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Derivative-free strategies for target-oriented inversion in 4D seismic

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Introduction

In this work, we address 4D seismic inversion using computational derivative-free optimization strategies. Our objective consists in discovering velocity variations in a target region of the reservoir comparing two seismic acquisitions in the same area, recorded with a time interval between them. The inverse process of imaging can be carried out by optimization, iteratively minimizing the optimization function, that means, the difference between synthetic (modeled) and observed (empirical) seismic data. 4D seismic inversion methods are typically computationally intensive, as most algorithms incur significant costs in the search for the global minimum of the objective function. Derivative-Free Optimization strategies offer an alternative approach by seeking the global minimum through extensive sampling of the search space, without requiring the computation of optimization function gradient information.

Method

In our study, we simulated a baseline and a monitor synthetic seismic acquisitions based on a typical velocity model from a Brazilian pre-salt field. The production-induced velocity anomaly within the reservoir is represented by a Gaussian-like perturbation centered in the middle of the reservoir zone. We used an OBN acquisition geometry with 1 source and 100 nodes. For the seismic inversion process, we use the difference between the baseline and monitor seismograms as input data to invert for changes in the velocity model. We tested two DFO strategies, initially, we implemented a greedy search algorithm, which progressively subdivides the reservoir region, tests candidate velocity values, and generates corresponding synthetic seismograms for comparison with the monitor data. The second strategy consists in applying the simulated annealing algorithm — a probabilistic global optimization technique — to minimize the misfit function that quantifies the difference between the observed and modeled seismic responses.

Results and Conclusions

With the techniques implemented so far, a reasonable target inversion was obtained. Our results indicate that DFO method is indeed an effective tool of 4D seismic imaging. The simulated annealing method achieved a misfit value of 1.8×10^{-4}, performing better than the greedy algorithm that shows a misfit of 2.5×10^{-4}. Furthermore, there is a perspective for testing other derivative-free strategies, such as swarming particle optimization. In particular, DFO approaches could serve as auxiliary tools for generating initial models for Full Waveform Inversion (FWI), given the critical dependence of the FWI outcomes on the quality of the starting model to ensure convergence towards reliable solutions.