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Real time seismic traffic light systems for hydraulic stimulations in deep geothermal systems

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In order to mitigate the risk associated with induced seismicity caused by hydraulic stimulations in deep geothermal systems so called traffic light systems (risk management plans) are used. These systems consist of a local seismic monitoring and an estimate of the current seismic hazard based on observed induced seismicity. The current hazard is compared to threshold values. Measures to reduce the seismic hazard (e.g. reducing the flow rate) specified in the risk management plan are taken, if thresholds are exceeded. Standard traffic light systems use the largest recorded magnitude or peak ground velocity to estimate current seismic hazard caused by induced earthquakes. We developed a real time technique that computes the probability of exceedance for an undesired magnitude using a statistical analysis of recorded micro-seismicity. Based on the in real time generated earthquake catalogue, we compute the magnitude of completeness, the b-value of the Gutenberg-Richter law, and the so-called seismogenic index. These three quantities are updated in real time, if more induced earthquakes are detected. Using the flow rate of the hydraulic stimulation, which we assume to be recorded in real time as well, we calculate the expected seismicity for the next hours. In particular, we compute the probability of exceedance for a predefined critical magnitude. The value is permanently updated and compared to predefined threshold values of the traffic light system. Additionally to the scenario of a continued stimulation with the current flow rate, we also consider the case of an immediate shut-in. For this scenario the probability of exceedance is computed using a modified Omori law. The developed algorithm is implemented in the real-time earthquake monitoring software SeisComP3 including a graphical user interface. So far the traffic light algorithm has only been tested in playback mode simulating a real time scenario. For example, using data of the Basel Deep Heat Mining project and selecting a probability of exceedance of 60 percent for a critical magnitude of ML = 2.7, our traffic light algorithm turns from green to amber four hours before the first magnitude 2.7 earthquake in Basel, and it turns to red two hours before this event.