Automatic detection and location of induced micro seismicity in geothermal fields: Testing Waveloc and Loki methods

Ecole et Observatoire des Sciences de la Terre

LABEX G-EAU-THERMIE PROFONDE

Photography encouraged

UNAM POSGRADO Ciencias de la Tierra

V. Ramos(1), M. Calò(1), M. Grunberg(2), A. Maggi(2), F. Grigoli(3)

(1)Posgrado ciencias de la tierra: Instituto de geofísica, UNAM

(2) EOST École et Observatoire des Sciences de la Terre

(3)ETH Zürich (Eidgenössische Technische Hochschule Zürich)

Abstract

One of the main challenges in seismic monitoring in geothermal fields is to automatically detect and locate induced microseismicity. As the number of stations increases, manual strategies become inefficient, slow and time consuming.

Several approaches have been proposed, however automatic procedures tend to fail dealing with small events and/or low SNR. In this work, we explore the capability of an automatic procedure to detect and locate microseismicity. First, we use Waveloc (Langet et al. 2014) to enhance the onset of seismic signals. We chose a low threshold to increase the number of detections, even if this means to get spurious or fake signals. Therefore, we apply Loki (Grigoli et al. 2016) for refining the locations. Finally, we use a classic machine learning cluster criterion to discriminate real from fake earthquakes signals.

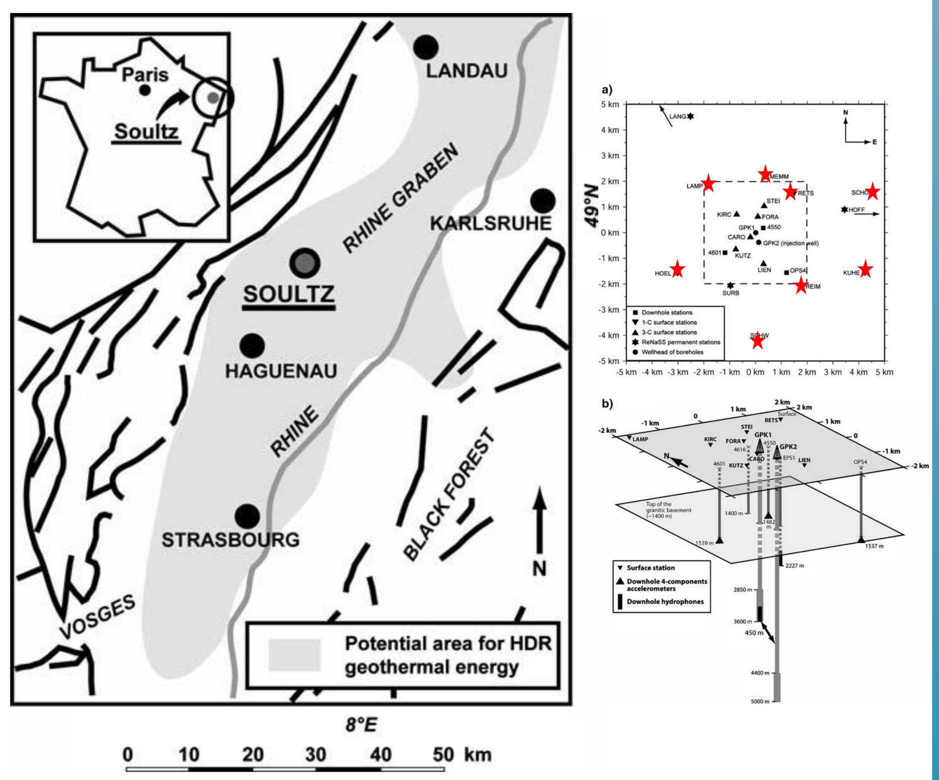
We applied the methodology to a dataset collected at the Soultz-sous-Forêts geothermal field (France) during the stimulation of the well GPK2 in 2000. We recover about 80% of the original catalog, from which 40% of the detected events were located with less than 1km of accuracy. However, we were able to detect and accurately locate 260 new events that were not present in the original catalog. Although the codes worked in not optimal condition for their operation and further optimizations are needed, the procedure seems to be able to provide reliable results.

