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2D multi-parameter elastic seismic imaging by frequency-domain L_1-norm full waveform inversion

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Full waveform inversion (FWI) is becoming a powerful and efficient tool to derive high-resolution quantitative models of the subsurface. In the frequency-domain, computationally efficient FWI algorithms can be designed for wide-aperture acquisition geometries by limiting inversion to few discrete frequencies. However, FWI remains an ill-posed and highly non-linear data-fitting procedure that is sensitive to noise, inaccuracies of the starting model and definition of multiparameter classes.

The footprint of the noise in seismic imaging is conventionally mitigated by stacking highly redundant multifold data. However, when the data redundancy is decimated in the framework of efficient frequency-domain FWI, it is essential to assess the sensitivity of the inversion to noise. The impact of the noise in FWI, when applied to decimated data sets, has been marginally illustrated in the past and least-squares minimisation has remained the most popular approach.

We investigate in this study the sensitivity of frequency-domain elastic FWI to noise for realistic onshore and offshore synthetic data sets contaminated by ambient random white noise. Four minimisation functionals are assessed in the framework of frequency domain FWI of decimated data: the classical least-square norm (L_2), the least-absolute-values norm (L_1), and some combinations of both (the Huber and the so-called Hybrid criteria). These functionals are implemented in a massively-parallel, 2D elastic frequency-domain FWI algorithm. A two-level hierarchical algorithm is implemented to mitigate the non-linearity of the inversion in complex environments. The first outer level consists of successive inversions of frequency groups of increasing high-frequency content. This level defines a multi-scale approach while preserving some data redundancy by means of simultaneous inversion of multiple frequencies. The second inner level used complex-valued frequencies for data preconditioning. This preconditioning controls the amount of the data involved in the inversion from the first-arrival time and allows us to mitigate the weight of the complex late arrivals during the first iterations of the inversion.

We applied our FWI approach to the SEG/EAGE overthrust model and the shallow-water Valhall model which is representative of oil and gas fields in North Sea. Results show that the L_1 norm provides the most reliable models for both applications, even when only few discrete frequencies are used in the inversion and outliers pollute the data. The L_2 norm can provide reliable results in the presence of uniform white noise only if the data redundancy is increased by refining the frequency sampling interval in the inversion, at the expense of the computational efficiency. The Huber and the Hybrid criteria are shown to be sensitive to a threshold, which controls the transition between the L_1 and L_2 behaviours, and which requires tedious trial-and-error investigations for reliable estimation. We show that the L_1 norm provides a robust alternative to the classical approach based on the L_2 norm for the inversion of decimated data sets in the framework of efficient frequency-domain FWI.