Detection of rate change of induced seismicity using ETAS model

*Hideo Aochi[1], Julie Maury[1], Thomas Le Guenan[1]

1. BRGM

ETAS (Epidemic-Type Aftershock Sequence) model (e.g. Ogata, 1983, 1988) is widely used for natural seismicity, mostly supporting the stationarity of the background seismicity rate caused by tectonics. On the other hand, induced seismicity rate evolves with on-going operation (fluid injection, etc.) and the assessment of non-stationary seismicity is important. In this study, we apply the ETAS model to detect the seismicity change and aim to characterize the obtained ETAS parameters with the operation information such as injected fluid volume.

A standard, stationary ETAS model consists of five parameters (μ, K, α, c, p). The first parameter μ (number of earthquakes par day) is usually considered stationary. The other four concern the cumulative effect of the triggered events. The ratio between μ and K tells that the importance of the "induced" events with respect to "triggered" ones in a sequence. However no explicit formulation of variable μ is known for non-stationary seismicity. Therefore, we are going to decluster the observed seismicity into μ (hereafter called "declustered seismicity rate") and the triggered part.

We have applied ETAS model on different data sets: 2000 Soultz-sous-Forêt, France (stimulation test at deep geothermal site), 2010-2013 Rousse, France (CO_2 storage experiment in depleted gas reservoir) and 2010-2018 Oklahoma, USA (waste water injection, principally). In particular, the seismicity in Oklahoma expands in space and time due to massive injection from multiple wells. We carry out a systematic regression on Oklahoma data (Oklahoma Geological Survey). Spatially, we select each area with a radius of 20 km to have a sufficient number of earthquakes. Temporally, we fix a time window of 200 events, shifting by 50 events, such that the regression is stable enough. After some trials, we determine two variables of interest (μ, K) by fixing the three other parameters. Figure 1 shows the regression result on the declustered seismicity rate μ and the total injected volume on the same area based on the data reported by Oklahoma Corporation Commission, Oil and Gas Division. The variable K does not change significantly. In Figure 1, total volume injected in Arbuckle layers is calculated for each area, and μ is calculated at the 53 areas where there are more than 250 earthquakes recorded of magnitude larger than and equal to 2.3 between 2010 and 2018. The peaks of μ appears from the end of 2014 to 2015. We find that the appearance of high μ does not always corresponds to the high injected volume area

We then analyze among the parameters. The acceleration of μ can be fitted through an exponential function of normalized total injected volume with a ceiling (μ_{max}). After the peak, the attenuation phase can be fitted with an exponential decay of time passed. The values of μ_{max} (about 3-4 eq/day at maximum among them) are not related to the injection itself so that this should be an intrinsic seismic potential at each area. The acceleration and attenuation rates show certain tendency with the other parameters. For example, μ may not increase rapidly for a high μ_{max}. At average, a coefficient of 0.83 (yr^{-1}) is found for an exponential equation of decay. This is much slower (by a factor of 10 and more) than the one we found in the Rousse case. This is because the injection continues anyway in the Oklahoma case.

In conclusion, our statistical analysis allows to follow (forecast) the seismicity evolution with the injection once it begins. However, it is hard to precise the turning points (beginning of the seismicity increase and its peak). The parameters (seismic potential) should be information to learn from the field and understanding the turning points needs mechanical insights within a fracture system.

Acknowledgement: This work benefits the fundings through GEODENERGIES Miss-CO2 (° 10-IEED-0810-03) and the European Union's Horizon 2020 research and innovation programme under grant agreement number ENER/H2020/764531/SECURe.