EPSC Abstracts
Vol. 13, EPSC-DPS2019-279-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Mars HF Surface Imaging by Processing SHARAD Off-nadir Echoes

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Abstract

Planetary Radar Sounders are spaceborne nadir-looking instruments operating in HF/VHF band (i.e., MHz range) specifically designed for subsurface investigations. However, a particular set of radar sounders echo power measurements, denoted as off-nadir surface clutter, can actually be exploited to produce surface images of a given investigated region. In this paper, we present a method for producing images that mainly represent surface roughness by using High Frequency (HF) radar sounder data. Here, the method is applied by combining the off-nadir data of the Shallow Radar Sounder (SHARAD) with the Mars Orbiter Laser Altimeter (MOLA) Digital Terrain Model to produce roughness images of the Martian surface. The application of the proposed method results in 20 MHz (5 m wavelength) Mars roughness images at about 300 m resolution. The obtained surface roughness images represent a valuable additional tool for geophysical analyses and landing zone risk assessment of the Martian surface.

1. Introduction

Radar sounders are nadir-looking electromagnetic sensors. These kinds of spaceborne or airborne radar systems transmit electromagnetic waves in the MHz range. In this frequency range, the transmitted radar pulses are capable of penetrating the surface and to localize and identify subsurface reflectors [1]. The data acquired by these sensors are affected by unwanted off-nadir surface echoes (denoted as clutter) due to the large illuminated surface footprint. This type of artifacts appear as unwanted echoes positioned at time delays similar to the ones of subsurface features. By exploiting an external geometric reference such as a digital elevation model, off-nadir surface clutter can be projected over a bi-dimensional image thus producing radar images of the target area [2].

In this paper, we present a method for deriving surface roughness images from radar sounding data. Here, we apply the method to the Martian case. Roughness images also provide information regarding the geometric structure of the investigated surface. Radar sounder off-nadir imaging has been successfully applied to the Kaguya Lunar Radar Sounder (LRS) data [2] thus producing images of the Moon surface at 5 MHz. In this work, unlike in [2], the range line is projected not only in the across-track direction but in all the possible directions. By exploiting multi-looking, radar image ambiguities are solved thus making unnecessary the westward and eastward illumination discrimination.

2. Proposed Method

Let $\mathbf{\Omega}(\phi, \eta)$ be the vector defining the given digital elevation model data points, where ϕ and η are the latitude and longitude of a given point respectively. Let $P(k)$ be the echo power for a given radar sounder range line as function of the range index k. For each echo power sample, the range distance $r(k)$ can be derived by inversion from the echoes time delay. The range distance $r_D(\phi, \eta)$ from each point of the digital elevation model to the spacecraft position $\boldsymbol{p}_{\text{sc}}$ is computed as $r_D(\phi, \eta) = |\mathbf{\Omega}(\phi, \eta) - \boldsymbol{p}_{\text{sc}}(\phi_0, \eta_0, h)|$, where ϕ_0, η_0 and h are the coordinates of the spacecraft position for each given radar acquisition point. For each range line, the roughness $\xi(n)$ for the $n-th$ power interval is computed as $\xi(n) = 1/P_0 \sum_{k=(n-1)N_s}^{nN_s-1} P(k)$ where P_0 is the nadir power and N_s is the interval size. The definition of roughness is similar to the one presented in [3] but we extend the definition of the roughness ξ to the entire range line and not only for the nadir return due to the association of the radar sounder data with the digital elevation model. Each roughness value $\xi(n)$ corresponds to a set of radar ranges $\{r(k)\}$. Therefore by performing the association between $\xi(n, r(k))$ and $r_D(\phi, \eta)$ is it possible to obtain the roughness image of a given range line denoted as $\xi(\phi, \eta)$. The final roughness image is computed by averaging over the same region the data acquired on multiple orbit tracks. The proposed method produces images mainly related to the roughness of a given target area. The echo power and the retrieved roughness are mainly related to the geometry of the surface features and in particular to the terrain RMS height variation. However, the produced images may bear information regarding the subsurface that may appear as an increase in the roughness value not strictly related with the surface roughness variation. This potentially ambiguous information, when present, can be exploited for subsurface targets evaluation.

3. Experimental Results

SHARAD is an HF radar sounder currently orbiting and operating around Mars. Its operational frequency is 20 MHz with 10 MHz bandwidth. The 10 MHz bandwidth results in 25 m range resolution in vacuum. In this work, we exploited the SHARAD Reduced Data Record (RDR) available on the Geoscience Node of NASA'S Planetary Data System (PDS). For what pertains the digital elevation model $\mathbf{\Omega}(\phi, \eta)$, we exploited the MOLA Experiment Gridded Data Record (MEGDR) publicly available on the PDS. The ground resolution of the roughness images is estimated to be about 300 m. As an example of results, Fig. 1 shows the SHARAD roughness image (300 m resolution) obtained by the proposed method over the Nili Fossae and the corresponding THEMIS infrared image (100 m resolution). The SHARAD HF image is obtained by exploiting about 70 orbital tracks. Even though subsurface scattering may be present in the resulting roughness image, one can appreciate the level of detail achievable by the proposed technique and the ambiguity free results (i.e. no westward/eastward illumination ambiguity as in [2]). The SHARAD roughness image highlights the smoothness of the Nili Fossae through (confirming the potential as landing site). The Fossae through is surrounded by more roughy areas (i.e. Highlands of Nili Fossae) such as the impact features located approximately at 74.72E, 19.30N which indeed show a higher value of ξ in the SHARAD image.

4. Conclusions

In this paper, we proposed a method for obtaining HF surface roughness images from radar sounding data. This is achieved by projecting the off-nadir surface clutter over a suitable digital elevation model (e.g, stereo camera, laser altimeter). We applied the proposed method on Mars data by pairing the SHARAD and MOLA data. As a result, we obtained 300 m resolution roughness images of the Martian surface. With respect to previous work, the obtained radar images show: (i) no mirror image ambiguity [2] as shown in the lunar case and (ii) an improved resolution and coverage with respect to previous roughness characterization with SHARAD data [3]. The produced SHARAD roughness images are useful for geophysical investigations and landing zone risk assessment of the Mars surface at a still rather unexplored wavelength range. The surface roughness images may contain information regarding subsurface structures. In the future, we plan to better investigate how to exploit these relevant information.

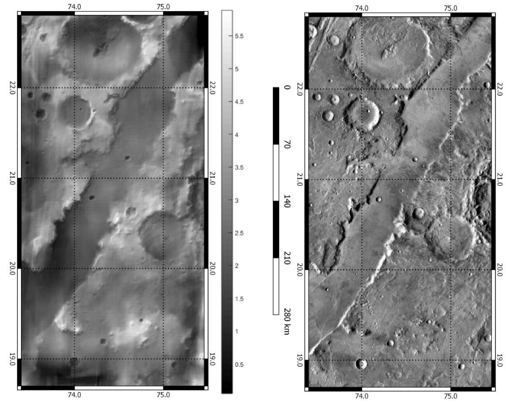

Figure 1: (Left) SHARAD HF (20 MHz) roughness image (300 m resolution) combined with MOLA hillshade obtained by the proposed method and (Right) THEMIS Infrared day (100 m resolution) of the Nili Fossae region.

Acknowledgment

This work was supported by the Italian Space Agency through "Attivita' scientifiche per JUICE fase C/D" under Contract ASI/INAF n. 2018-25-HH.0.

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