Architecture of soil structural diversity: from the micro to the landscape scale

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Irrespective the spatial scale, soils or terrestrial systems in general exhibit some sort of structure or heterogeneity. On one hand, this is a well known feature, on the other hand it is often neglected - or at least not considered adequately - in our daily scientific efforts for an improved understanding of processes from the pore space within soil to the heterogeneous pattern of soil properties within landscapes.
Another antagonism is that nearly all processes in soil depend on zones of gradients in terms of some state variables and hence they depend on heterogeneity and structural diversity, whereas the analyses of these processes are notoriously complicated by this heterogeneity. In any case, structural diversity and the related interfaces and gradient zones is an essential part of the very nature of soil and the processes therein

We address two critical questions which we feel are at the core for an improved system oriented understanding**:**
i) How is structural diversity generated and preserved? Here the answers are lying in the field of pedology but also in the field of soil mechanics and soil biology addressing important agents for structure formation in soil. ii) How to cope with structural diversity when modeling actual processes of flow, transport and biogeochemical interactions in soil? This addresses soil hydrology but also soil biology and biogeochemistry. The concept of hydropedology is intended to provide new insight related to these questions by the coupling of disciplines of hydrology and pedology.

In this contribution we discuss different avenues how structural diversity can be directly included in modeling soil processes. The impact of structural diversity is often lumped into ad-hoc model parameters which cannot be measured independently but need to be fitted to some experimental observations. In contrast, a direct link between structure and function will improve our understanding of soil processes and will increase the predictive power of the related models. This concept is exemplified for different processes at different scales:

1) Biogeochemical interactions in soil, including sorption and the turnover of soil organic matter, happen at the scale of pore-solid interfaces. The structure of the pore space is crucial for what a particle 'sees' when moving through soil. Experiments based on homogenized samples merely tell us what may happen potentially but not what is really going on. We present an approach to quantify and to model the complex pore geometry thereby linking directly-measured structural properties to the expected biogeochemical interactions in soil. The required instruments for non-invasive structure analysis become more and more available (e.g. X-ray microtomography). The observed structure can inform processes of structure formation which closes the loop between pedology and functions.

2) At the scale of soil profiles preferential flow is still an open problem for the prediction of soil water dynamics and solute transport. In groundwater, stochastic continuum theory has already demonstrated the possibility of translating structural aspects into process-relevant model parameters. However, within the unsaturated zone the highly transient conditions lead to hydraulic non-equilibrium that triggers preferential flow in a non-linear way.
Existing multi-domain models are based on conceptual 'effective' parameters that typically need to be calibrated to experimental observations and cannot be measured independently. We discuss an approach which considers the state space of water content and water potential as a probability space so that water content, water potential and hydraulic conductivity are no more tightly coupled by constitutive relations. Based on numerical simulations using well defined heterogeneities we demonstrate that the trajectories within this state space can be derived from structural properties in the form of variance, correlation length and topology of the local hydraulic properties.

3) At the scale of hillslopes and catchments surface runoff and interflow are large scale preferential flow events which are triggered by the hydraulic structure of individual soils (i.e. vertical profile of water capacity and hydraulic conductivities) and their spatial distribution pattern within the catchment. This structural

diversity determines the onset of fast lateral flows in response to external forcing by climatic conditions. It can be mapped by direct field measurements, geophysical exploration and remote sensing data. However such data are hard to get and, hence, are typically not available. As an attractive alternative, we discuss the approach of pedometrics to use more readily available data related to geology, relief, vegetation, and land management together with our understanding of soil genesis to set up a soil-landscape model providing a probabilistic spatial pattern of relevant soil attributes. This, again, would close the loop between pedology and actual hydrological processes.