EGU24-14828, updated on 21 Nov 2024
https://doi.org/10.5194/egusphere-egu24-14828
EGU General Assembly 2024

Spatio-temporal evolution of hypocenters and moment tensors derived from time-reverse imaging

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The location and focal mechanism of microseismicity induced during fluid injection experiments in geothermal wells can be used to infer the extent of fracturing and the orientation of the local stress field. Passive seismic instrumentation is typically deployed at the surface and in boreholes around the injection site to monitor microseismic activity. Recent methodological advancements enable locating the often thousands of seismic events in a timely fashion. However, the determination of focal mechanisms is often limited to a selected number of larger-magnitude events.

Time-Reverse Imaging (TRI) exploits the time-invariancy of the elastic seismic wavefield to propagate the seismic wavefield backwards in time from seismic stations through an adequate velocity model. Under ideal conditions, the wavefield will converge on the initial source location at the origin time. The excellent location accuracy for events with signal-to-noise ratios smaller than one and the capability of determining the moment tensor for each locatable event has been demonstrated in controlled synthetic and real studies. Numerous improvements and adaptations have been proposed to augment the resulting image volume used to identify individual seismic events. TRI is a promising one-stop solution for analyzing microseismicity but has two major disadvantages: (1) the computation time needed to simulate the high-frequency elastic wavefield prohibits the analysis of continuous hours or days of microseismic recordings, and (2) the identification of individual seismic events from TRI image volumes is susceptible to overestimating the number of seismic events due to noisy images.

Alterations of the TRI concept based on pre-computed Green's functions exist and provide a near-real time solution but require compromises in terms of location accuracy and minimal signal-to-noise ratio. The focal mechanism cannot be identified yet with these types of methods. Thus, the main challenge of applying TRI is reducing the needed computational time, while retaining most beneficial capabilities. This balancing act requires a careful analysis of possible compromises

through careful scaling of simulation parameters.

Here, we apply TRI to synthetic seismic recordings created with the sensor setup deployed during the injection experiment in April 2022 at the UtahFORGE test site. A combined elastic velocity model of the complex site geology is used with a network including real locations of fiber optic cables, deep and shallow borehole sensors, and nodal seismic sensors. This synthetic data is used to demonstrate the accuracy gain of using multiple types of sensors and the speed gain of using characteristic functions applied to the seismic recordings prior to back propagation. Accuracy and speed are compared for synthetic and real test cases to optimize their trade-off. Finally, instead of individually picking seismic events, we demonstrate the usefulness of interpreting the spatio-temporal evolution of hypocenters and moment tensors directly from the TRI results.