Earthquake-based Full-Waveform Inversion at the Exploration Scale from Dense Broadband Array Data

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In challenging environments with natural seismicity and where active source acquisition is expensive and dangerous, the question arises whether naturally occurring earthquakes offer useful information for hydrocarbon exploration. Here, we report on an experiment that installed 252/247 receivers to acquire data for two periods of 7 months, in the presence of significant rugged topography (elevations from 500 m to 3500 m). The station density is about 1 per 25 km² (compared to, e.g., USArray, where the average station spacing was 70 km). Data were recorded in a frequency band from 0.2 Hz to 50 Hz. Several thousand seismic events originating within the array bounds were identified in these data. A compressional-speed tomographic velocity model was derived using first-arriving phases. Centroid moment tensor (CMT) solutions have been obtained for about 4% of the identified events using Green's function-based multicomponent waveform inversion, assuming a layered velocity model. We are now working to improve that model by performing elastic full-waveform inversion for three-dimensional compressional and shear-wave speed perturbations, honoring the topography, after a prior full-wavefield-based reassessment of the earthquake source mechanisms. We are also aiming to increase the number of events considered in the inversion while weighting the data based on estimates of data quality. This is assessed with a flexible automated procedure that considers a variety of data attributes over a range of frequencies. We run simulations using the spectral-element package SPECFEM3D on a cluster that employs 4 GPU cards per simulation. We identify the promising areas of good initial fit from the highest-quality seismic traces and gradually bring the predictions in line with the observations via LBFGS model optimization. We review the results of our work so far, discuss how to continue to bring best practices from global seismology down to the regional scale, and consider the implications for using such passive experiments to complement or replace active exploration in such challenging zones.