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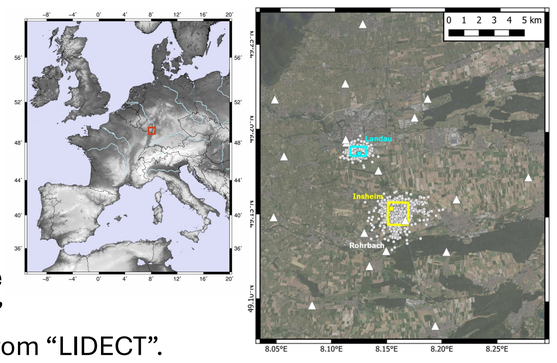
15 years of operating rules & research to minimize induced seismicity in RLP (SW Germany) - Application on a regional scale?

Schmidt Bernd[1]*, Steinberg Andreas[2], Gaebler Peter[2]
Seismological Service, State Authority for Geology and Mining Rhineland-Palatinate, Germany [1]*, BGR, Germany[2],
bernd.schmidt@lgb-rlp.de*

INDUCED SEISMICITY CLOSE TO GEOTHERMAL POWER PLANTS

LIDECT-Detector found **2996 induced events** close to geothermal power plants Landau and Insheim (Fig. 1 & 2) between 2013 and 2023 (Fig3) using stations from "research network Southern Palatinate":



550 are used here which have good constraints.
M_w magnitudes are determined using **absolute amplitude fitting** between 1-8 Hz in "GROND" using **isotropic sources** on stations with picks from "LIDECT".

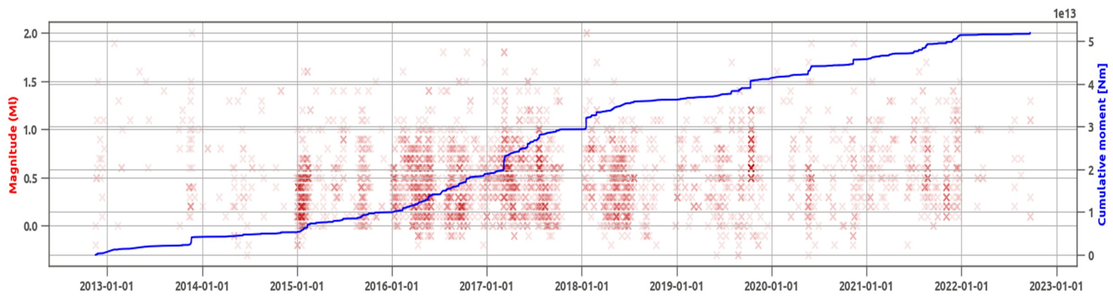


Figure 3: induced earthquakes 2013-23, Catalog available on: https://eida.bgr.de/lidect/fdsnws

ML BASED REAL-TIME DETECTOR *"LIDECT"*

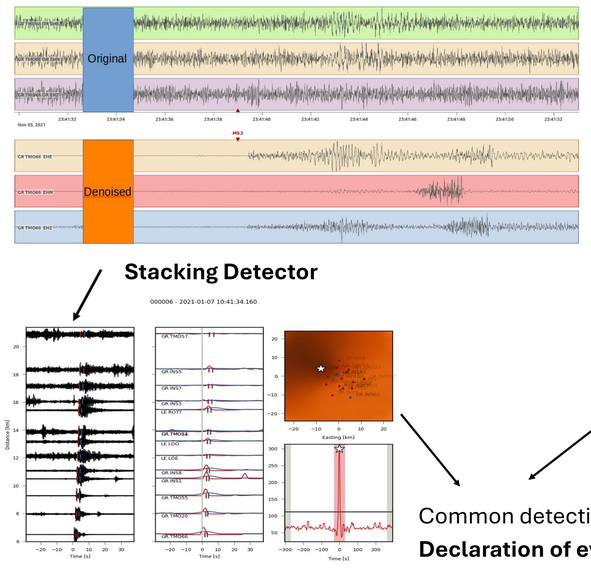


Figure 4: Example from an M_w 0.3 induced earthquake in Landau, denoising of data using **DeepDenoiser** (Zhu et al., 2020; Tibi et al. 2021)

