Towards calibrating an automatic detection system to monitor micro-seismic activity induced by geothermal projects in the Upper Rhine Graben

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ABSTRACT

The seismic monitoring of the Rittershoffen EGS project (Alsace, France) is performed in real time by an automatic detection system. This system is well-adapted since the biggest events are detected and accurately located using the maximum number of stations. However, it may be important to detect as many events as possible and to lower the magnitude of completeness of the automatic system, in order to better understand reservoir characteristics such as its geometry, its behaviour during the exploitation or its evolution with time. Moreover, geothermal projects are monitored by a growing number of stations, meaning that manual repicking of events will be more and more time consuming, and therefore expensive. It means that one has to rely more and more on automatic detection systems, not only to detect but also to accurately and consistently pick and locate as many events as possible and avoid fake events. In this paper we present the calibration and the improvements performed on the automatic detection system used to monitor the Rittershoffen EGS project.

1. INTRODUCTION

Designed to produce 24 MWth (170 °C, 70 L/s) with a doublet, the Rittershoffen EGS project is located 6 km eastwards of the well-known Soultz-sous-Forêts EGS project, in Northern Alsace, France. The first well, GRT-1, reached its final depth of 2580 m MD end of 2012 for targeting local normal-faults located at the interface between the clastic Triassic sandstones and the top crystalline basement. Numerous logs and hydraulic tests were performed beginning of 2013 and it has been decided to develop the permeability between the well and the reservoir. A reservoir development strategy has been performed and the results were positive, since the injectivity of the well was multiplied by a factor of five (Baujard et al 2015, Maurer et al 2013 and 2015, Recalde Lummer et al 2014). The second well, GRT-2, was drilled from March to August 2014 using a HH300 drilling machine. This machine is able to hang 270 t and was used to drill a deviated well of 3200 m length down to 2707 m depth TVD. After the drilling phase, production tests and circulations tests were performed. No reservoir development was required since production tests revealed a sufficient initial productivity index for developing an industrial project (Baujard and al 2015).

Before, during and after drilling operations, induced seismicity was monitored by a series of sensors. Since 2012, the induced micro-seismicity of both Soultz-sous-Forêts and Rittershoffen geothermal projects has been monitored by two joined permanent seismic networks composed of 12 surface stations in total (see Figure 1). As some induced seismic activity was expected during the reservoir development of the first Rittershoffen well, GRT-1, the permanent seismic monitoring network has been reinforced with a temporary short-period network:

- The Soultz seismic network is composed of short-period (1 Hz) seismometers, one or three components (L4C/L4C 3D), deployed at surface. Signals are digitized on site by 15-bit GEOSTAR data loggers and sampled at 150 Hz. The signals are then transmitted to a central site via a radio link where samples are synchronized with an external time receiver (DCF). At the central site, a SeisComp3 plugin fetches the GEOSTAR formatted data and makes it available through SeedLink to Strasbourg University (EOST), via an internet connection.
- The Rittershoffen seismic network is composed of short-period (1 Hz) three components seismometers (L4C 3D), deployed at the surface. Signals are digitized by Quanterra Q330S directly in miniSEED format at a sampling rate of 100 Hz, increased to 200 Hz by beginning of 2014, and are sent to a central site via a Wifi connexion. Here a SeisComp server makes data available to the Strasbourg University (EOST) via internet. Unlike the Soultz network, this architecture prevents any data losses in case of transmission failures since the data are always available at the server installed in the field.

