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Macroseismic observations of micro-earthquakes induced by an enhanced geothermal system

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Abstract

We report on macroseismic observations related to micro-earthquakes induced by an enhanced geothermal system in the capital region of Finland.
The largest induced event had a local magnitude of approximately 1.8 and was observed up to distances of almost 10 km on a Sunday evening.
We distinguish reports on heard disturbances – typically described as thunder- or blast-like – from combined shaking and sound sensations. The transmission of energy at frequencies that cause a variety of sensations is reflected in the reports as difficulty to describe the character and origin of the phenomena.

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Reference

Hillers G, Vuorinen TAT, Uski MR, Kortström JT, Mäntyniemi PB, Tiira T, Malin PE, Saarno T (2020) The 2018 geothermal reservoir stimulation in Espoo/Helsinki, southern Finland: Seismic network anatomy and data features. Seismological Research Letters 91(2A):770-786. https://doi.org/10.1785/0220190253

Introduction

Observations of ground shaking can be reported using the macroseismic questionnaire of the Institute of Seismology, University of Helsinki, Finland (ISUH). The online macroseismic data are obtained without any survey launched by seismologists. Combined with the denser seismic networks available today this means that macroseismic observations can often be associated with very small events, far below local magnitude M_L1, if they are shallow and occur close to population centers. This is attributed to the crystalline bedrock and low attenuation of seismic waves.

The reports obtained online since the early 2000s reflect the overall low level of natural seismicity in the country. The reports are mostly associated with local low-magnitude earthquakes, regional and global earthquakes, explosions, cryoseisms, and supersonic booms. The high rate of induced earthquakes related to the stimulation experiment of an enhanced geothermal system in 2018 thus represents a new phenomenon that led to more frequent macroseismic reporting in the capital region, documenting the effects of small-magnitude-induced seismic events on residents.

Methods and Materials

The macroseismic questionnaires related to small seismic events report transient observations by residents. They are at the threshold of human perception and do not allow an intensity assignment. The questionnaires discern between tremor and/or an acoustic effect, which is an individual judgement by each respondent. The observations belonging to the same time are plotted in a map, and their spatial distribution is analyzed.

Figure 1 shows 83 macroseismic datapoints, blue dots denote those reported as "tremor and sound" and red dots as "sound".

Figure 1. Macroseismic map for the largest induced seismic event on 8 July 2018 (M_L ~1.8).

