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Scale issues in the context of new questions, new variables and new models.

Compared to other fields in the geosciences, in hydrology the theoretical development of scale transfer, scalability and scaling is quite well established and advanced. Already in the 1980s en 1990s the fields of catchment hydrology and subsurface hydrology have provided a large body of literature about scale-dependency and scale-invariance of hydrological parameters, processes and variables. Seminal reviews have been provided by e.g. Blöschl and Sivapalan (1995) (Hydrology) and Wen and Gomez-Hernandez (1996) and Sanchez-Vila et al. (2006) (Subsurface hydrology), as well as more practical handbooks (Bierkens et al., 2000).

In this paper, we first use the framework of the scale-triplet as introduced by Blöschl and Sivapalan (1995) to place scale-transfer problems of past hydrological practice into a different context to answer the following question: what is the appropriate way of describing sub-support (i.e. subgrid or subcatchment) variability of processes and parameters in hydrological models? We argue that, if the scale of fluctuation of the process or parameter described is very large compared to the support scale (structure), a deterministic approach is most suitable. On the other hand, if the scale of fluctuation is small compared to the support (disorder), a simple univariate frequency approach can be used to solve sub-support variation. The most complex case occurs when the scale of fluctuation is comparable to the support of the problem: here either multivariate random functions or additional hydrologic theory are necessary to solve for sub-support processes. This also explains the difference between catchment hydrology, where for larger catchments simple subgrid schemes (VIC, ARNO) suffice, while for subsurface hydrological problems, where variation occurs at multiple scales, random function theory is the preferred method.

Next, using these insights we move to new hydrological questions that are currently being tackled by hydrologists, e.g. those that involve problems of flood risk, food security, access to safe drinking water and sustainable water consumption. We argue that these new problems have in common that they require answers at large extents but at the same time need process descriptions and/or answers at high resolution (small support). The scale of fluctuation of these problems is generally larger than the support used and of similar size of the required extent. This requires a multivariate frequency description of sub-support variation, or if answers are required at high resolution, new hydrological theory to explain variation deterministically at the smallest support. The success, of using developing and applying new hydrological theories to deterministically resolve sub-support variability is highly dependent on the use of high-performance computing and the availability of high-resolution data from remote sensing. We illustrate our arguments with examples from Himalayan water availability, groundwater depletion and flood risk mapping.