SAFER: The promising results of the Mars mission simulation in Atacama, Chile

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Abstract

The European Space Agency is developing capabilities to enable robotics driven planetary exploration. Remotely operated rovers are complex systems requiring the successful integration and harmonious operation of a platform, a suite of scientific instruments, and a remote operation control station. Field trials provide the best opportunity to expose such probes to a dynamic and natural environment in order to gain confidence in its operations effectiveness. Europe has a growing, but still limited experience in field testing. The SAFER project has in this context performed a Mars mission simulation executing part of the ExoMars reference surface mission, assembled lessons learnt, and analyzed how a European center of expertise should be developed.

1 SAFER and its objectives

The SAFER (Sample Acquisition Field Experiment with a Rover) project was performed under contract with the European Space Agency by a consortium led by RAL Space, UK, and composed of LATMOS, Space-X, Joanneum Research, Aberystwyth University, UCL, Leicester University, Astrium Ltd. and SciSys Ltd. The UK Space Agency supported the work undertaken during SAFER.

The overall objectives of SAFER were firstly to improve the ESA understanding of the role and required future modes of operating of a center for field testing at ESA Harwell, by preparing, executing and evaluating a Field Test on a realistic reference case.

The realistic reference case has been the rover sample acquisition procedure as defined in the ExoMars Rover Reference Mission, which has been executed using available models of relevant payload and prototypes of their ground control interfaces. The procedure has been executed with the following objectives:

a. Prove the effectiveness of outcrop search instrumentation,

b. Elaborate the strategy and procedures to implement the outcrop search and the acquisition of a subsurface sample of the outcrop.

SAFER used an early prototype of a rover emulating ESA's 2018 ExoMars rover, provided by Astrium and fitted with a trio of ExoMars instruments prototypes and emulators including the AUPE-2 PANCAM emulator from Aberystwyth University, the WISDOM ground penetrating radar prototype from LATMOS, and a CLUPI prototype provided by Space-X. All three instruments were used in-situ to identify promising sites for subsurface excavation. The bridget rover, provided by Astrium used batteries and no solar panels, and its maximum navigation speed has been 4cm/s.

The project was defined to contain a field campaign program with a dual team: One in location with the rover, and a separate remote control team, in a scenario emulating a real Mars exploration mission.

Some European Field campaigns have been performed before SAFER, in particular to test autonomous navigation (during the ESA SEEKER program in 2012 [2]), and to test and acquire ExoMars instruments data sets using the prototypes of PANCAM, CLUPI, and WISDOM. Remote operation experience was also gained by ESA as part of the ESA – CNES remote experiment conducted in 2011 [5]. However, the European experience in the preparation and conduction of field trials is still limited, and the transition towards systematically formally prepared and conducted trials will be greatly encouraged and supported by the creation of a network of experts and center of expertise gathering best practices, lessons learnt, and providing access to a database of precisely documented field trials locations.

2 The SAFER mission concept based on the ExoMars reference surface mission

The SAFER Trial was based upon the ExoMars Reference Experiment Cycle, defined in the ExoMars Reference surface mission at the time of the system PDR, held at the end of 2010 [1]. While the mission concept and implementation has evolved since, this particular scenario remains a valid and representative mission concept to validate critical aspects of the platform and payload operation.

The Scientific objectives of the ExoMars Rover mission consist of the search for traces of past and present life, characterization of the Martian geochemistry and water distribution at various locations, improvement of the knowledge of the Mars environment and geophysics, and identification of possible hazards before landing other spacecraft or, in the longer term, humans.

The core element of the ExoMars Rover Mission consists of a rover carrying a comprehensive suite of analytical instruments dedicated to exobiology and geology research, the Pasteur payload. The Rover travels several kilometers on the Martian surface searching for traces of past and present life, collecting and analysing samples from within surface rocks and from the subsurface, down to a depth of 2 m.

An Experiment Cycle comprises all actions necessary to select, approach, study a target location, and transmit the collected data to the Rover Operations Control Centre (ROCC). To achieve the ExoMars science goals, the Pasteur payload is composed a number of instruments. The ones relevant for SAFER, and for which prototypes/emulators have been used throughout the field campaign, are described in Table 1.

The SAFER project has implemented a subset of this operation cycle to better understand the platform/payload interactions, assess the feasibility/applicability of the proposed ExoMars Operation cycle, and propose if need be any improvement based on the SAFER trials.

