EPSC Abstracts
Vol. 13, EPSC-DPS2019-330-1, 2019
EPSC-DPS Joint Meeting 2019

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

Comparing the multifractal properties of Europan and Martian surfaces

C. Gerekos (1), C. Grima (2), G. Steinbrügge (2), K. Scanlan (2), D. Young (2), L. Bruzzone (1), and D. Blankenship (2)
(1) Departement of information engineering and computer science, University of Trento, Italy, (christopher.gerekos@unitn.it)
(2) Institute for Geophysics, Universtiy of Texas at Austin, USA.

Abstract

We present a comparative study of the roughness of Mars and Europa in terms of multifractal behaviour. The Allan variance profiles of Mars are derived using the MOLA dataset, and are compared to published profiles of Europan ridged plains and chaos matrix terrains. Once this work will be coupled to analyses of other Martian datasets, we expect to compile a rather exhaustive list of Europan surface analogues on Mars.

1. Introduction

The Jovian moon Europa is the target of two upcoming planetary science missions, the ESA spacecraft JUICE, due to launch in 2022, and the NASA probe Europa Clipper, due to launch in 2023. Both missions will include a radar sounder in their payload. JUICE's radar instrument, RIME, operates in the HF band, whereas Europa Clipper will fly the REASON instrument, which is a dual-frequency sounder composed of HF and VHF transmitters.

The surface of Europa has remarkable geological features such as complex systems of ridges and chaotic terrains, and is overall characterised by a high roughness at metre scale [1]. The characteristics of this surface roughness has a wide-ranging influence on the properties of backscattered radar echoes, and it is crucial for RIME and REASON that this roughness is well-understood.

While no radar data currently exists for the surface of Europa, there is an abundance of it on Mars, which has been studied for more than a decade by the MARSIS and SHARAD instruments, aboard ESA's Mars Express probe and NASA's Mars Reconnaissance Orbiter, respectively. Additionally, the surface roughness of Mars has been thoroughly characterised from laser altimetry and stereo imaging (*e.g.* [2][3][4]).

The fractal properties of the Europan surface were recently analysed at scales ranging between 30 m and 5 km from images of the SSI instrument aboard NASA's Galileo probe [5]. In particular, the scale-dependant Allan variation of different geological subunits of Europa have been characterised, many of which being piecewise linear functions with one or two breakpoints, depicting multifractal behaviour.

In this abstract, we propose to perform a similar analysis on Martian terrains using the MOLA dataset. Once coupled with other datasets (*e.g.* HiRISE or CTX), the aim is to identify all Europan analogues on Mars, and to analyse the properties of the corresponding MARSIS or SHARAD radargrams.

2 Methodology

The MOLA DEM covers latitudes within $[87°\mathrm{S}, 87°\mathrm{N}]$ and has a sampling of about 463 metres in both directions at the equator. This global DEM was subdivided in squares with length $L = 35$ km, spaced $0.25°$ apart. Each of these scenes was de-projected, and the average slope in both direction was removed.

For a given baseline Δ, the variance of the height differences (or Allan variance) of the discretised terrain $z(n)$ is given by

$$\sigma^2(\Delta) = \frac{1}{N}\sum_{n=1}^{N}\left[z(n) - z(n+\Delta)\right]^2, \qquad (1)$$

where n represents a given point on the surface and N the total number of points of the terrain z. For a self-similar terrain, the Allan variance possesses the property of scaling with a given power of the baseline. For two baselines l_0 and l_1 we have

$$\sigma(l_1) = \sigma(l_0)\left(\frac{l_1}{l_0}\right)^H, \qquad (2)$$

where H is a dimensionless quantity known as the Hurst exponent ($0 < H < 1$).

The $\sigma(\Delta)$ functions obtained by computing (1) at different baselines are typically linear or piecewise linear functions when plotted on a graph with logarithmic axes. These profiles were then fitted with continuous

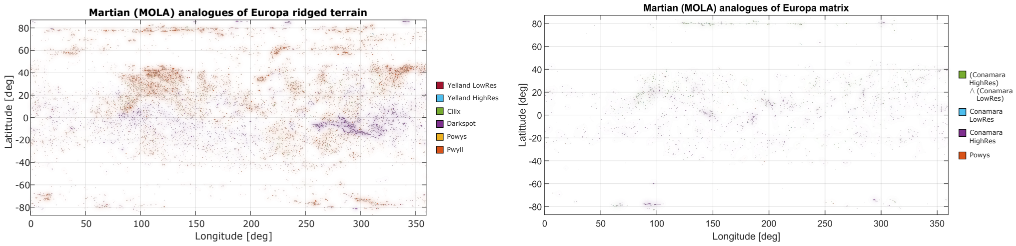

Figure 1: Cylindrically-projected map of all Martian (MOLA) analogues of Europan ridged plains (left) and chaos matrix terrains (right) as analysed in [5].

piecewise linear functions with 0, 1, or 2 breakpoints, so as to be able to accommodate all types of multi-fractal behaviour observed in [5]. The abscissae of the breakpoints correspond to the scales at which the fractal behaviour of the terrain changes, the slopes of the segments are the Hurst coefficients, and the intersection with the y-axis is the slope at 1 m scale.

Then, all the MOLA portions where the parameters of the fitting function described above matched the those of [5] were reported on a map. (Due to the low resolution of the MOLA DEM, we were forced to ignore any breakpoint at scales below 1000 m.)

3 Results

In this abstract, we focus on ridged plains and chaos matrix terrains, which cover most of Europa's surface.

Regarding ridged plains (fig.1-left), the profiles for Powys, Cilix and Yelland are almost absent from the Martian surface. Pwyll, on the other hand, is rather common, with clusters of analogues in the Isidis and Utopia Planitie, at high northern latitudes ($\approx 80°$N), and in Acidalia Planitia. Analogues of the Darkspot terrain can be found predominantly in equatorial regions, especially around Valles Marineris.

Regarding matrix terrains (fig.1-right), cluster of analogues for Powys ones were almost absent from the surface of Mars. Conamara ones, however are present in a zone around (0°N, 150°E), which corresponds to an Hesperian transition undivided unit [6], and one at high southern latitudes (80°S, 100°E).

4. Discussion and Conclusions

The Martian analogues of ridged terrains and chaotic matrix terrains seem to form meaningful clusters around defined geological units. This analysis is partial since the resolution of the MOLA DEM does not allow for faithful comparisons of roughness at sub-km scales. Thus, to precisely identify analogues, this study will be coupled to analyses of other Martian DEM datasets.

By analysing radargrams over these Martian analogues, we hope to better predict the performances of RIME and REASON over relevant Europan terrains.

Acknowledgements

This work was supported by the Italian Space Agency through "Attività scientifiche per JUICE fase C/D" under Contract ASI/INAF n. 2018-25-HH.0 and by the REASON investigation within the Europa Clipper project.

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