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The variability of seismo-acoustic nuisance patterns: a case study from the Helsinki geothermal stimulation

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With this contribution, we expand the discussion of effects that earthquakes induced by geo-energy projects can have on local communities, and that should probably be considered in future legislation or permitting processes. Inspired by consistent reports of felt and heard disturbances associated with the weeks-long stimulation of a 6-km-deep geothermal system in 2018 below the Otaniemi district of Espoo, Helsinki, we conduct numerical simulations of wave propagation in the solid earth and the atmosphere to assess the sensitivity of the ground shaking and audible noise patterns to various parameters. We explore the effects of three different local velocity models, realistic topography, variations of the source mechanism, and earthquake size on the loudness of the synthetic waves at frequencies up to 20 Hz, therefore reaching the lower limit of human sound sensitivity. We discuss the results of 18 elastic-acoustic coupled scenario simulations conducted on the Mahti high-performance computing infrastructure of the Finnish IT Center for Science CSC using the SeisSol wavefield solver. The computationally challenging simulations target the Otaniemi case study, i.e., we discretize a 12 km x 12 km x 15 km domain with a 2 km thick air layer over the solid earth domain. The earthquake point source is located at the 6.5 km deep location of the largest M1.8 event induced by the stimulation. In the target central area, we use a mesh with element lengths of about 14 m in the air and 97 m in the solid earth. Inside each element, we approximate the solution by a fifth-degree polynomial, by which we achieve a resolution of roughly 2.3 m in the air and 16 m in the earth. We develop an interactive visualization to facilitate instant access to the results governed by the different parameter combinations, where the synthetics are shown on top of a map of the Helsinki metropolitan region. This tool facilitates "what-if" analyses by quickly comparing the effects of fault orientation, source mechanism, and the velocity model. This supports effective communication of physics-based nuisance analysis to decision-makers and stakeholders, not only in environments such as the case study where there is little experience with natural earthquake phenomena. Together, these results resolve for the first time synthetic nuisance sound patterns at the 50 – 100 m scale in a densely populated capital region. The study highlights the mostly disregarded spatially variable audible effects that can negatively impact the public attitude towards geothermal stimulations, even if the ground shaking limits are safe, and it provides first estimates of the resources needed for comprehensive scenarios for future stimulation projects.