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Estimation of spatially-structured subsurface parameters using variational autoencoders and gradient-based optimization

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Abstract: Environmental models of the subsurface usually require the estimation of high-dimensional spatially-distributed parameters. However, the sparsity of subsurface data hinders such estimation which may in turn affect predictions using these models. In order to mitigate this issue, parameter estimation can be constrained to prior information on the expected subsurface patterns (e.g. geological facies). By using several examples of such patterns (e.g. those obtained from a training image), a variational autoencoder (VAE) learns a low-dimensional latent space that can be seen as a reparameterization of the original high-dimensional parameters and then estimation by means of gradient-based optimization can be performed in this latent space. Spatial parameters estimated in this way display the enforced patterns. VAEs usually include deep neural networks within their architecture and have shown good performance in reproducing high-dimensional structured subsurface models. However, they use a highly nonlinear function to map from latent space to the original high-dimensional parameter space which may give rise to local minima where gradient-based optimization gets trapped and therefore fails to reach the global minimum. Global optimization strategies may be used to solve this issue, however, a gradient-based inversion is preferred because of its lower computational demand. We propose using VAE together with gradient-based optimization in a linear traveltime tomography synthetic case with added noise and show that it often reaches low data error values and produces visually similar spatial parameters when compared with different test subsurface realizations. We also add regularization to the objective function to improve the number of times it reaches an adequate minimum. Finally, we perform a synthetic test with nonlinear traveltime tomography and show that the proposed strategy is able to recover visually similar spatial parameters with an error close to the added noise level.

***Keywords**:* parameter estimation; variational autoencoder; gradient-based optimization; spatial patterns.