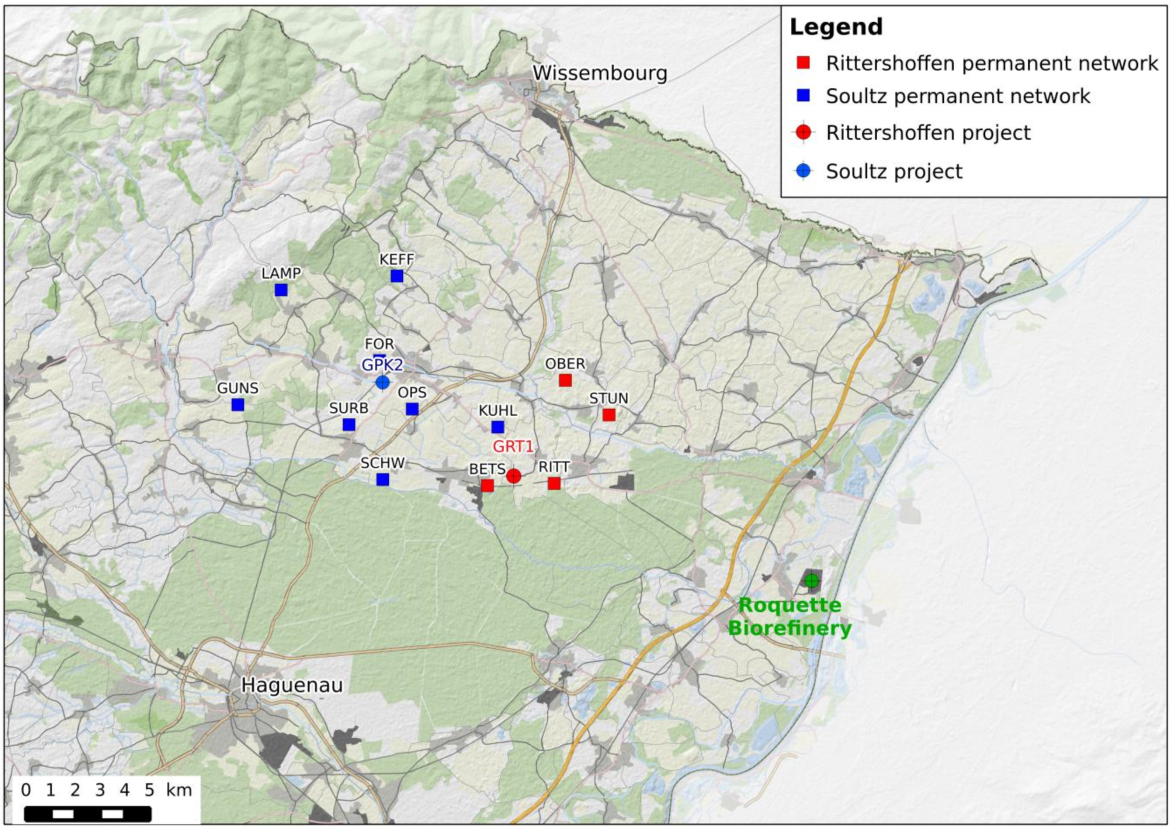

Figure 1: Map of the permanent seismological network designed to monitor the Rittershoffen and the Soultz EGS projects

As some induced seismic activity was expected during the reservoir development of the first Rittershoffen well, GRT-1, the permanent seismic monitoring network has been reinforced with a temporary short-period network. In total, up to 300 short-period stations were installed in a range of 25 km around the drilling platform (Gaucher et al 2013, Le Chenadec et al 2015, Lehujeur et al 2013, Lehujeur, 2015, Maurer et al 2015). This set-up varied as a function of the performed operations (see Figure 2). This temporary network was finally dismantled end of November 2014. It remained deployed after the production tests, so five months after the end of the drilling phase of the second well of the project.

