15 years of operating rules & research to minimize induced seismicity in RLP (Southwest Germany) - Application on a regional scale?

Bernd Schmidt[1], Andreas Steinberg[2] Peter Gaebler[2]
1 Seismological Service, State Authority for Geology and Mining Rhineland-Palatinate, Germany
2 BGR, Federal Institute for Geosciences and Natural Resources, Germany

RheinlandPfalz
LANDESAMT FÜR GEOLOGIE UND BERGBAU

ML based real-time detector "LIDECT"

- "LIDECT" found **2996 induced events** close to **geothermal power plants** Landau and Insheim between 2013 and 2023
- 550 are used here which have good constraints
- "Forschungsnetzwerk Südpfalz" which was in operation between 2013 and 2024 (MAGS and SEIGER projects)
- M_w **magnitudes** are determined using **absolute amplitude fitting** between 1-8 Hz in "GROND" using **isotropic sources** on stations with picks from "LIDECT"
- **Catalog available on:** *https://eida.bgr.de/lidect/fdsnws*
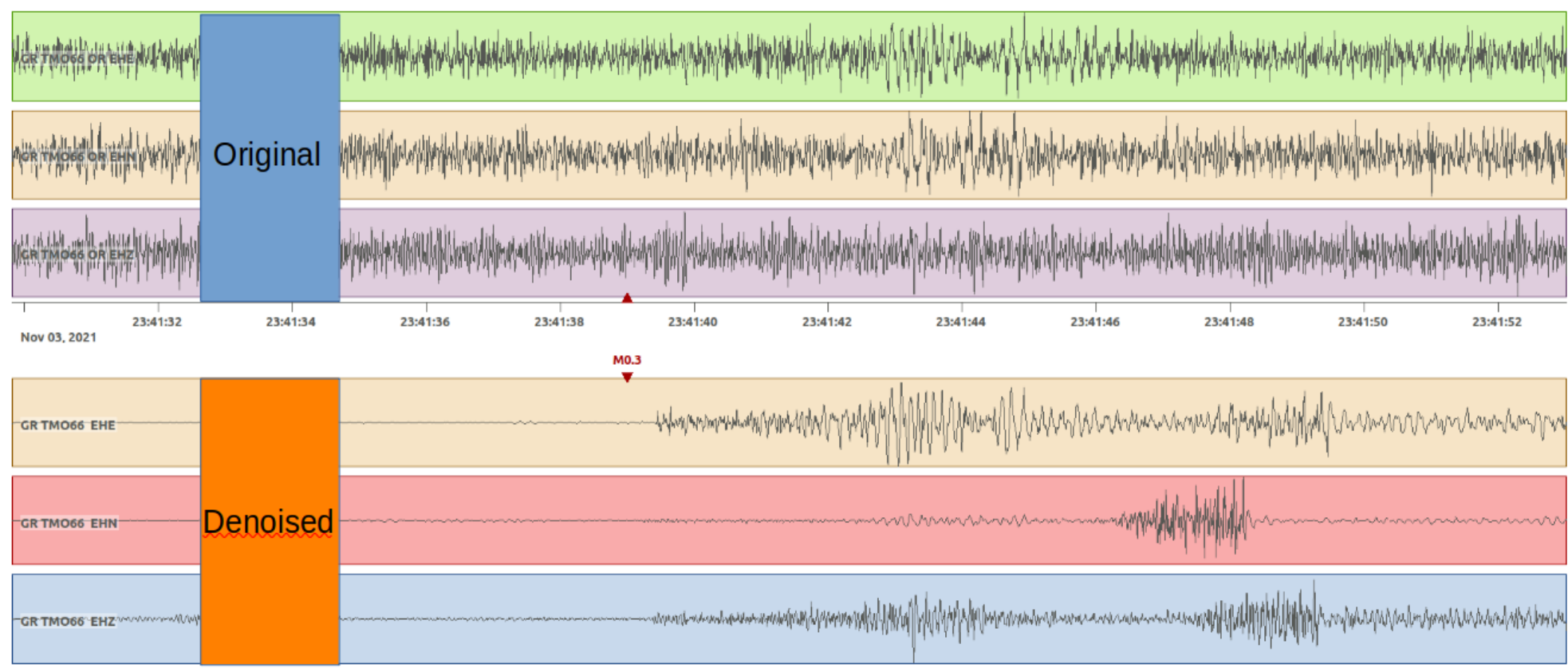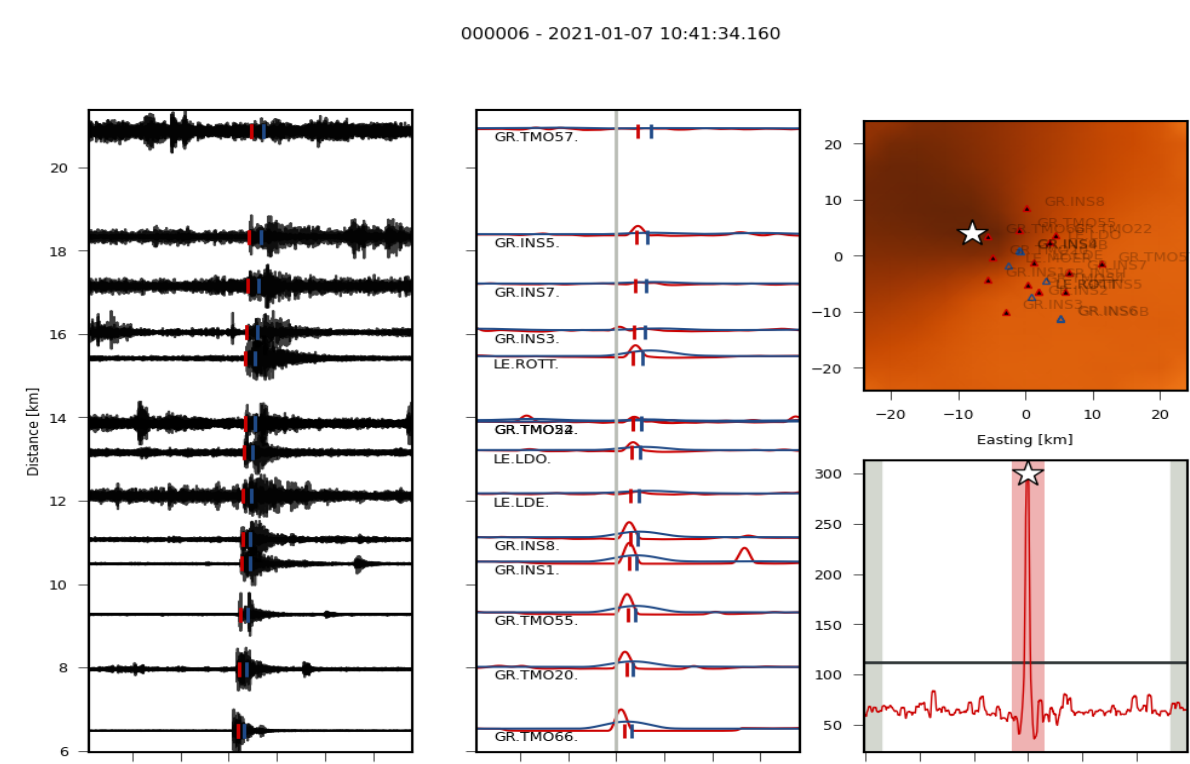
Example from an M_w 0.3 induced earthquake in Landau

