Geophysical Research Abstracts, Vol. 9, 10516, 2007
SRef-ID: 1607-7962/gra/EGU2007-A-10516

Fractal Metrology for images, signals and time series processing in Geosciences

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The comparative study of Geosystems fractal behavior requires harmonizing statistics and integral information management. A core set of fractal parameters extracted from multiscale images and time series, as well as by signal processing, is uncertain, scale and measurement algorithm dependent, dynamic and variable in space. The aim of our research is to standardize the polifacetic information coming from fractal approach to Geosciences and to harmonize statistically the different measurement proposals and standards. For this purpose we design the Fractal Metrology (Oleschko, 2006). The box of numerous reference techniques, useful for unbiased fractal parameters extraction from different sources, is calibrated. The Geosystem scale invariance is documented by simple measurement of histogram roughness and estimated in terms of Hurst exponent. The lacunarity is used as the precise measure of data translation invariance. A set of contrasting examples of fractal metrology application to satellite imaginary, georadargrams analysis, as well as to optical and scanning electron microscopy is providing. In order to unify these multiscale and heterogeneous data banks we introduce a new branch of Fractal Geometry: *Fractal Image Informatics* (Oleschko *et al*., 2004).

Fractal Image Informatics is devoted to systematic and standardized description of natural scenes, generalizing Pentland´s results about the fractal behavior of the optical images of rough natural surfaces (Pentland, 1984). We design a multistep fractal

assessment scheme in order to extract precise quantitative measures of different surfaces attributes, beginning with surface roughness. Our main hypothesis is that the multiscale images of self-affine fractal surfaces are also fractals. We have assumed, and showed by combination of laboratory experiments and computer simulation that the train of waves reflected from these surfaces or transmitted through the system, have the same (in statistical sense) fractal dimension correlated to the system permittivity networks, as well as to it's basic physical and mechanical properties (Oleschko *et al*., 2002; Oleschko *et al*., 2003).

Korvin (2005) have proved mathematically our original idea that the density distribution of grays across the optical image inherits the fractal dimension of the mapped surface. For this purpose, he has assumed that the reflectance coefficient is proportional to the focusing/defocusing factor of the local Gaussian curvature $G(x, y)$. Our numerous real-geosystems examples, as well as some simulated results, confirmed the scale invariance of set of rough surfaces, measuring their translation invariance and establishing the general power laws that relating the system attributes. These laws were integrated inside the Fractal Metrology devoted to the development and calibration of new, precise and exact quantifying procedures for Geosystem analysis.

At present, the Fractal metrology is constituted by more then twenty basic fractal descriptor, it one devoted to measure and to visualize the specific surface attributes. All procedures are fast, drastically reduce thresholding bias, promising to be universal. Two tools, coming from Fractal Image Informatics are especially useful for fractal description of rough images, signals and number distributions (time series). First one is called *firmagram analysis*, and is designed for the global roughness measurements. The second one, called *reference lines analysis*, is used for the local variability description. The roughness of firmagrams and reference lines is measured in terms of Hurst exponent.

In the beginning, the fractal metrology was applied to mineral weathering quantifying (Oleschko *et al*., 2004). It is accepted, that the weathering occurs over a wide range of scales. To link features through these scales is a major challenge for interdisciplinary weathering studies. Fractal approach seems to be especially useful for this purpose, quantifying the static and kinetic features of weathering. We introduce a multistep fractal weathering assessment scheme, showing its ability to extract fractal weathering descriptors from direct texture analysis of the mineral´s images. Our scheme enables to quantify the global and local information about the geometry of the weathering pattern. Mineral weathering signature may be used to develop geometric indices of weathering, and it is valid for genetically different minerals and rocks types, scale independent and apt to monitor the changes in the mineral´s roughness during the alteration.At the final point of this analysis, the *Local Fractal Analysis* is accomplished in order to reconstruct all roughness details and ensure the edge detection on the images. This procedure is similar to Digital Elevation Model, treating the gray tone as the false altitude.

The similar approach was applied to the detailed analysis of fracture arrays in real fault systems (Nieto-Samaniego *et al*., 2005) and porous media (Miranda-Martínez *et al*., 2006), proving its capacity to establish the power law relationships among the system attributes (the fracture concentration and density, principal measure of pores and solids *etc*.). Our results offer new perspectives for the measuring, modeling, classifying and forecasting of fracture and fault arrays in natural systems.

At the next step of fractal Metrology consolidation, we study the fractal scattering of microwaves from soils (Oleschko *et al*., 2002). The mathematical model relating the ground-penetrating radar record to the mass fractal dimension of soil structural pattern is developed and applied to the real-world systems (Oleschko *et al*., 2003). The fractal signature of the scattered microwaves strongly correlates with some physical and mechanical properties of studied porous medium. Our experimental data, mathematical model, and computer simulations have all proved that the range of fractal wave scattering from soils and sediments extends to the broad range of wavelength (from 10^{-2} to 10^{0} m). We propose to extract the fractal descriptors of solid and pore directly from the georadargram, which enriched the GPR future applications as a prominent tool for nondestructive *in situ* soil and sediments studies.

There are a lot of other applications which will be discussed in the present work.

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Acknowledgments

This research was supported by CONACyT (Grant 42571), México.