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# Sensitivity analysis and parameter estimation for distributed hydrological modeling: potential of variational methods

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Abstract. Variational methods are widely used for the analysis and control of computationally intensive spatially distributed systems. In particular, the adjoint state method enables a very efficient calculation of the derivatives of an objective function (response function to be analysed or cost function to be optimised) with respect to model inputs.

In this contribution, it is shown that the potential of variational methods for distributed catchment scale hydrology should be considered. A distributed flash flood model, coupling kinematic wave overland flow and Green Ampt infiltration, is applied to a small catchment of the Thoré basin and used as a relatively simple (synthetic observations) but didactic application case.

It is shown that forward and adjoint sensitivity analysis provide a local but extensive insight on the relation between the assigned model parameters and the simulated hydrological response. Spatially distributed parameter sensitivities can be obtained for a very modest calculation effort (~6 times the computing time of a single model run) and the singular value decomposition (SVD) of the Jacobian matrix provides an interesting perspective for the analysis of the rainfall-runoff relation.

For the estimation of model parameters, adjoint-based derivatives were found exceedingly efficient in driving a bound-constrained quasi-Newton algorithm. The reference parameter set is retrieved independently from the optimization initial condition when the very common dimension reduction strategy (i.e. scalar multipliers) is adopted.

Furthermore, the sensitivity analysis results suggest that most of the variability in this high-dimensional parameter space can be captured with a few orthogonal directions. A parametrization based on the SVD leading singular vectors was found very promising but should be combined with another regularization strategy in order to prevent overfitting.

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