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Stochastic analysis of the effects of soil heterogeneity on soil moisture variability

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The soil moisture θ is a key variable in the modeling of water and energy fluxes in soils; its value is a space random variable controlled by many factors, like e.g. the hydraulic properties of the soil, topography, interaction with surface water systems, precipitation and vegetation among others, in a non-linear fashion. Understanding and characterizing this spatial variability is one of the major challenges within hydrological sciences. We characterize the soil moisture spatial heterogeneity by a 3D stochastic semi-analytical model. The model focuses on the effects of the heterogeneity of hydraulic properties and assumes spatially variable soil properties described by their geostatistical variables. The First Order Approximation model for unsaturated media is adopted for the derivation of the soil moisture statistics. The model explicitly accounts for the typical scales involved in the determination of the spatial properties of saturation: the extent L, i.e. the domain size, the spacing Δ among measurements, and the dimension ℓ associated to the sampling device. For the analysis of the θ variability the relationship between the saturation standard deviation SD_S and its mean value $\langle S \rangle$ is considered; this curve shows an upward convex shape, the peak in the intermediate soil moisture range; this behavior is well documented among field investigations, theoretical studies and numerical simulations. It is found that the correlation scale I of hydraulic properties rules the spatial variability of saturation together with the scales L, Δ, ℓ. The shape of SD_S for very large L/I (ergodic conditions) confirms previous results. A scale effect manifests for small to intermediate L/I, for which SD_S increases with the extent L. This effect depends on the structural and hydraulic parameters such as the increasing sampling of different formations and it is consistent with a similar effect found in experiments. The influence of the support ℓ is to decrease the saturation variability and increase its spatial correlation. Finally the procedure indicates that a relatively small number of measurements N is required for a quite accurate estimate of the ensemble average of SD_S, of the order of $N \gtrapprox 16$ or even less for small domains; the required N may increase with the spatial variability of logconductivity σ_f^2.