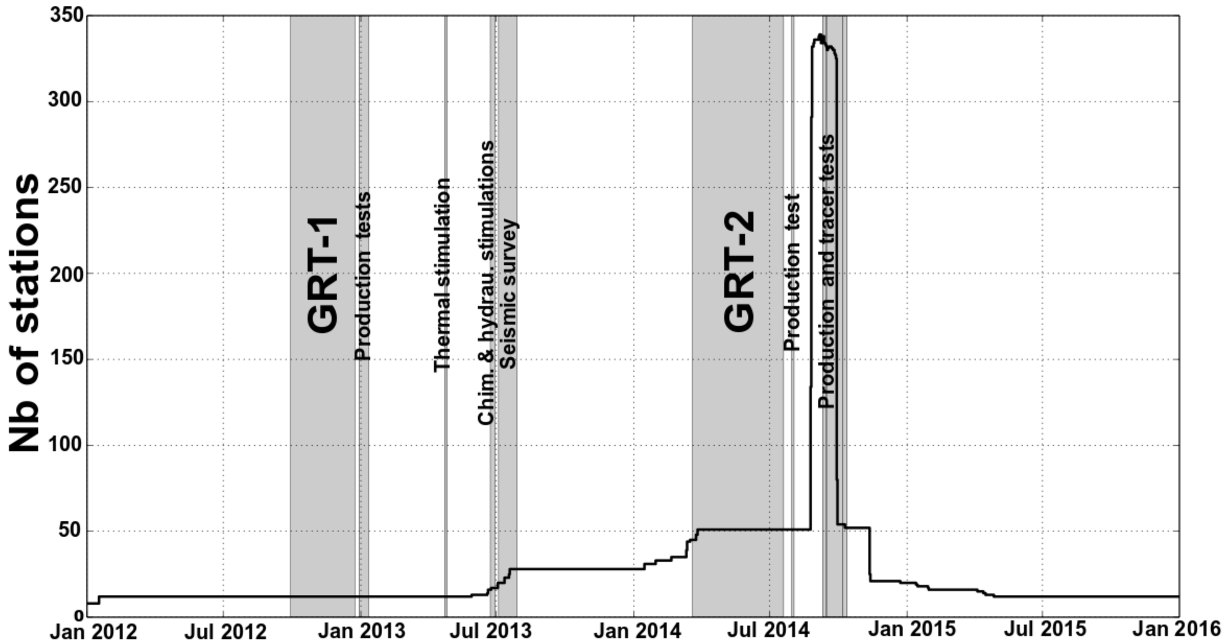

Figure 2: Number of stations installed as a function of operations performed on the drilling platform.

2. THE AUTOMATIC DETECTION SYSTEM

Signals of about 30 stations were sent to Strasbourg University in real-time, where they were processed and archived by an automatic detection system (SeisComp3). For the non-telemetered stations, waveforms were manually integrated to the system afterwards. To detect seismicity, this system is based on a STA/LTA method on the vertical components of each station. Once a pick is emitted, the system tries to locate a potential event with a given velocity model, using the surrounding picks eventually emitted on others stations. If the location algorithm converges, an origin is calculated. The system then tries to associate this origin with an existing event in its database. If no associated event is found, a new event is created in the database of the system into which the origin is included. The created automatic event has to be then checked by hand, in order to avoid any fake or mislocated event. Indeed, since the system only detects P-arrivals by STA/LTA method on the vertical component, mislocations are common and fake events could occur if the number of used stations is too low. To properly work, this system requires a huge number of parameters that have to be tuned adequately. Particularly for the monitoring of geothermal projects, such as Rittershoffen, the system needs to operate at a very local scale, whereas Seiscomp3 was originally designed to detect global or regional seismicity. For the microseismic monitoring of the Rittershoffen project, the work done by Charléty (2007) was first used to configure the automatic system.

3. VELOCITY MODEL

In order to locate micro-seismic events, a first 1D velocity model was built according to previous local studies based on the Soultz-sous-Forêts project (Cuenot et al 2008). Moreover, a second 1D velocity model was built based on sonic and stratigraphic logs performed in the GRT-1 well (Aichholzer et al., 2015) and from a vertical seismic profile (VSP) performed in July 2013 after the hydraulic stimulation of GRT-1 (Maurer et al 2016, see Figure 3).