Figure 5 & 6: 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

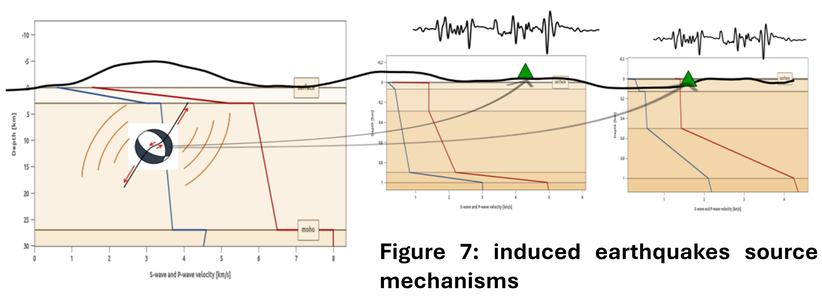


Figure 7: induced earthquakes source mechanisms

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[1] 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 (Dahm et al., 2018)
- **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

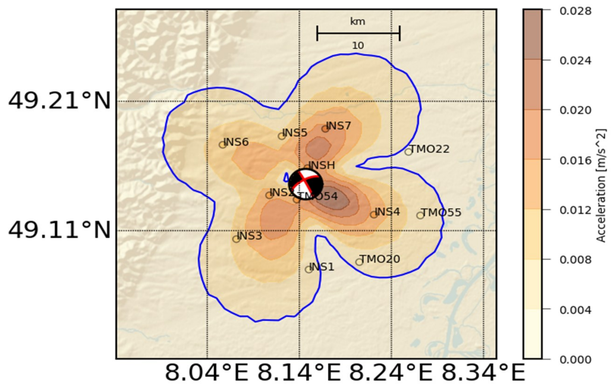
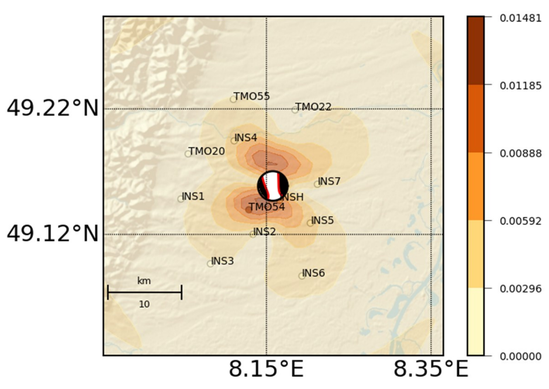
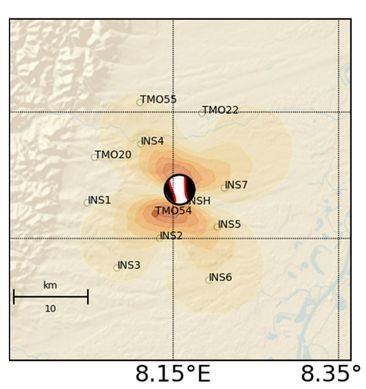


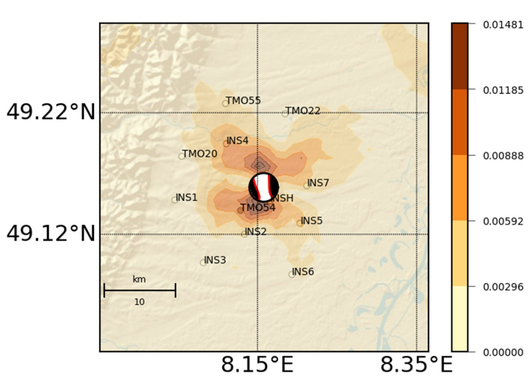
Figure 8: M_w 1.3 induced earthquake Landau 2021



