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3D frequency-domain full waveform tomography (FWT): A feasibility study

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Three-dimensional quantitative seismic imaging in complex environments such those involving deepwater, thrust belts, sub-salt and sub-basalt structures is one of the main challenges of seismic exploration with many underlying applications such that hydrocarbon exploitation and crustal-scale exploration of seismogenic zones. We present a 3D frequency-domain full waveform tomography (FWT) algorithm suited for wide-aperture seismic data. We aim to develop high-resolution P-wave velocity models at low frequencies.

The forward problem is solved with a finite-difference method that needs only 4 grid points per wavelength which is the optimal discrete criterion for FWT whose maximal resolution is half a wavelength. In the frequency domain, wave propagation modeling reduces to the resolution of a large sparse system of linear equations. To solve this system, we use a massively parallel direct solver which allows efficient multiple-source simulations once the matrix was LU factorized. Indeed, the drawback of this approach is the memory complexity and the limited scalability of direct solver which presently limit the size of the simulations which can be performed.

The inverse problem based on a classic gradient method consists of the successive inversion of few increasing frequencies. This defines a multiresolution imaging scheme and allows us to manage compact volume of data.

The code is fully parallelized and avoids disk swapping by keeping in core the foward-problem solutions in distributed format. We present several validations of our algorithm with synthetic examples of increasing complexity such that the SEG/EAGE

Overthrust model. The main structures were well imaged with a spatial resolution in accordance with the inverted frequencies. Further work is required to [i] perform more representative applications on larger computational platforms, [ii] assess the sensitivity of 3D FWT to the starting model and to the acquisition geometry and [iii] assess whether velocity models developed by FWT can be used as an improved background model for pre-stack depth migration (PSDM). Less demanding strategies to perform the forward problem in the frequency domain also need to be investigated such that domain decomposition method based on hybrid direct/iterative solver.