Centroid full moment tensor analysis of induced seismicity reveals fluid channels opened by EGS in the Helsinki region, southern Finland

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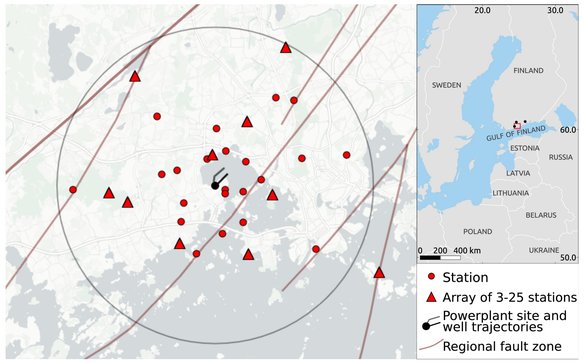
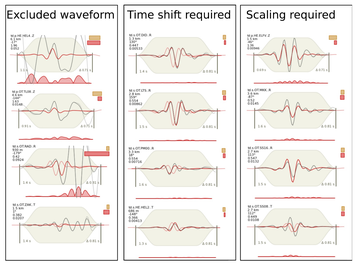
Introduction

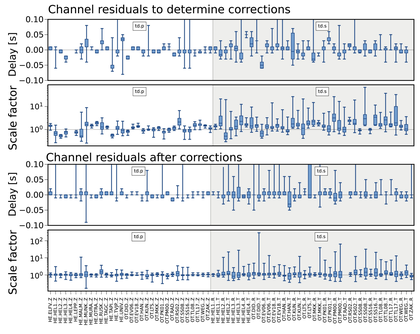
The goal of an enhanced geo-thermal system (EGS) is efficient energy extraction by increased fluid circulation between geothermal wells. Investigating the source processes of earthquakes induced by EGS stimulations yields insight into earthquake nucleation and fluid-rock interactions. The experimental 6-km-deep EGS in the Helsinki capital region, southern Finland is an intriguing natural laboratory in a cool Precambrian shield setting that yields excellent seismic data quality.

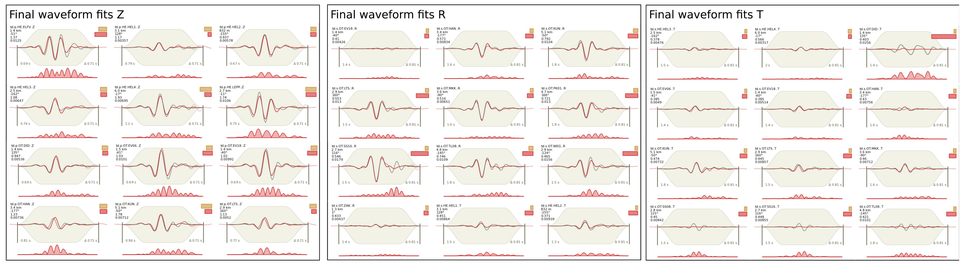


Methods

- Centroid full moment tensor analysis with the probabilistic source inversion tool Grond [1]
- P- and S-waveform fitting
- Synthetic waveforms are based on random source parameters and a homogeneous velocity model
- High signal-to-noise ratio waveforms are selected automatically
- Channel-wise correction coefficients for time shifts and amplitude scaling represent small scale crustal variations
- The application of both waveform selection and channel corrections improves solution quality substantially