Table 1: ExoMars instruments used in SAFER

	Instrument	Type of instrument	Measurement Objective
1	Panoramic Camera System (PanCam)	Two Wide-angle cameras and one high-resolution camera. On the mast	To visually characterise the Rover's environment and its geology. Also very important for scientific target selection.
2	Water Ice and Subsurface Deposit Observations on Mars (WISDOM)	Ultra High Frequency (UHF) Ground-penetrating Radar operating at 0.5 - 3 GHz	To establish the subsurface stratigraphy down to 3 meters depth. Also important to plan drilling strategy.
3	Close-Up Imager (CLUPI)	One camera with optics mounted on the side of the Drill box	To contribute to the characterization of the geological environment and to help to determine the details of the history and processes recorded in geologic material at micrometre to centimetre scale in Rover's area of activity.

SAFER has executed operations in compliance with the logic of each experiment cycle as defined in the reference surface mission; the key activities performed during SAFER are highlighted in Table 2.

Table 2: ExoMars key activities relevant to SAFER and its selected payload (in green)

6 Experiment Cycles	2 Vertical Surveys
Incremental transverse distance 100m > 500m	Drill and obtain sample from surface
- Visual & Ground radar within – ∅20 m	Sample distribution and analysis
Outcrop close-up observations (3 instruments)	Repeat sampling and analysis each 50 cm depth
Ground radar mapping	5 analysis cycles in total
Drilling (-1.5 m) and sample acquisition	
Sample distribution and optical inspection	
Sample milling and analytical characterization	

3 Field trials organization and field test rover

The SAFER trials took place in October 2013 in the Atacama Desert in Chile where the SAFER team was hosted by the European Southern Observatory (ESO) in Cerro Paranal; in parallel, a Remote Control Centre (RCC) was set up in Harwell, UK, in the Satellite Applications Centre Catapult. During the Mars mission simulation a field trials team composed of instruments engineers, geologists, and field trials engineers was on location in the Atacama Desert in Chile. The remote control team was composed of instrument operators, key members of the ExoMars programme team, ExoMars instruments principal investigators and a lead remote geologist, Dr. Susanne Schwenzer from the Open University. In the remote control centre (RCC), the controllers used a video wall to combine data from the rover's instruments with their own 3D planning maps to help the remote team to analyze instruments data, elaborate a science strategy, and produce plans of activities for each sol, as it would be performed during a Mars exploration mission. Each plan was dispatched to the local team in the field who then uploaded it to the rover, while trying to remain as 'invisible' as possible for the remote operators.

Figure 1: The RCC, Harwell, UK

A local control centre (LCC) assured the communication links with the RCC and the Field test Rover, and managed the maintenance and housekeeping of the rover platform and its payload.

Figure 2: The LCC, Atacama, Chile

3.1 The SAFER field test rover

The SAFER Field test Rover was composed of two platform level systems and three payloads. The rover platform, named Bridget, was supplied by Astrium Ltd and provided the locomotion, mechanical support, power distribution functions and communications. The on-board data handling system was provided by Scisys Ltd, and included GNC and payload triggering functions. Three payloads were used during SAFER:

AUPE-2, a PANCAM emulator provided by Aberystwyth University, a WISDOM prototype was provided by LATMOS in France and a prototype of CLUPI, a close up imager, was provided by Space-X.

The instruments were fitted on a dedicated payload interface rack that facilitated instrument mounting and calibration.

Figure 3: The SAFER rover in Atacama with the AUPE2 pancam emulator, WISDOM prototype, and CLUPI prototype

4 SAFER valley in Atacama

In order to prepare, execute and evaluate a Field Test on the realistic reference case of the ExoMars reference surface mission, the location of the field trials was of crucial importance. SAFER has been a technology-driven Mars mission simulation that requires scientific realism. Since the payload is confined to imaging and geophysics (ground penetrating radar), visual geology and physical properties are more important than compositional accuracy or analogy. The scientific attributes of the field site for SAFER has therefore been expected to satisfy the following criteria:-

• Morphological and tonal analogue of Mars surface

• Uncontaminated scene to horizon (no vegetation, no man-made features)

• Navigable yet not over-barren (with respect to science targets)

• Exposed solid geology and thin unconsolidated overburden (drift); Outcrops, float rocks, layering, tonal/textural anomalies, as well as sub-crops, buried horizons/boulders.

Field sites satisfying the above criteria would allow SAFER to exercise all, or elements of, the Experiment Cycles defined for the ExoMars mission [1].