denoising of data using **DeepDenoiser** (Zhu et al., 2020; Tibi et al. 2021)
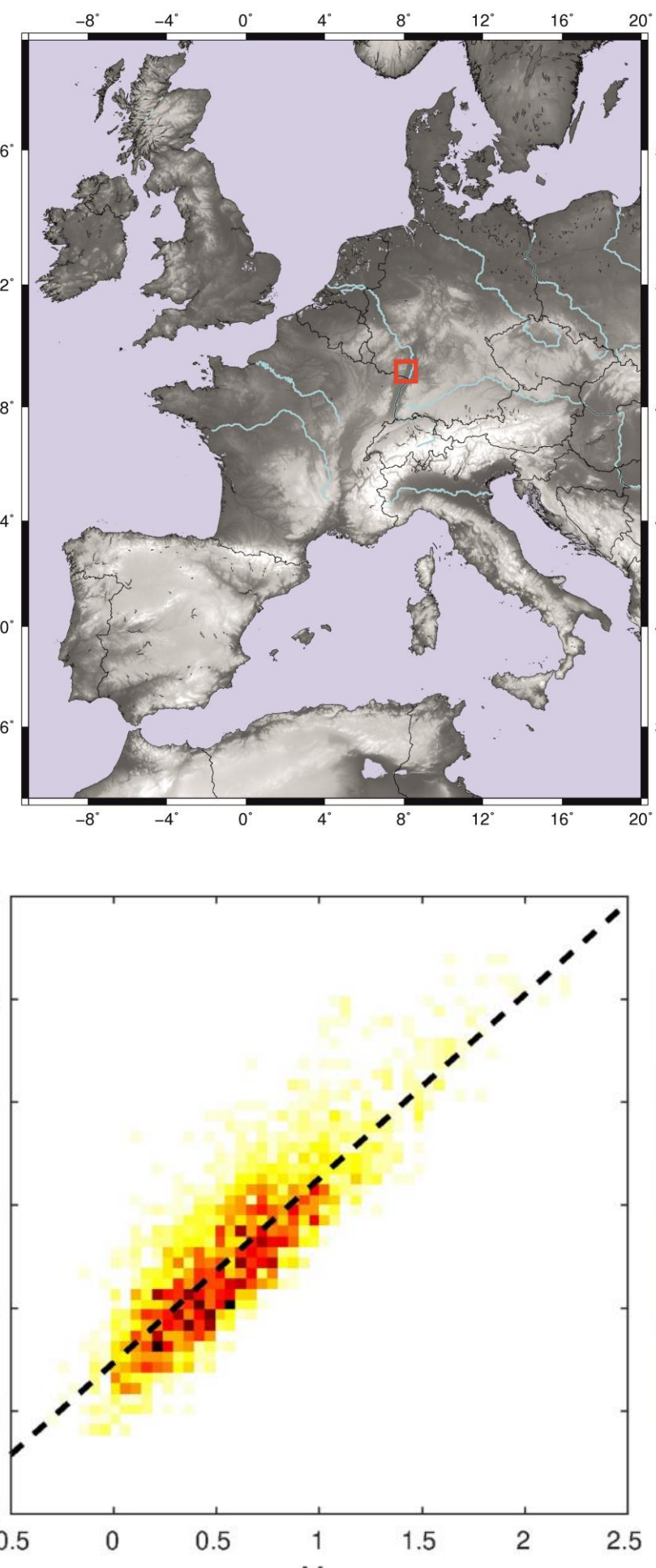