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Quantifying uncertainty sources in hydrological climate impact projections

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Impact modeling systems, consisting of an emission scenario, global and regional climate models, statistical post-processing methods and hydrological models, are commonly used to assess hydrological climate impacts. Uncertainties associated with the projected impacts arise from each element of the modeling chain. While propagating through the modeling chain, the uncertainties from various modeling steps might interact. Interactions mean that the uncertainty of projected climate impacts by an ensemble of, e.g., multiple hydrological models, depends on the preceding modeling steps. In order to quantify such interactions, one needs to generate an ensemble of projections that varies different elements of the impact modeling chain simultaneously. In this study, we conducted a modeling experiment in the Alpine Rhine catchment using an ensemble of 9 climate model chains (CMs) from the ENSEMBLES project (www.ensembles-eu.org), 2 statistical post-processing (PP) methods and 2 hydrological models (HMs). We address changes in the annual cycle of runoff and of different runoff quantiles for the period 2021-2050 relative to 1961-1990. Based on this database of 36 different modeling chains, we tried to answer the questions: (1) how large is the total uncertainty of the projections, and (2) how much do the three modeling chain elements (CMs, PP methods, HMs) and interactions between them contribute to the total uncertainty as estimated in (1). The results show that most of the projections agree on an increase of runoff in winter (+15.6 [range +5.5 to +40.7] %) and a decrease in summer (-13.8 [range -26.0 to +3.9] %). However, there is large uncertainty in the magnitude of the changes. We used an ANalysis Of VAriance (ANOVA) model to quantify the contributions of various uncertainty sources to the total uncertainty of the ensemble. We found that CMs are the most important source of uncertainty for changes in the annual cycle of runoff during most parts of the year, and over a large quantile range. We also found that interactions might be as important as CMs during winter and spring and for extreme runoff quantiles. This indicates that it is crucial to vary multiple impact modeling chain elements simultaneously in order to assess the full uncertainty of hydrological climate impacts. Concerning the design of future impact studies, our results indicate that one should invest more into having a balanced sampling of all possible uncertainty sources rather than increase the sample size of just one particular source. Furthermore, the employed ANOVA model for the decomposition of the total uncertainty is flexible and could be adapted to modeling experiments that include other uncertainty sources such as e.g. emission scenarios or land use changes.