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Tackling complexity in modelling mountain hydrology: where do we stand, where do we go?

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Abstract The modelling of mountain hydrology is characterized by a series of challenges: continuous accessibility of sites is usually difficult, the accuracy of measurements is limited or even unknown, and their areal representativeness is highly variable in space and time. The spatial variability of many variables that serve as model input undergoes significant scale dependence, and the validation possibilities for model output are limited. Finally, the quantification of uncertainties is usually limited to ensemble simulations across reasonable parameter spaces. Even though sophisticated mountain hydrology modelling schemes have been developed recently, many early concepts have survived: temperature index snowmelt modelling, the neglect of snow sublimation, pragmatic gauge corrections, evapotranspiration estimations, and simple soil- and overland flow representations. Many of these models lack the ability to be transferable in space and time, and in scenario applications they produce artefacts. By means of combining physically-oriented parameterizations and statistical approaches, multi-scale sensitivity studies and integration of remote sensing data in the meantime we can compile improved versions of our models. This is additionally facilitated by an increasing number of new hydrometeorological observatories in mountain areas that are currently built up. As an example of the potential and limitations of modelling mountain hydrology, we present an approach to combine a distributed hydrological model, physically-based snow process parameterizations and an artificial neural network for an enhanced modelling of water fluxes in a high Alpine catchment in the Berchtesgaden Alps (Germany). The hydrology there is highly complex due to the very steep topographic gradients, related spatial variability of all meteorological variables, the very heterogeneous snow cover and the karst nature of the groundwater system. We demonstrate the benefit of single model enhancements, and provide a generally climate change scenario-capable application. With operational observatories, international cooperation and networking, new opportunities arise for joint mountain hydrological process and modelling studies. We conclude with an outlook of upcoming scientific challenges in coupled human–natural water systems.

Key words mountain hydrology; modelling; scale dependence; snowmelt; glacier response; operational observatory; process-oriented approach; complexity; society