MARTIAN SURFACE RADAR REFLECTIVITY BY MARSIS.

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Introduction: Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) on board Mars Express is a decameter sounder radar, which can work in two different modes : subsurface or ionosphere sounding. The subsurface sounding uses 4 different frequency bands, which are centered to 1.8, 3, 4 and 5 MHz. Each band is 1 MHz wide. [1,2].

In this work, we study the reflectivity of Martian surface at radar wavelength (3-5 MHz) in order to evaluate the dielectric constant of the shallow subsurface. These values enable to constraint the nature of materials that composed the few tens of meters under the surface. The geology at this scale is poorly known because the classical instruments of the Martian exploration probe few microns to one meter of the surface. MARSIS offers the new opportunity to explore more deeply the surface.

Methods: For this study, it is necessary to calibrate the data and to separate the different effects that affect the reflectivity. Firstly, we present our extraction method of the surface echo power from the MARSIS radargrams. Next, we show our correction of spacecraft altitude changes and ionospheric absorption.

Once the surface reflectivities extracted from the radargrams and corrected from the ionospheric absorption, we have plotted a global map of the Martian surface echo power (global radar albedo map) at 3-5 MHz (see Figure 1).

For crossing tracks, we average the data from multiple measurements. MARSIS is a nadir looking radar and the Mars Express polar orbit does not allow us to sound the surface poleward of about 87°N and 87°S; this lack of data results in a gap centered at the pole.

This reflectivity map combines the different frequency bands of MARSIS because we observe few differences between them and thus we obtain a better coverage of the Martian surface.

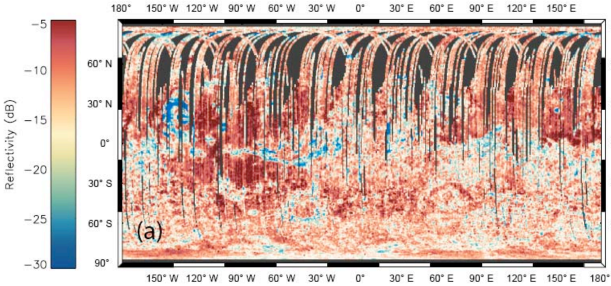

Figure 1: (a) Reflectivity map at 3-5 MHz of the Martian surface as seen by MARSIS. Red color corresponds to high reflectivity and blue to low reflectivity. Grey color corresponds to lack of data.

As expected for decametric radar waves, the roughest terrains on Mars like Olympus Mons Aureole, Valles Marineris, Hellas and Argyre crater rims, or the dunes around the north polar cap are associated with a very low reflectivity.

Simulation : A simulation of MARSIS radargrams has been developed at the Laboratoire de Planétologie de Grenoble to help in the interpretation of the radargrams.

This simulation is based on the Facet method as surface model [3], which is an extension of the Kirchhoff model. Such a model can be used because of the low surface roughness at radar wavelength [4], and is a significant gain of calculation time. The synthetic facetted surface is generated from MOLA data [5].

All MARSIS orbits have been simulated and we have extracted the surface echo power in the way as the MARSIS data. The dielectric properties of the surface are fixed in the simulation; therefore the simulation enables to estimate the contribution of the large-scale scattering, resulting from gentle surface undulation on a scale of few hundreds to thousands meters.

Most of the reflectivity models separate the effects of dielectric constant from those of roughness [6, 7]. We can now consider the simulator as a reference for the reflectivity in order to correct the roughness slops effect. The result of all simulations is given in Figure 2 as a global map of the simulated reflectivity of the Martian surface. As the facet size in the simulation is about 460 m (MOLA resolution), the topography below this size cannot be derived from the MOLA elevation model. It shows the limit of the simulation due to the limited resolution of MOLA maps, which does not enable to simulate the small-scale scattering resulting from variations of the surface height over a horizontal scale of tenths of meters. Fortunately, only few regions on Mars are characterized by an important roughness at small-scales [4].

As a result, we obtain the map in Figure 3 , which is the difference of logarithmic power (dB) between the data map (Figure 1) and the simulated map (Figure 2).

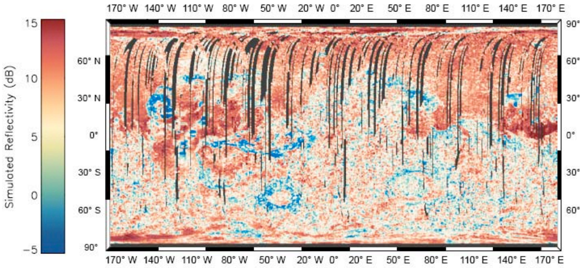

Figure 7: Reflectivity map realized with the simulated radargrams. Grey color corresponds to lack of data. The map is in cylindrical projection.

Results and Discussion: Tharsis region shows the highest albedo, which is consistent to a dielectric constant above 8. The dielectric values found in these regions are characteristics of dense, ice-poor, igneous rocks [8, 9].

A clear change in reflectivity is visible around 50°S-60°S latitude in Figure 3. This decrease is in a 3dB range. The mean dielectric constant is about 9 in the region over the boundary (toward the equator) and becomes about 5.5 in the region below the boundary (toward the pole). This boundary follows the limit in the southern hemisphere where the GRS instrument observes an important reservoir of hydrogen [10, 11, 12].

In order to understand this decrease of the reflectivity, we use the mixing formula of Maxwell-Garnett [13]. Supposing that the surface materials are composed by water ice ($\varepsilon = 3$) and volcanic rocks with a dielectric constant of 9 as found above the boundary, we find that that the tenths of meters depth must constains about 50% of water-ice in volume.

We are showing here that the abundant hydrogen reservoir observed by Boynton et al. [2002] continues more deeply in the subsurface (few tenths of meters), implying a huge volume of water.

The northern lowlands (Vastistas Borealis) are characterized by the lowest reflectivity ($\varepsilon \sim 2.8$) on Mars, which could involve the presence of ice rich and porous materials. We cannot exclude that multiple layers on the first 50 m depth could generate such a low reflectivity. We note also that the number of MARSIS sounding is poor in the north hemisphere and could affect this result.

We observe that few equatorial regions are characterized by a lower albedo than the surrounding terrains. These regions are close to Arabia Terra, Medusae Fossae and a area spreading along the boundary between northern plains and southern highlands at the south of Elysium Planitia (110°E-180°).

The observations described previously have some correspondences with the results of the Gamma Ray Spectrometer (GRS) on board Mars Global Surveyor (MGS), which has studied the hydrogen distribution in the first meter of the Martian surface [10, 11, 12].

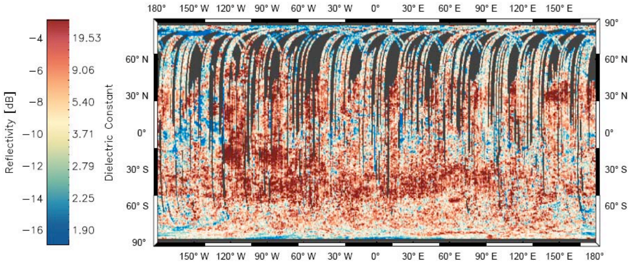

Figure 3: Reflectivity map corrected from roughness effect overlaid on MOLA shaded relief. As described in the text, the reflectivity has been calibrated using a reference region, which enables to give the corresponding dielectric constant. The map is in cylindrical projection.

If the presence of ice is expected at high latitudes, which easily explains the low dielectric constant closed to the pole, nevertheless it is more difficult to understand the low dielectric constant observed at equatorial regions.

References:

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