Soultz-sous-forêts data

Soultz-Sous-Forêts is a geothermal field located in the upper Rhine Graben, 50 km north of Strasbourg.

An hydraulic stimulation was performed in June/July 2000. During the experiment, more than 14,000 seismic events were detected by a surface network of 14 stations. From this catalogue, more than 11,000 events were manually picked and 7200 located with an accuracy of less than 100m (Cuenot et al., 2008). Furthermore, 3 down-hole sensors were recording in triggered mode, detecting more than 30,000 events

From the 14 stations installed at the surface, we use only the 8 with continuous records. The stations are 1C and short-period. In figure we observe the Soultz map, the seismic network and the wells as presented in Cuenot et al., 2018. In red are the 8 stations used in this work.

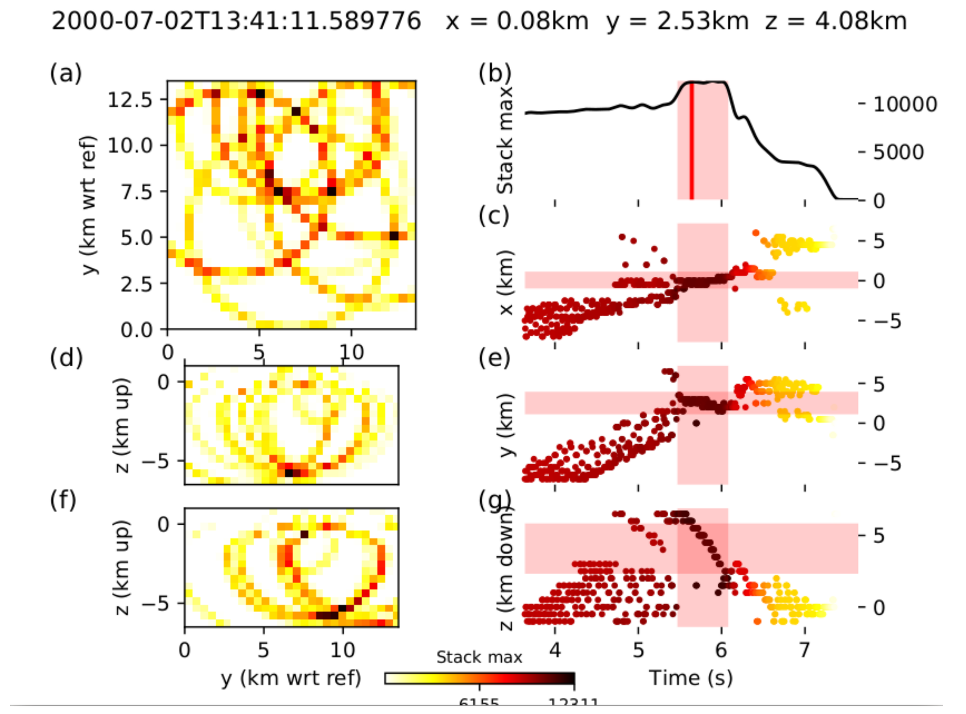


Waveloc

Waveloc (Langet et al., 2014), is a software package mainly developed to automatically detect and locate seismic events in continuous data records.

To make the detection, Waveloc compute the kurtosis on seismic traces in order to enhance the onset of the seismic signals. Then, Waveloc performs a grid search migration using predefined travel-time grids.

Waveloc it is a useful tool to perform preliminary detections in coarse grids associating the corresponding waveforms with a single event. In the image we can observe a migration example in our data.

