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Evaluating model structure uncertainty by a new approach to sensitivity analysis utilizing hydrological signatures

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Abstract: Model structure uncertainty is one of the most significant sources of uncertainty in traditional hydrological modelling and, above all, challenging to quantify. Structurally flexible models have recently become very popular in hydrology as they tend to allow a reduction of this uncertainty due to their flexibility in the mathematical representation of the hydrological response of a catchment. Reducing structural uncertainty within the flexible framework requires identifying (using top-down or bottom-up approaches) the most suitable (hydrologically consistent) model structure for a given watershed. To assess the models’ hydrological consistency, diagnostic model evaluation techniques are employed to test their capability of reproducing the watershed’s behavior, quantified utilizing hydrological signatures (e.g. flow duration curves). Among other evaluation approaches to balance model complexity is sensitivity analysis, which is traditionally conducted with respect to one or multiple summary statistics quantifying the goodness-of-fit between the time series of model simulations and observations.

In this study, we develop a novel sensitivity analysis approach based on Sobol’ SA, utilizing multiple hydrological signatures that are useful to constrain model outcomes. Our hypothesis is that the extra information provided by signatures would facilitate a more comprehensive evaluation of the model parameterization compared to the traditional sensitivity analysis using time series-focused aggregate summary statistics. In addition, the systematic application of the sensitivity analysis to groups of parameters which are linked to certain model structures could assist in the identification of the most suitable and consistent structure. To test these hypotheses, the proposed signature-based sensitivity analysis, as well as the traditional approach are applied to a range of model structures developed within a computationally efficient and flexible hydrological modelling framework called RAVEN. The main objective of the numerical experiments in this study is to demonstrate the applicability of the proposed sensitivity analysis approach in view of the model structure selection and, thus, the model structure uncertainty reduction.

Keywords: Model structure uncertainty; Flexible hydrological modelling; Hydrological signatures; Sensitivity analysis