ICE DETECTION OVER MARTIAN SURFACE USING SHARAD DATA Luigi Castaldo[1], Daniel Mège[1,2], Roberto Orosei[3], Giovanni Alberti[4], Joanna Gurgurewicz[1,5], [1]Institute of Geological Sciences, Polish Academy of Science, Podwale 75, 50-449 Wrocław, Poland, [2]Laboratoire de Planetologie et Geodynamique, Université de Nantes, UMR CNRS 611, France, [3]Istituto di Radioastronomia, Istituto Nazionale di Astrofisica, Via Piero Gobetti, 101, I-40129, Bologna, Italy, [4]CO.RI.S.T.A., Via J. F. Kennedy, 5, 80125, Napoli, Italy, [5]Space Research Centre, Polish Academy of Sciences, Bartycka 18A, 00-716 Warsaw.

Introduction: SHARAD is a synthetic aperture, orbital sounding radar, carried by NASA's Mars Reconnaissance Orbiter [1]. Although the study of signal subsurface is in fact the most common application, the echo from the surface itself is useful to study the first layer of the Mars surface. Favorable conditions of radar viewing geometry, interface scattering, surface and volume scattering, and material properties, may allow to develop a proper mathematical model and estimate the surface permittivity map. The study of the reflectivity of the surface echo is a means to obtain information on the composition and geometry of the ground. SHARAD is making significant new scientific data available toward addressing critical scientific problems on Mars, including the existence and distribution of buried paleochannels, 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 [2]. A mathematical method of calibration has been developed, adopting a models of surface scattering, in order to estimate the variation of geophysical parameter as geometry variations, slopes and material composition, across the Martian surface, and able to extract regions where presence of ice in the surface can be probable.

Scattering model: Scattering from natural surfaces plays a fundamental role in wave propagation and remote sensing. Mathematical models of the natural surfaces on Mars are not available because of surface complexity. Instead, a fractal geometry approach has been used, and proved useful because the surface under investigation does not have any artificial signal that would result in artefacts [3], [4]. Another reason for suing the fractal approach is that forces that model natural surfaces (gravity and microgravity, tensions, frictions, vibrations, erosion, thermal and freezing gradients, chemical reaction, etc.; as well as periodic and aperiodic happenings: seasons and vegetation changes, sun, wind, rain, snow, slides, subsidence, etc.) generate surfaces whose topological dimension is larger than 2 [5]. The backscattering is evaluated using the statistical parameters estimated along the orbit with the fractal theory for a monostatic radar configuration [6]. Taking care that the backscattering in the specular direction only occurs in the case of normal incidence, $\vartheta = 0$; in this case, the backscattering results are polarization independent:

$$\sigma_0 = \frac{|R_0|^2 k^2 T^2}{H} \frac{\Gamma^{\left(\frac{1}{H}\right)}}{\left(\sqrt{2}kT\right)^{(1/H)}} \qquad (1)$$

where H and T are respectively the Hurst and Topothesy coefficients, Γ is the gamma function, k is the wave vector and R_0 is the Fresnel reflection coefficient of the mean plane. The topography has been characterized by fractal processes [7] using the MOLA data [8] and estimating the Topothesy and Hurst coefficients over the whole Mars.

Calibration modelling: The signals extracted from the SHARAD data need still several corrections in power in order to be compared to each other. Electromagnetic waves propagate with a geometric attenuation factor of $1/h^2$. This means that, for the same reflective surface, the power intercepted by the Radar will decrease with increasing altitude. In addition to the gain variations due to the roll of the satellite, which are corrected in pretreatment, each of the configuration involves disturbance variables on SHARAD signal. Four typical configurations have been identified and studied: SS04, SS05, SS11, and SS19. The corrections to be applied to the signal are provided with data and are related with magnitude of it [9]. The geometry is affecting the power that the antenna detects the effective aperture on the ground which takes into account that the power backscattered from the ground is incident on the antenna. The along-track resolution is enhanced in SHARAD through what is called azimuth, Doppler, or synthetic aperture processing. This is another factor to take into account in the calculation of the normalized backscattered power. The calibration of the signal requires the determination of a constant that takes the backscattering gain due to the radar system and the surface into account in order to compensate the power losses due to the orbitographic phenomena [10]. The constant has been calculating starting from the power backscattered on a particular area on Mars where the permittivity constant is known, taking care to neglect all the terms depending on the geometry, ground and orbit. The calibration constant is needed also to com-

pensate for the power losses due to altitude changes; moreover the calibration constant must be valid over the whole dataset. Following is the formulation the calibration constant:

$$K_{ice} = \frac{G_{ice}\sigma_0 A_{eff} A_z}{P_r H^4} \quad (2)$$

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 of the ground, A_z is the azimuth factor, σ_0 is the radar cross section estimated for linear polarizations with fractal geometry.

