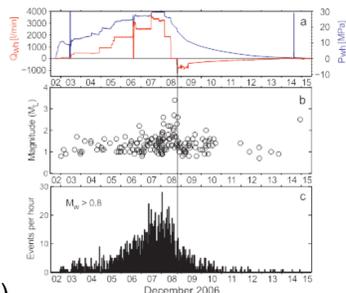


Background & Problem Statement

In December 2006, an extensive fluid injection was carried out below the city of Basel, Switzerland, to stimulate a reservoir for an Enhanced Geothermal System (EGS). Some details:

- ~11'500 m³ water injected into crystalline rock, 5km deep
- After 6 days, M_L 2.6 event exceeded safety threshold → reduced injection rate, then stopped completely → shut-in (closure of borehole)
- Hours later: widely felt M_L 3.4 event → well opened, rapid decay of seismicity
- Originally detected ~13'000 EQs (located ~3,500)
- Dec. 2009: project canceled – a seismic risk study suggested substantial risk of further felt and potentially damaging events [Baisch 2009]
- Mid-2011: ultimate shut-in; pressure increase at well-head
- Mid-2012: renewed increase of seismicity (M_L>1.0)



The well-monitored and well-studied induced sequence allowed many new insights in terms of reservoir creation. Until today, the **details of the long-term behavior** remained unexplored since a consistent catalog did not exist. We want to create one.

Highlights & Outlook

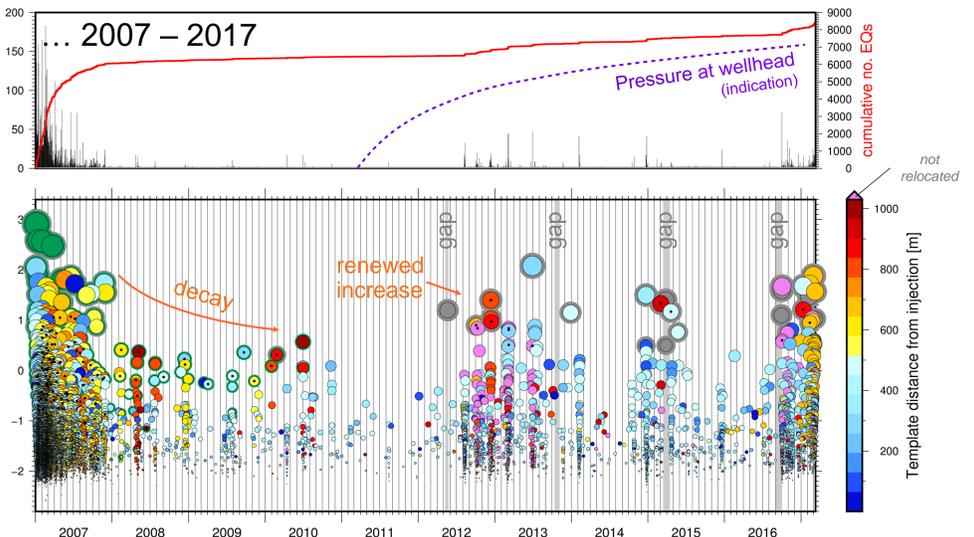
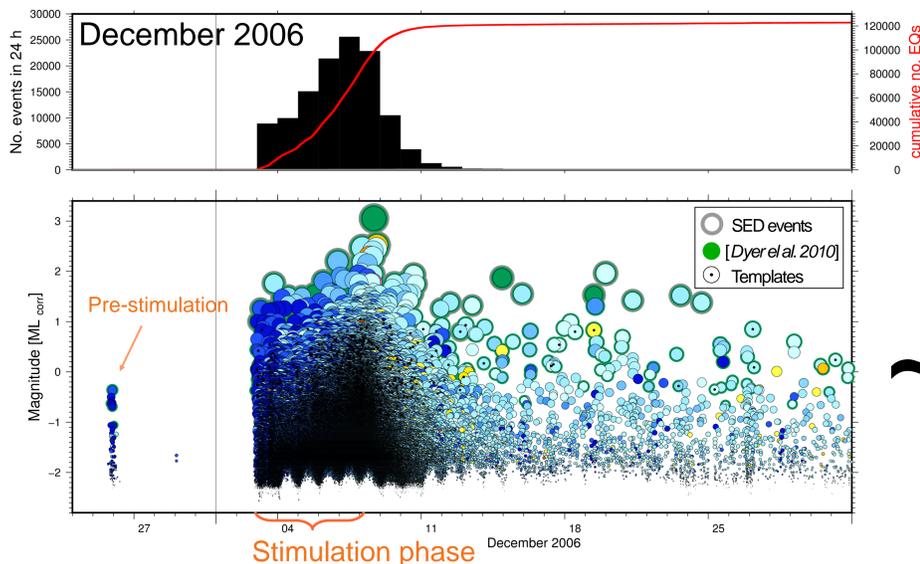
- Our newly obtained catalog ...
 - spans more than ten years
 - contains **more than 130'000 events**
 - features a uniform detection threshold and consistently determined magnitude
 - decreased the detection limit by more than one magnitude unit
 - increased the spatiotemporal resolution
 - statistical analysis in great detail:
 - resolved variations of the a- and b-value
 - derived temporal development of the seismic hazard
 - ...
- Detections confirm clearly the (re-)activity several years after injection; they tend to cluster
- Possible connection: pressure increase ↔ re-activation?
 - Questions:
 - Should the borehole be opened again?
 - How long do we have to monitor a closed EGS project?
- We hope to provide the basis for a better understanding of the processes that drive the induced seismicity in Basel
- We have also started to extend our analysis to other induced and natural sequences in Switzerland (see poster T. Kraft, tomorrow (Thu.), P1-09)

