Exploring the potential of transdimensional inversion on discrete fracture network models of hard rock aquifers

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Classic inversion methods used in geoscience research adjust a predefined number of parameters to the observed data. There are several situations however, when it is advantageous to keep the number of model parameters flexible during the inversion process. Imaging methods, that capture the distribution of specific parameters could especially benefit from this approach, as one can refine the model resolution locally in accordance with the model heterogeneity (Bodin and Sambridge (2009), Jiménez et al. (2016)). For models with discrete features, like discrete fracture networks (DFN), this flexibility in parameterization becomes essential when a limited amount of prior information is available and the number of discrete features is unknown before the inversion. Several successful applications of transdimensional inversion have been presented on different explorational methods. Still, many aspects of these applications are unexplored, and require further investigation to really make these techniques feasible to use in practice.

Our research focuses on the modeling of fractured media, where changes in fracture numbers during inversion means changes in the dimensionality of the inverse problem. In Somogyvári et al. (2017) it was shown, that the reversible-jump Markov chain Monte Carlo method (rjMCMC) can be successfully applied to identify the geometry of the main transport pathways in a fractured aquifer, based on tomographic tracer observations. The presented examples however were limited to 2 dimensions and no calibration of the hydraulic parameters of the fractures was performed. These limitations were required for the inversion to be completed in a feasible amount of time. One of our main objectives is to lighten the computational burden of transdimensional inversion, thus making it possible to increase the freedom of the inversion. The ultimate goal is to provide an inversion method capable of adjusting three dimensional fracture network geometries to observations, while also including the hydraulic properties of the individual fractures as free parameters in the inversion. Assuming that the input information can be extended (which is reasonable as the rjMCMC algorithm uses a Bayesian approach) the inversion theoretically could provide results in such complex situations.

The evolution of computers tends toward parallel computing, making parallelized codes more preferable. The rjMCMC algorithm however is strictly sequential, which could only be optimized by reducing the computational cost per accepted iteration. This can be ensured by advanced convergence schemes (such as the delayed rejection scheme (Bodin and Sambridge, 2009)) or by reducing the computational time of one iteration. By running multiple Markov chains in parallel, a true parallelization could be achieved. This however require further investigation, to make sure that the final combined set of DFN realizations represents a true mapping of the posterior of the inverse problem.

Transdimensional inversion methods provide ensembles of realizations as final results. However there are no well defined conditions to ensure these ensembles are complete mappings of the posterior of the inverse problems (and also when the inversion process could be considered finished). Convergence criteria of classic MCMC methods could not be applied in transdimensional cases as parameters of different realizations cannot be compared directly to each other (Bodin and Sambridge, 2009). Beyond that, most studies from geosciences only present the mean of the ensemble as the final result of the transdimensional inversion. We provide further analysis of the transdimensional dataset, including uncertainty assessment and statistical analysis. This could give further insight to the inverted data and could reveal possible limitations of the inversion, such as bi- or multimodality.

Transdimensional inversion with the rjMCMC algorithm faces challenges inherited from classic Markov chain Monte Carlo methods. This, along with the added extra demands from the transdimensional ensemble output means that the method requires major developments for practical use. We present some of the new directions and approaches that could make this methodology a practical tool for exploration activities.

References

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