4.1 Site selection

The CAFE analogue study final report [3] was used as input to the site selection process. The suitability of each candidate site for SAFER was evaluated using a scoring matrix and a list of project criteria/requirements. The results showed two potential candidates worthy of consideration for SAFER: the Atacama, Chile, and Death Valley, USA. The team had acquired a significant knowledge of the Atacama through SEEKER [2], and local geology support was accessible through Professor Chong from the Universidad Catolica del Norte in Antofagasta; the Atacama was then selected as primary site.

The terrain in the northern Atacama region of Chile is very Mars-like in terms of geomorphology (low-relief, undulating terrain) and similar tonal range, and is devoid of vegetation and man-made anomalies. Environmentally the area is extremely dry and illumination is likely to be constant, an important consideration for the multispectral imaging systems. Figure 4 shows a map of sites of interest located in the vicinity of the European Southern Observatory at Cerro Paranal, which provided a crucial hosting base during the trials. The map has been prepared by Prof. Chong and visited prior to the start of the trials. The map also shows the position of the European Southern Observatory at Cerro Paranal.

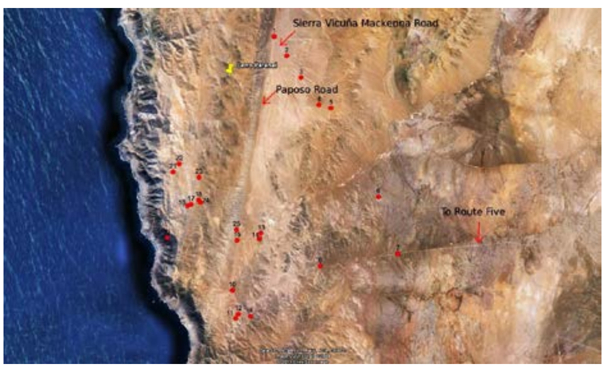

Figure 4: Map of the possible field trials sites, Atacama

Most of the sites identified on the map are of very high interest for future Mars exploration preparation testing activities; details are presented in the SAFER geology report [6]. This region of the Atacama is a remarkable Mars analogue.

The ESO Paranal Observatory is situated 130 km south of Antofagasta in the northern Atacama region of Chile (Figure 4). Between the Cordillera de la Costa and the Cordillera de los Andes (high Andes) to the east is the rain shadowed high desert zone of the Cordillera Vicuña Mackenna, where the SAFER Valley is located.

4.2 Selected site: the Yellow River site in the SAFER valley

The site chosen for SAFER was dubbed “Yellow River” (Figure 7) and lies within an area christened “SAFER Valley” (Figure 5). Other sites discovered during SAFER, and with excellent potential for future projects include terraced eroded outcrops near Vista Point (south of Yellow River), a large isolated outcrop en-route to Salar de Pajonales, and layered volcanic cliffs en-route to Lastarria volcano.

Figure 5: the SAFER rover system in location in the SAFER valley, Atacama, navigating around the pond area

4.3 UAV aerial mapping to generate orbiter data product for SAFER

A key element of the representativeness of the SAFER trials has been the availability of a UAV generated ortho-image and digital elevation map covering the SAFER valley (Figure 6), in a resolution similar to what can be expected from a Mars obiter data product used during and in preparation for exploration.

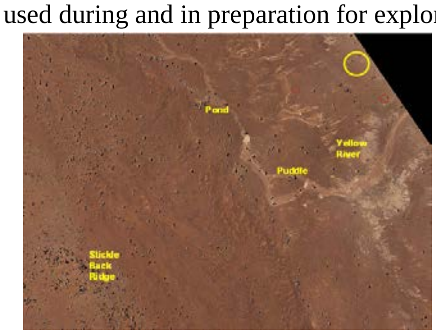

Figure 6: SAFER Yellow River site UAV aerial image used by the remote control center

The trials started in the top right corner of the map in Figure 6 where the yellow circle represents the location where the initial panorama was obtained (near the local control center). The Yellow River site is geologically rich in terms of morphology, tonality and feature attributes (i.e. texture, layering etc.) at a variety of scales. A number of areas within the site together with specific science targets were identified and catalogued during the brief site survey (see Figure 7).

