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Nonlinear Processes in Geophysics

Preface

"Nonlinear and Scaling Processes in Hydrology and Soil Science"

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Following the definition given by Nicol (1955): "*Hydrology is the study of the properties, distribution and effects of water on the Earth's soil, rocks and atmosphere. It also encompasses the study of the hydrologic cycle of precipitation, runoff, infiltration, storage, and evaporation, including the physical, biological and chemical reaction of water with the earth and its relation to life*". Hydrologists use science and math to solve water-related problems, including problems of quantity, quality and availability. For example, they may work to find subsurface reservoirs to be used for public drinking water supplies or irrigation water for farms; they may be involved in flood control or soil erosion and sedimentation issues; or they may be involved in environmental protection efforts, such as cleaning up hazardous waste spills or locating the safest areas for disposal of waste (Lin et al., 2006b).

On the other hand, soil science is a true interdisciplinary science that integrates the use of biology, chemistry, physics, geology, geography, climatology, hydrology, and mathematics to describe, interpret, and manage the soil and water environment (Kutilek and Nielsen, 2007). Soil represents part of the vadose zone which is hydrologically connected to both surface water and groundwater. Soil science is at a critical time for refocusing attention to studies of soil hydrology in various ecosystems (Lin et al., 2006a).

One of the challenges to progress in hydrologic and soil science research is the simple fact that the best developed theories, generally applied to certain time-space scale, cannot be easily extrapolated to quantify processes at other scales for which predictions are generally required. One problem that might occur is that not all processes take place at all scales, and so it is not possible to capture the dynamics of a certain process just by monitoring a particular isolated scale. Also, the timing and magnitude of different processes observed in hydrology and soil science varies between scales and events. Besides all these problems, both scaling and nonlinearity continue to be significant issues in these two areas. In spite of the progress that has been achieved in recent decades, there remains considerable interest in the subject.

In the broad area of soil science, geology and solid earth geophysics, observed features and underlying phenomena repeat from one scale to another. Such non-linear dynamics yield hierarchical distributions, space-time fractal sets or fields, self-organized critical events (Lovejoy and Schertzer, 2007; Gaonac'h et al., 2007). The mathematics and physics involved appear to provide a robust yet simple way to describe these phenomena over wide ranges of scale and represent a natural approach to characterizing such systems (Logsdon et al., 2008). Modelling and statistical approaches (including wavelets, fractals or multifractals, self-organized criticality, scaling models) are then able to extrapolate the observed properties to larger or smaller scales, resolutions. Specific application areas include volcanoes, remote sensing, topography, pedology, landscape morphology, distribution of minerals, geogravity, geomagnetism, the Earth's interior.

Also, the issue of scales and nonlinear physical, chemical and biological processes is of fundamental importance in hydrologic and soil science. The questions of how these processes are organized in space and time across a range of scales, how different processes interact at different scales, and how observations at one scale are related to those at another have profound implications for our ability to predict hydrologic cycle components (Krajewski et al., 2006). 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

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scales ranging from the complexity of organic matter at the nanosclae (Lehmann et al., 2008) to difference in soil types at landscape scales.

Answering these questions, in view of the undergoing environmental changes at all scales, requires concerted theoretical, modelling, and experimental efforts. This work is undertaken by research groups around the world, which try to cover aspects of scales and scaling in both groundwater and surface hydrology, including hydrometeorology and ecohydrology. Scaling research topics on hydrologic processes include scales ranging from laboratory through hill-slope, small (e.g. urban) basins, regions and continents to the entire Earth.

The European Geosciences Union (EGU) General Assembly took place in Vienna, Austria, between 15 and 20 April 2007. These five days provided an opportunity for a stimulating exchange of ideas in two sessions of the Nonlinear Processes in Geophysics (NP) Division:

– NP3.07 – Scale, scaling, and nonlinearity in solid earth. Conveners: Cheng, Q., Gaonac'h, H., Tarquis, A.

– NP3.08 – Scales and scaling in surface and subsurface hydrology.
Conveners: de Lima, J., Krajewski, W., Hunt, A.

This special issue on *Nonlinear and scaling processes in Hydrology and Soil Science* stems from these two EGU General Assembly sessions. The purpose of this special NPG Journal issue is to present research results on all aspects of scale and scaling topics on hydrological and soil processes and properties. Contributions of both scientific and engineering aspects of scaling research and applications are included.

The first three papers of this special issue focus on precipitation. Nikolopoulos et al. (2008) made a comparative *scaling analysis of rainfall* data from four different instruments: Doppler radars, S-band and X-band, an optical disdrometers and a tipping-bucket rain gauge. They found differences in variability and scaling characteristics in their measurements sending a caution message when attempting to translate results obtained in the time domain to the spatial domain. This highlights those fundamental issues in translating the temporal into spatial domain still remains.

De Lima and de Lima (2009) examine the *precipitation variability* in Madeira Islands with a complex topography, which is a subject not yet fully addressed. They study the invariance of properties observed across scales showing a scale-invariant and multifractal behaviour in the temporal structure of precipitation. This scaling is relevant from ten minutes up to two weeks. They highlight that the dependency of these findings on climatological, geographical, sample size among other factors, cannot be ignored.

