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Mixed deterministic and stochastic inversion strategy based on Bayesian sequential simulation for geophysical uncertainty assessment

Paolo Ruggeri, James Irving, and Klaus Holliger

Applied Geophysics Group, Center for Research of the Terrestrial Environment, UNIL, Lausanne, Switzerland (paolo.ruggeri@unil.ch)

Deterministic inverse methods offer a robust and proven means of obtaining estimates of spatially distributed subsurface parameters from geophysical data. However, assessing the corresponding uncertainty in the parameters for the general non-linear inverse problem remains an ongoing research challenge. Recently, much work in geophysics and hydrology has focused on the use of Metropolis-based Monte-Carlo methods for model parameter estimation within a framework of uncertainty. Such methods offer great promise for robust uncertainty quantification, but are severely limited by their high computational cost, which is related to the typically large size of the model space and the need for small parameter perturbations in order to ensure reasonable rates of proposal acceptance. One key aspect of reducing the computational load of these methods is to incorporate as much information as possible into the proposal distribution, such that the number of subsurface configurations that is tested is limited to a small subset of the total number of possibilities. Here, we explore whether a deterministically inverted geophysical image, which contains a significant amount of information regarding the overall configuration of subsurface properties, may be used as an effective "prior" for a subsequent stochastic exploration of the model space. In particular, we consider a Bayesian sequential simulation procedure to define the prior distribution, where proposal realizations of the subsurface parameters are geostatistically conditioned to a deterministic geophysical image within some broad degree of uncertainty around this image. This algorithm is incorporated into a Markov-chain-Monte-Carlo posterior sampling procedure, where each proposed realization is either accepted or rejected using a random decision rule based on the realization's predicted data misfit. From a practical point of view, such a mixed deterministic/stochastic inversion approach may allow for improved uncertainty assessment past traditional linearized approaches, while at the same time being computationally tractable. We test the overall procedure on mildly and strongly non-linear geophysical examples involving ground-penetrating radar and geoelectrical measurements. The obtained posterior parameter uncertainty is compared with the "true", unbiased posterior statistics as well as traditional linearized uncertainty estimates.