DE PASQUALE Giulia (2019): Probabilistic geophysical inversion with structure-based priors and unknown interface geometries


Abstract

Many physical, chemical and biological processes within the Earth's near-surface take place at boundaries. Thus, characterizing the depth and geometry of subsurface inter- faces and their uncertainties is of major interest in many fields of the Earth sciences. Geophysical methods are inherently sensitive to discontinuities within the physical properties of the subsurface, but interpreting the collected observations and reconstructing an image of the subsurface is challenging. The main limitation comes from the ill-posed nature of inversion problems. Classical deterministic inversion addresses this problematic through regularization, most commonly with the use of smoothness constraints that smear out any naturally-occurring interface. Probabilistic inversion instead models the unknown solution as a random variable by describing it through its posterior probability density function. Within this framework, the prior distribution has a strong influence on the posterior model realizations and the complexity of the inversion problem. Moreover, its formulation in case of limited a priori knowledge is not trivial. Here, we propose a probabilistic formulation and solution to the inverse problem of using (one or more) geophysical datasets to infer interfaces in the presence of heterogeneous sub-domains, when prior knowledge is scarce. With the aim of proposing an alternative formulation for "uninformative" prior in case of parameterization through spatial discretization, we develop a sampling algorithm that assumes an uniform prior on measures of model spatial variability, instead of the classical choice of uncorrelated log-uniform distributions for the model parameters. We demonstrate the ability of such structured-based prior inversion to sample satisfactory posterior model realizations and statistics on both synthetic and field-based datasets. The proposed method is theoretically solid, but its numerical implementation is limited to rather narrow prior ranges for the model parameters. Therefore, when we implement the probabilistic formulation of the inversion problem that separates the geometric and physical parameter updates within Gibbs framework, we instead constrain both the geometric and physical proper- ties to favor smooth spatial transitions through empirical-Bayes methods. We finally extend the developed empirical-Bayes-within-Gibbs algorithm to jointly invert multiple geophysical datasets in order to reduce the inherent ambiguity of single measurements interpretation. The coupling between the models that are able to explain the different geophysical datasets is done by considering a common interface. Synthetic and field based test cases demonstrate that the method is more accurate in sampling the target interface than inversion results obtained through deterministic inversion and that the results are further improved when jointly invert two datasets.



Key words: Inverse theory, Probability distributions, Tomography, Interfaces.