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Some evidences on critical behaviour of soil moisture dynamics

A. Di Domenico (1), G. Laguardia (2), M. Fiorentino(1)

(1) Department of Environmental Engineering and Physics, University of Basilicata, Potenza, Italy (didomenico@unibas.it / Fax: +39 0971 205139)

(2) Institute for Environmental and Sustainability, Research Center, EC, Via E. Fermi 1, T.P.261, 21020 Ispra (VA), Italy (giovanni.laguardia@jrc.it)

A river basin can be considered as an open and dissipative physical system whose input energy is represented by the precipitation with its space and time variability. In analogy to other physical systems, every change of energy corresponds to a change of entropy and the principle of minimum entropy production, leading to organization, has to be respected. Those concepts, widely investigated in relation to the river network organization, have a crucial role also on the soil moisture space-time dynamics.

The study of the soil moisture dynamics is essential in many hydrological processes since how much water infiltrates, evapo-transpirates and leaks depends on the soil moisture status both when precipitation occurs and inter storm periods.

Soil moisture can exhibit two distinct preferred states which control the mechanism of lateral redistribution of water content, namely local and non-local control (Grayson et al., 1997). They are responsible at the macroscopic scale of the appearance of the soil moisture spatial patterns which can be in their seasonal time dynamics spatially random or spatially connected. The switching mechanism between local and non-local control can be described in terms of the dominance of lateral over vertical water fluxes respectively due to the continuous rise of soil moisture which leads at certain point to sharp increase of hydraulic conductivity or vice-versa. Rodriguez-Iturbe et al. (1999) have derived the analytical expression for the steady state probability density function of soil moisture, whose behaviour suggests that, for a given climate, soil and vegetation, the system tends to switch between two preferential states, one characterized by low average soil water content and the other by high average soil water content. This feature has important implications for the dynamics of the ecosystems.

Another feature of the soil moisture spatial patterns is the *connectivity*, which represents their degree of organization and the existence of interconnected pathways. An increasing interest in hydrology for this property is related to its role on the runoff response. Bronstert and Bárdossy (1999) have shown the strong effect on simulated runoff incorporating connectivity into antecedent soil moisture patterns. Also the water movement in groundwater systems is critically affected by the presence of connected bands.

There are many evidences that allow to look at the soil moisture processes as a system subject to phase change between spatially random to spatially connected appearances. A physical system is subject to a phase transition process when it shows a discontinuous change of a macroscopic feature of the system under a continuous change of a system's state variable. A critical point phenomenon is a particular process in which the phase transition evidences a scale-invariant behaviour. The aim of this work is to investigate the critical behaviour of soil moisture at the basin scale in its space-time dynamics by means of the percolation theory and renormalization group method.

Those theories have been widely exploited in many sciences, such as geology, groundwater hydrology, and seismology. The principal advantage of the percolation theory is that it provides universal laws which determine the geometrical and physical properties of a system.

The main goal of the percolation theory is to investigate the relationship between the occupation probability p, which defines the probability of each site to be occupied, and the percolation probability $P_N(p)$, the probability of each site to belong to the largest cluster. In order to solve approximately the percolation problem, the renormalization group method, whose main concept is the coarse graining procedure, can be adopted. Due to the differences between the percolation theoretical model and the river basin system, it has been necessary to develop an ad hoc methodology.

The implemented methodology has been explored by applying to 365 daily soil moisture maps obtained by hydrological simulation on a natural catchment in Southern Italy. The soil moisture spatial patterns have shown critical point behaviour recognizable in a quick change from an unorganized to an organized structure, which is identified in a sharp change of the relationship $P_N(p)$. The existence of the critical point has been confirmed by means of the application of the coarse graining procedure, which provided an intersection between the$p_1(p_0)$ curve and the bisecting line at the same value.

The power trends of the occupation probability and the normalized size of the largest cluster, describing the soil moisture patterns as a function of certain reduced units near the critical point, yielding critical exponents, have been also investigated. The exponents give way to the possibility of classifying the process in a certain *universality* class, which is the central property of the percolation theory. Also this result gives evidence of critical behaviour, which should be corroborated by the value of critical exponent β for the percolation probability.

In order to evaluate the behaviour of the model to the choice of its parameters, a sensitivity analysis has been also carried out. The results demonstrate that the critical point is a structural feature, al least for this river basin.

This work seeks to contribute to the understanding of the organization of the soil moisture fields by discussing new concepts from a novel approach.

It has been only concerned by the willingness of discovering a critical point for the system analysed. This result could be relevant in the development of other application, such as of the study on the optimal soil moisture monitoring scale.