Findings of a multi-template approach

We scanned the recordings of the **deepest installed borehole station (2.7km)**. This station is very close (1.5–2.5km) to ~4.5km-deep reservoir, completely in the granite bedrock. It has the highest signal-to-noise ratio among all (borehole-)stations.

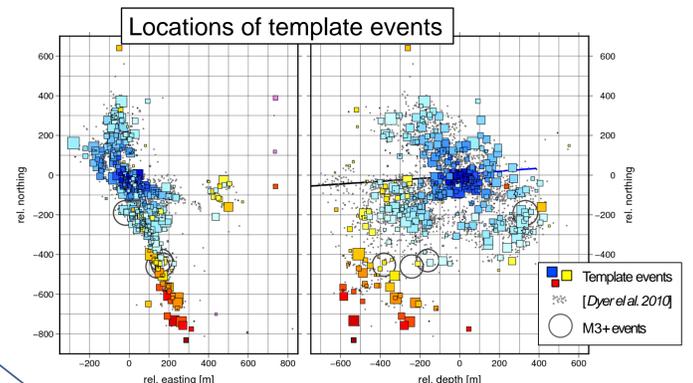
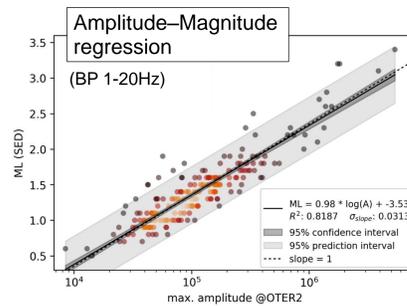
Technical details:

- Band-pass-filter of 5-80Hz; 500fps
- Removed 50Hz noise in the frequency domain
- The Z-channel failed in 2010. To be consistent, we only used the 2 horizontal channels. This might lead to wrong template associations.



The **color** of a detection indicates to which template it is most similar. Later events tend to occur and cluster more outwards. But also older (inner) fault patches get reactivated again.

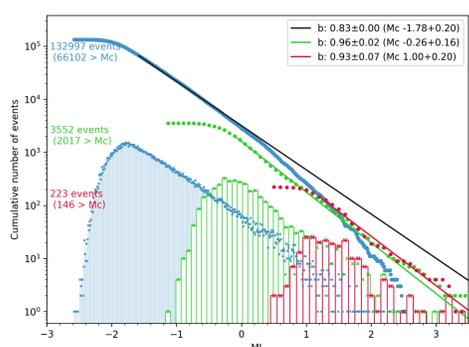
The orientation of the individual faults varies and deviates from the general orientation “seismic cloud” [Deichmann et al. 2014]. To reach an acceptable coverage of the complex seismicity in the stimulated volume, we selected **~500 templates** from >3'600 event waveforms and performed the scan on the EULER high-performance computer. The scan over more than 10 years of data took ~36 hours using an average of ~600 cores.



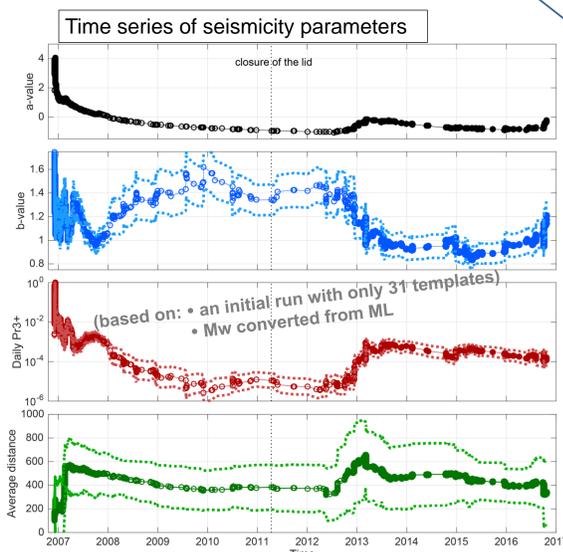
Earthquake statistics

The much more detailed sampling of the seismic sequence achieved by the multi-template detection effort significantly improved the completeness magnitude (M_c) of the catalog so that

that we can resolve **b-value** variation in unprecedented resolution and in particular assess the long-term evolution of the sequence during which the rate of network-detected events is pretty low.



FMDs of 3 catalogs: **ours based on template matching**, Dyer et al. 2010, and observed by the **Swiss Seismological Service (SED)**



Acknowledgements

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