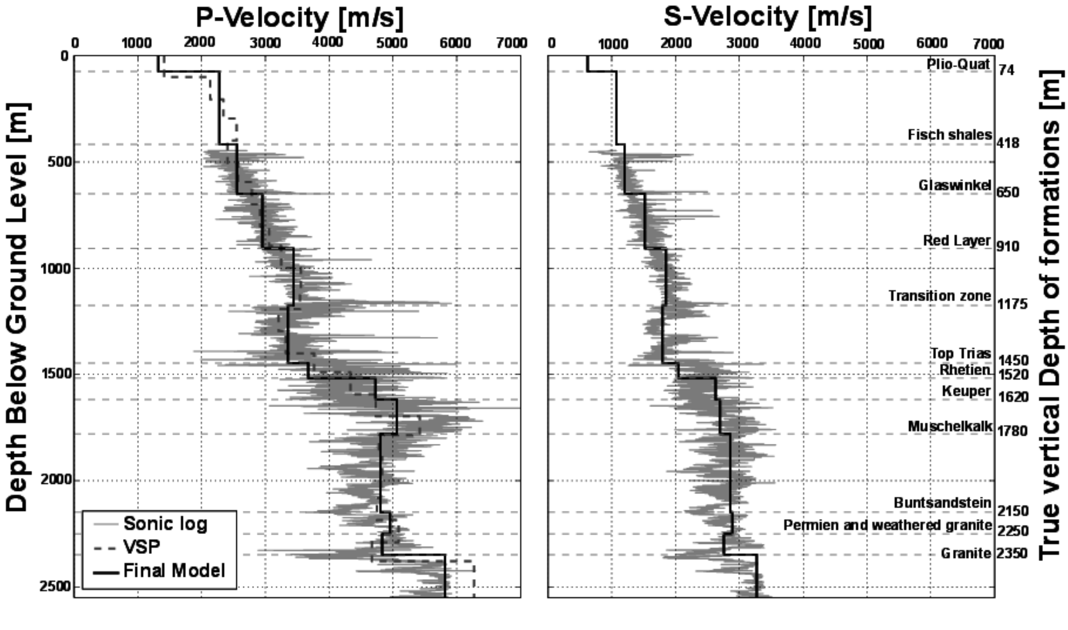

Figure 3: Velocity model of Rittershoffen used to locate the micro-seismic events

4. MAGNITUDE CALCULATION

The micro-seismic monitoring of geothermal projects revealed an issue mostly related to the small scale of such projects. The automatic system indeed provides local magnitude (MLv), since it has been originally created for monitoring global and regional seismicity. The calculation of the MLv is based on the maximal amplitude measured on the vertical component. The usual way to calculate a local magnitude is to proceed to a deconvolution of the recorded signals by the instrument response, followed by a convolution by a Wood-Anderson sensor instrument response. The local magnitude is then computed accordingly to the following equation [1]

[ ]

[1]

Where A is the maximum excursion of the Wood-Anderson seismograph, the empirical function A_0 depends only on the epicentral distance of the station δ. The problem is to evaluate the amplitude of very small events, with a very low signal to noise ratio. It leads to evaluate the amplitude of the low frequency noise (see Figure 4) and to an overestimation of magnitudes of events with a small signal to noise ratio.

