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Can knowledge of dominant runoff processes improve prediction of extreme floods? Evaluation of a mapping and modeling framework in three alpine catchments with strongly contrasting flood behavior

Maarten Smoorenburg (1), Felix Naef (1), and James W. Kirchner (2)

(1) Institute of Environmental Engineering, ETH Zurich, Zurich, Switzerland, (2) Institute of Terrestrial Ecosystems, ETH Zurich, Zurich, Switzerland

Predicting extreme floods in alpine catchments is challenging because flood behavior varies greatly and shows little correlation with basin-scale landscape characteristics. Here, we relate differences in catchment flood behavior to hillslope-scale storage and drainage mechanisms, using newly developed tools for geomorphology-based mapping and modeling of dominant runoff processes in alpine terrain. We report how dominant runoff process maps explain flood behavior in three contrasting alpine catchments and evaluate how the model's capability to predict extreme floods in the three catchments compares to predictions with simple, lumped, benchmark models calibrated in each catchment.

The largest floods in all three meso-scale catchments are caused by long-duration storms of moderate intensity, but their flood runoff behavior differs strongly: the Hinterrhein (54 km^2) has a fast flood runoff response, the Dischma (43 km^2) has a damped flood runoff response, and the Schaechen (108 km^2) has a damped response during small events and remarkably strong response during extreme events. The dominant runoff process mapping tool explicitly considers the drainage timescale of subsurface flows, which was found to be important during long duration storms in the Schaechen catchment.

The maps of dominant runoff processes explain differences in flood behavior well, including the strong response of the Schaechen during the most extreme events, and the large difference in flood response between the Dischma and Hinterrhein catchments, which is not well correlated to commonly used catchment descriptors. Application of the model to the most extreme event in the Schaechen and small and large events in the other catchments gave satisfactorily results. In contrast, the *in situ* calibrated lumped models only predicted extreme flood runoff well in the Hinterrhein, with large overestimation bias in the Schaechen and strong underestimation in the Dischma.

The presented work indicates that: (a) maps of dominant runoff processes may provide a useful description of catchment organization and flood behavior in a wide range of catchments; (b) the developed framework allows useful up-scaling of small-scale hydrologic understanding in contrasting alpine catchments; and (c) this framework may provide a more reliable basis for predicting extreme floods than purely inductive methods like (regionalized) flood statistics or rainfall-runoff models calibrated to small events.