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Preface

“Modeling soil system: complexity under your feet”

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A clear statement in these lines textually cited (Byers et al., 1938) defines the framework of this special issue: “*True soil is the product of the action of climate and living organism upon the parent material, as conditioned by the local relief. The length of time during which these forces are operative is of great importance in determining the character of the ultimate product. Drainage conditions are also important and are controlled by local relief, by the nature of the parent material or underlying rock strata, or by the amount of precipitation in relation to rate of percolation and runoff water. There are, therefore, five principal factors of soil formation: Parent material, climate, biological activity, relief and time. These soil forming factors are interdependent, each modifying the effectiveness of the others*.” Due to these various processes associated to its formation and genesis soil dynamics reveals high complexity that creates several levels of structure using this term in a broad sense.

The term of complexity is very ambiguous, and in a general usage tends to be used to characterize something with many parts in intricate arrangement (Johnson, 2007). Frequently, complexity is tied to the concept of a “system”, a set of elements (or parts) which have relationships among them differentiated from relationships with other elements outside the relational regime (Wilson, 1980). Therefore, we could look at soil as a complex system: “*a system composed of interconnected parts that as a whole exhibit one or more properties (behavior among the possible properties) not obvious from the properties of the individual parts*” (Joslyn and Rocha, 2000).

Soil complexity can thus be observed at different physical levels (i.e. frequency distribution of aggregates sizes, order of strata, etc.), biological levels (i.e. oxidable organic matter availability, population distribution, etc.), interaction levels (i.e. mineral paths between compartments, etc.), or evolutionary levels (short-term variations on water availability, long term erosion, etc.). Even more, there are feedbacks that operate through pathways involving soil physical properties, chemical and biogeochemical properties and processes, and biological properties, including the community composition of the microbiota and soil fauna. These processes take place at spatial scales ranging from the complexity of organic matter at the nanosclae (Lehmann et al., 2008) to difference in soil types at landscape scales. This strongly suggests that several properties of feedback systems, such as their complexity, specificity, and strength relative to other ecological factors, as well as the temporal and spatial scales over which they operate should be considered studying soil systems. A key challenge in soils research is to bridge the spatial scales at which processes happen with the larger scales at which soil functioning is observed and managed. This requires advances in technologies to characterize at a range of spatial scales combined with a new mathematical framework to capture the complexity of soils as a system (Young et al., 2008).

Our vision is that heterogeneity and complexity at small scales determines functionality and sustainability at larger scales, and we combine mathematical approaches and experimental systems to determine important environmental and ecological problems. This special issue includes selected papers presented at EGU (European Geoscience Union) session titled “Soil Complexity and Nonlinearity”, held in Vienna, Austria, in April 2009. The purpose of this special issue is to stimulate further research into cross disciplinary modeling and quantification of the soil system. New developments in

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mathematics, statistics and physics are increasingly finding applications in soil science, and we therefore believed that it was appropriate to bring together several researchers who deal with the complexity of soils at a range of spatial scales.

After a rigorous reviewing process 14 papers were accepted into this special issue. The papers address how application of technologies at a range of spatial scales combined with novel statistical and modeling approaches can be used to advance our knowledge on soil functioning. This spread of papers from diverse disciplines also shows how complexity analysis is becoming a mainstream tool in every area of the soil science, both as a way to analyze data and as a framework to understand and model soil processes, especially these last also seen in the context of interactions with the field of biosciences. We will describe briefly these papers sorting them by the scale at which they have been focus beginning at geological maps and finishing at a microscopic level.

Cheng et al. (2010) use a fractal filtering technique on the basis of a spectral energy density vs. area power-law model (*generalized self-similarity S-A model*) to decompose mixed geochemical landscapes caused by various scales of geological processes and features. The anomalies not only coincide with the locations of known mineral deposits, new anomalies were delineated in other locations as potential target areas for new mineral deposits of the same type.

To monitoring moisture conditions of lichens and mosses, being used for carbon balance modelling, in an efficient way the remote sensing technology can provide valuable information. Neta et al. (2010) studied the spectral reflectance obtained at different moisture conditions and spatial resolutions of these species in order to upscale the information derived by spectral indices. They used the *singularity index*, derived from multifractal models, that quantifies the scaling invariance of the spectral reflectance.

Grau et al. (2010) combined well known methods of *Multicriteria Decision Analysis* (MCDA) applied to ameliorate soil erosion and degradation in Salta Province (Argentina). ELECTRE, PROMETHEE and AHP were use to select among different alternatives to prepare an integral plan to ameliorate or/and solve this problem taking in account eight criteria and five alternatives. The results show a high level of consistency among the three different multicriteria methods.

