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Addressing ices in the solar system via their fractal dimension measurement

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Fractal geometry is able to describe natural processes in an accurate and effective way. In particular, the Fractal Dimension (FD) is a convenient parameter for the description and classification of the roughness of bare natural surfaces.

In the present work, we focus on the specific case of the ice material in the deep space arena. The characteristics of ice significantly change, depending on the involved formation mechanisms, ice composition, and position of the celestial body with respect to the snow line. Seasonality, weathering, tectonics, and cryovolcanism are some of the main phenomena dictating essence and shape of icy layers. The ice surface FD is certainly depending on the phenomena that contributed to its generation and modifications: therefore, FD is a convenient parameter to classify, and discriminate different kinds of ices.

Basic techniques, able to estimate the FD from SAR data via spectral analysis, are available. However, specific problems arise for FD estimation in the deep space arena. They are mainly related to the limited resolution, noise level, and adopted instrumentation. We show that by using some peculiar characteristics of deep space SAR sensors (i.e. the burst acquisition mode), and by implementing appropriate processing procedures, optimized estimation techniques can be designed.

The experimental implementation of above mentioned techniques is presented: these are first applied to an inner area of the Earth Antarctica ice sheets, by using Sentinel-1 SAR images (ESA data), and conventional processing techniques. As a second step, the original Sentinel-1 SAR data are used to simulate SAR scattering from ices in the Solar System: space resolution is degraded, noise is added, and the burst acquisition mode processing implemented. It is shown, for both cases, how it is possible to highlight the different geodynamical mechanisms and morphological developments leading to the final shape and features of the explored area.

The used data-set is acquired in C-band, so that the issue of signal penetration inside the ice surface is relevant, and the physical parameters dictating the penetration depth of the signal inside the ice layer are illustrated. In the case of a significant penetration depth, the possible presence of balls, impurities, lack of ice homogeneity, and limited thickness of the ice profile (i.e. the boundary reflection) are the dominant component of the scattered field, rather than the ice surface roughness. Therefore, comparison of results by using higher and lower frequencies exploring signals (lower and higher penetration within the ice's layer, respectively) may provide additional information of the ice under examination.

Moreover, it is illustrated how the joint use of data obtained from different sensors can support geophysical and morphological interpretation: the example of SAR data used in conjunction with altimeter data is presented.