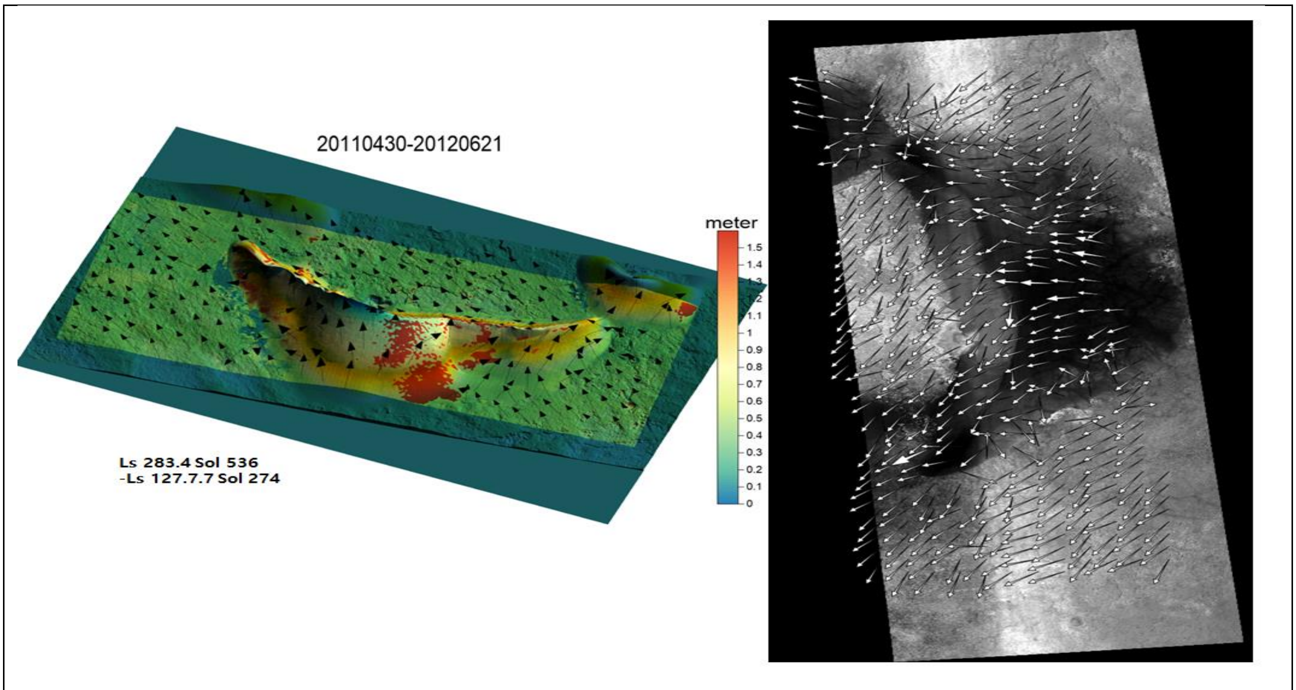

Figure 10: The detected migration pattern over Kaiser dune.

