Schweizerische Eidgenossenschaft
Confédération suisse
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Schweizerischer Erdbebendienst
Service Sismologique Suisse
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Swiss Seismological Service

ETH zürich

Seismic Network Performance Analysis and Ground-Truth Test: application to Geothermal Development in Switzerland

Verónica Antunes[1], Toni Kraft[1], Tania Toledo[1], Verena Simon[1], Stefan Wiemer[1]

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March 20th 2025

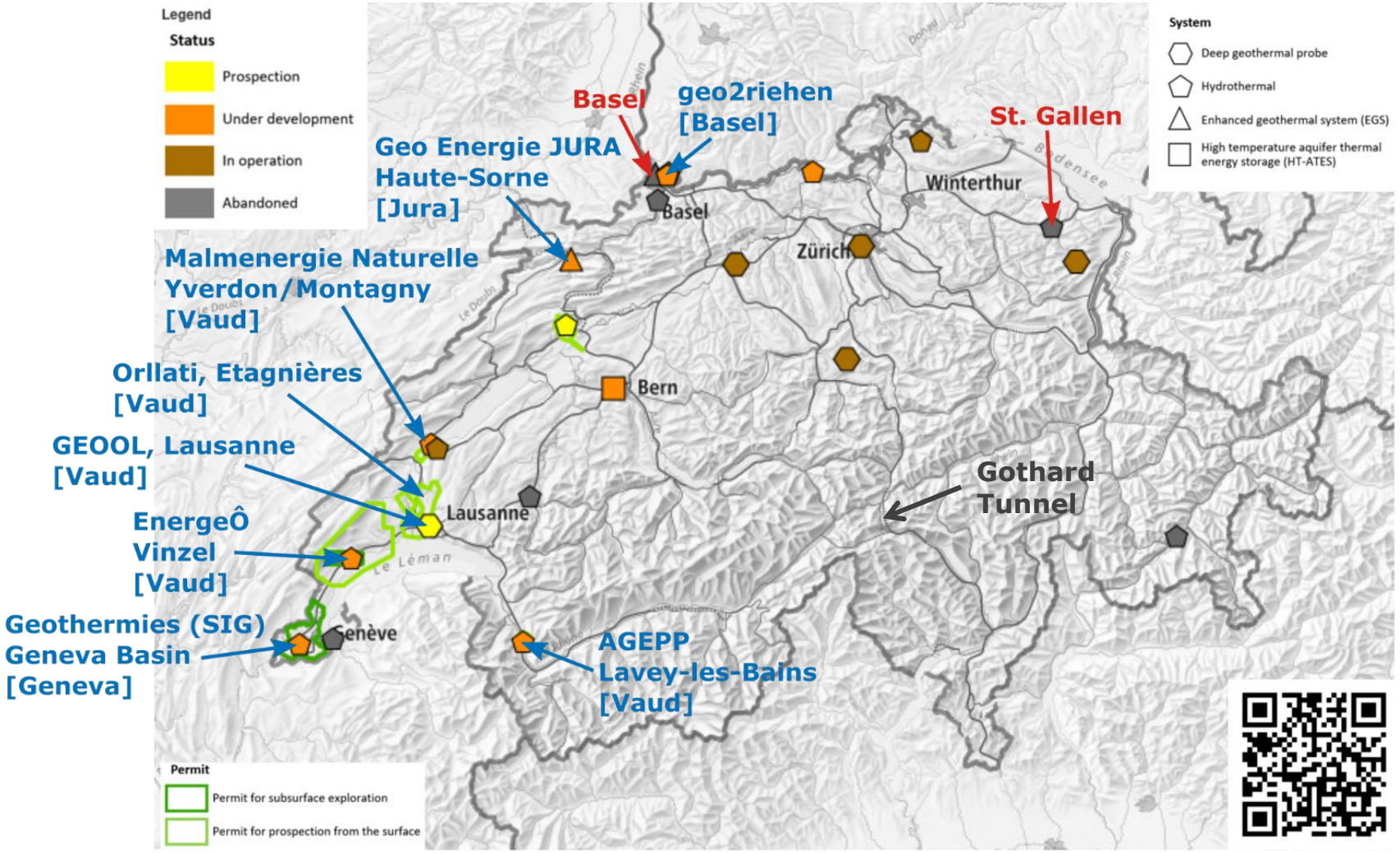
- **Induced Seismicity** is a **major concern** for various geotechnical applications: tunnelling, mining, CO_2 storage, deep geothermal exploration

- **Managing Induced Seismicity** risk with **mitigation measures** is essential to the safe development of such projects

- **Induced seismicity regulations** place specific requirements on the sensitivity and accuracy of **seismic monitoring** networks

- Reliable tools for **seismic network design** and **performance evaluation**, are essential to ensure compliance and mitigate induced seismicity risk

- [GEOBEST2020+ project]

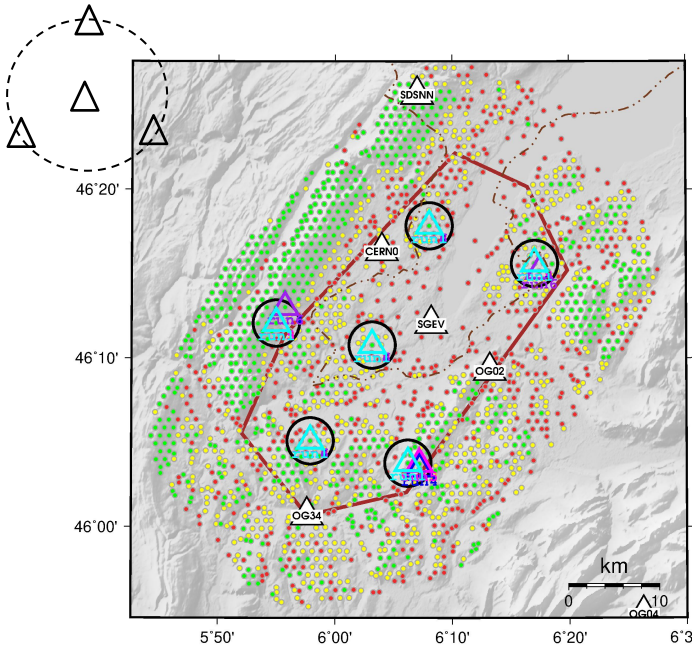


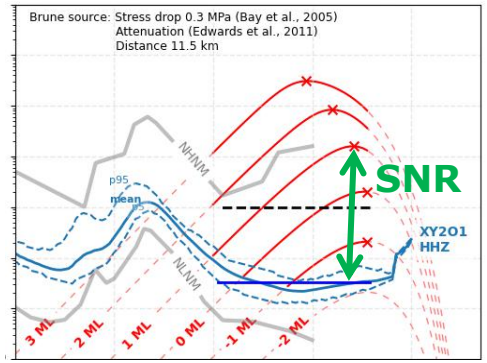
Workflow to ensure the **minimum monitoring requirements** established in:

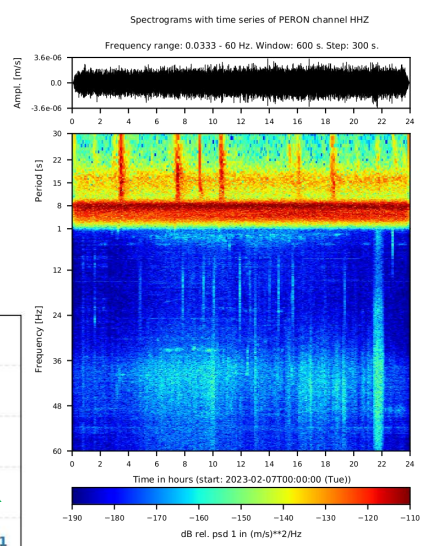
Kraft, T., Roth, P., Ritz, V., Antunes, V., Toledo, T., Wiemer, S. (2025). **Good-Practice Guide for Managing Induced Seismicity in Deep Geothermal Energy Projects in Switzerland (Version 3)**. SED-Report. https://www.research-collection.ethz.ch/handle/20.500.11850/714220

