Updating prior geologic uncertainty with GPR traveltime tomographic data

J. Lopez-Alvis, Urban and Environmental Engineering, University of Liege,
F. Nguyen, Urban and Environmental Engineering, University of Liege,
T. Hermans, Department of Geology, Ghent University

Key words: uncertainty, GPR tomography, multiple-point geostatistics, Bayesian

Introduction

In a Popper-Bayes approach, the prior probability states the initial degree of uncertainty, which should be taken very large, and the collected data should only be used to falsify unlikely scenarios [1]. In this context, geophysical methods provide data sets limited in resolution but with relatively large spatial extent enabling to narrow the uncertainty of the prior.

Geological scenario is one of the uncertain parameter often neglected in uncertainty analysis. It can be represented through training images from which multiple-point geostatistics (MPS) simulations can be drawn. Generating multiple simulations within each scenario enable us to consider within-scenarios spatial uncertainty [2].

GPR traveltime tomography is sensitive to porosity variations and hence it might assist in obtaining a spatial distribution of facies. The method provides good resolution in imaging structures with high wave velocity which also makes it suitable to identify continuity patterns. It is also the starting model for more complex full waveform inversion which cannot work without it and where uncertainty has been seldom investigated.

When simulating flow and transport in the subsurface, identifying preferential flow paths is necessary and their magnitude can be quantified using connectivity metrics [3]. When updating the prior uncertainty using geophysical data it might be useful to compare different scenarios based on its connectivity.

This work aims at using GPR traveltime data to update the prior probability distribution using two different distance definitions: the Euclidean distance and one based on connectivity metrics. By doing this we can assess the value of this geophysical method in updating prior uncertainty and also compare the effect of the two distances for this type of data.

Methods

We follow a similar approach to [4]. Within a Bayesian framework, applying this methodology results in an updated prior that can be later used to obtain a posterior distribution constrained to dynamic data. In this way, geophysical data are used to falsify/validate the prior geologic uncertainty.

The updating process (Figure 1) consists of the following steps:

(1) Defining a wide prior distribution $f(p)$ taking into account uncertainty in both continuous and discrete parameters p, e.g. geometrical parameters and depositional environments. We use training images and MPS simulations to model this uncertainty.

(2) Transforming the facies distribution into a distribution of geophysical properties, by using petrophysical relations which can also include uncertainty (either on the parameters of the relation or the relation itself). Forward modeling of GPR traveltimes in each of these simulations is applied to get the geophysical response

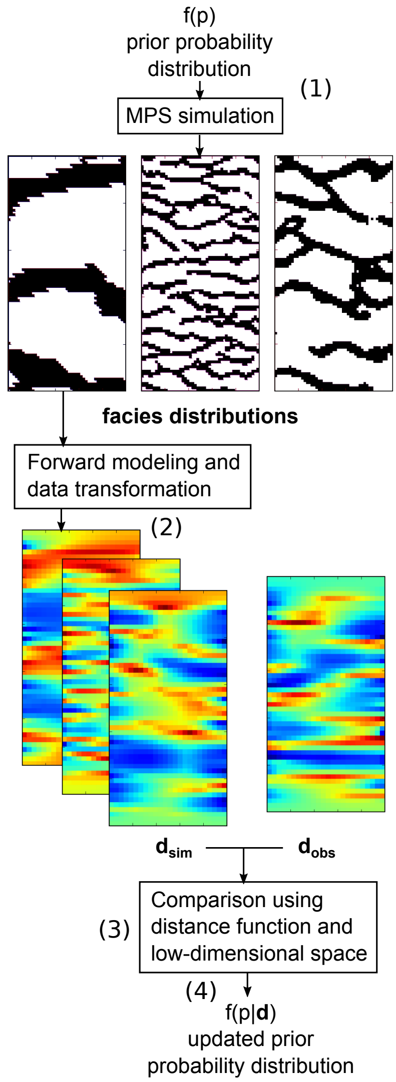

Figure 1: Updating of prior distribution

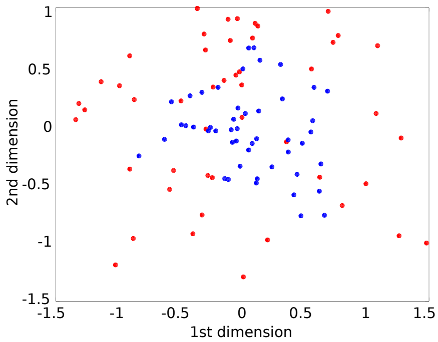

Figure 2: MDS plot showing similarity of the GPR response using facies simulations with two different scaling factors: big channels (red) and medium channels (blue)

and additionally some data transformation can be used (e.g. regularized inversion).

(3) Computing of distances between any two models (including the model from observed data) using the Euclidean distance and a distance based on connectivity metrics. We then use multi-dimensional scaling (MDS) to project these distances in a lower dimensional space (Figure 2).

(4) Estimate probability density $f(\mathbf{d}|p)$ in this lower dimensional space by using kernel smoothing [1] and calculating $f(p|\mathbf{d})$ through Bayes' rule.

Results

We generate prior probability distributions considering uncertainty in several parameters including geological scenario, geometrical properties and petrophysics. This contrasts with other studies where only one type of uncertainty is considered (e.g. [1, 4]). MPS simulations are generated and one of them is chosen as the true model. Then the methodolgy is evaluated in terms of its ability to constrain uncertainty around this model.

Using GPR traveltime tomography to update prior uncertainty shows that this method is more discriminant than other methods (e.g. surface ERT [4]), meaning that GPR traveltime data further reduce prior spatial uncertainty. Regarding uncertainty in geological scenario, GPR tomography results in more scenarios getting falsified. When considering alternative petrophysical relations and different values for the parameters of these petrophysical relations, GPR traveltime data significantly reduce the prior uncertainty.

As previously suggested, the methodology can be used to compare different geophysical methods in terms of their ability to narrow prior uncertainty, e.g. ERT versus GPR, or traveltime tomography versus full waveform inversion. It is also possible to integrate time-lapse data in the workflow, which leads to further constrain of prior uncertainty and is particularly beneficial if this uncertainty is to be considered for dynamic modeling of a related process.

References

[1] H. Park, C. Scheidt, D. Fenwick, A. Boucher and J. Caers. History matching and uncertainty quantification of facies models with multiple geological interpretations, *Comput. Geosci.*, **17**, 609–621, (2013).

[2] L. Feyen and J. Caers. Quantifying geological uncertainty for flow and transport modeling in multi-modal heterogeneous formations. *Adv. Water Resour.*, **29(6)**, 912–929, (2006).

[3] P. Renard and D. Allard. Connectivity metrics for subsurface flow and transport. *Adv. Water Resour.*, **51**, 168–196, (2013).

[4] T. Hermans, F. Nguyen and J. Caers. Uncertainty in training image-based inversion of hydraulic head data constrained to ERT data: Workflow and case study. *Water Resour. Res.*, **51**, 5332–5352, (2015).