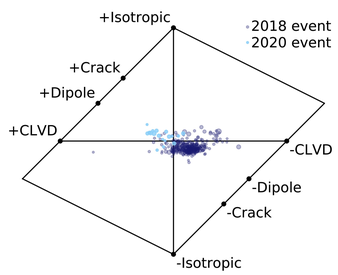


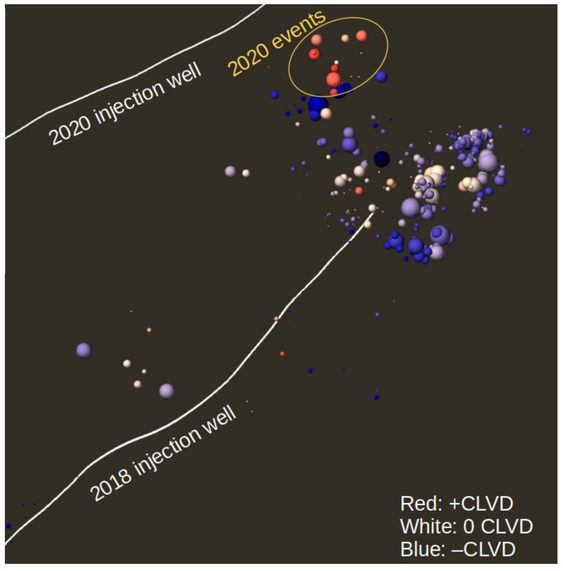


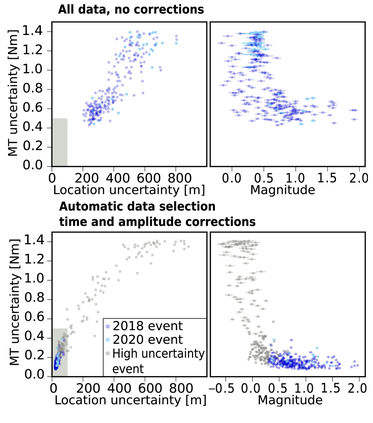


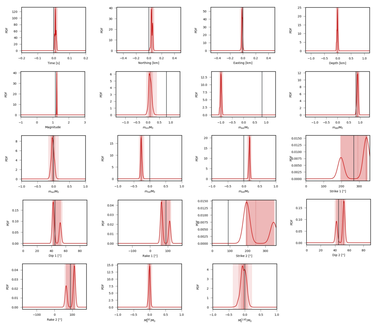
Results

- Results for 283 events from the 49-day 2018 stimulation and 18 events from the 16-day 2020 stimulation in the moment magnitude range 0.3–1.9 are presented
- The solutions are dominated by reverse faulting mechanisms
- The DC component is usually dominant with variable CLVD and small isotropic components
- 2018 events shows average compressive non-dc component, whereas 2020 events show an average opening component
- Within the 2018 event distribution trend towards more negative CLVD with increasing distance to the injection well
- Clustering analysis of the DC component reveals different fracture sets in different parts of the stimulated rock volume



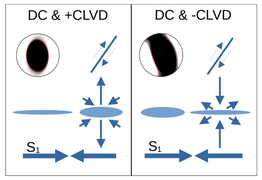


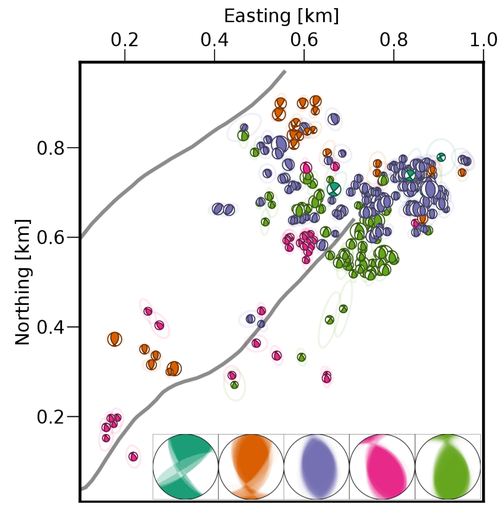




Discussion

The 3D event distribution reveals spatial variation in the physical source processes and suggests a dependance between fracture processes and pore pressure. Positive CLVD contribution in seismic sources close to the injection well indicates localized fracture opening under constant volume with a simultanous adjacent shear event. Farther from the well, seismic sources have negative CLVD contribution which is indicative of fracture lengthening under constant volume. The closing component in the 2018 event distribution and the opening component in the 2020 event distribution suggest a difference in the local stress conditions. A closing component in the earthquake source in a crystalline rock medium under a highly compressive stress field suggests aseismic fracture opening and volume increase prior to fracture lenghtening and closing during earthquake rupture.





Conclusions

- High quality data sets from a crystalline shield setting enables inversion of high resolution moment tensors with a probabilistic waveform fitting method
- CLVD component indicates opening or closing of fluid filled fractures
- Different fracture sets can be indentified in DC mechanism clusters
- Event nucleation process varies with pore pressure gradient

References

[1]Kühn, D., S. Heimann, M. P. Isken, E. Ruigrok, and B. Dost (2020). Probabilistic Moment Tensor Inversion for Hydrocarbon-Induced Seismicity in the Groningen Gas Field, The Netherlands, Part 1: Testing, Bull. Seismol. Soc. Am. 110, 2095–2111, doi: 10.1785/0120200099

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