Scientific Calibration of Sharad Data over Martian Surface

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***Abstract*—SHARAD (SHAllow RADar) is the sub-surface sounding radar provided by the Italian Space Agency (ASI) as a facility instrument to NASA's 2005 Mars Reconnaissance Orbiter (MRO). The main activity of SHARAD is to make significant new scientific data available toward on Mars, including subsurface layering and an improved understanding of the electromagnetic properties of the surface regions, further insights into the nature of patterned ground, and other morphologies suggestive of the presence of water at present or in the past[1]. The goal of this paper is to describe the method developed for correlating the data to the Martian surface permittivity. The North polar cap has been used as reference back-scatterer, in this area the data indicate an almost pure water ice composition, and thus whose dielectric properties are known [2]. An automatic procedure to estimated the other factor contributing to surface echo strength, i.e. scattering due to surface roughness, has been developed and the fitting of the data to a theoretical model based on fractal geometry has been performed. The result presented is the possibility of estimate the permittivity of Mars surface from the set of radar back-scatterer measurement and the possibility to produce maps of the dielectric constant of the Martian surface and detailed reconstruction of the surface material of Mars.**

Keywords*—Sharad; Mars surface; permittivity; mapping; signal calibration; fractal backscattering estimation, Mars

I. INTRODUCTION

Mars Reconnaissance Orbiter (MRO) is a spacecraft designed to conduct reconnaissance and exploration of Mars from orbit. It was launched August 12, 2005, and attained Martian orbit on March 10, 2006. In November 2006, after five months of aerobraking, it entered its final science orbit and began its primary science phase. MRO contains a host of scientific instruments such as cameras, spectrometers, and radar, which are used to analyze the landforms, stratigraphy, minerals, and ice of Mars. It paves the way for future spacecraft by monitoring Mars' daily weather and surface conditions. One of the mission's main goals is to map the Martian landscape in order to choose landing sites for future surface missions and to understand the geologic stratigraphy of the planet. MRO's Shallow Subsurface Radar (SHARAD) experiment is designed to probe the structure of the Martian surface and subsurface. It also gathers planet-wide information about underground layers of ice, rock and possibly liquid water that might be accessible from the surface. SHARAD uses HF radio waves between 15 and 25 MHz, a range that allows it to resolve layers as thin as 7 m. (23 ft) to a maximum depth of 1 km (0.6 mi). It has a horizontal resolution of 0.3 to 3 km (0.2 to 1.9 mi) [3]. In order to achieve the desired spatial resolution, both in depth and along the ground track, SHARAD received echoes have to be properly processed on ground. The method through which vertical resolution is achieved is called range processing, or range compression, while horizontal resolution is enhanced through what is called azimuth, Doppler, or synthetic aperture processing[4]. The primary objective of the SHARAD experiment is to map, in selected locales, dielectric interfaces to several hundred meters depth in the Martian subsurface and to interpret these results in terms of the occurrence and distribution of expected materials, including competent rock, regolith, water and ice. It is acknowledged that the surface of Mars will not be uniformly amenable to using radar sounding in the search for subsurface interfaces. However, it will be possible to find conditions of favorable radar viewing geometry, interface scattering, surface and volume scattering, and material properties, which may allow the identification of subsurface layers from orbit. When strong internal reflections do occur, they will be identifiable as aqueous only by contextual inferences drawn from the characteristic geological context of water habitats. Independent of any ability to directly detect water or ice, SHARAD should make significant new scientific data available toward addressing critical scientific problems on Mars, including the existence and distribution of buried paleo-channels, subsurface layering, an improved understanding of the electromagnetic properties of the "stealth" region, further insights into the nature of patterned ground, and other morphologies suggestive of the presence of water at present or in the past. In addition, it should be possible to answer certain kinds of geologic questions, such as the character of the surface below the polar ice caps and the nature of some of the layered terrains [5]. SHARAD data gathering and processing should be transparent to the user, the first requirement, for the majority of users of SHARAD data, is that the data collection and processing techniques used to produce the images should be irrelevant, and scientific properties should be the main interest. A goal for the remote sensing scientist would be to model the relationship between some geophysical parameter and some set of radar backscatter measurements, so the scientific characterization of the data is needed to describe the data using an external calibration [6]. The classical method to calibrate the data i.e. checks of the form of the impulse response, point targets such as trihedral corner reflectors, with a large RCS (Radar Cross Section) [7] cannot be employed on Mars surface. A novel method of calibration has been developed, radiometric calibration can be checked if the data on "ground truth" where the variations of the geophysical parameter are available. Several parameters affect the surface echo power: the dielectric constant, roughness, slope. Most backscattering models separate the effect of the dielectric constant, from those parameters [8], a model to take in account the effects of scattering due to surface roughness and slope has been made using theory of electromagnetic scattering from fractal surfaces and estimating the parameters from topographic data provided by laser altimeter MOLA [9, 10, 11].

