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Dynamical process upscaling for deriving catchment scale state variables and constitutive relations for meso-scale process models

E. Zehe (1), H. Lee (2), M. Sivapalan (3)

(1) Institute of Geoecology, University of Potsdam, (2) Centre of Water Research, University of Western Australia, (3) Departments of Geography and of Civil & Environmental Engineering University of Illinois

In this study we propose an uspcaling approach for the assessment of (a) sub-catchment/REW scale state variables, and (b) of catchment/REW scale soil hydraulic functions which embed/reflect the effects of critical subscale soil heterogeneities in the unsaturated zone on parameterizations of water flow at the next higher scale. The test area for this investigation is the well observed and studied Weiherbach catchment, which is located in a Loess area in south-west Germany. The approach adopted is to use the spatially averaged outputs and internal state variables generated by a highly detailed physically based numerical model that represents the dominant heterogeneities which are typical for this Loess area, and which has been previously shown to closely portray the dynamics of various state variables and fluxes within the study catchment. For these reasons, this detailed numerical model is deemed to be landscape and process compatible. By running this landscape and process compatible model with boundary and initial conditions observed in the Weiherbach catchment, and different assumed structures for soil heterogeneities, we generated time series of catchment-scale average soil saturations in the unsaturated zone by averaging the corresponding distributed model outputs. Due to the differences in assumed spatial patterns of soil heterogeneities and of macropores, the resulting different model structures yield clearly different time series of catchment scale average soil saturation values. The time series of catchment-scale average soil saturation values generated in this way from the landscape and process compatible model structure are, therefore, deemed as best estimates of the actual time series of average catchment scale soil saturation within the study catchment since the model embeds the fingerprints of typ-

ical patterns of soils and macropores and is shown to be physically consistent with a distributed set of soil moisture and discharge observations inside the catchment. Finally, we also derive hillslope scale soil hydraulic functions from simulated hillslope scale drainage experiments for the different assumed hillslope model structures. Different patterns of soil and macroporosity within the hillslope yield clearly different hillslope scale soil hydraulic functions, and these differences are consistent with the REV soil pore spectra of the soils. Assuming simple parametric functions for the soil water retention curve and the hydraulic conductivity curve we then obtain different parameters characterizing these soil hydraulic functions for the different assumed model structures. The different parameters obtained for these different model structures thus embed within them fingerprints of the assumed subscale soil patterns and structures on water flow in the unsaturated zone at the next higher scale, in the sense of Vogel and Roth (2003). The ultimate motivation for this analysis is that the so derived, hillslope or sub-catchment scale soil hydraulic functions will become intrinsic components of physically based numerical models, which use subcatchments as building blocks. Lee et al. (2006; this issue) have utilized hillslope scale soil hydraulic functions, derived similarly with the use of the same landscape and process compatible model, for the parameterisation of the CREW model, which is a numerical implementation of the REW approach (Reggiani et al., 1998; Reggiani et al., 1999), and showed that these lead to successful implementation of the model in the Weiherbach catchment. Their findings show clearly that the presented upscaling approach does indeed yield useful constitutive relations and target state variables for development and validation of meso-scale hydrological models based on the REW approach, embedding within them the fingerprints of the dominant within-catchment heterogeneities on simulated subsurface flow dynamics at the REW-scale.