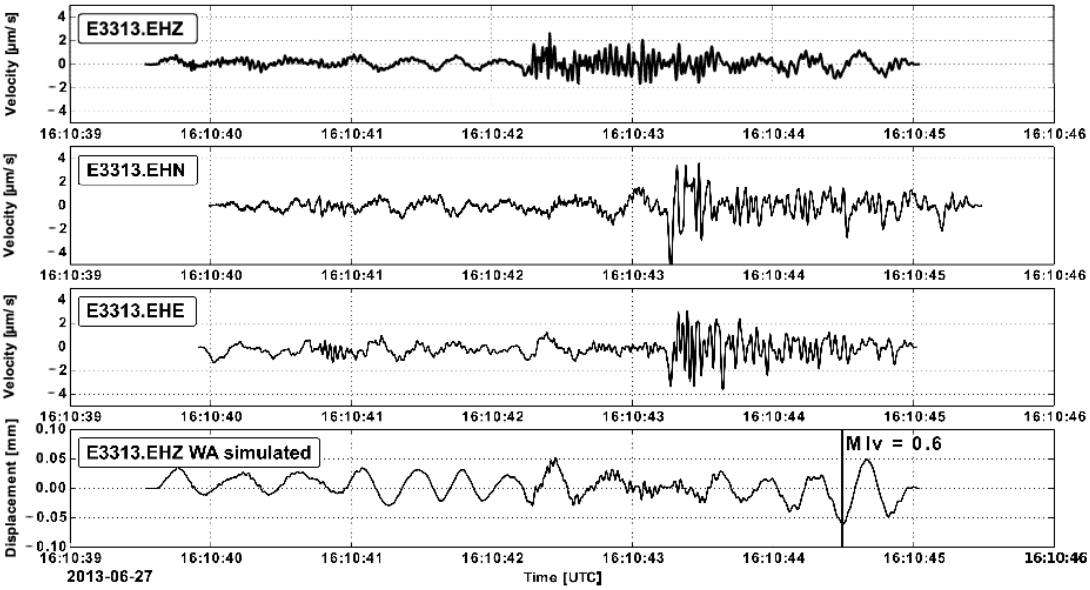

Figure 4: Example of a local magnitude computation performed on a temporary station (1 Hz sensor) signal of a 0.5 Mlv induced micro-seismic event.

Figure 5 shows the Mlv magnitudes of the induced micro-seismic events automatically detected during the hydraulic stimulation, superimposed on a spectrogram of the vertical component of the closest permanent station installed in the nearby village. The average value of the smallest magnitudes shows first a decrease and then an increase over the night hours, forming a "V" shape, corresponding to the daily reduction and augmentation of the anthropic noise.

It raises the problem of the physical signification of those Mlv magnitudes values for very small events. Moreover geothermal project managers, as well as drilling authorities, use magnitudes as a decision-making tool regarding the duration and intensity of pumping levels during hydraulic stimulations and as a threshold of ground shaking tolerance related to acceptability issues. Regarding this aspect, other type of magnitudes (duration magnitude Md or moment tensor magnitude Mw) or even a direct measure of PGA/PGV (Bommer et al 2006) may have to be considered for this purpose, instead of local magnitude for events with a low signal to noise ratio. Hence, an Md calculation module was implemented in the framework of this work to the automatic system.