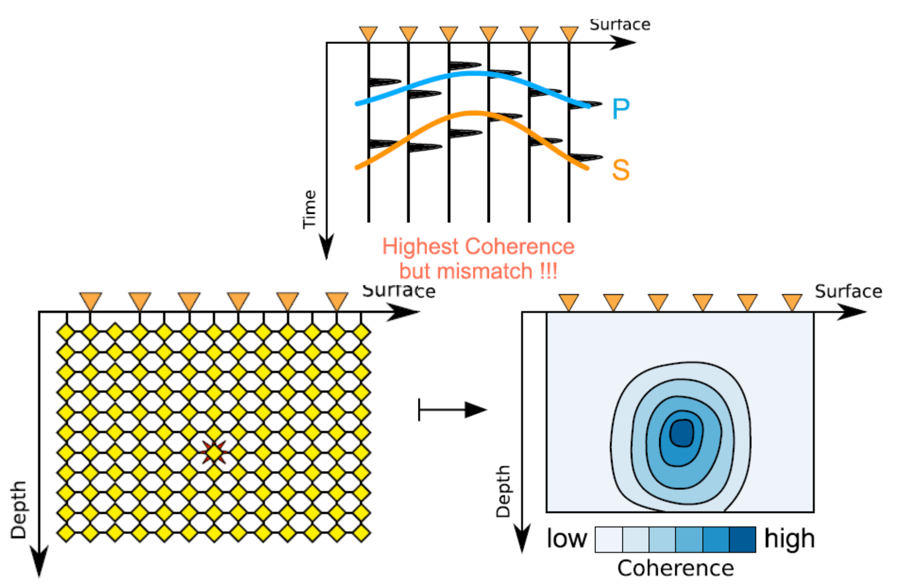


Loki

Loki (Grigoli et al., 2016), is a software package to automatically locate and relocate earthquakes signals. In its actual version, Loki needs a predefined event catalogue within the windows record.

Loki uses Short Time-Long Time Averages (STA-LTA) of characteristic functions processed with the Principal Component Analysis (PCA) to accurate detect P and S arrivals. Then, a coherence matrix is computed using a waveform stacking method to extract the point with maximum value as the source.

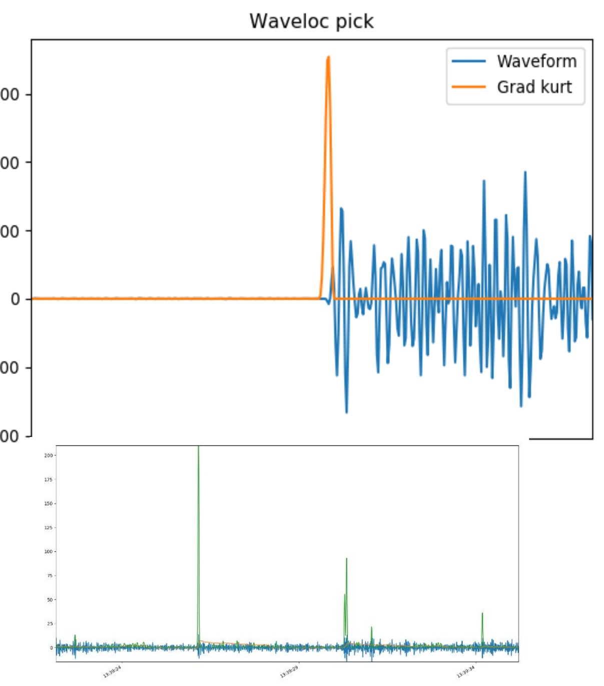
For a single event, Loki can compute successive locations within closer STA-LTA windows. This procedure allows to compute a weighted solution, and a error criterion (Err_max) consisting on the covariance of the locations.



