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Focal Mechanism Determination of Induced Microearthquakes in an Oil Field Using Full Waveforms from Shallow and Deep Monitoring Networks

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We present a new method using high frequency full waveform information to determine the focal mechanisms of small, local earthquakes monitored by a sparse surface network and a deep borehole network in a petroleum field. During the waveform inversion, we maximize both the phase and amplitude matching between the observed and modeled waveforms. In addition, we use the polarities of the first P-wave arrivals and the average S/P amplitude ratios to better constrain the matching. An objective function is constructed to include all four criteria. An optimized grid search method is used to search over all possible ranges of source parameters (strike, dip and rake). 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 using the Discrete Wavenumber Method based on the 1-D layered medium from the sonic logs and traveltime tomography results. Optimizations in filtering and cross-correlation are performed to further speed the grid search algorithm.

For the surface network, we first performed a comprehensive synthetic test including 27 synthetic events. The synthetic test shows that our method is robust and efficient even with inaccurate velocity models ($\sim$10% random perturbation) for different hypocenters and source types using only the vertical component of seismograms. Waveforms between 3-9 Hz are used to determine the focal mechanisms of induced seismicity (-0.50$<$ M_w $<$1.0) with the surface network. The method is then applied to the deep network in the same field, consisting of five boreholes with eight-level of receivers at different depths in each borehole. Due to the proximity of borehole receivers to the seismicity, we were able to record the seismograms of very small induced seismicity. Waveforms between 15-40 Hz are used to determine the focal mechanisms. The determined focal mechanisms give a good match in all four criteria in our objective function. The majority of the normal faulting events have a strike direction parallel with the major NE-SW faults in the region, and reverse faulting events have a strike almost perpendicular to the direction. This result indicates that the maximum horizontal stress trends in the NE-SW direction, which is consistent with the well breakout measurement and current knowledge about the stress regime in this area.