# First results of nanoseismic monitoring at geothermal sites

Investigation of the location accuracy of small arrays by induced seismicity during the stimulationphase of the Deep-Heat-Mining project in Basel

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#### Table of Contents





- 3 Relative Localization
- 4 Completeness Magnitude





#### Facts and Location

- Located at the south-east end of the Upper Rhine Graben
- High geothermal gradient, 200°C expected in 5 km depth
- Fracing done by the Hot-Dry-Rock Method
- Stimulation period of 21 Days with a volume of 50 000 m<sup>3</sup>
- Stimulation aborted after a magnitude  $M_L = 2.6$  on the morning of the 6<sup>th</sup> day at a volume of 11 500  $m^3$
- In the afternoon of this day a magnitude  $M_L = 3.4$  earthquake took place followed by 3 magnitude  $M_L > 3.0$  in the two month to follow
- A total of about 12 000 seismic events were detected



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### Installed Networks

- SED and Geothermal Explorers: 6 boreholes with a seismometer in depths between 317 m and 2740 m
- SED: 7(+13) seismometers in the vicinity
- Our Setup: 2 small arrays in a distance of 2.1 km (SNS1) and 4.8 km (SNS2) from the 6<sup>th</sup> of December 12:45 UTC until the 8<sup>th</sup> 9:30 UTC
- 20 Events were used for comparison in a magnitude range of  $0.7 \le M_L \le 2.2$





- Comparing the localization accuracy to other networks (single surface stations, borehole seismometers), methods (master event, double difference) and programs (Reloclin, hypoDD)
- Active fault mapping, resolving the structure, direction, orientation and area of the fraced underground



#### Measurement technique

#### Sensors

- 1x 3 component (V, NS, EW) seismometer
- 3x 1 component (V) seismometer
- 2x microphone (optional)
- 400 Hz sampling rate
- 40-200 m aperture



#### Localizations



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Comparison of the localization results of the SED and ours

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## Results in Hypoline



Comparison of the localization results of Hypoline: absolute (jackknifing) vs. relative (master event)



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#### Master Event and Double Difference



Epicentral distribution:

- a) Master Event Method (Deichmann et al. 2007) (190 Events)
- b) Double Difference algorithm (Kahn 2008) (3000 Events)



#### Master Event and Double Difference



20 events in each method, average localisation difference Deichmann et al.: 420m in x and 110m in y direction Kahn: 110m in x and y direction.



#### Hypoline, Master Event and Double Difference





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### Hypoline, Master Event and Double Difference





## Hypoline, Master Event and Double Difference

- Seismometer
- ★ Master event (HypoLine)
- ★ Master event (RELOCLIN)
- ★ Double difference (SVD)
- ★ Double difference (LSQR)



Comparison of the 20 events in each method: Master event by Hypoline and Reloclin (Console and Di Giovambattista, 1987) Double Difference by HypoDD (Waldhauser, 2001), solution methods: SVD and LSQR



#### Event classes

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#### Event classes





#### Event classes





 $M_L = 2.5$ 



#### Event classes





 $M_{L} = 1.4$ 



#### Event classes



 $M_L = 0.6$ 



#### Event classes

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$$M_{L} = 0.3$$



#### **Evaluation** Overview



Temporal appearance of the four event classes



- High localisation accuracy can be achieved with Hypoline
- Reloclin and hypoDD unsuitable for few stations
- Completeness magnitude in progress, expected:  $M_L \approx 0.0$



## Thank you for your Attention!