Methodology

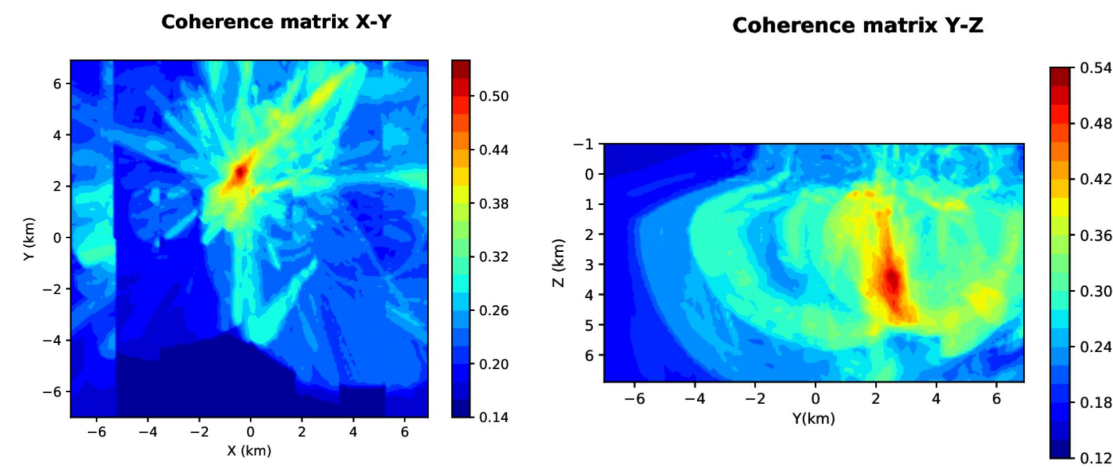
1.- Waveloc. We perform a preliminary detection with a coarse grid of 0.5 km and low detection level to build a preliminary catalogue.

Waveloc works on the basis that seismic noise has a Gaussian distributions of amplitude. In the figure on the right, we can observe the kurtosis trace computed for a well recorded event. The time window is of 1.5 s. In the lower window, we can see the kurtosis trace highlighting the existence of small events, in a time window of 10 s.



2.- Loki. For each event detected by Waveloc, we perform several locations with consecutive STA-LTA windows in order the to obtain an estimation of possible errors.

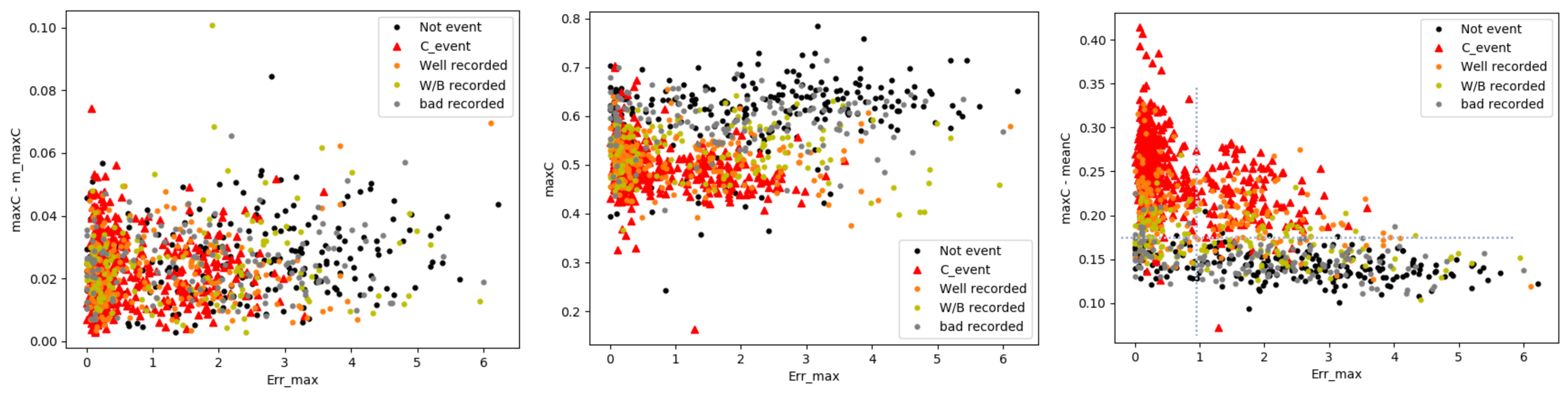
Since Loki uses the PCA, three component stations are desirable. To overcome this lack of information, we compute the Hilbert transform to our data. Below, we can see a horizontal and vertical section of the coherence matrix for a well recorded event.



