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# Optimizing Seismic Monitoring Networks for EGS and Conventional Geothermal Projects

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In the past several years, geological energy technologies receive growing attention and have been initiated in or close to urban areas. Some of these technologies involve injecting fluids into the subsurface (e.g., oil and gas development, waste disposal, and geothermal energy development) and have been found or suspected to cause small to moderate sized earthquakes. These earthquakes, which may have gone unnoticed in the past when they occurred in remote sparsely populated areas, are now posing a considerable risk for the public acceptance of these technologies in urban areas. The permanent termination of the EGS project in Basel, Switzerland after a number of induced ML$\sim$3 (minor) earthquakes in 2006 is one prominent example.

It is therefore essential for the future development and success of these geological energy technologies to develop strategies for managing induced seismicity and keeping the size of induced earthquakes at a level that is acceptable to all stakeholders. Most guidelines and recommendations on induced seismicity published since the 1970ies conclude that an indispensable component of such a strategy is the establishment of seismic monitoring in an early stage of a project. This is because an appropriate seismic monitoring is the only way to detect and locate induced microearthquakes with sufficient certainty to develop an understanding of the seismic and geomechanical response of the reservoir to the geotechnical operation. In addition, seismic monitoring lays the foundation for the establishment of advanced traffic light systems and is therefore an important confidence building measure towards the local population and authorities.

We have developed an optimization algorithm for seismic monitoring networks in urban areas that allows to design and evaluate seismic network geometries for arbitrary geotechnical operation layouts. The algorithm is based on the D-optimal experimental design that aims to minimize the error ellipsoid of the linearized location problem. Optimization for additional criteria (e.g., focal mechanism determination or installation costs) can be included. We consider a 3D seismic velocity model, an European ambient seismic noise model derived from high-resolution land-use data, and existing seismic stations in the vicinity of the geotechnical site. Additionally, we account for the attenuation of the seismic signal with travel time and ambient seismic noise with depth to be able to correctly deal with borehole station networks. Using this algorithm we are able to find the optimal geometry and size of the seismic monitoring network that meets the predefined application-oriented performance criteria.

This talk will focus on optimal network geometries for deep geothermal projects of the EGS and hydrothermal type, and discuss the requirements for basic seismic surveillance and high-resolution reservoir monitoring and characterization.