II. SHARAD DATA

SHAllow RADar Reduced Data Record (SHARAD RDR) data product has been used which is the Level 1B data consisting of received echoes Doppler filtered, range compressed and converted to complex values, correlated with the auxiliary information needed to locate observations in space and time and to process data further on[12]. Level 1B data users are expected to be mainly geologists interested in determining the structure of the shallow Martian subsurface. The input of the procedure is the whole set of Level 1B on the PDS (Node of NASA's Planetary Data System). The SHARAD Level 1B Tool, which has been developed by CO.RI.S.T.A. within the SHARAD Ground Data System activities has furnished the set of the data. The Level 1B data has been used in time domain to extract the information scattered from the Martian surface. Data from MOLA (Mars Orbiter Laser Altimeter) topographic data has been used to estimate the topographic parameters. We have to notice that SHARAD is quite different from a classic SAR (Synthetic Aperture Radar), backscattering is direct consequence of surface roughness and surface slope. An appropriate tool has been developed to take in this two component in the signal calibration processing. The nocturnal set of data has been used in a way that there is no contribution of the ionospheric effects to compensate as propagation of the signal through the ionosphere of Mars has the potential to produce a distortion of the waveform, because the ionospheric plasma has a dielectric constant which is frequency-dependent, and thus introduces a variation of group velocity from low frequencies to high frequencies within the chirp. This would cause degradation of the signal to noise ratio and the presence of artifacts in the signal in a way similar to that discussed for temperature-induced distortions. Ionospheric effects are not uniform over Mars, however: the ionosphere is excited by solar radiation, and its effect are much stronger on the day side of the planet than on the night side. Thus, data acquired on the night side usually do not need any correction, while observations on the day side require the use of a method. Each SHARAD Data Product is an aggregation of SHARAD data blocks. A data block is produced through the processing of one or more received echoes, and constitutes a single observation of the instrument. Each Data Product will contain data from one or more data blocks collected continuously using the same operation mode, instrument status and on-board processing scheme, that is using a single OST line. The content of each SHARAD data product is highly variable in terms of number of data blocks, and depends on how operations for the instrument were planned during a given data collection period. Echoes can be coherently summed on-board in groups: this is called pre-summing. Depending on the operating scenario, different levels of pre-summing can be selected, i.e.: pre-summing 1 (no pre-summing), 2, 4, 8, 16, 28, 32. When pre-summing "N" is selected, the samples from N sequential PRIs are summed sample-by-sample, thus reducing the data rate by a factor N. The result of the sum of N echoes is referred to as a data block[13]. The selection of the operation mode of the radar is essential because the pre-summing is changing and a different calibration of the data may be needed. An automatic tool to discern how to operate on different operation mode has been developed. Scientific Calibration of SHARAD data is not possible using a classical approach, as previously mentioned, because no available measurement on-situ of the antenna backscattering on well-known target is available. The task to search for areas and whit a known permittivity and small standard deviation of backscattering signal after correction the from surface roughness and surface slope has been performed.

III. Signal Modelling

A scientific model has been developed to fit the Martian surface to the attended correlation with permittivity. The detection of the surface echo is made with the assumption the echo is expected to have the most powerful energy, due to a high dielectric contrast. The radar backscatter for a known target is extracted from the data.

The model it is based on the following main assumptions:

- only two main interfaces are considered, i.e. the open space and the surface.
- The first interface it is suppose to be empty space
- The second interface is supposed to be homogeneous and non dispersive media, it is rough, being characterized by a backscattering coefficient $\sigma_s^0(\theta)$ depending on incidence angle θ and a dielectric relative constants ε_s (the real parts);

With these assumptions, powers related to surface directly measurable from radargrams can be evaluated by using classical "radar equation" [14].