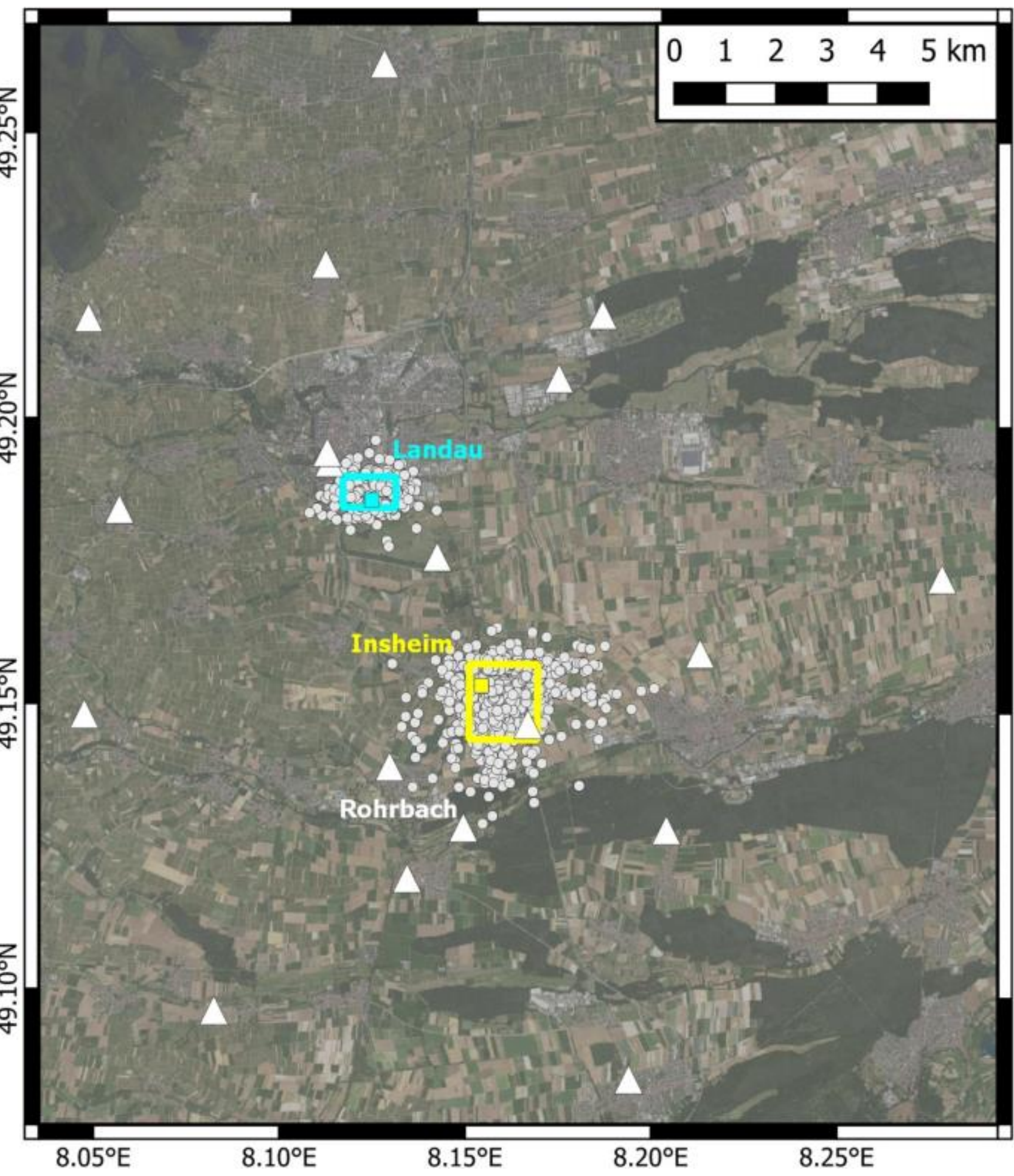
Stacking Detector
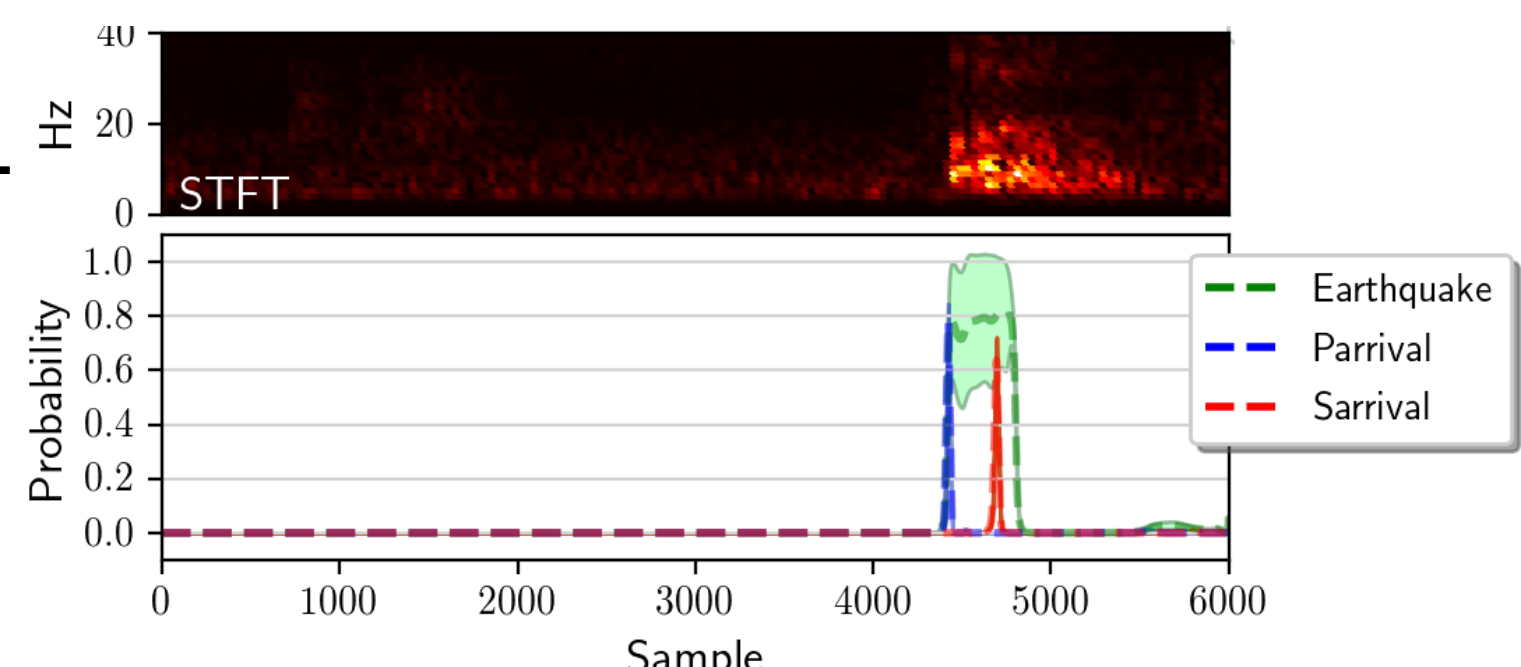