The estimation of the permittivity constant comes from the following formulation:

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

where Γ is the Fresnel reflection coefficient at normal incidence at the plane interface between two media with refractive indexes and G is the two ways gain of the antenna on the surface.

Discussion on extraction of ice-rich regions: The determination of regions in which the probability of bearing ice in the first layer (0-15 m deep; ~6 m in case of pure ice) of the Martian surface is high, is obtained using the real part of the permittivity constant of the ice (3.14), estimated by other means. Figure 1 shows the map of the standard deviation of the global Mars permittivity, which gives the measure of the uncertainty of any permittivity calculated with the method illustrated above. The global standard deviation of the whole map has been calculated and used to assess which regions have a permittivity constant close to ε_{ice}. Figure 2 shows the map of the standard deviation for the regions that are possibly covered with ice. This signal is originally highly dependent on physical parameters (permittivity and roughness) characterizing the near surface, and comparing it with the map on Figure 2 we can therefore potentially learn about the distribution of the ice-rich regions.

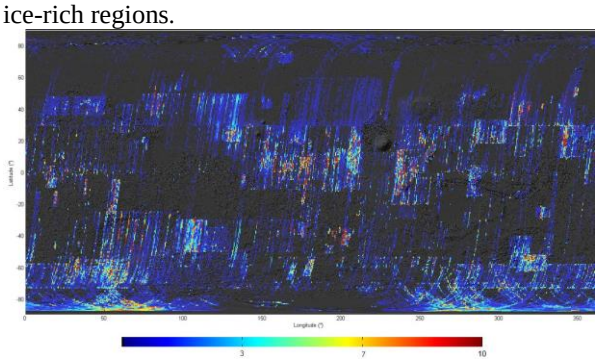

Figure 1 Global map of the std(ε) for the whole Mars model.

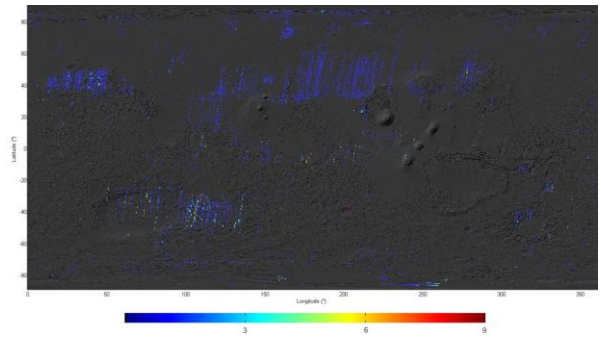

Figure 2 Global map of Std(ε_{ice}) of potential ice-rich regions.

References:

[1] Seu, R., et al., (2007) SHARAD sounding radar on the Mars Reconnaissance Orbiter, *J. Geophys. Res.,112, E05S05, doi:10.1029/2006JE002745.* [2] Gray, L., et al., (1990) Synthetic aperture radar calibration using reference reflectors, *IEEE Trans. Geosci. Remote Sensing, vol. 31, pp 374-383.* [3] Mandelbrot, B. B., (1983) *The fractal geometry of nature, Editor Freeman, San Francisco.* [4] Brown, S. R., C.H. Scholz, (2012) Broad bandwidth study of the topography of natural rock surfaces, *JGR, 90, doi: 10.1029/JB090iB14p12575.* [5] Franceschetti G., et al., (1999) Scattering from natural rough surfaces modeled by fractional brownian motion two-dimensional processes, *IEEE Trans. Antennas Propag., 47, 9, 1405–1415.* [6] Franceschetti, G., D. Riccio, (2007) *Scattering, Natural Surfaces, and Fractals, BURLINGTON (MA) Academin Press.* [7] Orosei., R., et al., (2003), Self-affine behavior of Martian topography at kilometer scale from Mars Orbital Laser Altimeter data, *JGR, 108, Issue E4, pp. GDS 4-1, CiteID 8023, DOI 10.1029/2002JE001883.* [8] Kreslavsky, M.A., Head, J.W., (1999), *Kilometerscale slopes on Mars and their correlation with geologic units: initial results from Mars Orbiter Laser Altimeter (MOLA) data. JGR, 104, pp.* 21911–21924. [9] Slavney S., R. Orosei, (2008) Shallow Radar Reduced Data Record Software Interface Specification, *PDS Geosciences Node.* [10] Castaldo L., et al., (2013) Scientific Calibration of SHARAD Data over Martian Surface, *Signal Processing Symposium, IEEE /ISBN Copiright Reg. No. ISBN 978-1-4673-6318-1.*