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Estimating fracture aperture and related parameters using tube-wave data

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Fracture apertures can be estimated using optical or acoustic televiewer data. However, televiewers detect only fractures that are thicker than a resolution-dependent threshold and the obtained aperture is only representative for the immediate vicinity of the borehole. Tube-waves are waves propagating along a borehole wall, which can be considered as an interface between a solid and a fluid. Tube-waves contain information about the effective hydraulic fracture aperture, which in our case is the constant aperture of a hypothetical fracture that contains the same fluid volume as its observed equivalent.

We aim to estimate the effective fracture aperture through a stochastic inversion approach using full-waveform tube-wave recordings from vertical seismic profiling (VSP) experiments. To sample the solution-space efficiently, we use the DREAM(ZS) algorithm, which is a Markov chain Monte Carlo (MCMC) algorithm exploiting an archive of past states using differential evolution to determine the next step of the Markov chain. We invert for the fracture aperture and inclination as well as for the bulk and shear moduli of the formation. The standard deviation of the data error and the shape of the source-wavelet are inferred as well. The algorithm exploits the amplitude ratio between the incident P-wave and the generated tube-wave. As the preprocessed VSP recording serves as input, no picking of events is required.

The algorithm assumes zero-offset VSP data, which places the seismic source at the wellhead. Furthermore, it is assumed that the background medium is homogeneous. In the presence of an inhomogeneous background, we subsequently invert for sections along the borehole, which can be considered as being approximately homogeneous. As the whole medium between the seismic source at the borehole top and the section under investigation is considered homogeneous, the source-receiver distance needs to be virtually elongated or compressed to compensate for variations in the background moduli above the considered section. This can be done by adding the vertical location of the source position as an additional unknown parameter.

First experiments with synthetic data featuring constant background parameters demonstrate that the algorithm is capable of retrieving the fracture aperture and the elastic formation moduli, even in the presence of multiple fractures with different apertures and inclinations. Thereby, the standard deviation of the data error and the shape of the wavelet are adequately estimated. Conversely, the inclinations of the fractures can only be constrained with significant uncertainties.