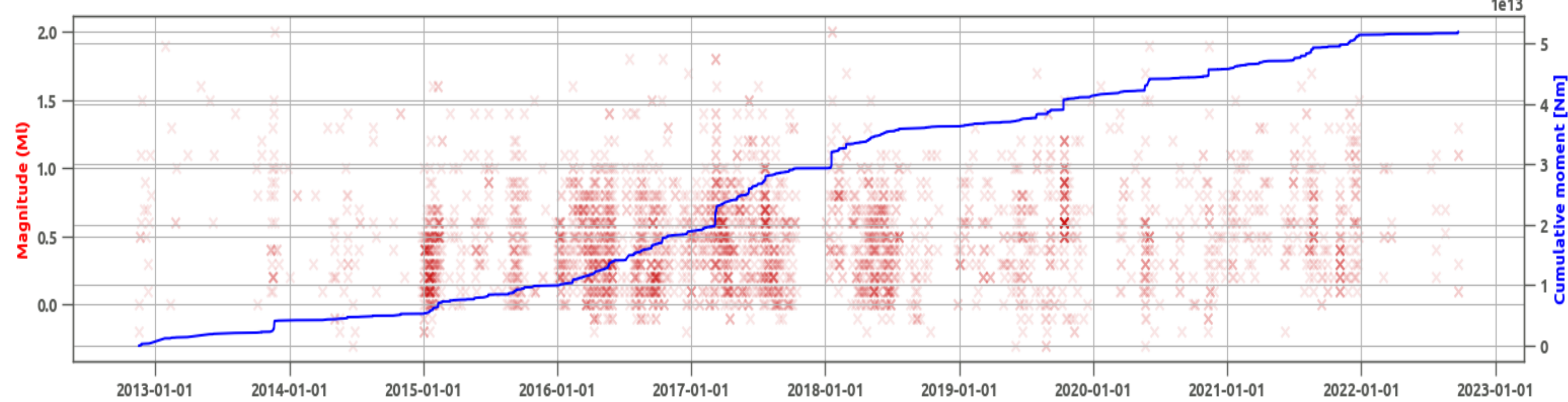
EQT (Mousavi et al, 2020)
Transfer learned on MAGS/SEIGER project picks