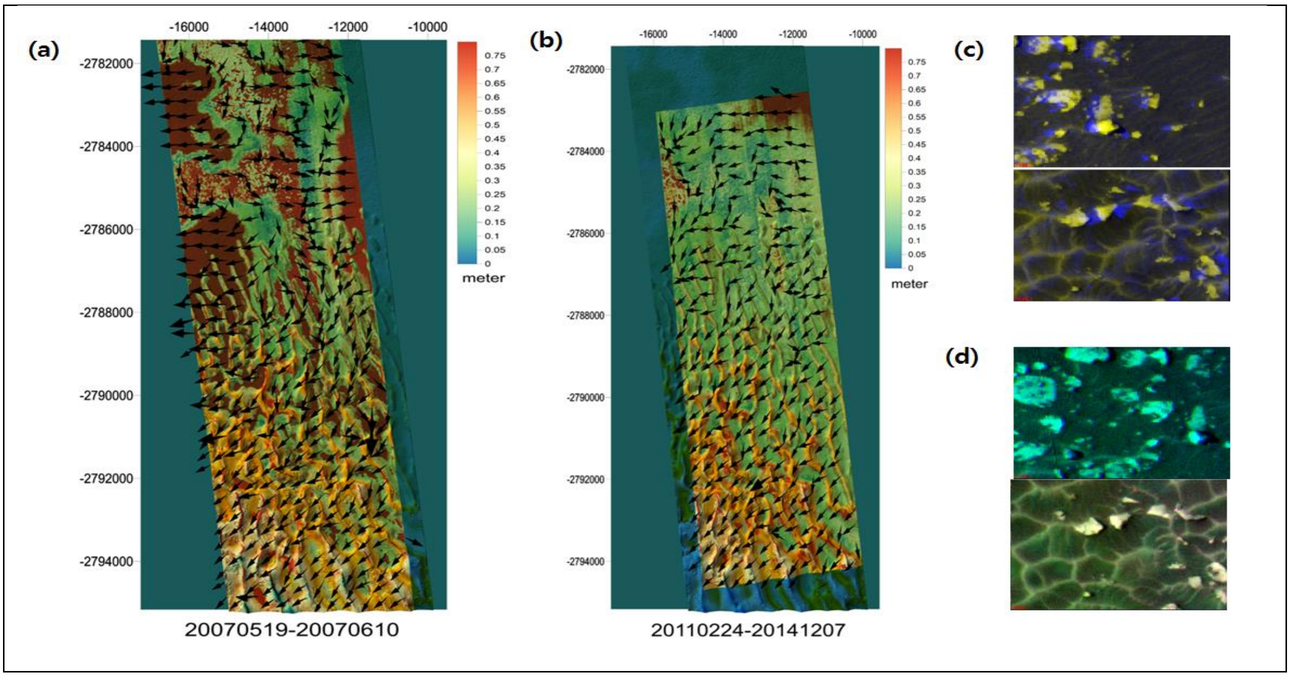

Figure 11: The dune migration detections over Kaiser crater. Note (a) and (c) represented a small mis-registration by photogrammetric error.

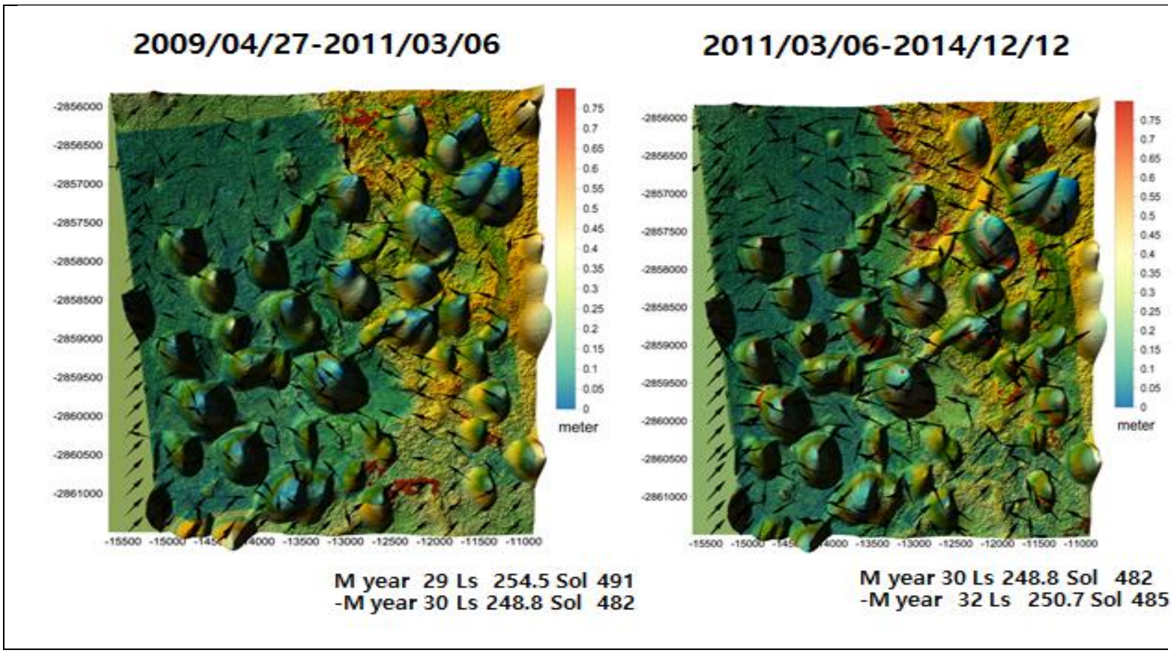

Figure 12: The dune migration detections over Wirtz crater.

