Updating structural uncertainty through dimension reduction of geophysical data

When studying uncertainty in geosciences we usually have to deal with: (1) very high dimensionality in both data and parameters, (2) complex models to describe the subsurface, and (3) nonlinear forward models to simulate data. All these facts hinder the quantification of uncertainty as the estimation of the corresponding joint probability distribution is not straightforward. In this study, we follow a Bayesian approach to obtain the marginal probability distribution of structural parameters given the geophysical data. We approximate this distribution with a combination of Monte Carlo sampling, data dimension reduction and kernel density estimation. We use synthetic GPR cross-borehole traveltime data with added noise and consider two structural parameters: (1) geological scenario, a discrete parameter, and (2) preferential orientation, a continuous parameter. The focus of this work is in comparing different dimension reduction techniques to assess which one gives the most accurate estimation of structural uncertainty. We generate the Monte Carlo samples starting with the structural parameter, then applying multiple-point geostatistics to obtain the subsurface realization and finally simulating traveltime data with the geophysics forward model. We follow four different strategies: (1) apply multidimensional scaling directly on traveltime data (2) use histograms of traveltime data as features and then apply multidimensional scaling to further reduce dimensions, (3) transform data into geophysical images by means of regularized inversion and then apply multidimensional scaling, and (4) obtain connectivity features from these geophysical images and then apply multidimensional scaling. Using defined features results in the most accurate estimations of structural uncertainty as measured through cross-validation, both for the histogram and the connectivity, but working with the former is computationally more efficient since it does not require obtaining the geophysical image. Data dimension reduction is useful when approximating the marginal probability distribution of structural parameters but the accuracy of this distribution depends on the ability of the dimension reduction technique to retain the most informative part of the data with respect to the parameter of interest.