Common detection:
Declaration of event

Based on "Lassie" detector by Kriegerowski et al. (*https://git.pyrocko.org/pyrocko/lassie*)
Threshold based on current noise level and active stations

ML based ground motions and impact estimation

- We present as an fast and first order alternative a **physics based deterministic** approach for generation of ground motion maps, with physics derived **uncertainties**

- We use *machine learning* (Steinberg, Andreas, et al. Estimation of seismic moment tensors using variational inference machine learning. *Journal of Geophysical Research: Solid Earth*, 2021, 126. Jg., Nr. 10, S. e2021JB022685) to determine the source mechanisms and to enhance the production of ground motion
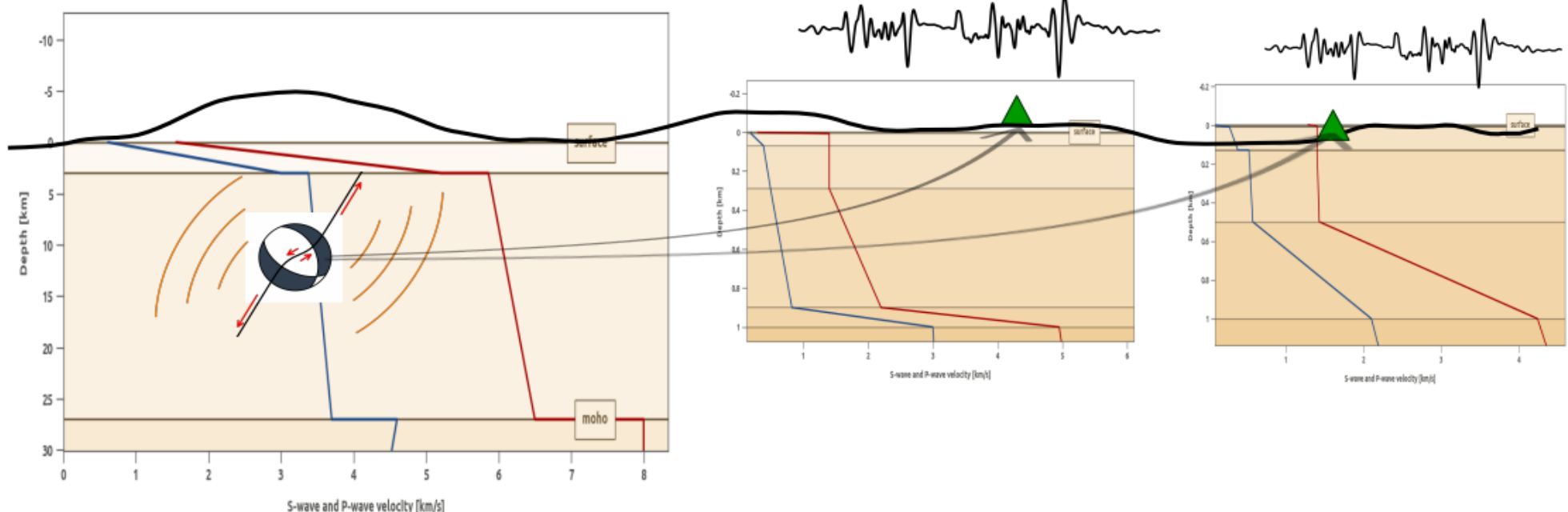
- We use **Pyrocko** (Heimann et al. 2017) to facilitate the deterministic ground motion calculation
- Calculation of full synthetic waveforms for grid of assumed surface receivers
- **Qseis** (Wang, 1999) and **Crust2** used for GF store creation and as **1-D** earthmodels
- V_{s30} based on the topographic slope (Allen et al. 2009) or microzonation used to create local site specific underground model, combined with the Crust2 model this creates a pseudo **2-D** GF-store setup

Trafic Light System
for deep geothermal energy

Stage	PGV	decisions & notes
6	1 event > 20 mm/s or 5 events > 10 mm/s	Shutting down the power plant
5	5.0 mm/s < V < 10.0 mm/s	Notification; Operation with a minimized flow rate over a longer period of time in consultation with the mining department
4	3.0 mm/s < V < 5.0 mm/s	Notification; Events evaluations, further gradual flow rate reduction
3	1.0 mm/s < V < 3.0 mm/s	Notification; Events evaluations, temporary gradual flow rate reduction
2	0.5 mm/s < V < 1.0 mm/s or 5 events in 12 h after level 1	Notification; temporary flow rate reduction
1	0.2 mm/s < V < 0.5 mm/s	Notification; Documentation of all vibrations
	V < 0.2 mm/s	No reaction

Geothermie / Lithium   18.11.2024   Folie 7

Trafic light rules (TFL) from the mediation process deep geothermal energy in the region "Vorderpfalz" – March 2014*

*Ministry of Economic Affairs, Transport, Agriculture and Viticulture Rhineland-Palatinate

