Wave propagation simulation on a 3D model of the Ruhr district for locations of seismic monitoring

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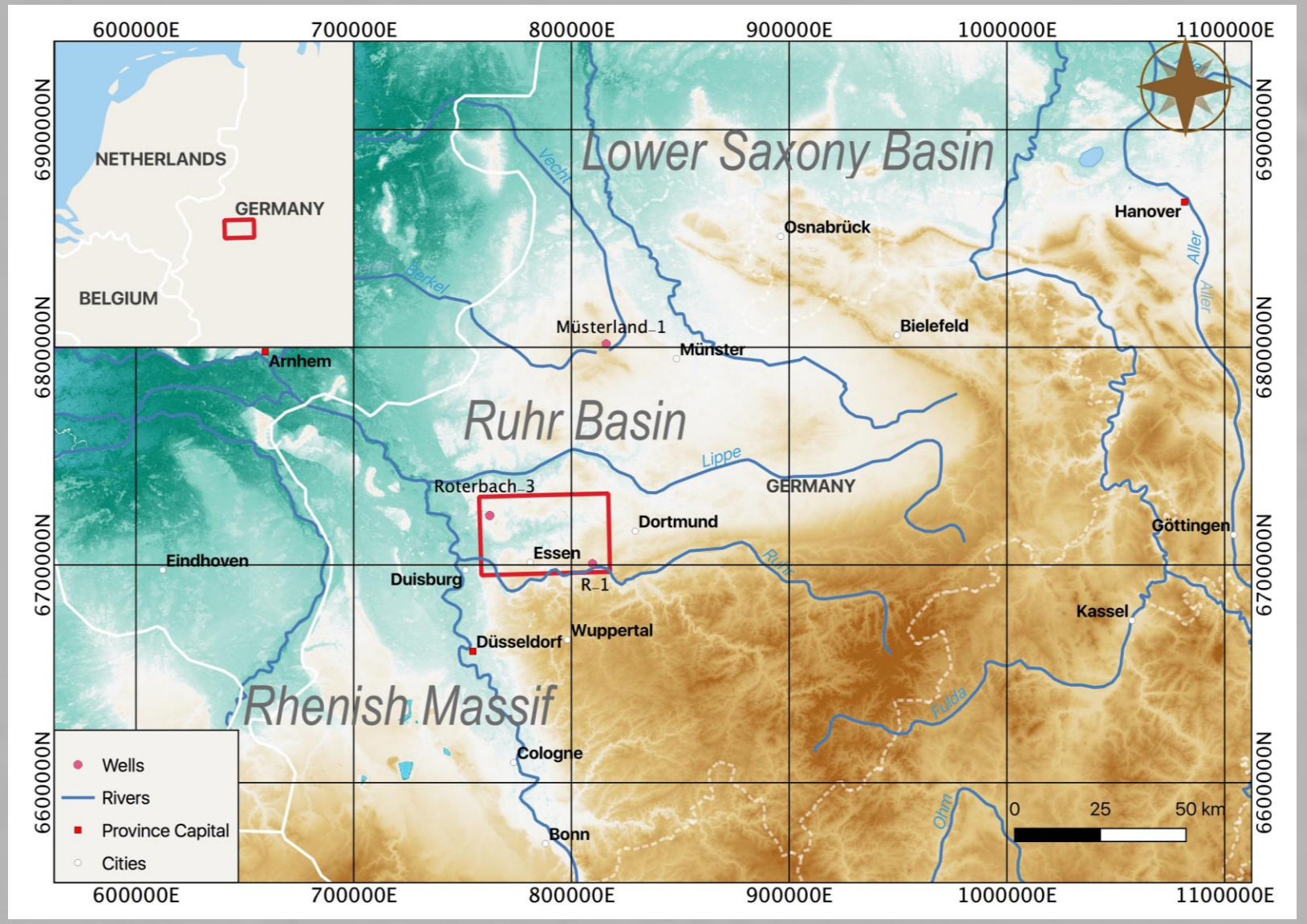
Introduction

- The Ruhr district
  - It has geothermal potential and demand.
  - Opportunities for development of deep geothermal projects.
- Target
  - Analysis wave propagation through displacement of vertical component.
  - Definition of maximum energy zones.
  - Proposal for the localization of new seismic monitoring stations.

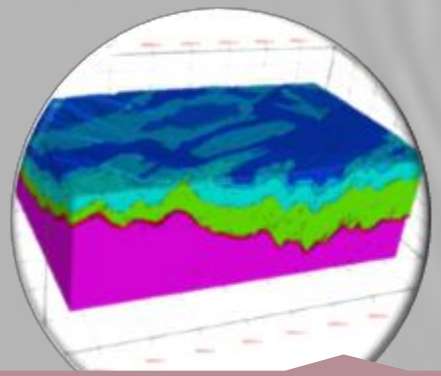


Location of the project area and wells used to create the geological model.

Workflow

Wave propagation was performed by a finite difference scheme (Saenger 2004) using the source description and a geological model of the area.

