Submitted Abstract

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Abstract

Highly simplified approaches continue to underpin hydrological climate change impact assessments across the Earth's mountainous regions. Fully-integrated surface-subsurface models may hold far greater potential to represent the distinctive regimes of steep, geologically-complex headwater catchments. However, their utility has not yet been tested across a wide range of mountainous settings. Here, an integrated model of two adjacent calcareous Alpine headwaters that accounts for 2D surface flow, 3D variably-saturated groundwater flow, and evapotranspiration is presented. An energy balance-based representation of snow dynamics contributed to the model's high-resolution forcing data, and a sophisticated 3D geological model helped to define and parameterize the subsurface structure. In the first known attempt to calibrate a catchment-scale integrated model of a mountainous region automatically, numerous uncertain model parameters were estimated. The salient features of the hydrological regime could ultimately be satisfactorily reproduced – over an 11-month evaluation period, the Nash-Sutcliffe efficiency of simulated streamflow at the main gauging station was 0.76. Spatio-temporal visualization of the forcing data and simulated responses further confirmed the model's broad coherence. Presumably due to unresolved local subsurface heterogeneity, closely replicating the somewhat contrasting groundwater level signals observed near to one another proved more elusive. Finally, we assessed the impacts of various common model simplifications and assumptions on key simulated outputs, finding strongly affected model performance in many cases, and explored the region's future hydrology under not only future climatic but also future vegetation scenarios. Although certain outstanding challenges must be overcome if the global uptake of integrated models in mountain regions is to increase, our work demonstrates the feasibility and benefits of their application in such complex systems.