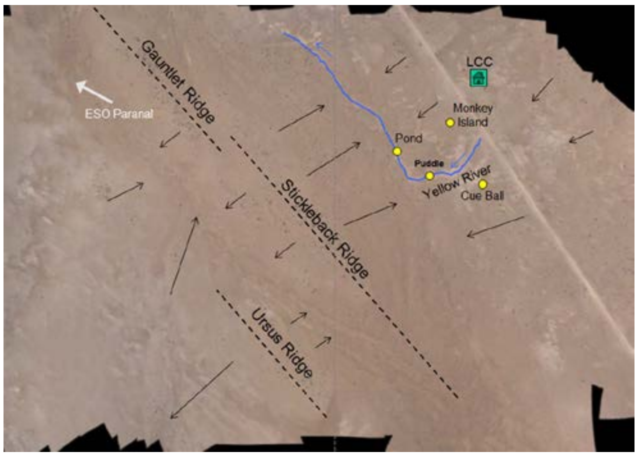

Figure 7: Main geological features at the Yellow River site

Arrows denote slope direction and inclination (long = shallow, short = steep). The position of the LCC is shown to the east of the dirt road (B-750).

5 Operations synthesis

The Field trials were kicked off on Tuesday October 8th, 2013 and lasted until Saturday October 13th 2013.

A total of six plans, corresponding to six Martian sols of activities, were prepared by the remote operations team in Harwell, UK, and executed by the rover system in the Atacama Desert, in Chile. An average of one to two sols per day was executed during the field trials.

Figure 8 represents the overall trajectory of the rover in the SAFER valley over the course of the six sols, together with the corresponding instruments and activities operation executed. Table 3 details the operations executed, distance traversed and duration of each Sol.

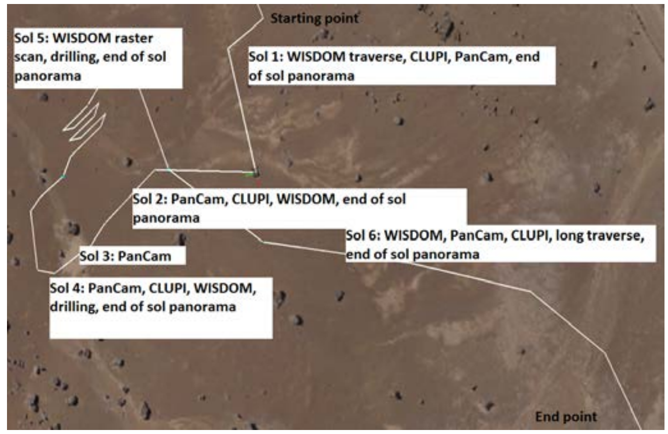

Figure 8: Overall operations achieved in five days, with a total of six sols of activities executed.

The total exploration of the site performed by the SAFER rover system is located on an area of approximately 70m x 130m; while the majority of the investigations covered a small region as shown figure 8, the last large traverse enabled the science team in the remote operations center to acquire additional details on targets located on a second site. The SAFER operations included a raster scan as part of the WISDOM instrument operation.

The SAFER project has allowed in particular the co-acquisition of a CLUPI, AUPE2 PANCAM emulator, and WISDOM extensive dataset in the Atacama Desert, in Chile.

Table 3: Operations synthesis per Sol during the field trials

Sol	Operations	Distance (metres)	Duration (mins)
Tuesday 8th			
Sol 1	Long traverse through the environment towards "Pond" capturing extensive instrument data.	40.49	190.7
Wednesday 9th			
Sol 2	Imaging at the start and then a 100 degree rotation and traverse to "Pond"	34.26	74.5
Thursday 10th			
Sol 3	Navigate across pond performing imaging and Wisdom scans	15.0	93.7
Sol 4	Navigate around the back of "Pond" and associated boulders and back across the stream performing Wisdom scan along the way	23.05	53.05
Friday 11th			
Sol 5	Imaging of interesting rocks before traversing to an open region to perform a raster scan.	50.7	161.6
Saturday 12th			
Sol 6	The plan returned to targets identified during the previous sol. After which a long traverse to the "Yellow river" was performed.	130.58	250.7
Grand total during trials		**294.08**	**824mins (13.7hrs)**

5.1 SAFER science campaign, and most important science target remotely identified

While SAFER had technology development and testing objectives rather than science objectives, the trials campaign transformed into a rich and successful Mars mission simulation activity.

