Virtual Experiments to Explore Non-Linear Soil Moisture-Hydrology Interactions at the Hillslope Scale

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The highly non-linear links between soil hydrology and runoff generation at the hillslope scale are poorly understood. As such, a framework for the general characterization of hillslopes is still lacking. While field studies have contributed to our understanding, such work is still of limited value because of the small number of places and events that have been characterized to date. This presentation explores how models can be used to identify characteristic forms of non-linearity on the hillslope scale (e.g. threshold behavior, hysteresis) and their controls on lateral flow generation. We present a number of virtual experiments with a 3D physically-based finite element model using the Richards equation to systematically investigate topographic and vadose zone controls on subsurface stormflow generation and the implications for the hillslope storage-discharge relationship. Topographic and stormflow data from an existing hillslope research site with an installed subsurface flow collection system were used to build and calibrate the model. The aim of the model calibration was to create a virtual model environment that reflects the general flow behavior of this hillslope, not to reproduce observations exactly. Experimental studies at this hillslope have demonstrated a highly non-linear subsurface flow response dependent on storm total precipitation (fill and spill behavior). The model domain was 28 m by 48 m with an average slope of 13 degrees, consisting of an irregular geometry based on GIS data for two layers that represent the topography of the soil surface and the bedrock surface, respectively. The parameterization of the soil and bedrock properties was based on field measurements of soil moisture and saturated hydraulic conductivity. After successful calibration, topography and vadose zone characteristics (i.e. slope angle, soil depth, surface and subsurface topography, antecedent moisture conditions) were systematically varied. Results are presented as a matrix for assessing the non-linear interplay between rainfall and soil moisture at the hillslope scale and for identifying the relative importance of the varied characteristics for the spatial and temporal evolution of subsurface moisture patterns.