

Automatic picking for induced seismicity in Iceland using an EAT (Empirically Aggregated Template) methodology

Laure Duboeuf⁽¹⁾, Volker Oye⁽¹⁾, Inga Berre⁽²⁾, Eirik Keilegavlen⁽²⁾, Ben Dando⁽¹⁾

¹ Norsar, Gunnar Randers vei 15, Kjeller, Norway, laure@norsar.no ; ² Universitetet i Bergen, Norway

1

With the development of geothermal activity, the amount of seismic events is so huge!

Yes, in the Reykjanes Geothermal field, we detected more than 7000 events in only 4 months

- Reykjanes Geothermal Field
 - SW Iceland (red rectangle)
 - Fluid injections
- 2 sensor networks
 - 8 permanent & 30 temporary stations
 - 3D components
 - Short & Broadband
- Objectives
 - Relating microseismicity & fractures
 - Testing & Improving methods for numerical modeling of fluid flow

2

Such complex seismic data...

Low Signal to Noise Ratio Emergent P-phase

Difficult P & S-onset identification

How to pick them? Manually? No!

Strongly depends on the operator

- Not consistent
- Too large a dataset
- Data complexity
- High processing time

NO MANUAL PICKING

3

AUTOMATIC PICKING

We could identify some beautiful events, and pick P- and S-phases.

Like Master Events?

Example of a Master Event

Yes! Then, we can compare the Master event picks with the event we want to pick (child event).

We obtain P and S-picks of the child event based on the cross-correlation values and their time-lags.

BUT

If there is a lack of seismic traces in a master event, how the child event can be picked?

We could create an empirical template which will be representative of Master Events: **EAT**

Examples of Master Events with a lack of seismic traces

4

EAT : Empirically Aggregated Template

From several candidate Master Events, we select the best seismic traces for each sensor. Then the selected traces are aggregated into a single pseudo event: the EAT.

The EAT represents a cluster of Master Events, so it is representative of all events with similar characteristics.

EAT is not a physical event! It can only be used to pick other events, not for source parameter computations!

I need a summary

9

Example of automatic P- and S-picks for a child event

8

- 3. Using the coherence time between sensors, wrong and uncertain picks are removed.
- 2. P- and S- phases are picked from time-lag for the maximum cross-correlation coefficient when it is greater than a defined threshold.
- 1. For each sensor, cross-correlation for both the P- or S- performed for the entire trace length of the child event.

2nd stage : Picking P- and S-phases of the child event

1st stage : Selecting the best EAT for a child event

- 2. The best EAT for each child event is selected based on the highest cross-correlation coefficient.
- 1. Compute the maximum cross-correlation coefficient between the considered child event and each EAT.

STEP 3 : Pattern Matching

6

STEP 1 : Identification of events

Finding the best representative events of the dataset and picking their P- and S-phases.

Representative events do not just mean the beautiful ones, but also those events where some traces are missing.

This step can be done manually or automatically

5

The automatic picking algorithm

```

    graph TD
      A[Seismic dataset] --> B{Identification of beautiful representative events}
      B --> C[EAT definition]
      C --> D[Pattern Matching]
      D --> E[Picks of child event]
      E --> F[QC]
      F --> C
  
```

1st processing

3rd stage : Building of the EAT

EAT example

- For each sensor and event, compute the SNR.
- Keep the trace for each sensor with the best SNR.
- Gather all sensors : EAT.

7

STEP 2 : EAT definition

1st stage : selection of a set of Master Events

- Identified events from step 1
- Number of P- and S-picks
- Signal to Noise Ratio (SNR)

Example of Master Event

For example :

- 7 seismic traces
- 14 P- and S-picks
- SNR > 2

Master Event

Not necessary to have all stations if the event is characteristically similar to others...

2nd stage : Defining clusters of Master Events

- Clusters are created from
 - similar events : cross-correlations on P- and S-phases (x-corr)
 - events close to each other : travel times between events (dtt)
- Independent of velocity model but dependent on P and S picks

3rd stage : Building of the EAT

3D view of the Master Event clusters

Seismic traces on one sensor for a Master Event cluster

10

Parameter adjustment : a challenging purpose

One of the big challenges with this method is to find optimum parameters...

Just for the EAT creation, there are 6 parameters! And 9 for the picking part...

EAT parameters: P- & S-window length, Filter, SNR, P & S picks %, Min X-corr, Min dt, Min S-X-corr, Mean or median?

Auto picking parameters: Trace rotation, Trace stacking, Filter, Min P-X-corr, Min S-X-corr, Step for scanning trace, Min ts-tp, P- & S-window length

11

To go further ...

We could apply this method to the seismic data from the Reykjanes geothermal field.

Thus, we can improve the accuracy of our first results!

- Relative location
 - Geothermal locations
 - 2-6 km depth
 - Induced events
- Not possible to relocate events
 - Outside of the geothermal field
 - Surround 2.6 km depth
 - Natural events
- Clustering
 - Except cluster 3, only relocated events
 - Could indicate geological fractures

First result location from the analyzed seismicity of the Reykjanes Geothermal field

... To be explored in the light of more events

12

Conclusion

- This method
 - Allows automatic picking of events from an aggregate of waveforms (an EAT) from different but representative events.
 - Is powerful as the EAT events are selected to have similar characteristics to the child event and have a high signal to noise ratio.
 - Is complicated by the number of parameters to adjust
- This method will
 - Be used to automatically pick seismic events from the Reykjanes geothermal field.
 - Allow us to increase our database of picked events.
 - Allow us to improve our results and mapping of the fracture network (Duboeuf et al., 2019 EGC)

Acknowledgments

We would like to thank the Research Council of Norway (RCN) for funding the ERS project and ISOR (Iceland) for the data access.