M_w 1.3 induced earthquake Landau 2021
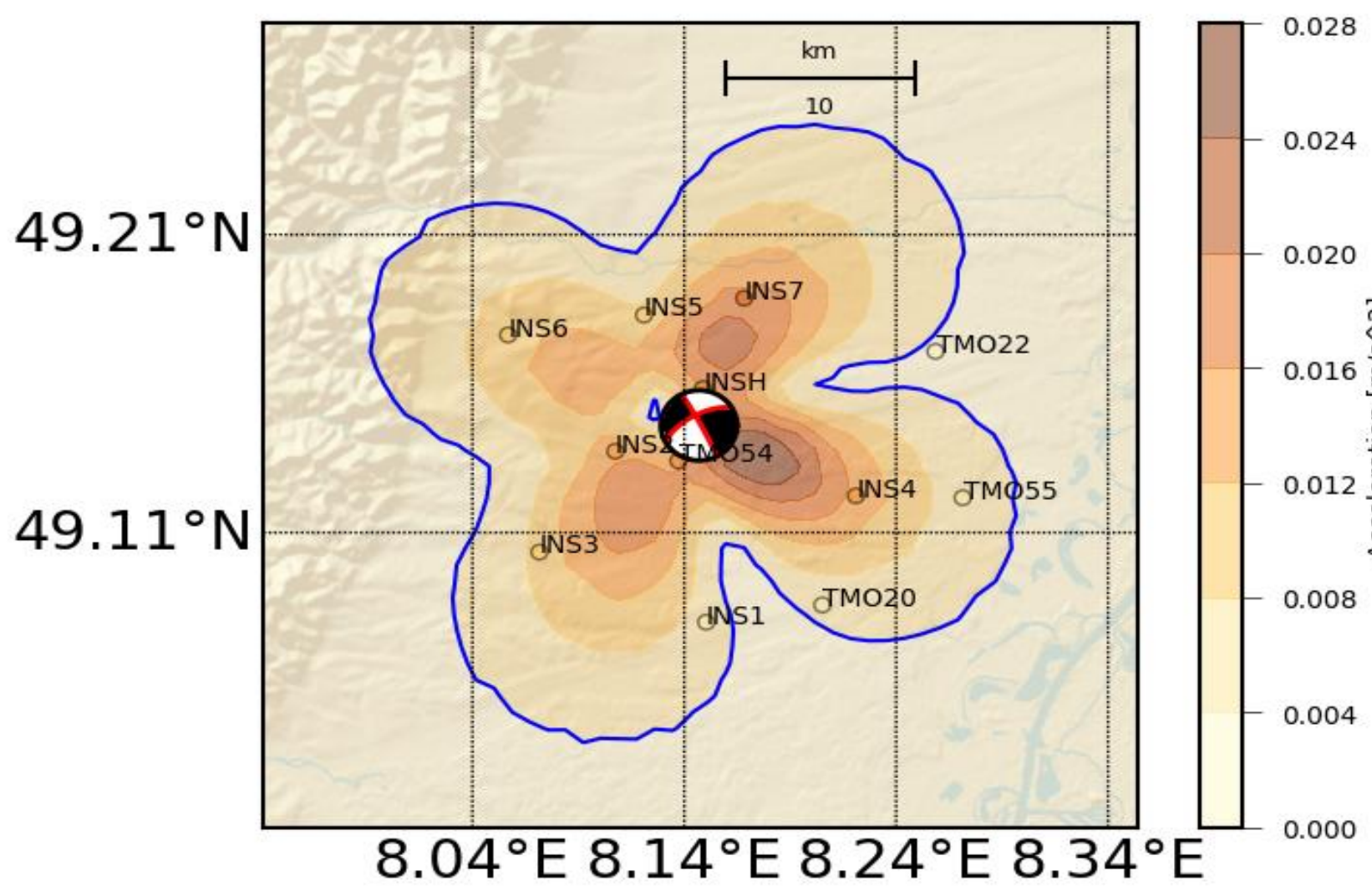
- Microzonation measurements for the region deliver velocity
- profiles and Vs30 values
- V_{s30} tends to overestimation for the Landau/Insheim catalog
- 2-D full waveform modeling performs better

