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Impact and uncertainty of climate projections on Alpine catchments using high-resolution models

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Hydrological processes in mountainous catchments will be subject to climate change on all scales, and their response is expected to vary considerably in space. Typical hydrological studies, which use coarse climate data inputs obtained from General Circulation Models (GCM) and Regional Climate Models (RCM), focus mostly on statistics at the outlet of the catchments, overlooking the effects within the catchments. Furthermore, the role of uncertainty, especially originated from natural climate variability, is rarely analyzed. In this work, we quantified the impacts of climate change on hydrological components and determined the sources of uncertainties in the projections for two mostly natural Swiss alpine catchments: Kleine Emme and Thur. Using a two-dimensional weather generator, AWE-GEN-2d, and based on nine different GCM-RCM model chains, we generated high-resolution (2 km, 1 hour) ensembles of gridded climate inputs until the end of the 21st century. The simulated variables were subsequently used as inputs into the fully distributed hydrological model Topkapi-ETH to estimate the changes in hydrological statistics at 100-m and hourly resolutions. Increased temperatures (by 4°C, on average) and changes in precipitation (decrease over high elevations by up to 10%, and increase at the lower elevation by up to 15%) results in increased evapotranspiration rates in the order of 10%, up to a 50% snowmelt, and drier soil conditions. These changes translate into important shifts in streamflow seasonality at the outlet of the catchments, with a significant increase during the winter months (up to 40%) and a reduction during the summer (up to 30%). Analysis at the sub-catchment scale reveals elevation-dependent hydrological responses: mean annual streamflow, as well as high and low flow extremes, are projected to decrease in the uppermost sub-catchments and increase in the lower ones. Furthermore, we computed the uncertainty of the estimations and compared them to the magnitude of the change signal. Although the signal-to-noise-ratio of extreme streamflow for most sub-catchments is low (below 0.5) there is a clear elevation dependency. In every case, internal climate variability (as opposed to climate model uncertainty) explains most of the uncertainty, averaging 85% for maximum and minimum flows, and 60% for mean flows. The results highlight the importance of modelling the distributed impacts of climate change on mountainous catchments, and of taking into account the role of internal climate variability in hydrological projections.