Revealing Fracture Planes with a High-Resolution Catalog of Induced Microearthquakes

Chengping Chai, Monica Maceira, Hector J. Santos-Villalobos,
Singanallur V. Venkatakrishnan, Martin Schoenball, Pengcheng Fu, Clifford Thurber,
Paul C. Schwering, Timothy C. Johnson, Hunter A. Knox, and EGS Collab Team

Description of the Supplemental Material
The supplemental material includes a figure showing the recovered checkerboard P- and S-wave models (Figure S1); a figure comparing the seismic event locations updated with a fixed homogeneous velocity model and through double-difference tomography (Figure S2); a figure showing the P- and S-wave residuals with and without tomography (Figure S3); a paragraph documenting the calculation of the first Fresnel zone (Text S1); a video showing a comparison of the original and updated seismic catalogs using an interactive visualization (Video S1).

Text S1.
The dominate frequency (f) of the recorded passive seismic signal is around 3-20 kHz. The majority (68%) of measured travel times (t_0) range from 1.4 to 3.7 ms. The average P-wave velocity (v) is 5.9 km/s. Using the following formula from Chai et al. (2020), the first Fresnel zone width (r) ranges from 1 to 5 m.

$$r = v\sqrt{\frac{t_0}{2f}}$$

The dominate frequency (f) of the active source signal is around 5-10 kHz. The majority (68%) of the source-station distance (d) ranges from 11 to 42 m. Using the same P-wave velocity and the following formula, the first Fresnel zone width ranges from 2 to 5 m.
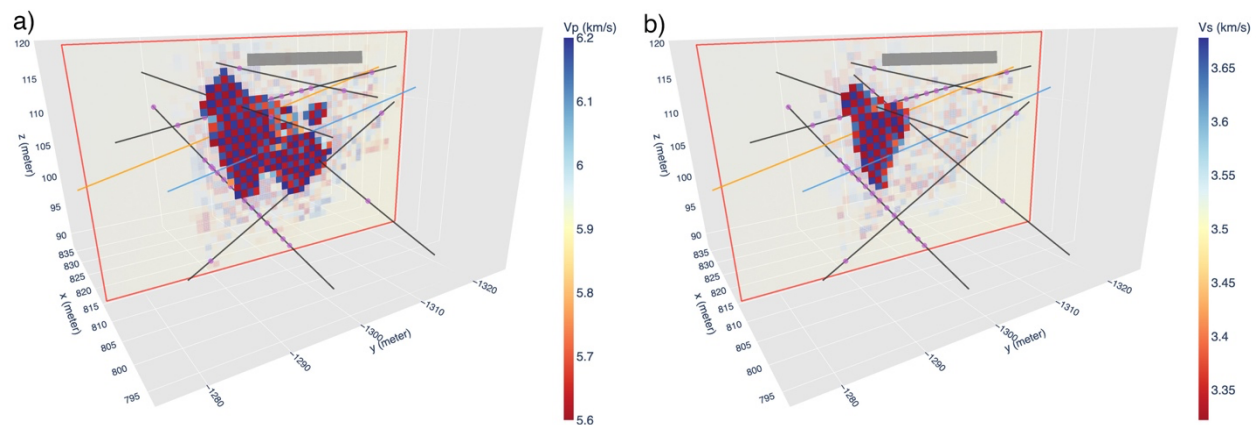
$$r = \sqrt{\frac{d \cdot v}{2f}}$$

