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# The induced Basel 2006 earthquake sequence: Statistical properties and a new probability-based monitoring system

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To stimulate the reservoir for a proposed enhanced geothermal system (EGS) project in the city of Basel, approximately 11500 m3 of water were injected between December 2nd and 8th, 2006, at high pressures into a 5 km deep well. A six-sensor borehole array, installed by Geothermal Explorers Limited at depths between 300 and 2700 meters around the well to monitor the induced seismicity, recorded some 11200 events during the injection phase, more than 2400 of them locatable. The largest reached ML 3.4 and was strongly felt in the city of Basel. We study the statistical properties of this unique dataset, with a focus on: 1) Unraveling the space-time history of recording completeness, a necessary step for subsequent analysis; 2) Mapping the spatial and temporal evolution of seismicity parameters (earthquake productivity 'a' and earthquake size distribution 'b') with the aim of relating observed seismicity parameters with physical properties (stress evolution, fluid migration etc.); 3) Modeling the decay of the sequence once injection was terminated, with the aim of forecasting how the seismicity will evolve in the coming months and years; 4) Modeling the seismicity during the injection phase in order to develop and calibrate probabilistic forecasting tools that may help in real-time monitoring and decision making for future EGS systems.

We analyze seismicity parameters in map and cross-section for different time windows: The entire sequence from 3.12.2006 to 19.06.2007 and the sequence before the M3.4 event on 8.12.2006. The b-values vary from 0.8 to 1.8, a-values between 1.5 and

3 and the completeness from M-0.2 to M0.2. High b-values often coincide with low completeness values and vice versa, especially in the cross sections. High b-values are found in the NW part of the volume, intermediate values are found around the casing shoe, where the water was injected. The smallest b-values are found in shallower parts to the SE.

Our study shows that the still ongoing decay of seismicity can be modeled using the Omori-Utsu aftershock decay law. Considering the uncertainties both in the modeling of the aftershock sequence decay and in the background rates inferred from the past 25 years of regional monitoring, it will take between 5-28 years for the seismicity to return to the regional background rate at the 95% confidence level. To model the driven part of the sequence we treat each earthquake as independent and sum their generic triggering probabilities as a function of time. We then convert the resulting forecasted rates of events for all magnitude bins into hazard, using standard intensity based ground motion relationships. The resulting time-dependent hazard assessment could be used to design a novel probabilistic real-time monitoring system for enhanced geothermal systems, allowing for the definition of hazard or risk based thresholds for guiding the injection pressure evolution.