2.2.4 Future Work

UoS developed a software and a photogrammetric technique to measure Martian dune migration and applied them over three test areas. Overall, the detected dune migration speed with the best possible photogrammetric adjustment is close to static. Also it appeared that the observed dune migrations may not be genuine but mostly photogrammetric errors, if a proper geodetic control is not applied.

Future work which will be developed from UoS WP6 component as follows:

1) Disambiguation of photogrammetric errors and genuine migrations by time series analysis
2) Intercomparison with aerodynamic simulations
3) Multiview angle observations to measure aerodynamic mobility if proper image sets are available.

Currently advanced time series analysis techniques to segregate photogrammetric errors and aeolian migration are under development and algorithms will be continuously updated to find denser measurements.

Once after a full set of automated process is established, it will be applied to major dune fields in the Martian digital dune DB (Hayward et al., 2007) and will also be integrated with the stereo/photoclinometric processors to extract volumetric change measurements.

2.3 Automatic Block Falls Detection Processing (DLR)

During several conference presentations and, as a final demonstration, at the iMars public dissemination event that took place on the 14th of March 2017 at UCL in London, Lida Fanara reported on her work at DLR in detecting ice block falls near the north polar cap. Block falls in this area have recently been observed in HiRISE images from different acquisition dates. The north polar ice cap keeps a record of the planet's climate changes in its stratigraphy. Due to the importance of detecting block falls for estimating the erosion rate of the steep north polar scarps in order to understand the evolution of the ice cap, this topic has been selected as one of the science case studies for change detection in iMars.

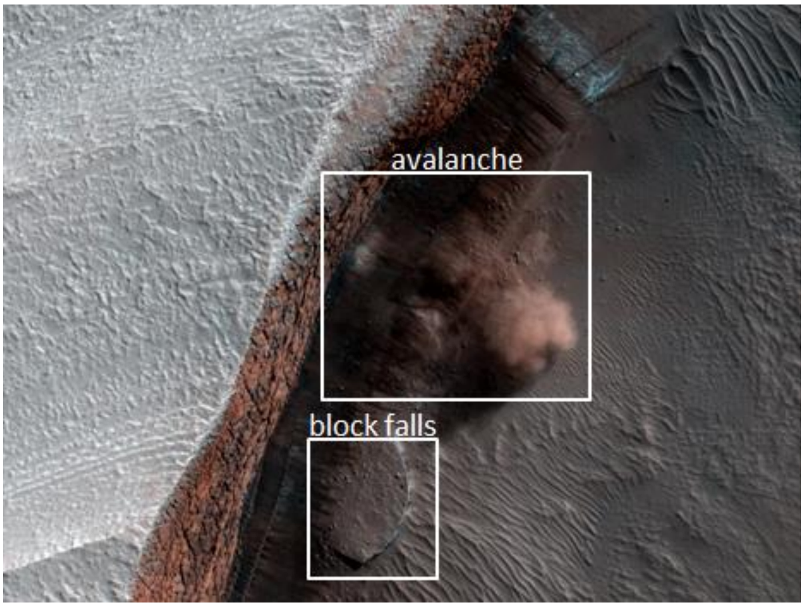

Figure 13: Active north polar scarp, credits: NASA/JPL/University of Arizona.

This work is based on images taken with HiRISE on board the NASA MRO mission, on a set of specifically adapted techniques for change detection, and on detailed evaluation of the results of the tools for change detection. The challenges that were faced during the co-registration of the images as well as the importance of this topic, and how the needed sub-pixel accuracy was achieved, can be clearly demonstrated. The automatic change detection method that was developed to detect block falls between images of different times is described in detail. Density maps of block fall events at a steep north polar scarp were produced and discussed. A scientific paper on this work is currently being prepared for submission to a peer-reviewed journal.

