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Using high-resolution stochastic climate ensembles to model the impacts and uncertainty of hydrology in mountainous catchments

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Hydrological projections in the context of a changing climate may display high levels of uncertainty, particularly when examining small temporal and spatial scales. To project the response of hydrological processes to the increasing global temperatures, scientists and practitioners rely on chains of numerical models, each contributing some degree of uncertainty to the overall outputs. Furthermore, the randomness intrinsic to climate phenomena, known as internal climate variability, contributes to the uncertainty of the hydrological projections in the form of an irreducible stochasticity. In this work, we quantify the impacts and partition the uncertainty of hydrological processes emerging from climate models and internal variability for two mountainous catchments in the Swiss Alps and across a broad range of scales. To that end, we used high-resolution ensembles of climate and hydrological data produced using a two-dimensional stochastic weather generator (AWE-GEN-2d) and a distributed hydrological model (Topkapi-ETH). We quantified the uncertainty in hydrological projections towards the end of the century through the estimation of the values of signal-to-noise ratios (STNR). We found small STNR values (<-1) in the projection of annual streamflow for most sub-catchments in both study sites that are dominated by the large natural variability of precipitation (explains ~70% of total uncertainty). Furthermore, we investigated specific hydrological components that are critical in the model chain with detail. For example, snowmelt or liquid precipitation exhibits robust change signals, which translates into high STNR values for streamflow during warm seasons and at higher elevations, together with a larger contribution of climate model uncertainty, suggesting that an improvement of the involved models has the potential of significantly narrowing the uncertainty. In contrast, extreme flows show low STNR values due to large internal climate variability across all elevations, which limits the possibility of narrowing their estimation uncertainty due to a warming climate. This study demonstrates that high-resolution hydro-climatic ensembles enable the quantification of hydrological projections across spatial and temporal scales, which can be used to assess the potential for narrowing hydrological uncertainties.