Final Report for project MARSIS Clutter Simulator Encore (MACSE)

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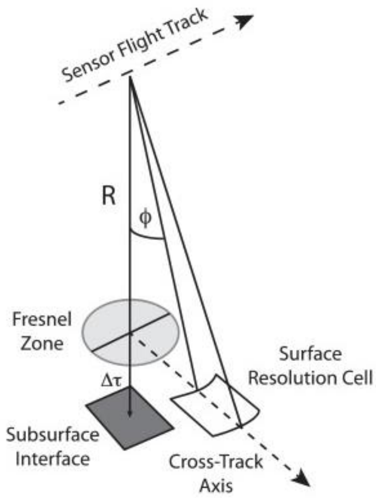
Project description and results

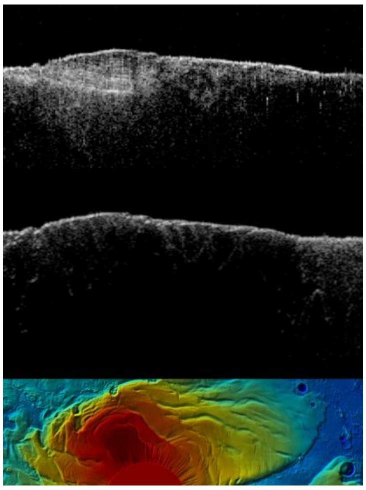
MARSIS is a synthetic-aperture, orbital sounding radar carried by the European Space Agency spacecraft Mars Express. MARSIS transmits through a dipole, which has negligible directivity, with the consequence that the radar pulse illuminates the entire surface beneath the spacecraft and not only the near-nadir portion from which subsurface echoes are expected. The electromagnetic wave can then be scattered by any roughness of the surface.



If the surface of the body being sounded is not smooth, then part of the incident radiation will be scattered in directions different from the specular one: areas of the surface that are not directly beneath the radar will scatter part of the incident radiation back towards it, and thus produce surface echoes that will reach the radar after the echo coming from nadir, and that can be mistaken for subsurface echoes (Fig. 1).

Figure 1: diagram illustrating the observation geometry of MARSIS. The area labelled as Fresnel zone is directly under the spacecraft and is the one from which the first echo detected by the radar originates. Both the subsurface interface at nadir and the off-nadir surface resolution cell produce echoes that will reach the radar after the nadir echo.

To validate the detection of subsurface interfaces, numerical electromagnetic models of surface scattering have been used to produce simulations of surface echoes, which are then compared to real echoes: echoes reaching the radar after nadir surface echoes will be identified as coming from the subsurface if they are not present in simulations; conversely, any secondary echo that is present in both real and simulated data must be interpreted as coming from the surface.



In this proposal, a parallelized and numerically optimized version of a code for the simulation of radar surface scattering is used to compute the expected echo from the surface of Mars using a global topographic dataset produced by the Mars Orbiter Laser Altimeter (MOLA). An example of the result produced by the code is shown in Fig. 2

Figure 2: comparison between MARSIS real and simulated data. A MARSIS radar section of the Martian subsurface cutting through the Southern polar cap is shown at the top, above a simulation of surface echoes for the same observation . The bottom part of the figure shows a shaded-relief, false colour topographic map of the area produced using the MOLA topographic dataset.

Relation to other projects

The development of the code used in MACSE started as a grant awarded by CINECA to rewrite an existing Matlab© code in C, adapting it to parallel computing. After the successful completion of this task, the code was tested and run on the FERMI machine at CINECA. Thanks to these tests, the CPU time required to simulate the entire set of MARSIS observations could be estimated. The resulting amount made it clear that HPC resources were required, and we were advised by CINECA experts to submit a proposal to PRACE.

We successfully applied to the 8th PRACE call in 2013 and we were assigned 7M hours on the SuperMUC computer at the Leibniz-Rechenzentrum in Garching for the period from March 4, 2014 to March 3, 2015. We were able to produce simulations for the entire MARSIS dataset, consisting at the time of more than 7000 observations.

In order to simulate observations acquired after the conclusion of the project, in 2016 a Class C ISCRA proposal was presented to CINECA, receiving 30'000 hours on the PICO supercomputer for the period from March 11, 2016 to December 11, 2016.

Subsequently, the simulations continued thanks to the MACSE project, which received 1'000'000 hours on the MARCONI supercomputer at CINECA for the period from January 1, 2018 to May 31, 2018. Unfortunately, only a small fraction of the available CPU time could be utilized because of the loss of a key person in the project, without which it became impossible to run the code.

In the meantime, several other potential applications of the code in other projects were devised. Unfortunately, at the moment the MACSE team does not have the capability to modify the existing code for those applications. Once this problem is solved by securing the required skills and competences, a new proposal will be presented at the first opportunity to continue work on MARSIS data and to develop and test new versions of the code.

Benefits provided by the INAF/CINECA MoU

This project, being tied to an experiment that is currently operating at Mars and will presumably continue to do so in the next years, requires the submission of multiple proposals over several calls. Timely analysis of MARSIS data would in fact require the ability to perform simulations shortly after data acquisition, which would be best achieved through a limited CPU time allowance that could be renewed over time for an indefinite period.

The setting provided by the MoU does not make this possible, but it simplifies access to HPC by allowing submission of medium- and small-size projects at regular intervals through a slimmer, faster procedure requiring a smaller amount of information to be provided for proper evaluation.

It is hoped that the existence of projects with recurrent needs for resources is recognized within the MoU framework, and that a procedure to handle this kind of proposal is devised. It is likely that many projects within INAF will share this feature, given the long duration of space missions coupled with the need for timely analysis of data.

Project impact

Unfortunately, the MACSE project could produce only a small fraction of its expected output because of the circumstances described in the previous sections. However, the dataset resulting from the collective output of all projects related to MACSE has made its way into a number of presentations at conferences and publications on refereed journals. In particular, radar observations over the Martian polar terrains, both at the North and South poles, have been re-evaluated to better constraint the dielectric properties of materials within and below them. The Medusae Fossae Formation, a deposit of finely grained material suspected of harbouring ice in its depths, has been analysed in its full three-dimensional structure. Finally, the complex geology of Lucus Planum, an area hitherto ignored by studies using MARSIS data, has been unravelled from the complex and laterally inhomogeneous stratigraphy.

The complete set of simulations produced through the code, representing more than ten years of data acquisition by MARSIS for a total of almost 8'000 observations, is a unique tool for the interpretation and validation of MARSIS data, that will bear fruits for years to come. Until now, in fact, high-precision simulations were too computationally expensive to be used in mass interpretation of the data, and their use was confined to a limited number of observations, as it can be gleaned from published research. With this dataset, investigations hitherto deemed materially impossible are now feasible. The first and foremost scientific use of the simulations is, as said, the identification of surface echoes in radar traces, to discern them from the sought-after subsurface interface detections. However, simulations make also possible, for example, to identify the extent of signal distortions caused by the ionosphere, which change the shape of the surface echo, allowing a more precise correction of their effects on the data.

Within the next two years, thanks to resources provided by the European Space Agency, the simulations produced through MACS will be included in the same public archive from which MARSIS data can be downloaded, the Planetary Science Archive. This will increase the scientific output of the experiment, making it possible for a larger community to perform the same type of detection and validation of subsurface interfaces now possible for the MARSIS experiment team. Also, simulations will enable the creation of higher-level data products such as three-dimensional models of the Martian subsurface, although this endeavour will require a time of the order of a few years, with the resources currently available to the experiment team.