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A new Bayesian approach of tomography and seismic event location dedicated to the estimation of the true uncertainties

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The monitoring of hydrocarbon reservoirs, geothermal reservoirs and mines commonly relies on the analysis of the induced seismicity. Even if a large amount of microseismic data have been recorded, the relationship between the exploration and the induced seismicity still needs to be better understood. This microseismicity is also interpreted to derive the fracture network and several physical parameters. The first step is thus to locate very precisely the induced seismicity and to estimate its associated uncertainties. The microseismic location errors are mainly due to the lack of knowledge of the wave-propagation medium, the velocity model has thus to be preliminary inverted. We here present a tomography algorithm that estimates the true uncertainties on the resulting velocity model. Including these results, we develop an approach that allows to obtain accurate event locations and their associated uncertainties due to the velocity model uncertainties.

We apply a Monte-Carlo Markov chain (MCMC) algorithm to the tomography of calibration shots for a typical 3D geometry hydraulic fracture context. Our formulation is especially useful for ill-posed inverse problem, as it results in a large number of samples of possible solutions from the posterior probability distribution. All these velocity models are consistent with both the data and the prior information. Our non linear approach leads to a very satisfying mean velocity model and to associated meaningful standard deviations. These uncertainty estimates are much more reliable and accurate than sensitivity tests for only one final solution that is obtained with a linearized inversion approach.

The Bayesian approach is commonly used for the computation of the posterior probability density function (PDF) of the event location as proposed by Tarantola and Valette in 1982 and Lomax in 2000. We add here the propagation of the posterior distribution of the velocity model to the formulation of the posterior PDF of the event location. This new formulation gives much more reliable results. Indeed, for this example, the resulting probability map show that the true hypocenter is not even located in the confidence region of the standard PDF whereas it is located in the confidence region of our new posterior PDF.

We finally apply our approach to a subset of real microseismic data recorded in a block-caving mine. We compute the posterior probability density function for a set of velocity models to assess if better estimates of the velocity model and of the seismic event locations can be reached with our approach in this mining context.