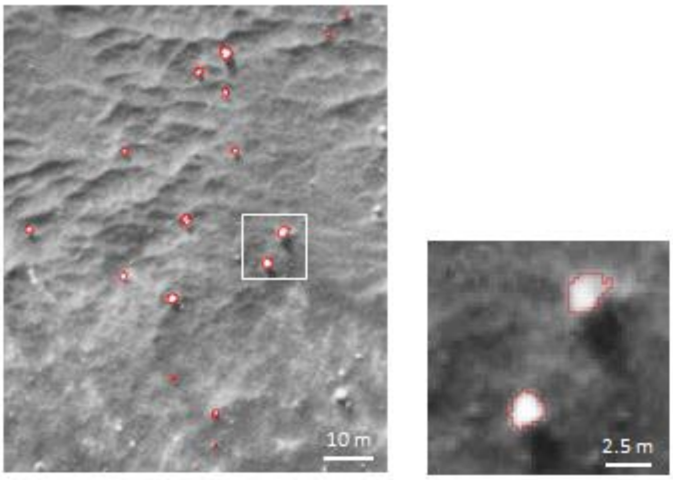

Figure 14: In red: detected block falls between two HiRISE images.

3. Conclusions and future steps

Deliverable D6.3 showcased the use of automatic change detection tools to assist the discovery of unreported instances of dynamic surface features, as well as the discovery of new surface features. While this deliverable concludes the related work conducted within iMars it is by itself just a preliminary scientific study, validating the automation hypothesis for Mars science (or even planetary science, in general). The full impact of this work will be revealed over the next few years, when the output of this work will be delivered for a more thorough scientific analysis to planetary scientists and Mars experts, who will assess each of the automatically detected results according to their scientific importance. We believe that this task, which for the time being is beyond the reach of automation, will be the most important legacy of iMars project.

4. Publications resulting from the work described

UCL conference contributions				
Conference/Meeting	City	Kind of contribution	Date	Title
EPSC	Estoril	Talk	2014/9	Identifying candidate temporal changes on Mars through image matching
EPSC	Nantes	Talk	2015/9	Identifying dynamic features on Mars through multi-instrument co-registration of orbital images

ESA BiDS	Madrid	Poster	2016/3	Big data from Mars, towards building global planetary data analysis tools
Martian Gullies and their Earth Analogues	London	Talk	2016/6	Automatic detection of changes in Martian gullies from co-registered high-resolution visible images
ISPRS	ISPRS	Talk	2016/7	Identifying Surface Changes on HRSC Images of The Mars South Polar Residual Cap (SPRC)
Mars Polar Science and Exploration	Reykjavik	Talk	2016/9	Production of HRSC Base DTMs for Multi-Instrument Auto Coregistration and Orthorectification over the Mars South Polar Region (SPRC)
EPSC-DPS	Pasadena	Poster	2016/10	Analysis of Spatial and Temporal Coverage of Multi-Instrument Optical Images for Change Detection Research on the Mars South Polar Residual Cap
EPSC-DPS	Pasadena	Poster	2016/10	Automatic detection of surface changes on Mars –a status report
LPSC	Texas	Poster	2017/3	Observable Changes at CTX to HRSC-Scale Over The South Polar Residual Cap

Table 1: UCL conference contributions

DLR conference contributions				
Conference/Meeting	City	Kind of contribution	Date	Title
ISPRS WG	Berlin	talk	2015/9	Analysis of HiRISE DTM for studying topographic change by mass wasting at the north pole of Mars
EPSC	Nantes	talk	2015/10	Towards identifying mass wasting by change detection in HiRISE images of the north pole of Mars
EGU	Vienna	poster	2016/4	Detection of block movements in ortho-rectified HiRISE images of the north pole of Mars
ISPRS	Prague	talk	2016/7	Mass movements' detection in HiRISE images of the north pole of Mars
Mars Polar Science and Exploration	Reykjavik	talk	2016/9	Frequency of block displacements at the north pole of Mars based on HiRISE images
EPSC-DPS	Pasadena	talk	2016/10	Frequency of block displacements at the north pole of Mars based on HiRISE images
Ices in the solar system	Madrid	talk	2017/01	Erosion rate and seasonality of block falls at the north polar scarps of Mars based on HiRISE images

Table 2: DLR conference contributions.

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