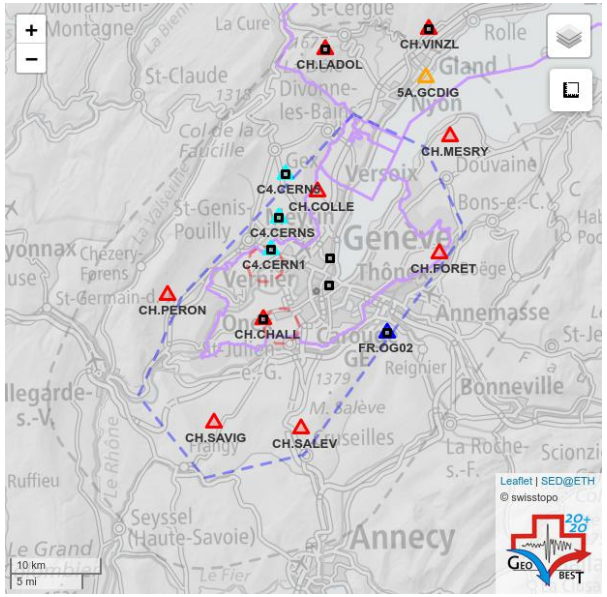
Mc=1.0M_L / 0.5M_L; Horizontal precision 0.5 km; Vertical precision 2 km

Network Geometry → Site selection & Noise Analysis → Network installation









Seismic monitoring network in Geneva

Kraft et al., 2013; Antunes et al., *in prep*

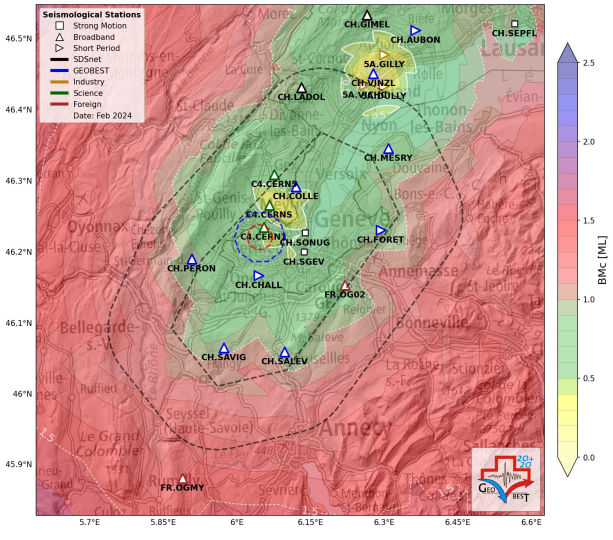
Workflow to ensure the **minimum monitoring requirements** established in:

Kraft, T., Roth, P., Ritz, V., Antunes, V., Toledo, T., Wiemer, S. (2025). **Good-Practice Guide for Managing Induced Seismicity in Deep Geothermal Energy Projects in Switzerland (Version 3)**. SED-Report. https://www.research-collection.ethz.ch/handle/20.500.11850/714220

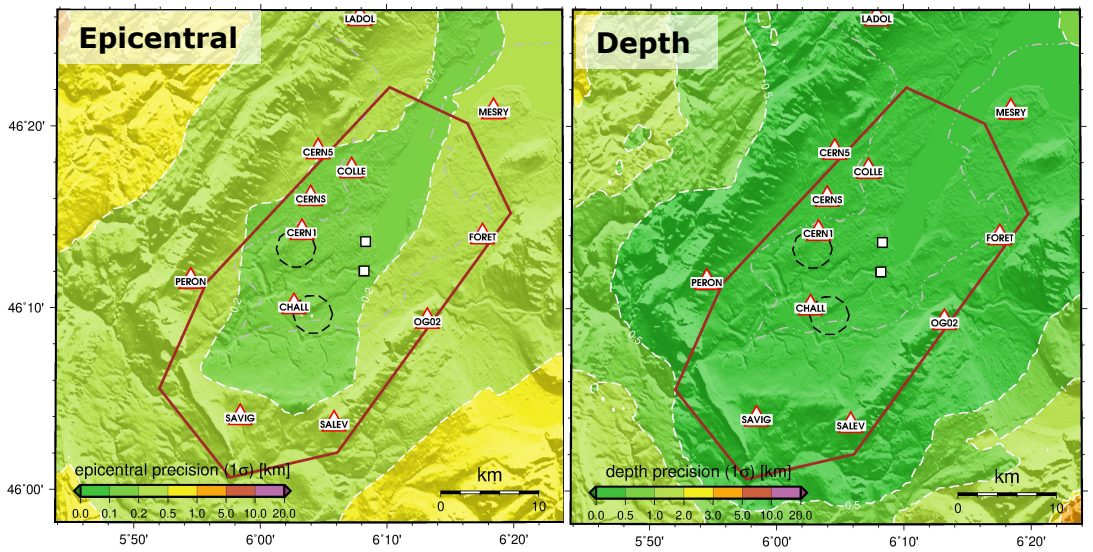
Mc=1.0M_L / 0.5M_L; Horizontal precision 0.5 km; Vertical precision 2 km

Network performance evaluation → Seismic monitoring starts

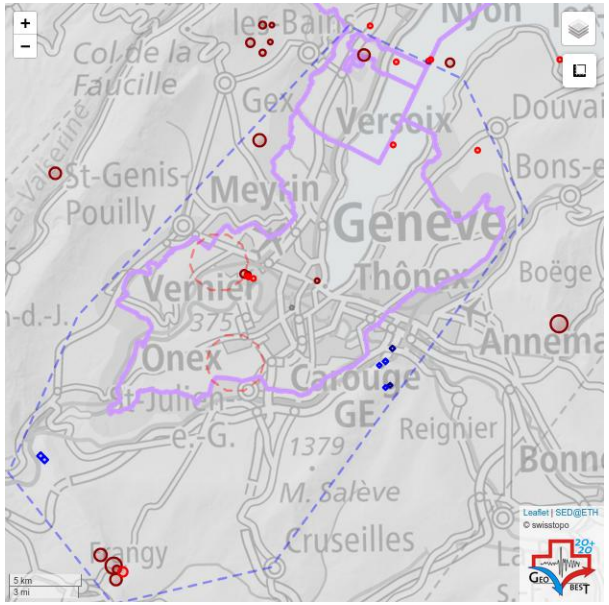
BMC



LocErr



Kraft et al., 2013; Antunes et al., *in prep*



Seismicity in the Geneva Basin

AGEPP, Lavey-les-Bains [Vaud]

Natural seismicity

Detection methods:

1. Seiscomp-SED STA/LTA (scdetect)

- SED (4/5-stat detector)

- MuAn (3-stat detector)