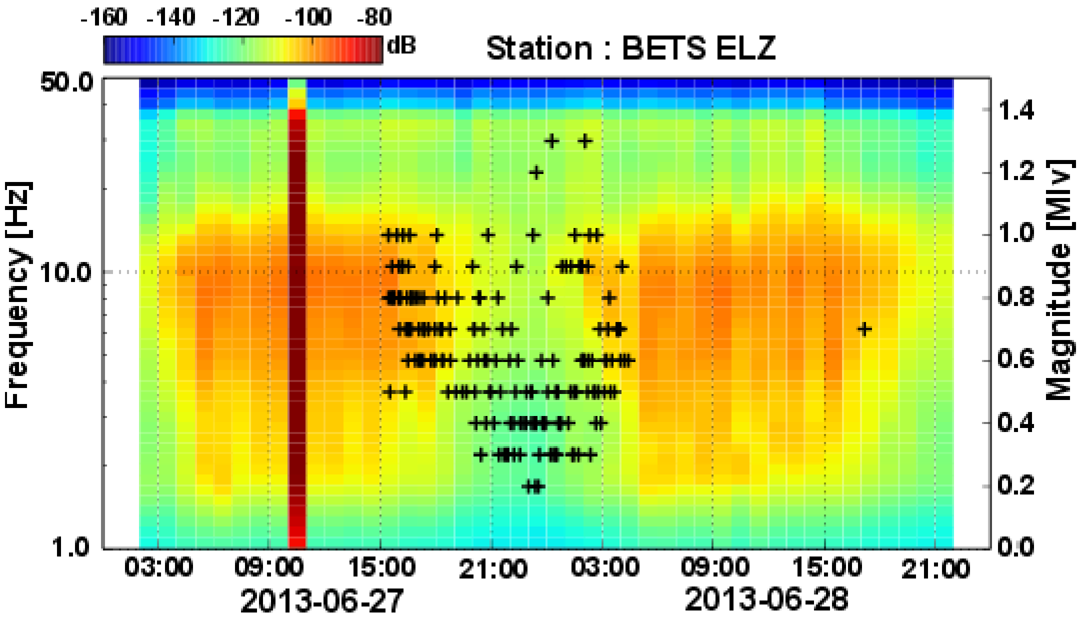

Figure 5: Mlv magnitudes of induced micro-seismic events automatically detected during the hydraulic stimulation on a spectrogram of the vertical component of the permanent station installed in Betschdorf.

5. IMPROVEMENTS OF THE AUTOMATIC SYSTEM

The micro-seismicity was continuously monitored during the operations carried out to enhance the first well, GRT-1, connections to the reservoir. In total 217 induced events were automatically detected, however a much larger number of events were visible. Hence, manual processing of all visible events was initiated to build an exhaustive catalogue of the seismicity induced during these operations. For the first 9 hours of the stimulation about 870 events were manually picked and located into the new velocity model. Duration magnitudes (Md) were also computed, constituting a reference catalogue. The seismic cloud is located south-westwards from the open-hole section of GRT-1, at an average depth of 3 km. Its orientation is globally NE-SW from the open hole section and its extension has a range of about 1 km in the West-East direction and 1.5 km in the North-South direction (see Figure 6).

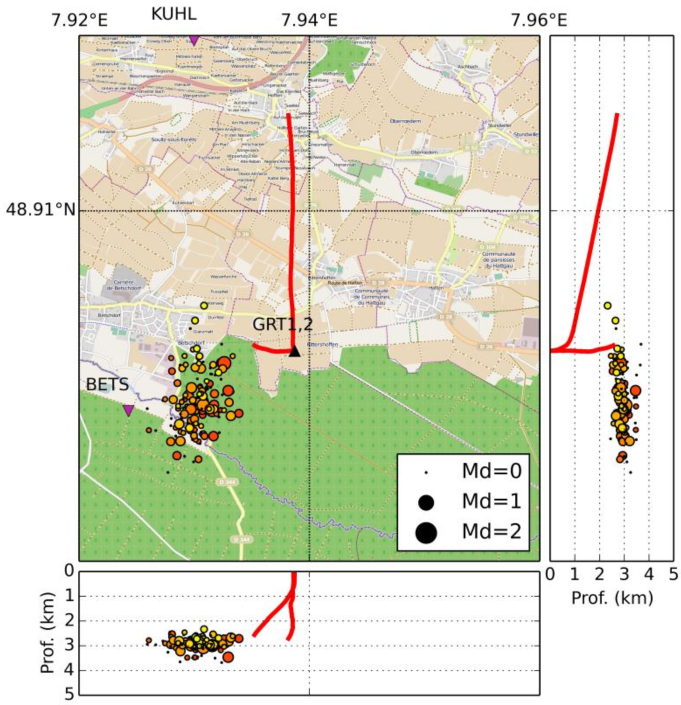

Figure 6: Location and magnitude of the 870 events constituting the reference catalogue. The color is an indication of the time of occurrence (blue to red: beginning to the end of the stimulation)

A comparison between the automatic and the reference catalogue indicates that the rate of the automatic detection system was less than 10% of the total number of visible events, leaving room for further improvements of the real-time seismic monitoring of geothermal projects. An intensive work has been performed on tuning the detection and location parameters, based on waveforms playbacks from the reference catalogue. The main changes consisted in adapting the system to work at a very local scale, more adapted to geothermal projects, by adapting filtering and event association procedure. All duration magnitudes of the events of the reference catalogue were calculated, allowing to evaluate the magnitude of completeness of the automatic system to 0.5 (Md) (see Figure 7). However, missed events between magnitudes 0 and 0.4 are all due to overlapping events, known to be extremely difficult to be detected by a STA/LTA method, meaning that we probably reached the limit of detection of the method. The total recovery rate of the automatic system on the reference catalogue was more than 20% (Figure 7). Finally, the corresponding parameters were used to monitor the induced seismicity later in the project.

