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Focal Mechanism Determination Using High Frequency Full Waveform Information

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In this investigation, we use high frequency full waveform information to determine the focal mechanisms of small, local earthquakes induced by oil/gas production and monitored using a sparse surface seismic station network. During the waveform inversion, we maximize both the phase and amplitude matching between the observed and synthetic waveforms. In addition, we use the polarities of the first P-wave arrivals and the S/P amplitude ratios to better constrain the matching between the synthetic and observed waveforms. The objective function is constructed to include all four criteria. Due to the complexity in the objective function, it is almost impossible to directly perform an inversion with derivative techniques. Instead, an optimized grid search method is used to search over all possible ranges of fault strike, dip and rake, as well as a predetermined range of earthquake locations. To speed up the algorithm, a library of Green's functions is pre-calculated for each of the moment tensor components and possible earthquake locations. Careful optimizations in filtering and cross-correlation are performed to further improve the grid search algorithm, such that no filtering and cross correlations are performed in searching through the parameter space of strike, dip, and rake. Consequently, speed is boosted tenfold by these optimizations in filtering and cross correlation.

We applied the new method to dozens of induced seismic events in an oil field. The events were randomly chosen from the event catalog with good signal to noise ratio. Satisfactory matching between synthetic and observed seismograms is obtained, and the calculated focal mechanisms of the induced earthquakes are consistent with our knowledge of local geology.