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Microseismic monitoring: new accurate estimate of velocity model uncertainties and consequences on location uncertainties

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Passive seismic monitoring is now a standard tool to follow the evolution of hydrocarbon, geothermal as well as CO2 geological storage reservoirs. Despite the fact that large volumes of data have already been acquired in one of the contexts just mentioned, our understanding of the relation of the microseismicity to the geometry of fractures is still very poor. Very precise location of seismicity is the first step to better understand and delineate hydraulic fracture geometry. Among many factors that contribute to microseismic location errors, the largest contribution is due to the lack of knowledge of the wave-propagation medium. In spite of efforts to build the “best” velocity model derived from surface seismic and/or logging data, these models are very often not adapted to the microseismic context and are characterized by numerous uncertainties. These uncertainties are often enhanced due to the poor aperture of the microseismic monitoring networks. Precise location of hypocenters requires deriving a very accurate velocity model using calibration shots; the inversion to obtain this model is a difficult task but cannot be neglected.

In addition, this required calibration/inversion for the velocities is a totally non-linear problem. In this work, we propose a tomography algorithm based on a simulated annealing approach to overcome this non linearity. In general, the output of this kind of algorithm is a unique velocity model reached for a given convergence criterion. On the opposite, our algorithm continues exploring the velocity models once the convergence criterion is reached and we keep all the accepted velocity models which have cost functions smaller than the picking uncertainties. This methodology leads us to add to the common resulting estimated velocities their associated uncertainties. This allows identifying the regions of the velocity field where the velocities are well constrained and thus reliable and also the regions where the velocities are poorly constrained. We illustrate our method on a 3D geometry in a hydraulic fracture context. Our method allows to express the best and the mean velocity model as well as the associated standard deviation. This strategy results in the estimation of the true uncertainty on the velocity model, which is much more accurate than the common roughly estimated percentage of uncertainty on the velocity model.

We finally take advantage of this non linear approach to estimate the probability of an event location associated to the velocity model uncertainties. This new strategy consists, for one microseismic event, in computing the best locations in a subset of all the acceptable velocity models given by the tomography algorithm. The number of occurrences of the best location at a given position (X, Y, Z) for the model subset gives the probability of this location. The resulting probability map shows that the commonly used probability density associated to the picking uncertainties must not be used to represent the probability density associated to the velocity model uncertainties. Traveltime picking and velocity model uncertainties should thus not be mixed.