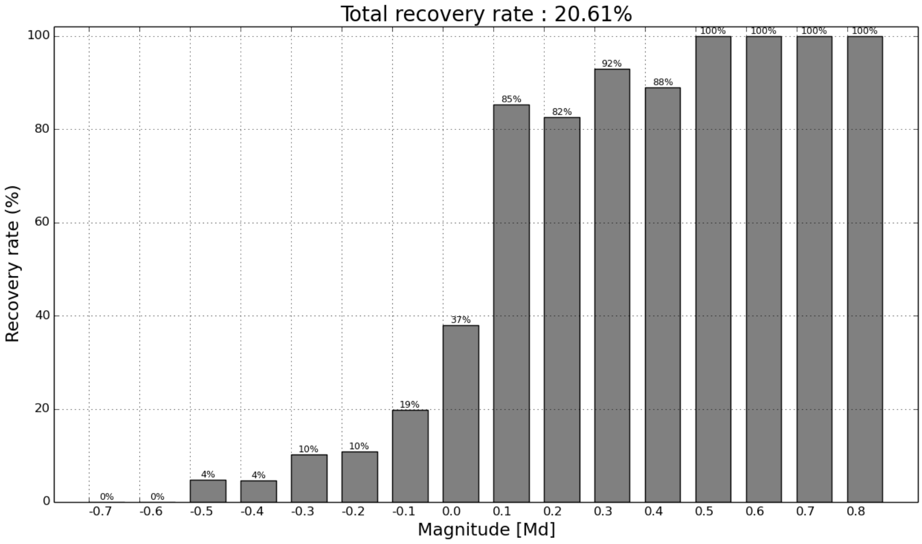

Figure 7: Recovery rate of the automatic system as a function of the Md magnitude compared to the manually picked catalogue

6. DISCUSSION AND CONCLUSION

It is important to distinguish two aspects of the seismic monitoring of geothermal projects. First the reduction of risks associated with EGS geothermal project requires that all operations are accompanied by a real time recording of seismic signals, to assess accurately the state of the natural seismicity before the drilling operations and to detect any rise of seismicity that could be related to those operations. In this context, the acceptability issues are prevailing, and the main goal of the seismic monitoring is to provide accurate locations of events in the vicinity of the drilling platform. The goal is then to warn the project management in case of a rise of an unexpected induced seismicity. In the case of the Rittershoffen project, we clearly demonstrated that we can develop a successful EGS project (deep drilling, TCH stimulations, industrial flowrates) without generating induced micro-seismicity event that could be felt on surface. Secondly, the seismic monitoring of geothermal projects could also be used to perform reservoir imaging. The goal is then to increase the knowledge of the reservoir, such as its geometry or its evolution with time.

In the first case, the automatic system as it is set up is perfectly playing its role, since the biggest events are detected and accurately located using the maximum number of stations. However, in the second case, it is important to detect as many events as possible and to lower the magnitude of completeness of the automatic system. Moreover, as we presented in this paper, geothermal projects are monitored by a growing number of stations, meaning that manual repicking of events will be more and more time consuming, and therefore expensive. For that reason, one has to more and more rely on automatic detection systems, not only for detection but also to accurately and consistently pick and locate as many events as possible and avoid fake events.

Further improvements are still possible if we consider the recovery rate of the current automatic system compared to the exposed reference catalogue. Indeed, events with a low signal to noise ratio are very difficult to detect with this method. And a major problem, regarding the detection of seismicity induced by operation of geothermal operation, as thermal, chemical or hydraulic stimulations, comes with the high number of micro-events triggered in a short period of time. It usually generates small magnitude events with low signal to noise ratio that quite often overlap. Thus, a complementary method of detection has to be considered, such as correlation, since we tend to reach the limits of the detection capacity of the STA/LTA method.

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