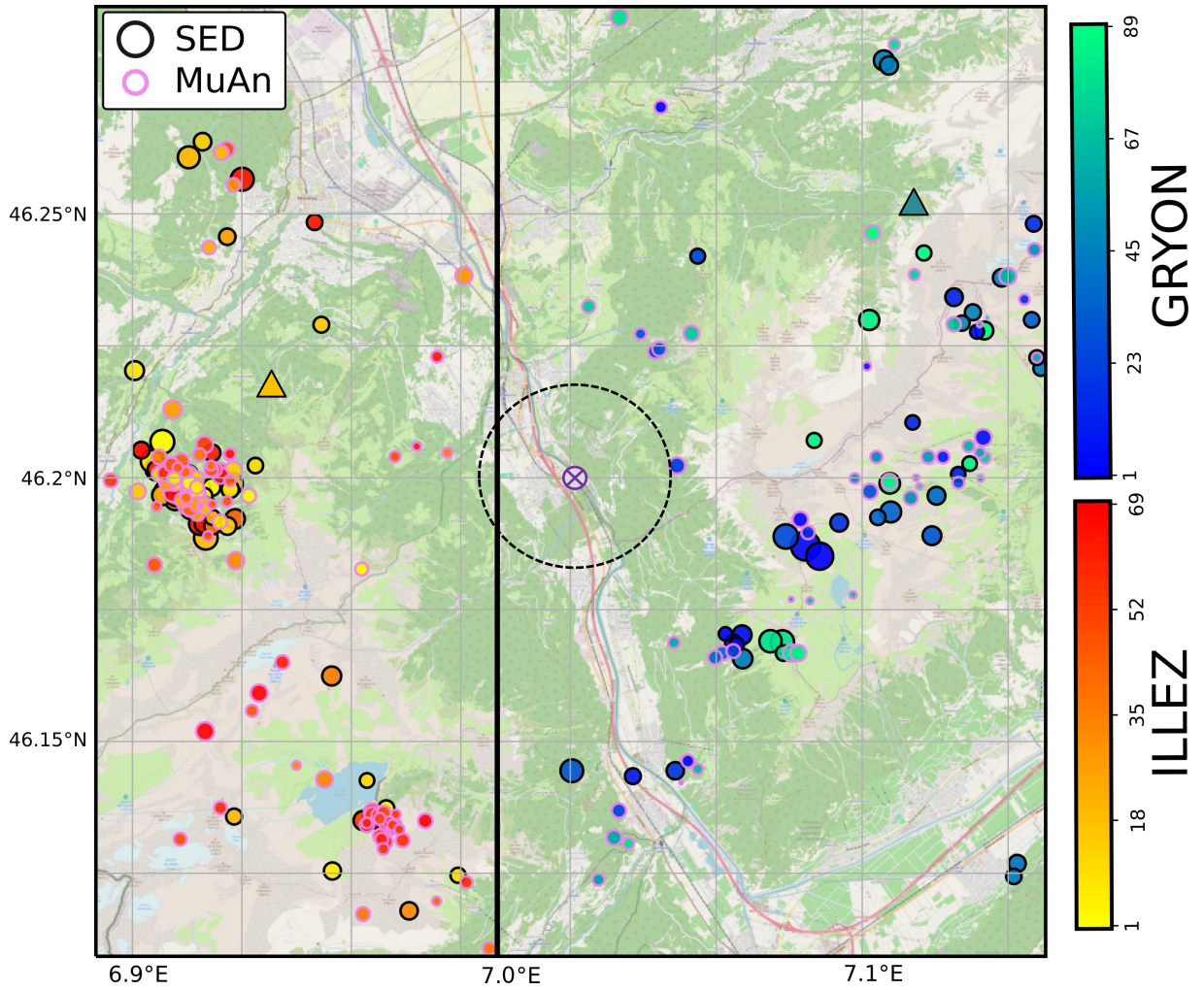
2. Enhanced "MuAn" catalogue

Feb/22 - Sep/22

- Machine Learning + Migration
  > MALMI: EQ-transformer + LOKI
- Coherence
  > Pyrocko/Lassie

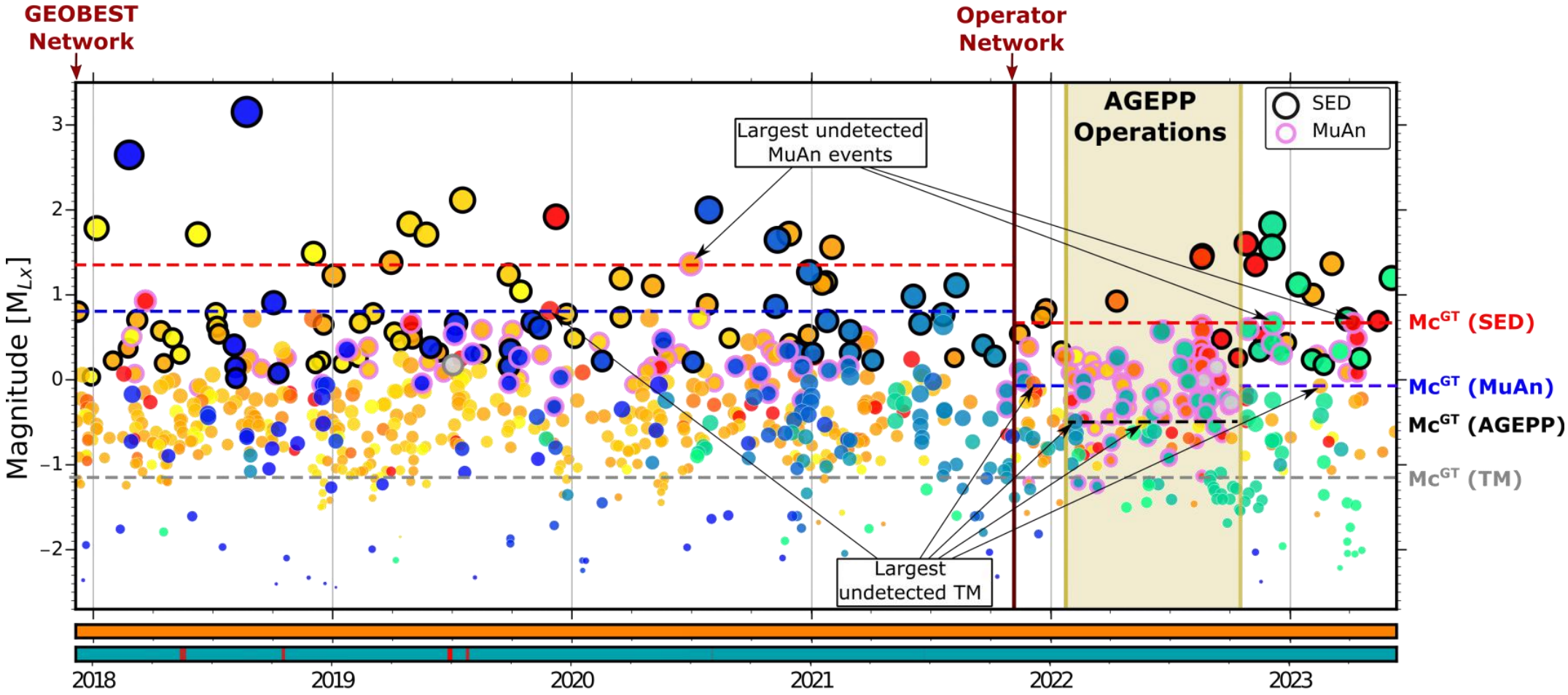
3. Template Matching / QuakeMatch:

- Evaluate the full performance of the seismic network
- More sensitive detection method
  > 263 EQ total events as input: 89 (**GRYON**) + 69 (**ILLEZ**) Templates



Kraft et al., 2013; Antunes et al., *in prep*

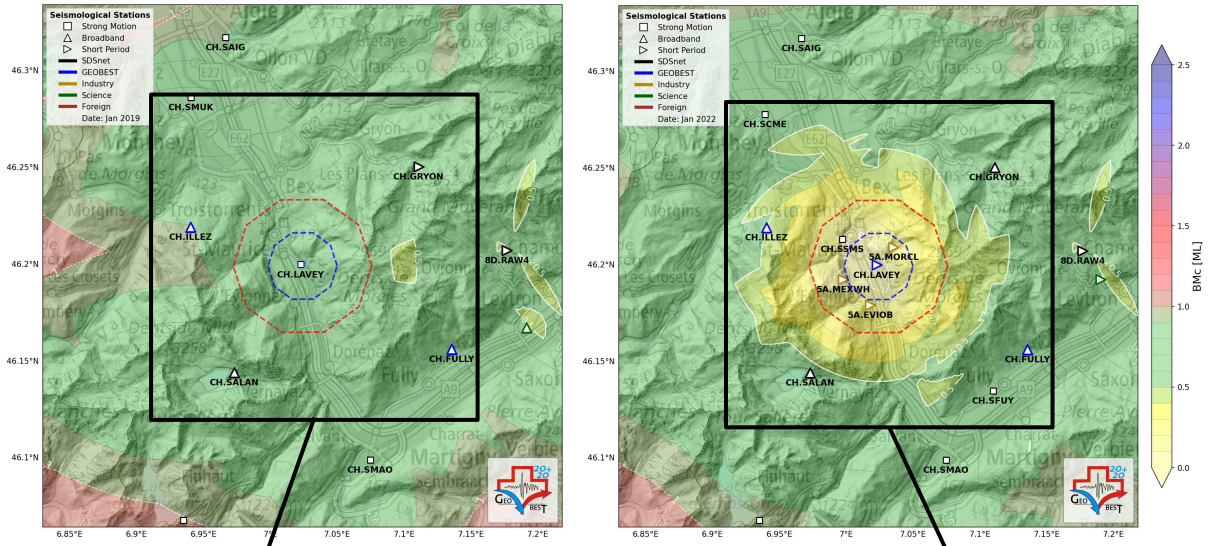
AGEPP, Lavey-les-Bains [Vaud]