There are two papers focus on the chemical-physical process involving heavy metals and non volatile metabolites that have a profound impact in soil health and nutrient cycle. Fallico et al. (2010) observed the efficiency remediation of saturated and unsaturated soils to remove heavy metals by permeable reactive barrier (PRB) made of broom fibres. Based on laboratory experiments with broom fibres, at different compactness, a hydraulic characterization in space (permeability and porosity) and time (*kinetic degradation*) were obtained explaining the results observed in PRB.

Isidorov et al. (2010) studied the interaction between forest and soil through Scots pine and Norway spruce needle litter. Through several chemical analysis they draw a complex frame of the *factors controlling changes* of leaf litter's chemical composition during its decomposition dividing it in abiotic and biotic not being clear the type of relation between both groups.

Haskard et al. (2010) and Milne et al. (2010) use statistical tools to answer questions on different problems such as spatial prediction of soil potassium content and residual effects on wheat biomass of fertigation treatments applied to a previous crop respectively. In these works they have to use recent techniques: linear mixed model, *non-stationary models* and the *maximum overlap discrete wavelet packet transform* (MODWPT). These techniques are designed to separate the real data information, explaining its variations, from noise that does not present any correlation.

Torres-Arguelles et al. (2010) and García-Moreno et al. (2010) use soil images at field scale to extract information on structural patterns and soil surface roughness. The former studied soil's physical and chemical degradation through these images combining techniques coming from Fractal Geometry, Metrology, Informatics, Probability Theory and Statistics coined it as *Fractal Metrology* (FM). They show the usefulness of FM applying it to three porous media with contrasting structure but similar clay mineralogy dominated by montmorillonites. García-Moreno et al. (2010) present a simple field method to estimate soil surface roughness (SSR) that is more reliable, low-cost and convenient than traditional ones. It is based on shadows cast by soil structures capture by a picture under fixed sunlight conditions. They establish a relationship between *shadow index* and the SSR estimated by well known techniques such as the chain set and pin meter methods

Focus on the SSR context; Vidal Vazquez et al. (2010) assess soil surface micro-topography in field conditions using *multifractal parameters*. They successfully study the decay of initial surface roughness induced by natural rainfall under different soil tillage systems measured with a pin meter. These parameters combined with classical indexes, such as random roughness (RR), improve the prediction of water storage in the soil surface.

Gil et al. (2010) estimated the relationship between emitter discharge and the directly measured radius of the spherical cavity around the emitter outlet at different conditions. An application of this relation to predict *water distribution uniformity* in subsurface drip irrigation (SDI) units and its effect on the estimation of irrigation performance in soil is illustrated.

In a theoretical frame, Perrier et al. (2010) used *renormalisation functions* to study a 3-D multi-scale connectivity and estimate critical filtration size (CFS) from soil structural models. This study opens a new methodology to estimate soil filtration efficiency.

Cortina-Januchs et al. (2011) approach a difficult issue as to differentiate soil void/pore from CT scan soil images that is a crucial step in many soil process studies. They present a methodology in three steps: image processing (image erosion), *clustering techniques* (K-means, Fuzzy C-means and Self Organising Maps) and *artificial neural networks* (ANN). Unlike image segmentation based on histograms, this method allows a deeper analysis of the areas where the pore and soil are mixed.

Pajor et al. (2010) use X-ray computed tomography soil images to quantify and characterize the pore geometry at microscopic scales (30 µm) that are relevant for fungal spread in soil. With this porpoise, they used a *Generalized Estimation Equations* (GEEs) model with normal errors and *first order autoregressive correlation structure* to test the effect of bulk-density and distance from the site of inoculation on fungal biomass densities. Then a *fungal growth model*, parsimonious in construction, was used to analyse the effect of these geometric descriptors on fungal invasion. Their results clearly show that the degree and rate of fungal invasion is affected mainly by pore volume and pore connectivity.

Bio-geoscience studies can benefit significantly from the use of complexity concepts, as the interactions between different processes, particularly its physical, biological and chemical components are of great importance. Indeed, the importance of these interactions is a direct consequence of the inherent non-linearities in these systems that make it impossible to make progress by studying the components in isolation.

It is hoped that this volume will act as a vehicle to promote the diffusion of complexity approaches in biogeosciences and opens up the dialogue with all scientists that use classical procedures. Since its beginning, complexity theory has found in the natural sciences a source of inspiration and an ideal application field for theories and models. This can be considered as a mature starting point for an improvement of soil sciences and biogeosciences analysis, involving more and more scientists of the research community.

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