Figure S1. Slices of the recovered (a) P- and (b) S-wave seismic velocity model when the source are fixed at the original locations using data simulated with a checkerboard model. The highlighted area is better recovered. The dimmed area is not well constrained due to lack of data coverage.
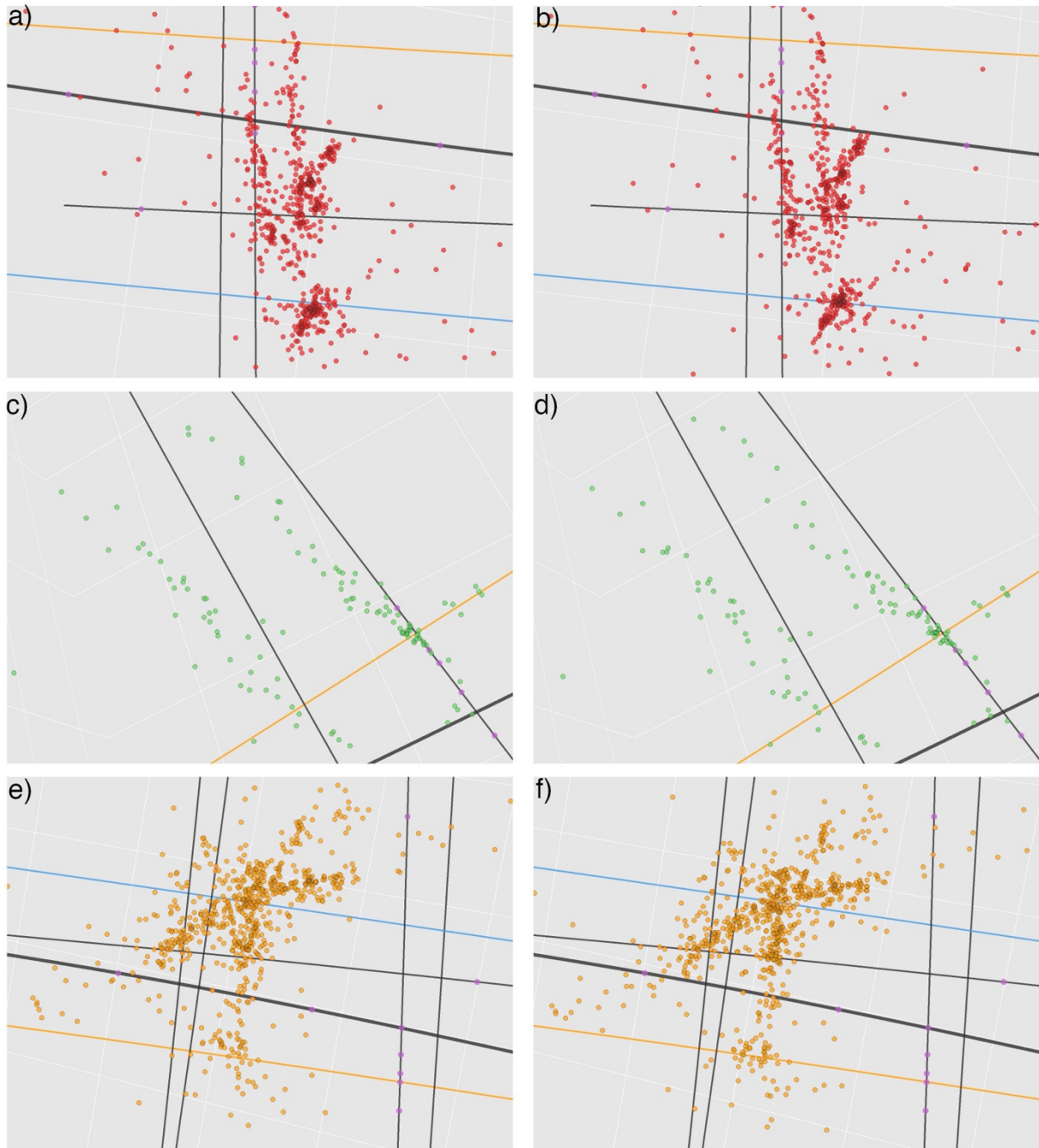
Figure S2. Comparisons of updated seismic event locations (dots) using a fixed homogeneous velocity model (a, c, and e) and with the velocity structure inverted simultaneously (b, d, and f). (a) and (b) correspond to stimulations in May 2018. (c) and (d) correspond to stimulation in June 2018. (e) and (f) correspond to stimulations in December 2018. Colored lines are the same as in Figure 9.
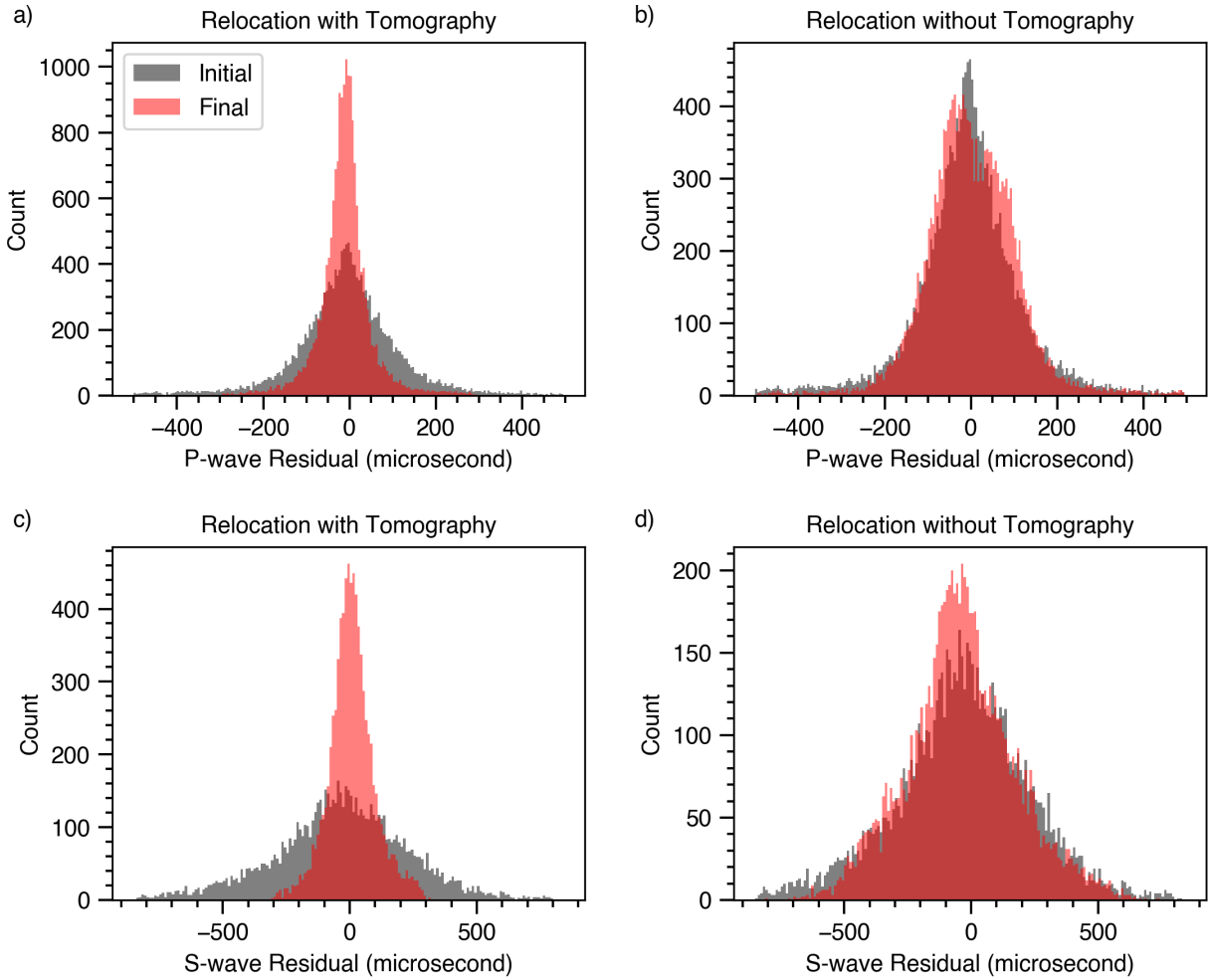
Figure S3. Histograms showing (a and b) P-wave and (c and d) S-wave residuals for inversions with the optimal inversion parameters. The seismic event locations were updated without tomography in (b) and (d). The event locations were relocated with tomography (a) and (c).

Video S1. A screen recording of an interactive visualization that compares the original and updated seismic catalogs in 3D.