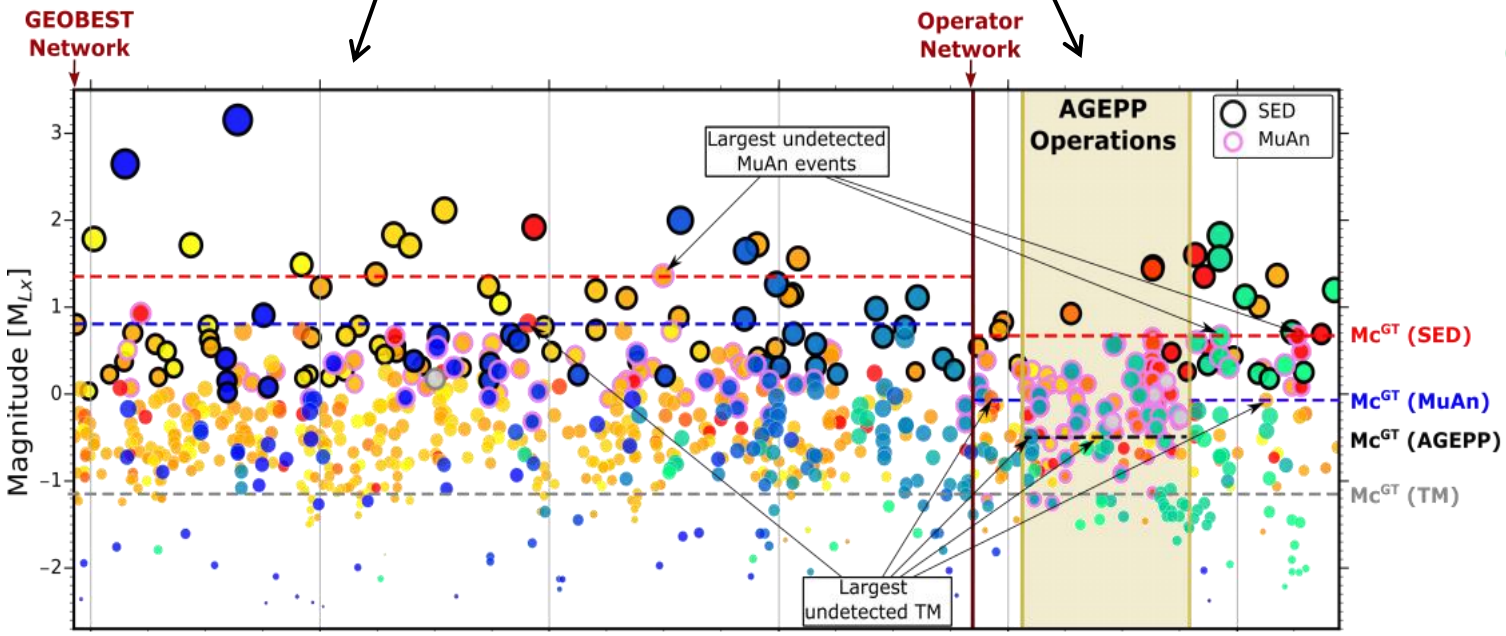


> 263 EQ total events as input: 89 (**GRYON**) + 69 (**ILLEZ**) Templates

Mc ~ -1.2 M_{Lx}

Kraft et al., 2013; Antunes et al., *in prep*





We develop a **workflow** to design and evaluate the performance of a seismic monitoring network based on numerical methods.

We apply our workflow to all GEOBEST **baseline monitoring networks** (e.g., Geneva basin).

We **tested** our tools using natural seismicity from the vicinity of the AGEPP geothermal project at Lavey-les-Bains, Vaud (Switzerland):

Ground Truth Performance Testing (GTPT)

Theoretical BMC
~ 0.8 ML | [0.5,-0.1] ML

Measured Mc
~ 0.8 ML | -0.1 ML

Good agreement!

GTPT shows that the GEOBEST network planning tools proposed give realistic network performance predictions

THANK YOU !

Questions?

GeoBest2020+

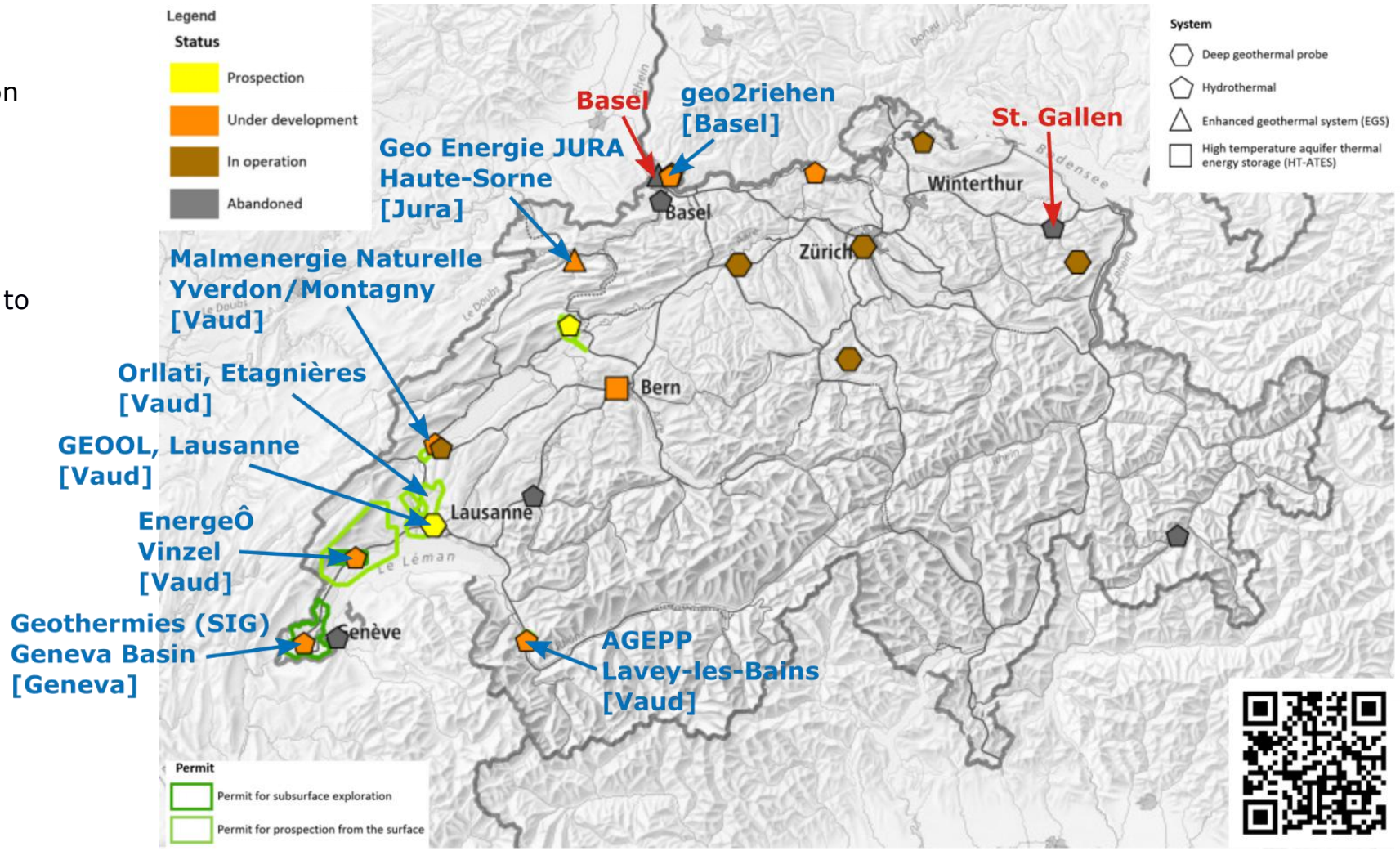
- **In Switzerland** the **cantons** are **responsible** for the underground exploration

GEOBEST2020+ project

- Develop **seismic monitoring guidelines** to **manage induced seismicity risk** in Swizerland (Kraft et al., 2025)

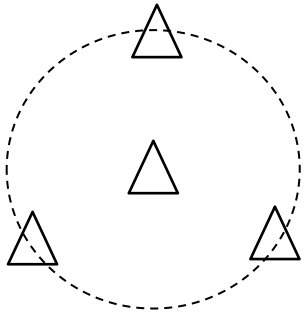
- Supports cantonal authorities to adequately **handle** the **risk** of **induced seismicity** for deep geothermal projects in Switzerland.

