Supplement of Hydrol. Earth Syst. Sci., 21, 3953–3973, 2017
https://doi.org/10.5194/hess-21-3953-2017-supplement

Hydrology and Earth System Sciences
Open Access

Supplement of

HESS Opinions: The complementary merits of competing modelling philosophies in hydrology

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Supplementary Material

HESS Opinions: The complementary merits of competing modelling philosophies in hydrology

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S1 – Example: climate effects on spatial process heterogeneity

As an example, consider the interception and unsaturated root-zone storage processes in energy limited cool and humid environment. In such environments, large parts of catchments do often exhibit only limited storage deficits and can remain hydrologically connected for much of the year. The elevated precipitation volumes and short inter-storm durations together with limited energy supply for evaporation will result in both stores that are often filled close to their capacity, notwithstanding their potentially significant storage capacities (e.g. forest). As little additional water can be stored, the systems converges towards a linear response, i.e. what is going in, goes out without significant storage changes and largely independent from spatially heterogeneous storage capacities across the entire catchment. Thus, in that example, any spatial heterogeneity of storage capacities, as for instance dictated by different land cover across the catchment, does not significantly influence the hydrological response and may therefore neither be meaningfully identified by the available data nor actually necessary to account for in a model. As the same applies for other processes, it can be argued that lumped top-down models, if rigorously tested, may indeed be capable of meaningfully reproducing the observed hydrological response under these specific environmental conditions. However, the more arid the climate and the higher the seasonality of precipitation, the more pronounced the importance of the storage capacities and their spatial heterogeneity become: after a dry period, forested hillslopes with higher interception and root zone storage capacities than grasslands will need more water to overcome the storage deficits. Thus grasslands will, due to the lower storage deficit that needs to be overcome, establish hydrological connectivity earlier than forests, which has, depending on the areal proportion of the two landscape elements within the catchment, considerable potential to influence the entire catchment response. A lumped formulation of the process will then indeed lead to a considerable misrepresentation of the hydrological system if a model customized for cool and humid conditions is applied under drier and warmer conditions, and further exacerbated by pronounced differences in topographic relief and/or land cover within the catchment.

S2 – Example process complexity: Interception

As an example consider which individual processes a description of vegetation interception at different hierarchal levels of detail may, amongst others, involve. At the level of individual tree branches, it can be split in into the individual respective interception capacities of a branch and its leaves. While the first is controlled by the mechanical water loading capacity of the branch, which in turn is a function of branch geometry, wind speed, wind direction and precipitation phase, the latter also depends on the phenology of the plant under consideration. Applying classical mechanics, information on material properties and geometry of the branch-leave system together with time series of wind speed, wind direction, energy supply and precipitation then allows to compute time series of water storage in as well as drip and evaporation from the branch-leave system. At a higher hierarchal level, the level of the individual plant, the detailed, mechanistic description has to be extended to a three-dimensional cascade of individual, interacting branch-leave systems, each characterized by its own position and geometry and therefore affected by differences in wind exposure, direct precipitation input as well as throughfall from systems above. For individual young plants with a few branch-leave systems, depending on how many of the material and geometric can be determined with some level of confidence, and how many may require some degree of lumping and simplifying conceptualizations, a mechanistic description may remain a feasible option. Yet, the overall interception at the level of a plant is the result of a distribution of different individual thresholds, i.e. interception capacities. With increasing complexity, the resulting non-linear system then becomes increasingly problematic to predict with a detailed, small-scale description, due to uncertainties in boundary conditions, forcing and system states (e.g. Zehe et al., 2007). At the subsequent stand level, the detailed properties of different plants of the same species but also other species and the composition of plants at a given stand need to be known in addition if interception wants to be treated in a detailed way based on small scale physics. This is effectively not possible with current day observational and computational technology and may for a long time not be. In absence of the required detailed observations, observations at a higher hierarchal level and/or calibration are required to establish a meaningful process parameterization. Both dictate a lower degree of process detail and thus a higher degree of integration to limit the effects of equifinality. In a system that is set in the realm of organized complexity - too random, i.e. unobservable, to be treated in a deterministic way and too organized to be treated in an exclusively statistical way (Dooge, 1986) - zooming out then often results in the emergence of simple, generalizable functional relationships of the process under examination (here: interception) with some system properties (here for example Leaf Area Index, e.g. Samaniego et al., 2010) at that scale.