3.- Discrimination of error: Training computer. To differentiate fake signals from real detections, we decided to use a cluster criterion: This means that we set clusters in categories within a training window to search the parameters that best allow to separate them. The remnant events should have similar behavior.

We select a training window of 5 hours where 1206 detections were manually observed. We group the events in four clusters based on: i) Well recorded events. ii) Moderated recorded. iii) Badly recorded. iv) Not an earthquake. We also plot the events of the Cuenot catalogue as comparison. We test several error criteria searching for the parameters that best allow to separate the clusters. In the images below, we can see three approaches from which plot of covariance of successive locations (Err_max) vs [mean coherence – maximum coherence diference gave best results.

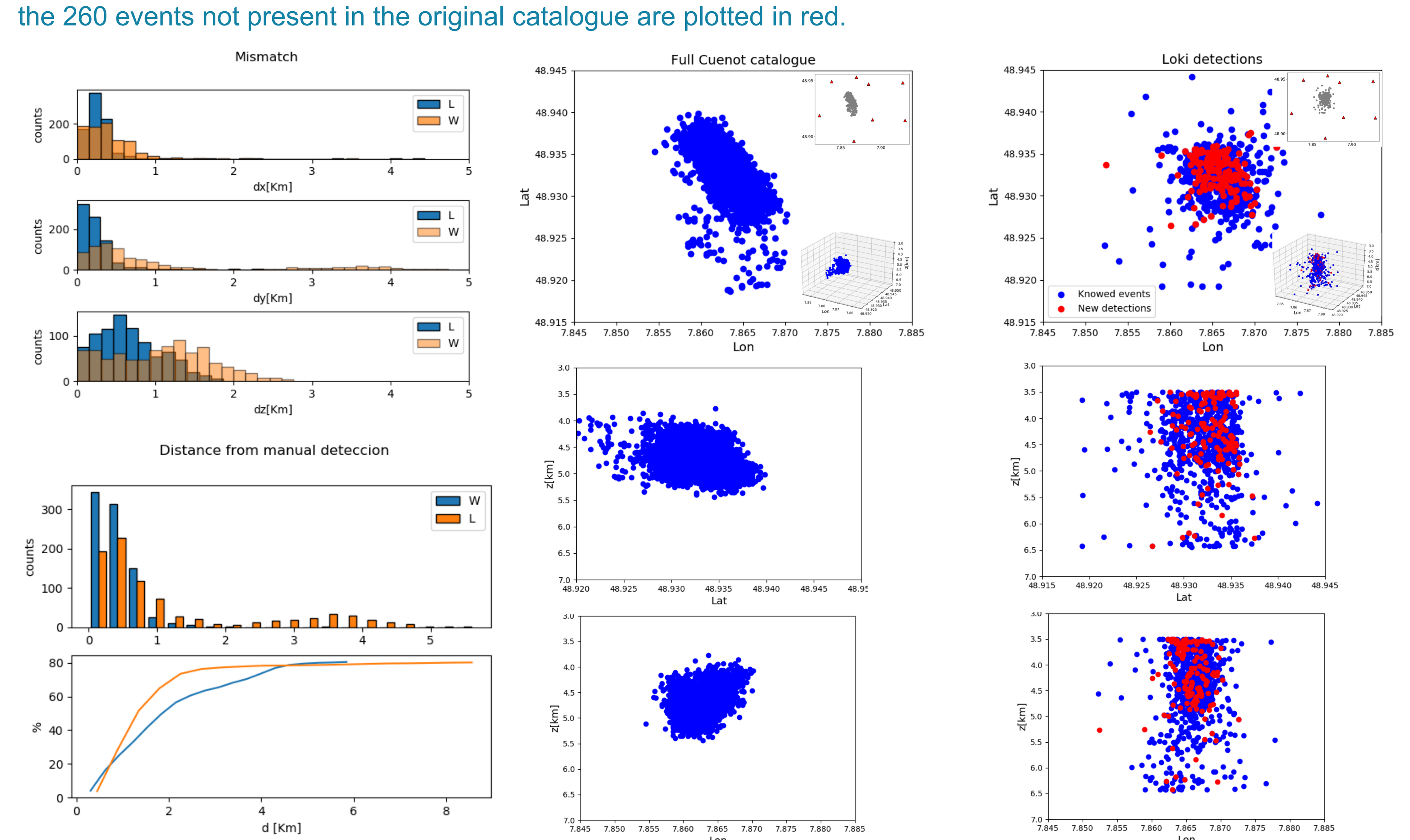
For this dataset, there is no evidence of complexity or variables dependency. We conclude that the difference between the mean coherence and the max coherence is enough to differentiate real from fake events. In the other hand, ther Err_max is useful to select the well located events. We set our tolerance in (>0.18) and (>0.5) respectively.