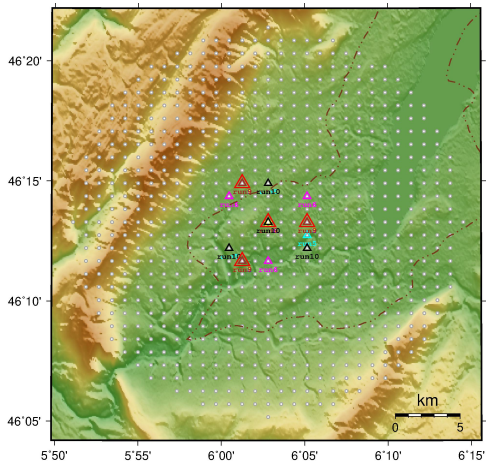
- Provides operator-independent:
- **Seismological expertise**
- **Baseline seismic monitoring**



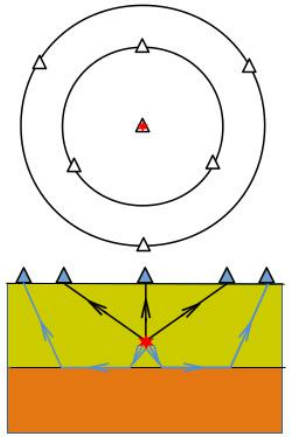
NetOpt3D: Network Design

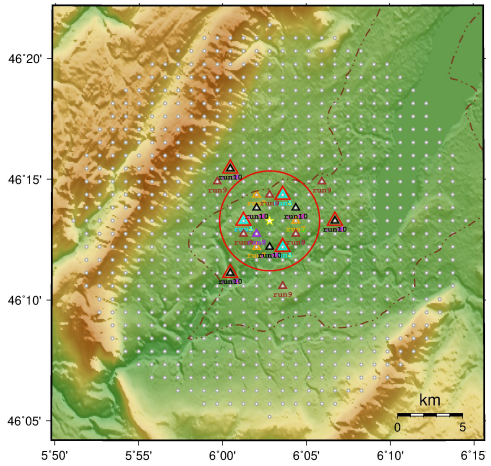
Homogeneous: 4 stations, 1.5 ML, Noise Levels, 10 runs





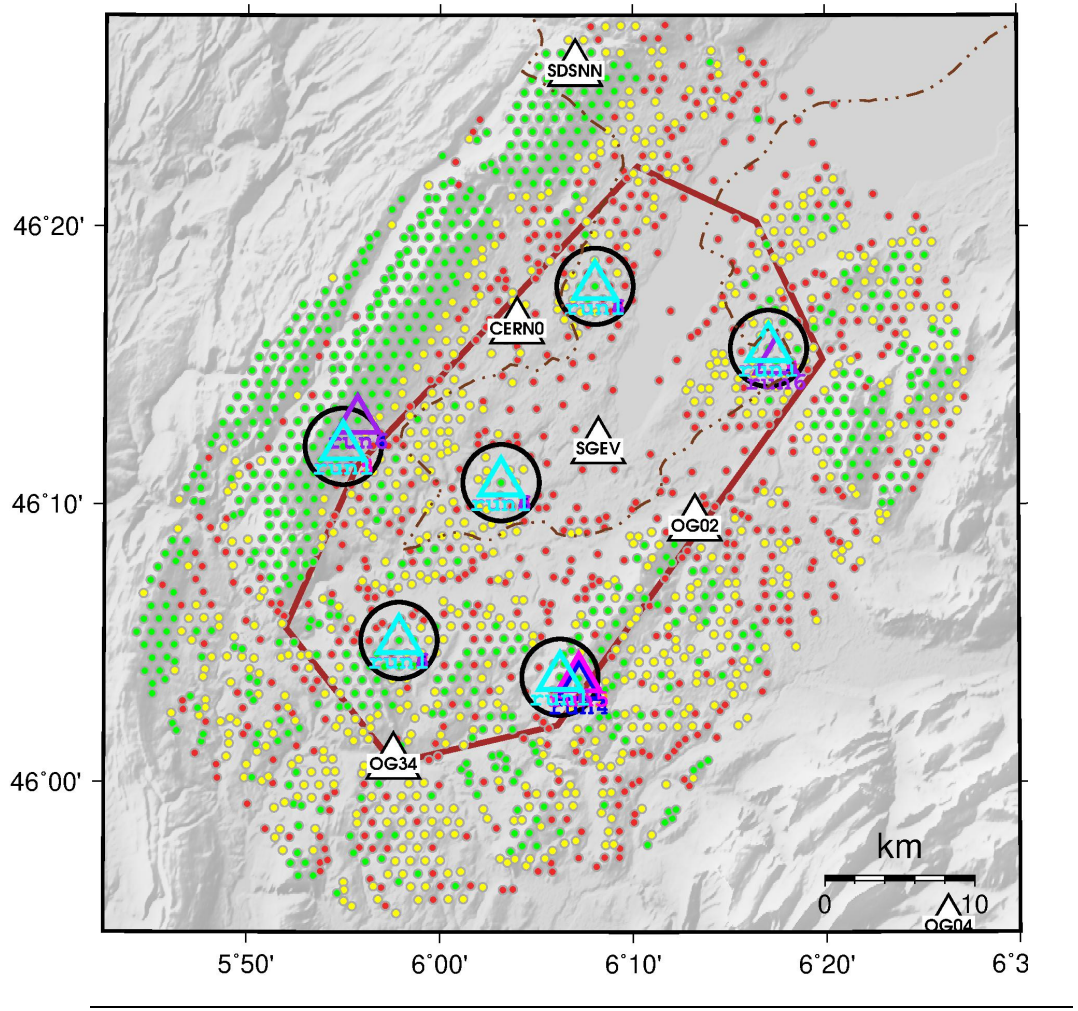
1D Vel Mod: 6 stations, 1.5 ML, Noise Levels, 10 runs