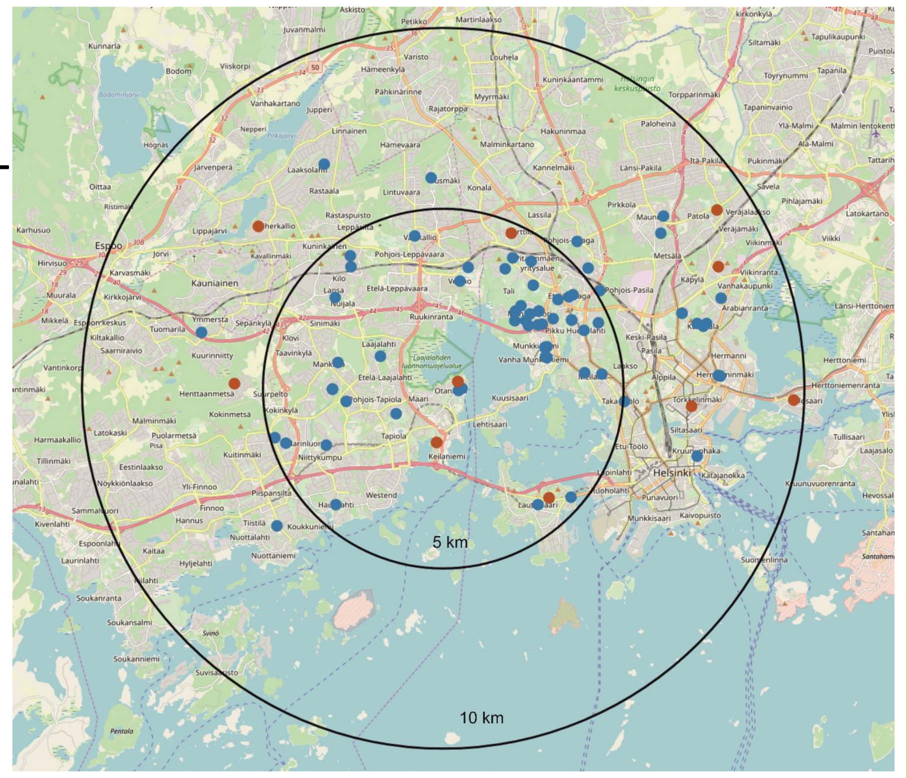
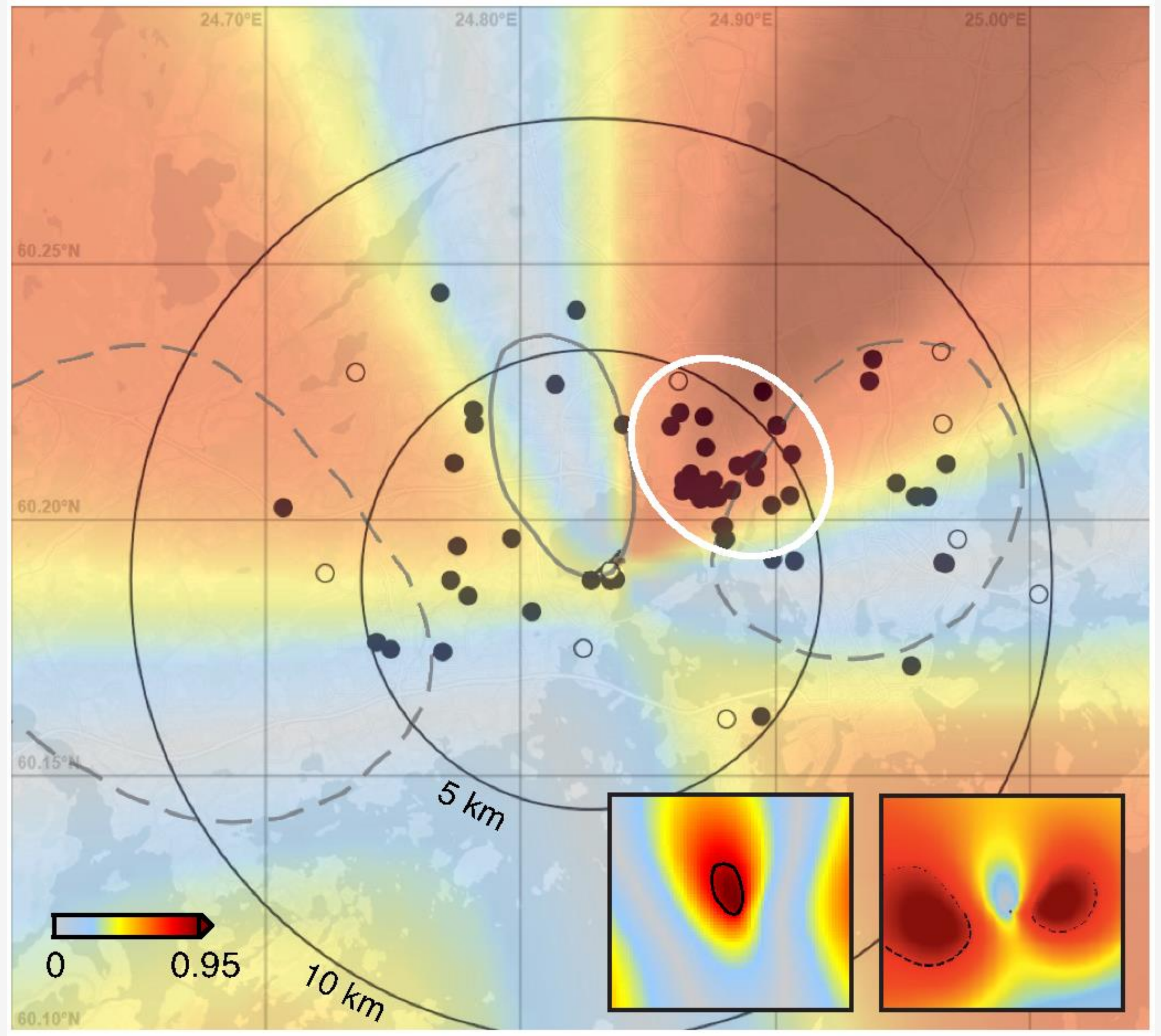


Figure 2. SH-wave radiation pattern of the largest induced event in 2018. Absolute values are shown.



Results

Figure 2 shows the SH-wave radiation pattern of the largest induced earthquake with M_L ~1.8 (Fig. 1). Absolute values are shown. Filled and open circles correspond to locations from which felt and heard disturbances were reported, respectively. The white ellipse indicates Munkkivuori and adjacent neighborhoods, where events repeatedly disrupted nighttime sleep. These neighborhoods are located in the direction of the strongest SH radiation. Solid and dashed contours correspond to the P-wave and SV-wave radiation patterns shown in the insets. Values are scaled by the maximum in each distribution. Attenuation is not accounted for.

Discussion

ISUH collected a total of 220 responses during the stimulation in 2018. Responses to four of the largest induced earthquakes with magnitudes in the M_L 1.6-1.8 range contribute to more than 60% of the reports. The anthropogenic activity pattern modulates the observation and response threshold. The M_L 1.4 event on Thursday 5 July, at 10:01 local time, passed almost unnoticed, whereas effects associated with the M_L 1.8 event on Sunday 8 July, 20:36 local time, were widely reported (Figs. 1,2).

Some respondents reported that they had been observing ground vibrations many times during some weeks before submitting their questionnaire. However, the times of these events were not specified, which challenges an overall assessment of how many induced earthquakes were observed by the general public.

The macroseismic observations collected by ISUH cover a range of attitudes toward the experienced disturbances.

Conclusions

We conclude that the main features of the public response pattern are, fundamentally, controlled by the tectonic situation, that is, by the radiation pattern of reverse faults that are activated by the fluid injection. Secondary geological or societal effects such as variations in the propagation medium and local soil properties, the population density, or the affinity to report the phenomena likely explain the variable density of points in areas that experience similar radiation-pattern-controlled ground motions.