A. Model: Calibration Constant Extraction

The calibration of the signal needs a constant that takes in to account the backscattering gain due to the radar system and the surface. The determination of this constant will be applicable as first on known geophysical area of Mars where the real part of the dielectric constant has been previously estimated with infeasible value and the slope is low. The chosen calibration area is located on the North Polar Cup (84N 82N 180E 200E). The area consists of primarily water-ice with a few percent dust [15], over this area the radargrams show the minimum registered noise. The choice is made over an area sufficiently flat, where the estimation procedure to extract the surface Power Echo opportunely filtered it is made avoiding the system noise. The slope and the 3dB angle has been estimated using the MOLA data and the real part of the dielectric constant in known on the calibration area. The ground swath of the radar and the slopes has been estimated with fractal geometry of the area. The backscattering is evaluated using the statistical parameters estimation along the orbit with the fractal theory for a monostatic radar configuration [16]. The Mars Orbiter Laser Altimeter (MOLA) data and the theoretical formulation [17] has been used, to estimate the Topothesys and Hurst coefficients, over the whole Mars ground. The Calibration constant must be calculated over the whole records, its formulation is following:

$$K_{ice} = \frac{G_{ice}\sigma_0 A_{eff} A_z}{P_r H^4} \tag{1}$$

where G_{ice} is the antenna gain on the ice, P_r is the received power, H is the altitude of the spacecraft, A_{eff} is the antenna effective area at 3dB, A_z is the term that takes in account the broadening factor, due to the not ideal matched filter used in azimuth compression, and also of the displacement in the sampling of data acquisitions for the operation mode used, σ_0 is the radar cross section estimated for linear polarizations.

B. Model : Data Calibration

The surface power echo is extracted from the Level 1B, the estimation of the slope and the 3dB angle made using the MOLA data. It is needed to estimate what the radar is observing using the fractal geometry of the area [18]. The backscattering is evaluated using the calibration constant, it is necessary to compensate for the power losses due to altitude changes. The Fresnel reflection coefficient at normal incidence at the plane interface between two media with refractive indexes i and j respectively, is defined as followed

$$\Gamma = \frac{\sqrt{(\varepsilon_i)} - \sqrt{(\varepsilon_j)}}{\sqrt{(\varepsilon_i)} + \sqrt{(\varepsilon_j)}} \tag{2}$$

the automatic tool will be able to estimate the dielectric constant from the following equation

$$\Gamma = \frac{K_{ice} G P_r H^4}{\sigma_0 A_{eff} A_z} \tag{3}$$

where in this case G is the two ways gain of the antenna on the surface.

IV. Results

In this section, are shown the results obtained by the proposed calibration method using the full dataset of SHARAD in all the Operational mode available further is showed the result for a particular area of interest: Argyre Planitia. The calibration method uses as calibration set of data which are the RDR located on the North Polar Cap, Figure 1 show the occurrences of the dielectric constant after calibration of that area; it clear the response of the model, mainly the occurrence of the dielectric constant it is near 3.14 which is the input data for the calculation of the calibration constant.

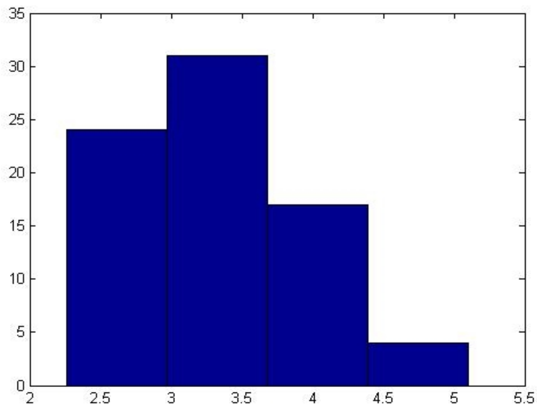

Figure 1 *Occurrences of the dielectric constant in the calibration area after calibration*

Following are showed respectively in figure 3 and 4 the dielectric constant map of Mars and the Power map of the RDR. It is evident from the correction due to the model of the power backscattered, and that there is not direct relations between the two maps because the model operates taking out the accounting of the backscattering due to the tomography of Mars. The model takes in account the only contribution due to the material.

