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The sensitivity of hydrologic processes across North America considering model structure and parametric uncertainty

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Information on the sensitivity of model parameters and model components such as processes are essential for model development, model improvement, and model calibration, amongst others.

In this work we apply the method of the extended Sobol' Sensitivity analysis (xSSA) which not only considers parametric uncertainty but also fully incorporates structural uncertainties (Mai et al. (2019) WRR; under review). The results of such an analysis yield not only the traditional parameter sensitivities but also sensitivities of model process options (e.g., different snowmelt algorithms) and sensitivities of model processes (e.g., snowmelt, infiltration, baseflow).

The Raven hydrologic modelling framework (http://raven.uwaterloo.ca) allowing for flexible model structures is employed in this work. We used three options each for infiltration, quickflow, and snow melt as well as two options each for baseflow, and soil evaporation. Rather than considering 108 (3x3x3x2x2) discrete model setups, we used weighted sums of all process options yielding an infinite number of models tested.

The analysis is performed for 5797 basins across Canada (CANOPEX; Tarek et al. (2019) HESSD) and the US (USGS). The lumped basin setups use daily precipitation and minimum/ maximum daily temperature. The sensitivity analysis is based on 20 years of daily streamflow simulations (1991-2010) after two years of spin-up (1989-1990). No observed streamflow is required for the analysis.

In total more than 450 million model runs were performed to determine sensitivities of parameters, process options and processes (51%, 35%, and 14% of model runs, respectively) across the almost 5800 basins. The computational demand was about 12 core years producing 23 TB of raw model outputs.

The analysis allows for unique, new insights into the importance of hydrologic processes and parameters (practically) independent of the model (structure) used. A few highlight results are: 1) Baseflow and other sub-surface processes are of low importance across North America- especially when time points of high flows are of interest. 2) Percolation, evaporation, and infiltration show very similar patterns with increased importance in South-eastern US and west of the Rocky Mountains. 3) Up to 30% of the overall model variability can be attributed to snow melt in regions

that are snow dominated (Northern Canada and Rocky mountains). Potential melt shows a similar gradient as snow melt with sensitivities of above 60% in the Province of Quebec and the Rocky Mountains. 4) Direct runoff (quickflow) is the most sensitive of all hydrologic processes- especially in South-Eastern US it is responsible for more than 80% of the model variability.