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Which level of model complexity is justified by your data? A Bayesian answer

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When judging the plausibility and utility of a subsurface flow or transport model, the question of justifiability arises: which level of model complexity can still be justified by the available calibration data? Although it is common sense that more data are needed to reasonably constrain the parameter space of a more complex model, there is a lack of tools that can objectively quantify model justifiability as a function of the available data.

We propose an approach to determine model justifiability in the context of comparing alternative conceptual models. Our approach rests on Bayesian model averaging (BMA). BMA yields posterior model probabilities that point the modeler to an optimal trade-off between model performance in reproducing a given calibration data set and model complexity. To find out which level of complexity can be justified by the available data, we disentangle the complexity component of the trade-off from its performance counterpart.

Technically, we remove the performance component from the BMA analysis by replacing the actually observed data values with potential measurement values as predicted by the models. Our proposed analysis results in a "model confusion matrix". Based on this matrix, the modeler can identify the maximum level of model complexity that could possibly be justified by the available amount and type of data. As a side product, model (dis-)similarity is revealed.

We have applied the model justifiability analysis to a case of aquifer characterization via hydraulic tomography. Four models of vastly different complexity have been proposed to represent the heterogeneity in hydraulic conductivity of a sandbox aquifer, ranging from a homogeneous medium to geostatistical random fields. We have used drawdown data from two to six pumping tests to condition the models and to determine model justifiability as a function of data set size.

Our test case shows that a geostatistical parameterization scheme requires a substantial amount of hydraulic tomography data to be justified through the eyes of BMA, while a zonation-based model can be justified with more limited data set sizes. The actual model performance (as opposed to model justifiability), however, depends strongly on the quality of prior geological information. Overall, the proposed analysis provides valuable support for model evaluation and selection in light of limited data.