4- comparing locations.

Here, we show the distribution of errors with both, Waveloc and Loki results compared with the locations provided by Cuenot et al.(2008). In the histograms (left), we can see that most of the events analyzed present horizontal differences of less than 0.5 km. However variability in depth resulted large. Till now, approximately 40% of the Cuenot catalogue was recovered with a difference in the hypocenter coordinates of less than 1 km.

Also, we show the seismic cloud as presented by Cuenot (center) and our final locations (right). In our seismic cloud, the 260 events not present in the original catalogue are plotted in red.



Results

In a subset of 24 hr of continuous records, we detected 3067 potential events with Waveloc. In the same slot of time the original catalogue consists of 1056 events. 2019 of the potential events were set as real detections, from which 260 were located accurately (covariance <= 0.1)

We recover 80% of the events reported in the Cuenot catalogue, from which 40-50% were accurately located. Errors in locations, specially in depth, can be explained by the reduced amount of stations. We only use 8 1C stations. The Cuenot catalogue was built using a larger network consisting in 8 1C, 6 3C and 3 down-hole sensors.

Both methodologies showed a great performance and good results, even working in restricted conditions (one component sensors and fewer stations).

The present workflow were able to automatic detect and locate seismicity during the stimulation of the 2000 in Soultz-sous-Forêts geothermal field.

Acknowledgements

* This work is supported by the project GeMEX PT5.2.N: 267084 funded by CONACyT-SENER: S0019, 2015-04
* Thank to the “LabEx G-EAU-THERMIE PROFONDE” for funding my travel/stay in ETH Zürich (Eidgenössische Technische Hochschule Zürich)
* Thanks to the EOST, UNAM and CONACyT for hosting and/or supporting me in the development of this work.

References

* N. Langet, A. Maggi, A. Michelini, F. Brenguer, 2014. Continuous Kurtosis-Based Migration for Seismic Event Detection and Location, with Application to Piton de la Fournaise Volcano, La Réunion. Bul. Seis. Soc. Am., vol 104, no 1, pp 229-246, doi: 10.1785/0120130107
* Cuenot, N., Dorbath, C. & Dorbath, L., 2008. Analysis of the microseismicity induced by fluid injection in the Hot Dry Rock site of Soultz-sous-Forêts (Alsace, France): implications for the characterization of the geothermal reservoir properties, Pure appl. Geophys., 165, 797–828.
* Grigoli, F., Cesca, S., Krieger, L., Kriegerowski, M., Gammaldi, S.,Horalek, J. & Dahm, T., 2016. Automated microseismic eventlocation using Master-Event Waveform Stacking. Sci. Rep., 6, doi:10.1038/srep25744