Uijlenhoet et al. (2009) analysed the fractal correlation dimension of homogeneously *distributed raindrops*. Their analytical results show that the empirical results presented on fractal scaling behaviour of raindrops in space (Lovejoy and Schertzer, 1990) can be explained by edge effects in the instrument used. They concluded that the Poisson homogeneity hypothesis of the discrete nature of rain fall cannot be rejected.

Runoff is the subject of two next papers. Cheng et al. (2009) made a comparison of peak flow events characterization with three different methods: return period, concentration-area (C-A) plot and local singularity index. They conclude that in the Oak Ridge Moraine area (Canada) flow events with 10 yr or above return period show a self-similarity characteristic of flow events with small return period and strong local singularity index for the major flooding events. At the same time, they point out that meanwhile Pearson III distribution (used in the return period) fits the values in general, a C-A plot provides an effective mean for differentiating extreme large flows events from the regular ones.

De Lima et al. (2008) addressed the issue of the *time evolution of the sediment granulometry* transported by overland flow. They present results of laboratory experiments designed to study the influence of moving rainfall storms on the dynamics of sediment transport. They conclude that storm movements have a high influence on the grain-size distribution and that downstream-moving rainfall storms have a stronger stream power than other storm types.

Soil microrelief and structure are dealt with in the three papers from Paz-Ferreiro et al. (2009), Vidal-Vázquez et al. (2009), and Tarquis et al. (2008). Focusing on soil microrelief, the authors try to describe and quantify with several indexes the evolution of surface with cumulative rainfall under different tillage systems and crop cover conditions. Paz-Ferreiro et al. (2009) estimates the classical parameters in soil erosion, such as: Random Roughness (RR), Limiting Difference (LD), and Limiting Slope (LS). At the same time they introduce two scaling indexes: fractal dimension (D) and crossover length (l) estimated from the data set. They show how D and l variation can differentiate better the evolution of soil surface microrelief under certain treatments.

Vidal-Vázquez et al. (2009) employed the multifractal (MF) approach to characterize topographical point elevation data sets and the RR index. This data was acquired by high resolution laser scanning. They conclude that the MF parameters best discriminate the evolution of the soil microrelief after a rainfall event and give complementary information to the evolution of RR.

Respect to *soil structure*, Tarquis et al. (2008) studied it based on 3-D images captured with a computed tomography technique. They calculate mass fractal dimension (D_{m}) and entropy dimension (D_1) on these images corresponding to different soil horizons. They show, in their work, how the threshold criteria influence the porosity, D_{m} and D_1 values. However, the increase of D_{m} and D_1respect to porosity defines a characteristic feature for each horizon that indirectly differentiates each horizon structure.

Rodrigues et al. (2008) describe several small-scale experiments to simulate *transport through fractured formations* similar to those found in natural environments. They try to evaluate several procedures for the calculation of the volume available for the circulation of fluids in fractured media as well as several tracer tests. They conclude that reverse tracer tests don't give symmetric results pointing out some differences in the fracture morphology. Their results also point out that the volume available can be estimated using transport models that not take into account diffusion process.

Remote sensing is the subject of the paper by Hahn and Gloaguen (2008). They show how to estimate soil types based on field observations and remote sensing data. They select input variables for Support Vector Machines (SVM) considering that the relation between the soil types and the attributes obtained from the remote sensing data were expected to be non-linear. One of the key points for the right estimation is the input variable selection that is discussed by the authors.

Soil moisture is addressed in Gebremichael et al. (2009) and Oleschko et al. (2008). The former establish a comparison of the scaling characteristics of spatial soil moister fields between microwave radiometer observations and simulations using the GEOtop model. Both present a scale-invariance property in the generalized variograms of these fields. On the contrary, they present contradictory results on spatial organization and average soil water content. They point out that model simulations can be used to reproduce correctly the total streamflow at the outlet of the watershed. However, further considerations have to be taken to accurately reproduce the runoff evolution.

Oleshko et al. (2008) characterized the spatial distribution of volumetric and gravimetric soil water content. They estimated the fractal dimension of recorded backscattered Ground Penetrating Radar (GPR) traces and their roughness through the Hurst exponent. Mapping the spatial variation of GPR fractal dimension with a krigging analysis of the soil properties studied showed statistical differences among different soil managements.

Finally, Biswas et al. (2008) deal with *soil Nitrogen spatial variability* related to topography. Soil Nitrogen and elevation were measures along two transects of 3m length each. They applied a wavelet spectra, cross wavelet and wavelet coherency to study scale specific components of variation and correlation for each measure and transect. In this way, we can observe which scales contribute most to measure variation, or to see at which scales measures are most correlated.

The progress of science depends increasingly on an advanced understanding of the interrelationships among different fields and their knowledge and techniques (Koenig, 2001). We hope that this volume will act as a vehicle to promote the diffusion of scaling/multiscaling approaches in hydrology and soil science opening up the dialogue with all scientists that use classical procedures. Since its beginning, scaling theory has found in the natural sciences a source of inspiration and an ideal application field for theories and models (Mandelbrot, 1983). This can be considered at a mature stage point for an improvement of soil and hydrologic science analysis, involving more and more scientists of the research community.

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