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Magnitude estimates of earthquakes induced by the geothermal stimulations in Espoo/Helsinki, southern Finland: a comparison of different approaches

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In 2018 and 2020, two weeks-long geothermal reservoir stimulations were performed some 6 km below the Helsinki capital area, Finland. The seismic activity was recorded by a set of surface broadband sensors and 100 geophones installed by the Institute of Seismology, University of Helsinki, as well as Finnish National Seismic Network stations. The local magnitudes (M_L) of the recorded earthquakes are estimated using a Finnish local magnitude scale and the local magnitude of the largest induced event was 1.8. We apply three different approaches for estimation of moment magnitudes (M_W) to a data base of ~400 induced seismic events from the 2018 stimulation to explore the variability and sensitivity of the magnitude estimates. This is important for real-time monitoring and decision making when the induced event magnitudes approach the pre-defined magnitude limit, and to assess which trends can be robustly associated to earthquake source physics. (1) We employ a time-domain calculation of source parameters based on the application of Parseval's theorem to the integrals of the squared spectral displacement and velocity for the horizontal S-wave trains. The time window between the S-wave arrival time and twice the length of the S-wave travel time is considered for the S-wave train isolation. (2) We obtain moment magnitude estimates from an inversion of 50 s long three-component envelopes based on radiative transfer. (3) We apply a moment tensor inversion to 0.71 s long P and 0.81 s long S-wave signals. We fit a linear M_L-M_W conversion model to the values obtained from the different approaches. Considering the available local magnitude range between –0.5 and 1.8, a comparison of the linear conversion models shows that the moment magnitudes form the envelope inversion are systematically larger by ~0.2 units compared to those obtained from the moment tensor inversion. While the moment magnitudes determined by the time-domain calculation consistently exceed those of the envelope inversion for small local magnitudes (by ~0.2 units), they tend to yield similar estimates towards the larger local magnitudes. Other source parameter systematics include that the smallest seismic moment is obtained with the moment tensor inversion, and the largest with the time-domain equivalent of the spectral integrals. An initial extension of the analysis to 2020 data yields M_L-M_W as well as corner frequency-M_W scaling relations that are, interestingly, different compared to the 2018 results; we will present updated results that inform about the reliability of these trends.