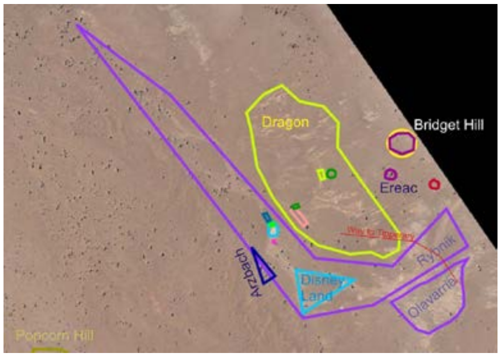

Figure 9: RCC overview map with annotated target of interests as identified by the RCC

One notable science discovery has been achieved using the SAFER rover platform and instruments, remotely operated from the RCC at Harwell, UK: A WAC image supposed to capture Porto North [6] revealed a previously unknown outcrop (subsequently called Carnot) underlying the surface.

At this point, one image changed the entire long term plan: Porto North was missed in the shot, instead a small outcrop, invisible downhill on the earlier panoramas, showed up (Figure 10). This outcrop could potentially even show sedimentary features. Figure 10 shows the outcrop named Carnot, whereby the structure of the rock face and the structure of the top of the surface suggest sedimentary depositional features. At this point, Carnot became the most important science target. The new long term plan was to first carry out the planned investigations, then cross back and return to Carnot for detailed investigations, including high resolution imagery.

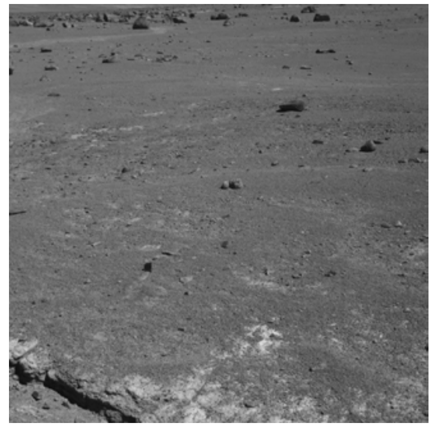

Figure 10: Discovery image of outcrop Carnot

The extensive remote science campaign [6] performed during SAFER has allowed the co-acquisition of a CLUPI, AUPE2 PANCAM emulator, and WISDOM extensive dataset in the Atacama Desert, in Chile. Such dataset is recognized to be of high added value for future activities supporting planetary exploration, including the testing of landing sites selection process using UAV aerial data from the Atacama region, and the use of the extensive instruments dataset acquired in a remarkable Mars analogue region for the preparation of remote decision making process for ExoMars and future Mars exploration missions.

6 Investigating the ExoMars reference surface mission sample acquisition procedure – the SAFER outcomes

6.1 Assessment of the effectiveness of outcrop search instrumentation

The operations implemented during SAFER to test the effectiveness of outcrop search instrumentation were composed of the remote identification of a suitable outcrop, and the subsequent traverse to it using PanCam and WISDOM. This process has been achieved successfully during SAFER as a total of 3 complete science campaigns in the Yellow River site were completed [6].

An end of sol panorama was added to the original plans for both Sol 1 and 2 to support the preparation of the following plans; the identification of candidate outcrops and traverse to the selected target outcrop has been executed successfully; in practice more imaging has been done than what was planned originally: To compensate for the rover not reaching its desired destination on sol 1 and to image secondary targets of interest which were identified during the planning process.

6.2 Elaboration of the strategy and procedures to implement search and acquisition

The operations implemented during SAFER were composed of the survey of target outcrops and acquisition of subsurface samples, using PanCam, WISDOM, CLUPI, and the simulated orbital imagery obtained through UAV aerial mapping. The entire sequence could not be performed as a single plan or during a single Sol; Sol 4, Sol5 and Sol 6 each contained part of the "survey target outcrop and acquire subsurface sample" list of tasks:

During Sol 4, the survey of the target was performed in the dry riverbed, and its boundaries were studied with all imaging payload, and WISDOM soundings were performed. This took an entire sol. During Sol 5, the WISDOM raster scan was performed; it took an entire Sol and it was only partially executed due to the rover battery discharge. During Sol 6, drilling, and samples acquisition and survey were performed, once the rover had exited the area to be sampled. Because drilling operations were manual, they could not be performed simultaneously with rover operations in the same area.

The WISDOM raster scan of about 45.7m in total distance took 02:31 hours to complete; the RCC planned only one WISDOM raster scan to cope with time constraints. This objective was achieved but required three sols, the last one being necessary as drilling operations were manual.

6.3 Opportunistic experiment cycle

The Opportunistic Cycle differs from the Reference Cycle by providing the flexibility to perform sub-surface sampling on the way to the target outcrop.