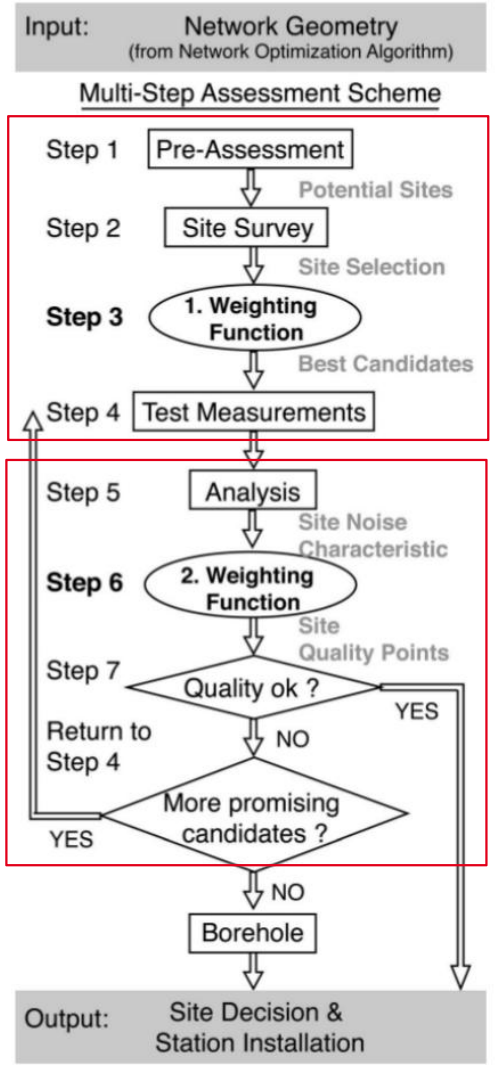


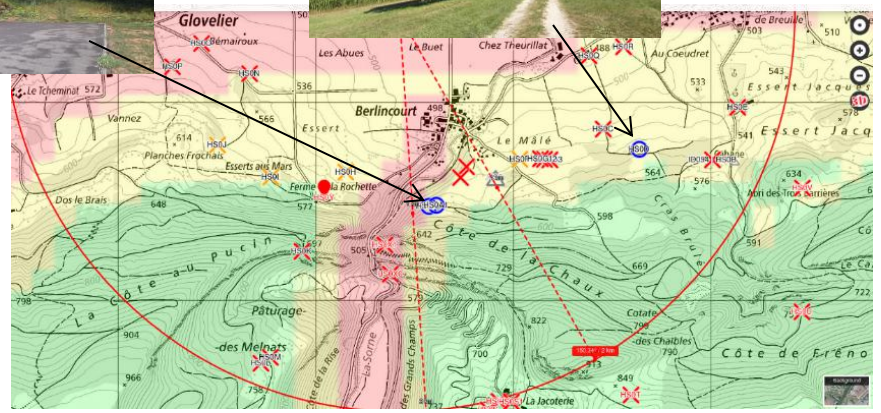
Kraft et al., 2013; Antunes et al., *in prep*

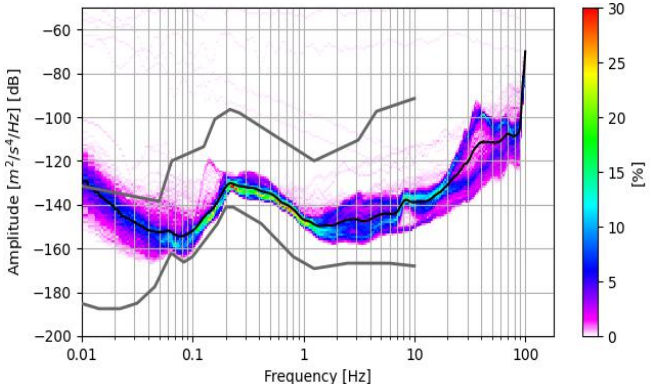
Geneva Basin (3D VM): 6 new stations, 1.5 ML, Noise Levels, 6 runs

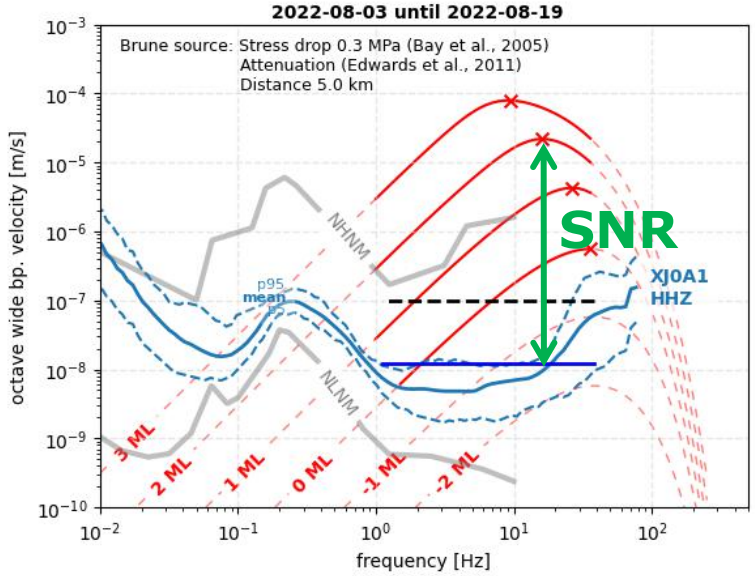


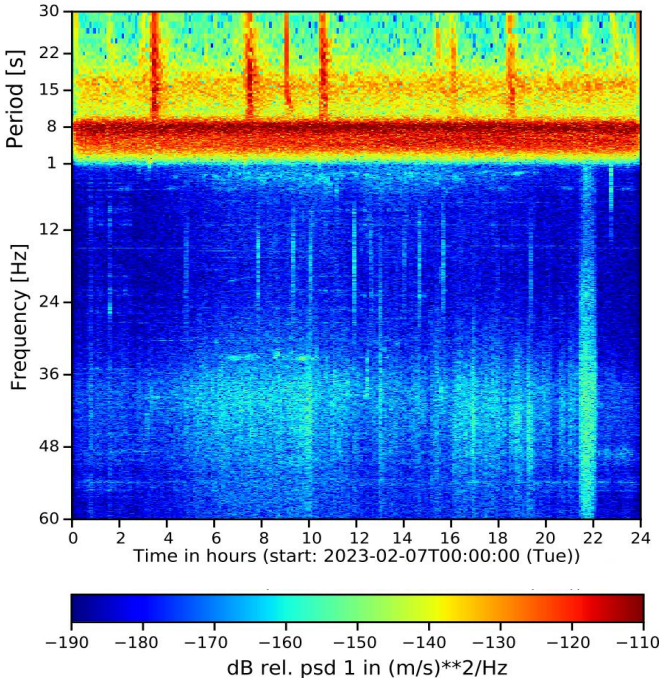
Site Selection & Noise Analysis











Plenkers et al., 2015; Antunes et al., *in prep*

BMC: Bayesian Magnitude of Completeness

Bulletin of the Seismological Society of America, Vol. 101, No. 3, pp. 1371–1385, June 2011, doi: 10.1785/0120100223

Bayesian Estimation of the Spatially Varying Completeness Magnitude of Earthquake Catalogs

by A. Mignan, M. J. Werner,* S. Wiemer, C.-C. Chen, and Y.-M. Wu

Geophysical Journal International

Geophys. J. Int. (2013) **195,** 474–490
Advance Access publication 2013 July 5

doi: 10.1093/gji/ggt225

Optimization of a large-scale microseismic monitoring network in northern Switzerland

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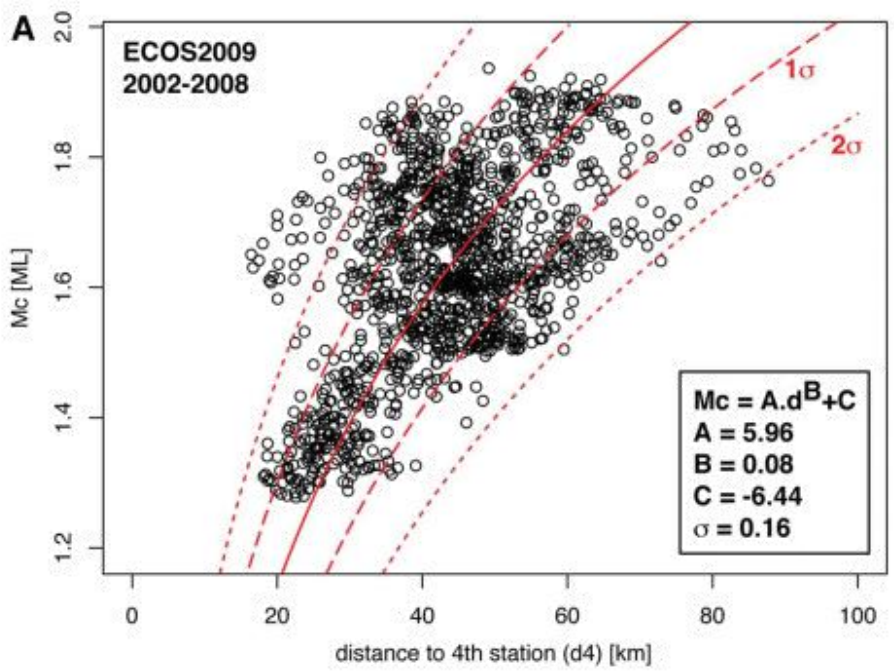
[2]*Institute of Geophysics, ETH-Zurich, Switzerland*