Full waveform modelling with V_{S30}



Full waveform modelling without V_{S30}



Using prediction form **ML**

Figure 9: M_w 1.5 - 2020-11-09 at Landau site, max. PGV @1-20 Hz, ground motion prediction: 20s v_s 0.2s

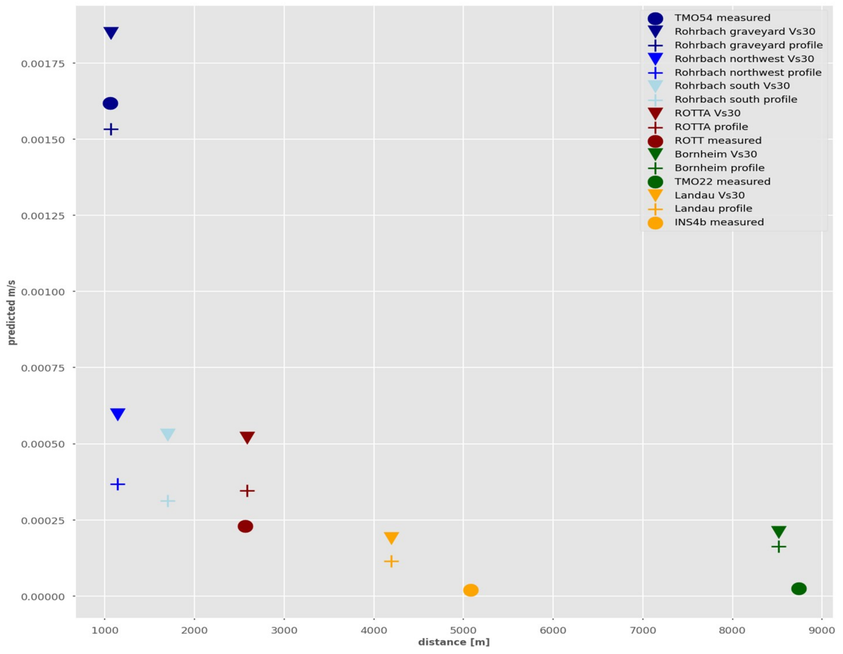


Figure 10: microzonation measurements for the region deliver velocity, V_{S30}, profile & measured. V_{S30} tends to overestimation for the Landau/Insheim catalog. 2-D full waveform modeling performs better

COMBINING TLS & PGV & LIDECT-DETECTOR

The TLS applied to deep geothermal energy in Rhineland-Palatinate is a tiered plan for monitoring and managing induced seismic activities that may result from geothermal installations. This system specifies specific measures to be taken when certain thresholds of Peak Ground Velocity (PGV) are reached or exceeded. It includes six levels, ranging from no response to the shutdown of the power plant. Calculated deterministic shake maps (Research joint project SEIGER) showing ground velocity for the seismic event in Insheim now can be used to verify the traffic light system, once without considering the local geology and once considering the local geology.

By introducing an advanced detection algorithm (stacking and ML-EQT), also known as a LIDECT detector, the approximately 900 events from the period 2013-2023 could be expanded to a number of approximately 3.000.

Traffic 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

- Shutting down the power plant
- flow rate reduction
- Evaluations
- Information

Figure 1: Traffic light rules (TFL) from the mediation process deep geothermal energy in the region "Vorderpfalz" – March 2014[2]

CONCLUSION

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

Acknowledgements
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REFERENCES

[1]Steinberg, Andreas, et al. : Estimation of seismic moment tensors using variational inference machine learning. Journal of Geophysical Research: Solid Earth, 2021, 126. Jg., No. 10, S. e2021JB022685
[2]Ministry of Economic Affairs, Transport, Agriculture and Viniculture Rhineland-Palatinate, Germany