This cycle proved to be easily implemented on Sol 4; imaging the rover track was considered to be a rich and necessary opportunistic task in addition. A drilling site was identified en route to the targeted WISDOM raster scan area and all items of the opportunistic experiment cycle were implemented on a single Sol except the manual drilling operations which required the rover to have vacated the area in order to allow manual trenching.

6.4 Alternative WISDOM sounding campaign patterns

During the SAFER field campaign, only one WISDOM raster scan has been planned and performed in the field. It was not executed entirely and the unfinished scan took 02:31 hours. The RCC team realized rapidly that the WISDOM scan requires time during which other operations cannot be performed, and that the trenching activities, required to evaluate the accuracy of WISDOM data for each scan, could only be performed when the rover had left the scan pattern area so that the manual trenching operations would not be in the field of view of the rover; this greatly limited the opportunities to perform multiple pattern campaigns coupled with sampling.

The lessons learnt from SAFER have highlighted that the evaluation of WISDOM pattern efficiency and impact on the precision of WISDOM data should be performed as a separate, single purpose activity containing only WISDOM scans and sampling in areas pre-identified as geologically suitable. This recommendation has been addressed to the Agencies and to the ExoMars team [7].

6.5 Evaluation of the accuracy of WISDOM data and surface mineralogy data

The SAFER field campaign has allowed demonstrating that WISDOM successfully detected the change in subsurface nature at a depth of about 60cm, which was proven through trenching and sampling at the Honfleur site in Yellow River [6]. It has also demonstrated that WISDOM achieved in the Atacama Desert a penetration depth between 1.5 to 3 meters depending on the locations, with a number of coherent additions limited to 10 making one sounding last around 2 sec.

The Atacama Desert being expected to be a realistic geological Mars analogue, this provides elements of answer with respect to the coherent addition settings of WSDOM to be selected for ExoMars in order to reach a depth of 1.5m to 3m.

For Exomars, the number of coherent additions is planned to be around 40, which would give 6 extra dB allowing in typical environments (characterized by a loss ~10dB/m) to go to depths >2.5 – 3 m into the subsurface.

7 A future center for field trials at ESA Harwell

A center for field trials at the European Space Agency Harwell site, UK, would be the solution to transition towards systematically formally prepared and conducted trials [7]. In addition, such a center will provide answers to the European space robotics and exploration community looking to receive help for testing novel technologies in visually rich and representative environments [7]. The community has also expressed the need to have access to the data products generated by previous field engineering campaigns for in house testing [4], and have access to an accurate database of possible test site characteristics for both remote areas and European local trial, which the center could disseminate. The mission of the center of expertise has been proposed to be the following: “Support the development and testing of novel technologies enabling planetary exploration and Human spaceflight application through field engineering support, enabling the rapid testing of technologies in rich and representative environments, for a safer exploration, and bring together the European community active in technology development and testing for exploration.”

A flexible, modular range of services would need to be offered; they would encompass the following key services: access to a network of experts, support development and testing activities on location at both local and remote sites, providing access to a field engineering data archive including aerial and instrument data. In addition, the center would provide access to robotic platforms when required and to a remote operations center for field trials.

The center of expertise is proposed to organize regularly planned sequences of field trials, considering customer needs [7]; these might include a low-scale, local testing campaign in a Mars Yard or quarry or a larger scale end-to-end field trials campaign in a remote Mars or Lunar analogue.

8 Conclusions

The SAFER campaign results are opening the way to successful, safe, and optimized planetary exploration for the European Space Agency:

Firstly, remote operations with an average of two Martian sols per day were achieved, including the successful implementation of ExoMars based, remotely driven search and acquisition strategies. Drilling down to more than a meter was achieved by manual operation. Three complete science campaigns were achieved in Atacama, fully remotely. The entire archive of instruments and aerial data has been transmitted to the European Space Agency in order to be used in future activities, together with geological samples collected in the Atacama for future reference.

Secondly, SAFER lessons learnt have been transmitted to the European Space Agency’s planetary exploration teams and in particular to the ExoMars team.

Thirdly, SAFER opens the way to efficient, easy, and cost effective future field trials activities; an extensive expertise in the organization of such trials has been developed, as well as a detailed knowledge of the Atacama region which has proven to be a highly representative analogue for Mars mission simulations.

Finally, the SAFER team has assembled a comprehensive strategy for developing field trials in the future while maximizing the expertise acquired during the project; a UK based center of expertise for field trials has been proposed to support the necessary development and testing of novel technologies enabling European planetary exploration.

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