Accepted 2013 June 3. Received 2013 May 28; in original form 2011 November 14

$$Mc = A.d^B + C$$



$$Mc = 5.96 * d^{0.08} - 6.44$$

d - distance to the 4th station

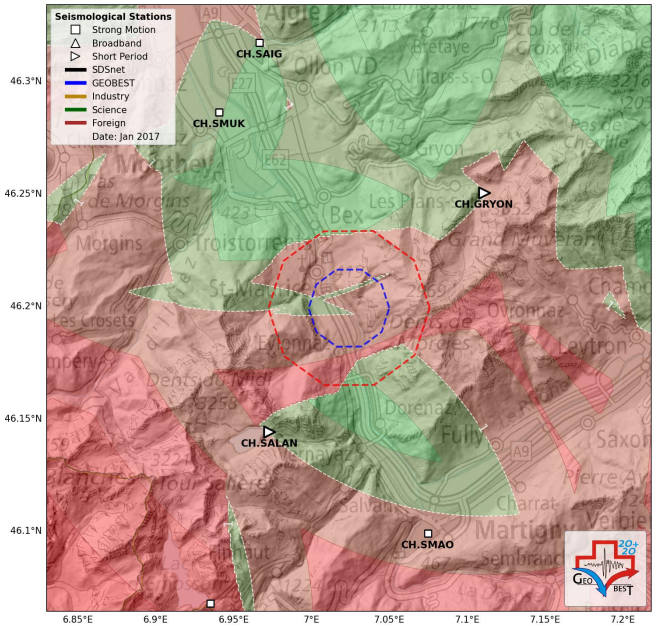
Kraft et al., 2013; Antunes et al., *in prep*

Optimized to include the real noise levels at the stations

BMC: Bayesian Magnitude of Completeness

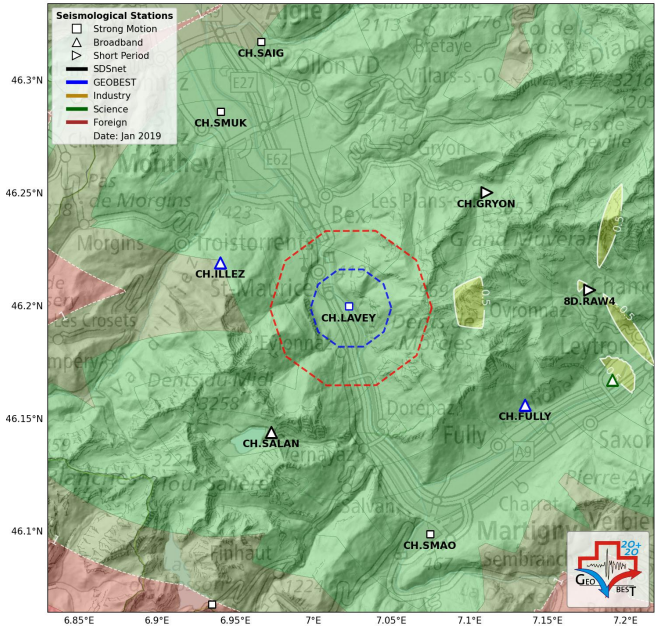
AGEPP, Lavey-les-Bains [Vaud]

Before Geobest Netw



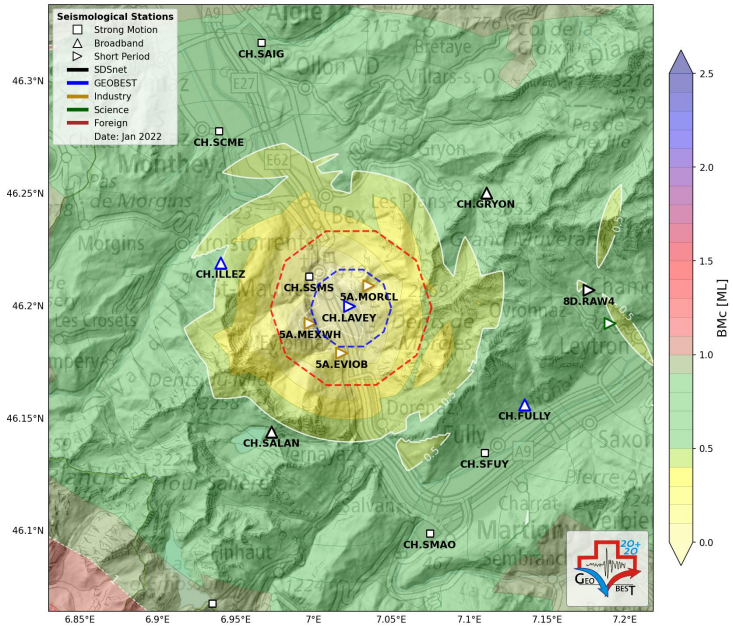
BMC: 1.2-1.3 (ML)

After Geobest Netw installation



BMC: 0.7-0.8 (ML)

After Operator Netw installation



BMC: ~0.1 (ML)

Kraft et al., 2013; Antunes et al., *in prep*

BMC < 1.0 ML

LocErr: Location Uncertainties

AGEPP, Lavey-les-Bains [Vaud]

We use a **synthetic catalogue** of events of different magnitudes at the targeted depth:

- Mean Swiss EQ stress drop of 0.3 MPa (Bay et al., 2005);
- Swiss Mw/ML scaling relation (Edwards et al.,2015);
- Swiss crustal attenuation model (Edwars et al., 2011);
- 3D P-wave velocity model (Husen et al., 2003);
- Average radiation pattern for P and S (Aki, 1976);
- Network geometry;
- Real noise level measured at the stations.

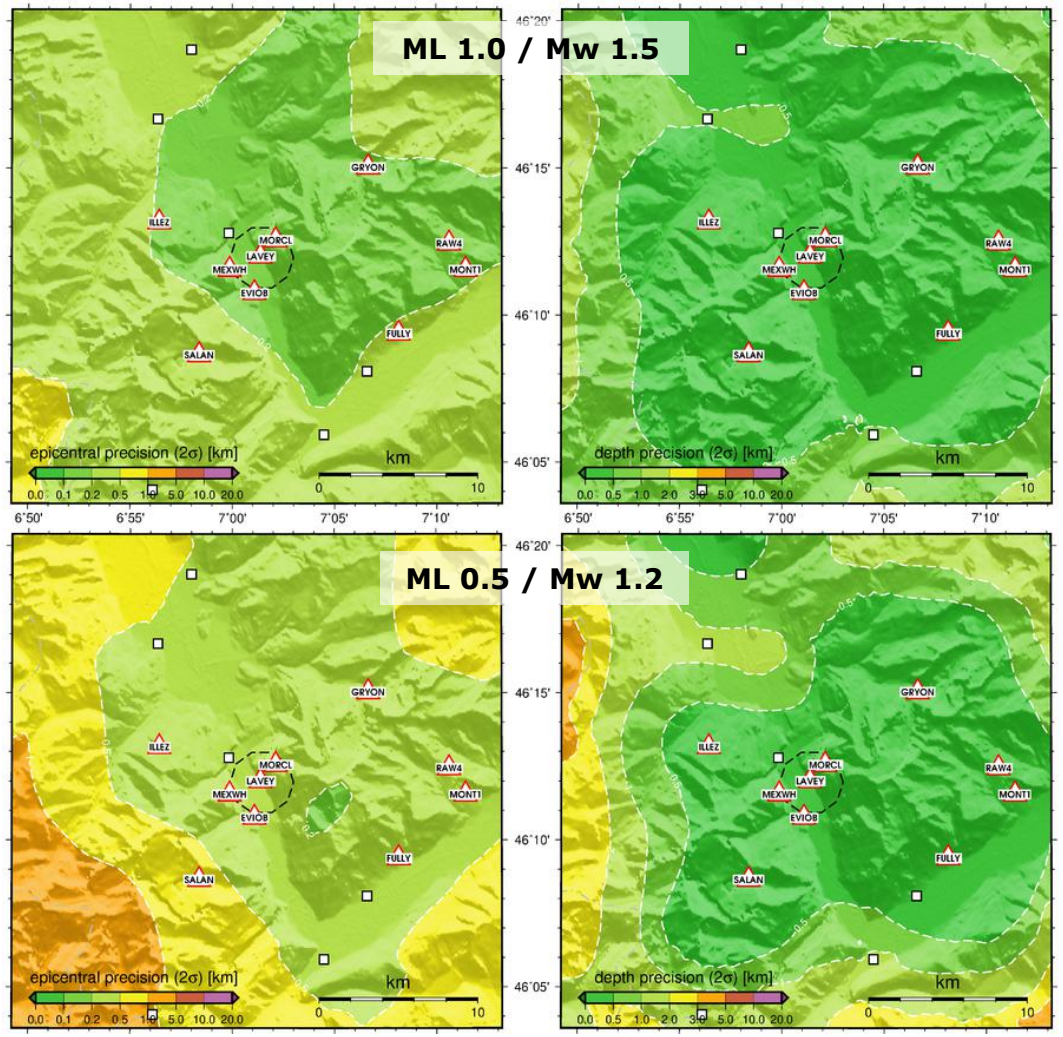
$$\Delta t = \left(log_2 \left(1 + \frac{SNR}{20} \right)^2 * f_{max} \right)^{-1}$$