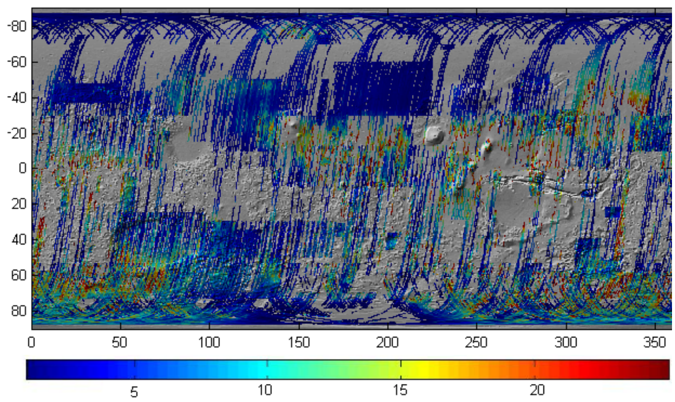

Figure 2 *Map of Mars Dielectric constant*

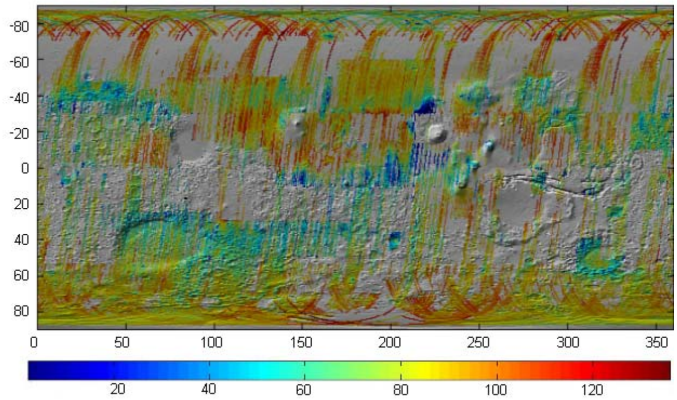

Figure 3 *Map of the Sharad RDR data surface extracted Power (linear scaled)*

The figure 4 shows a particular interesting area individuated form the map which is located in the area 320°E, 50°S the area is called Argyre Planitia. The first results of the map shows it has in some parts a low dielectric constant. This could be due to the presence of ice near the surface.

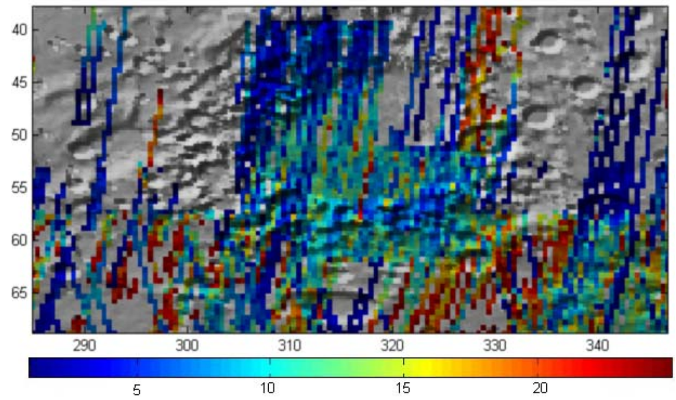

Figure 4 *Map of the Dielectric constant of Argyre Planitia*

V. Conclusions

This paper describes a method to extract the dielectric constant of the surface of Mars from the echoes of the subsurface sounding radar SHARAD. Echo relative strength is equated to reflectivity, and the effects of surface roughness are modeled using the MOLA topographic dataset. The resulting information provides insight on the nature of the materials constituting the Martian surface. In particular, low values of surface permittivity indicate either a very loose, porous regolith or an ice-rich terrain, whereas high values are characteristic of solid rock. Of particular interest is the area of Argyre Planitia, a large impact basin centered at 320°E, 50°S whose rim is very rugged and ancient. It has been found that the southern half of the rim has a high dielectric constant, as expected, while the northern half, which is extremely similar from the geologic point of view, exhibits a much lower permittivity. This fact points to the possibility that the northern part of Argyre Planitia contains large quantities of ice in the ground, perhaps a relic of a past ice age such as the lobate debris aprons found elsewhere at similar latitudes on Mars [19].

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