Full waveform modelling with V_{s30}

Full waveform modelling without V_{s30}

Using prediction from **ML**
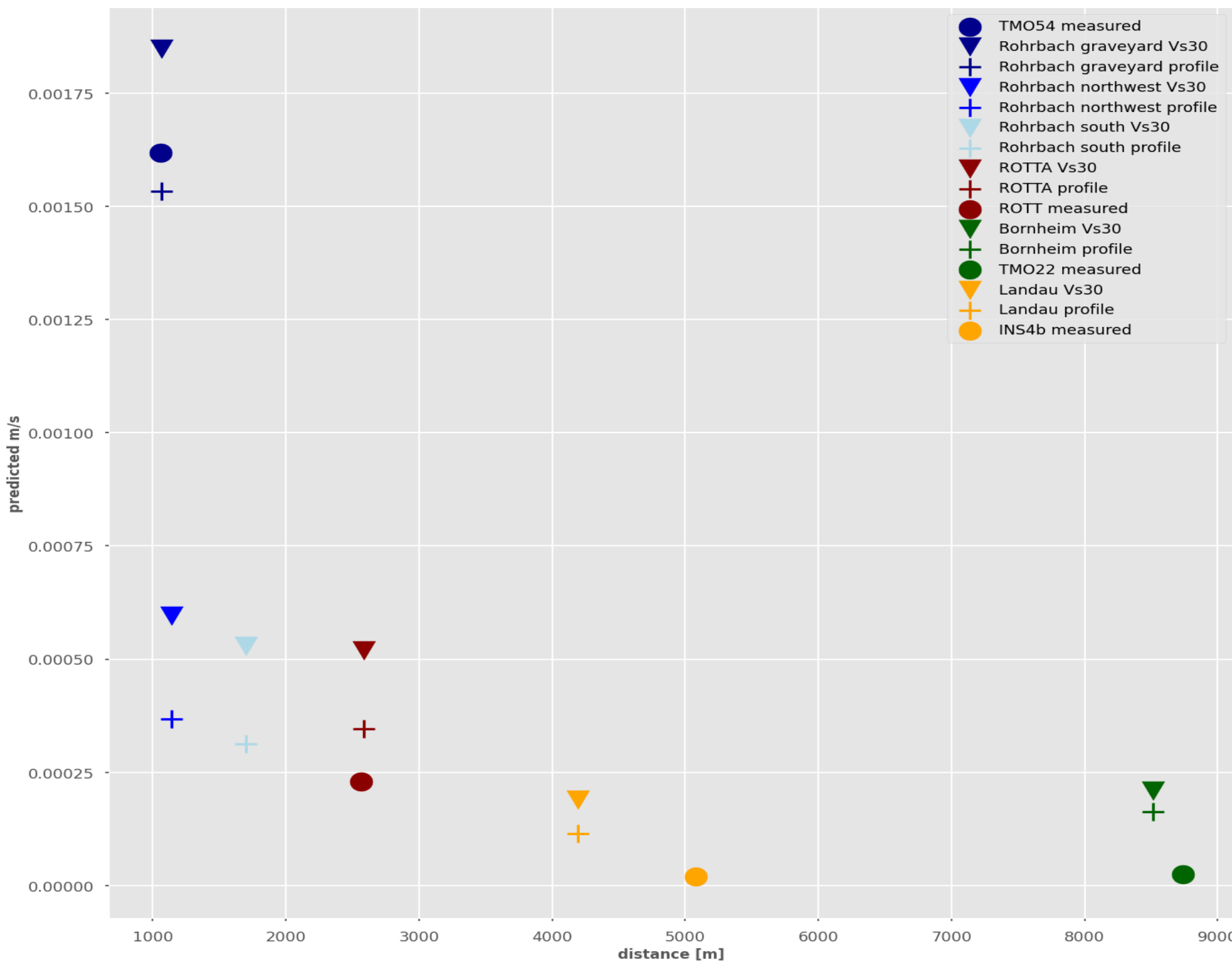
- M_w 1.5 2020-11-09 at Landau site
- max. PGV @1-20 Hz
- Ground motion prediction: 20s v_s 0.2s

Conclusions

The significant induced earthquakes of 2009 in Landau led to increased monitoring and research efforts, as well as the application of stricter operating procedures. By introducing an advanced (applied **retroactive**) detection algorithm (stacking and EQT), also known as the LIDECT detector, the approximately 900 events from the period 2013–2023 could be expanded to a total of approximately 3,000. Calculated deterministic ground motion maps (SEIGER project), which represent the ground velocity for the earthquakes in Insheim, can now be used to verify the traffic light system – once without considering the local geology, and once with the local geology.

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