Aki, 1976

f_{max} - signal bandwidth (Brune source spectra peak frequency, 1-40 Hz)

Kraft et al., 2013; Antunes et al., *in prep*

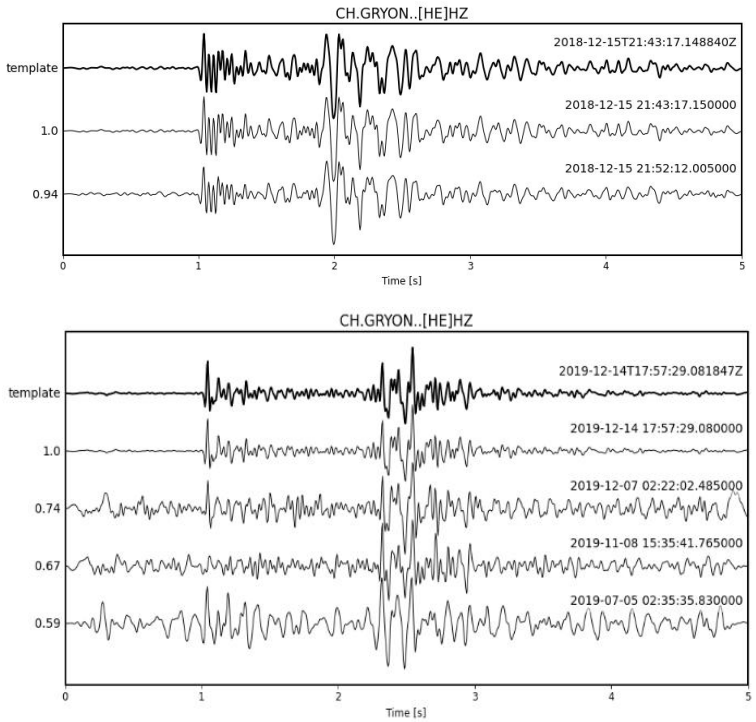
Location Uncertainties (3km, 2σ / 95% confidence level)



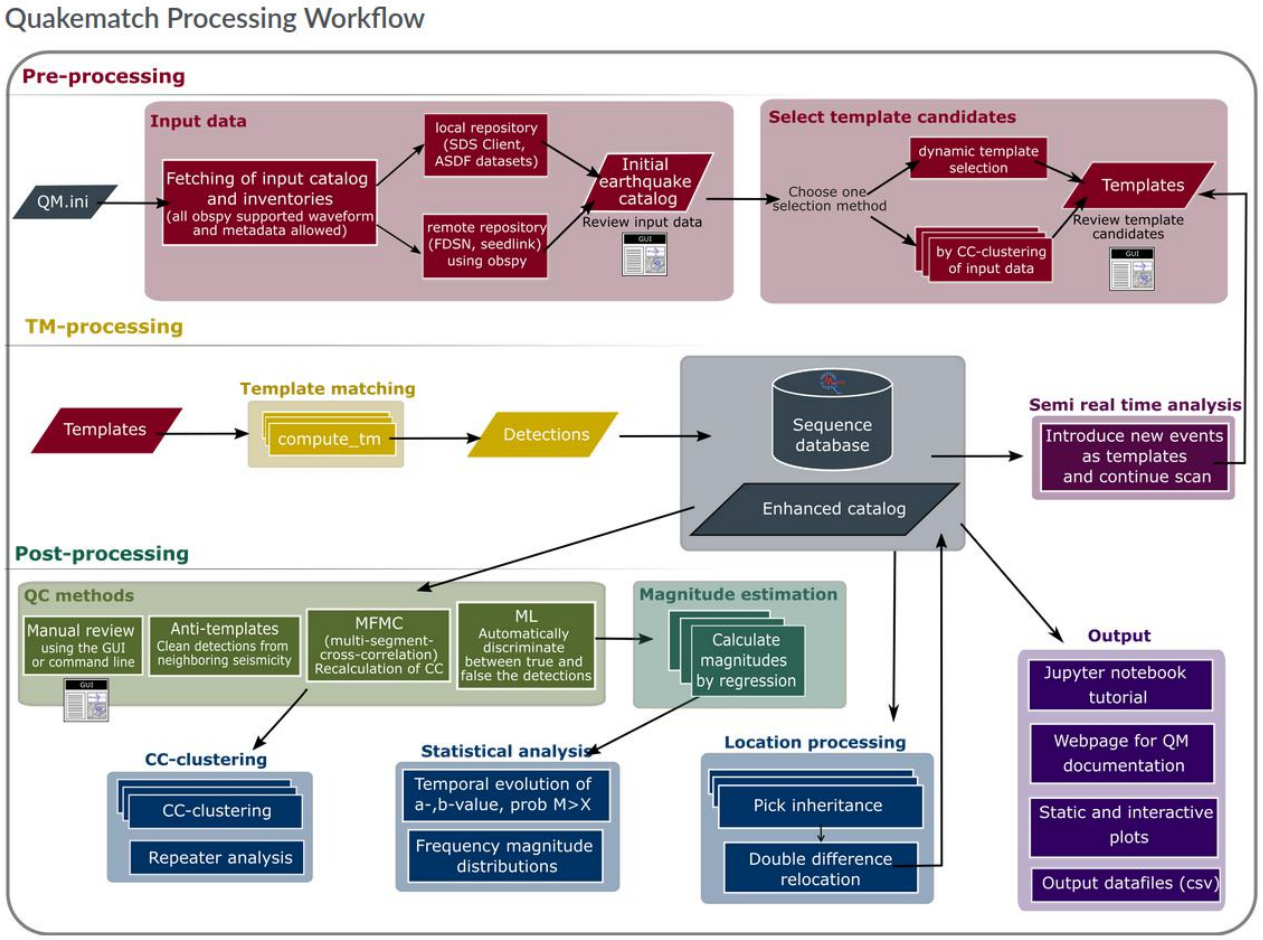
Epicentral Precision ≤ 0.5 km

Depth Precision ≤ 2.0 km

Quakematch: Template Matching



Uses one station cross-correlation to detect earthquakes of smaller magnitudes that are usually missed by detection routines (e.g., STA/LTA)



A new toolbox based on SeisMatch (Herrmann et al., 2019)

Toledo et al. (*in prep*), PICO session F (Thursday, 17:30)