Elastic model + Realistic seismic source + Full elastic wavefield simulation = zones to monitoring in detail



Model based on the geology

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Fault map of the area

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Wave propagation in the model

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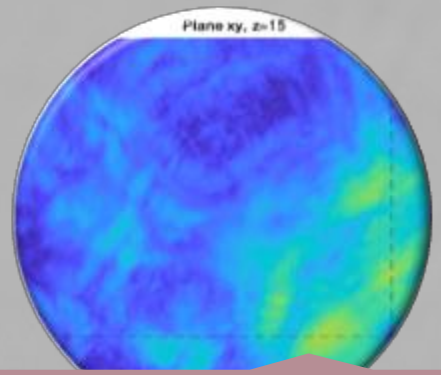


Maximum energy density

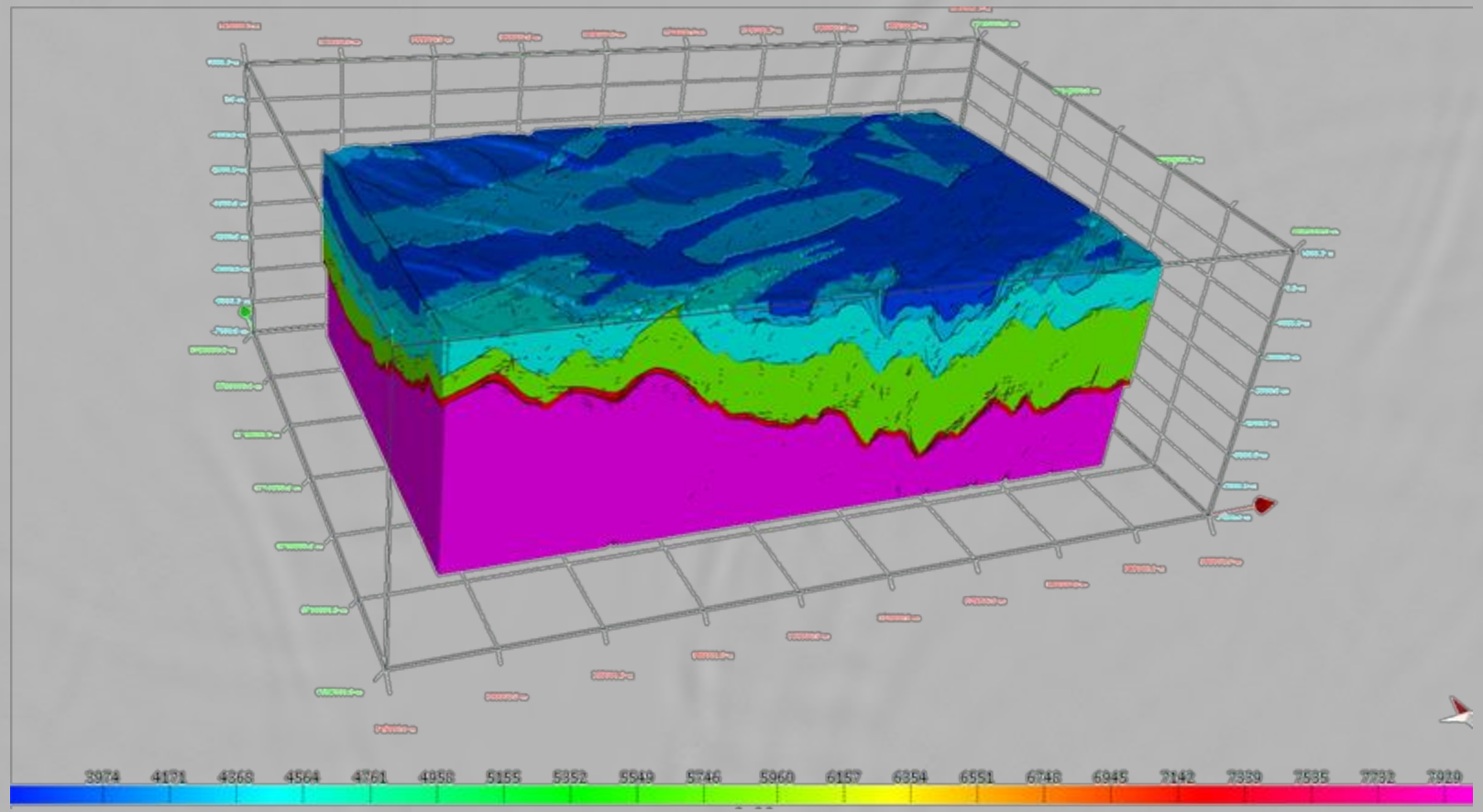
more

Elastic model

The geological model is the base for the elastic model. It contains the variables: density, the velocity of the P and S wave per layer.
The elastic model is necessary for the solving of the elastodynamic wave equation (Saenger 2000).

Values for each layer

Layer	Vp	Vs	Rho
Sediments	3580	2331	2023
T9a_westfal_c1	3896	2379	2195
T9b_westfal_b1	4198	2421	2483
T9c_westfal_a2	3818	2367	2424
T9d_westfal_a1	4292	2434	2492
T9e_namur_c_b	4511	2464	2532
T9f_namur_ab_b	5764	2668	2687
T9g_unterkarbon_b	7270	3048	2857
TDevon	8144	3343	2943

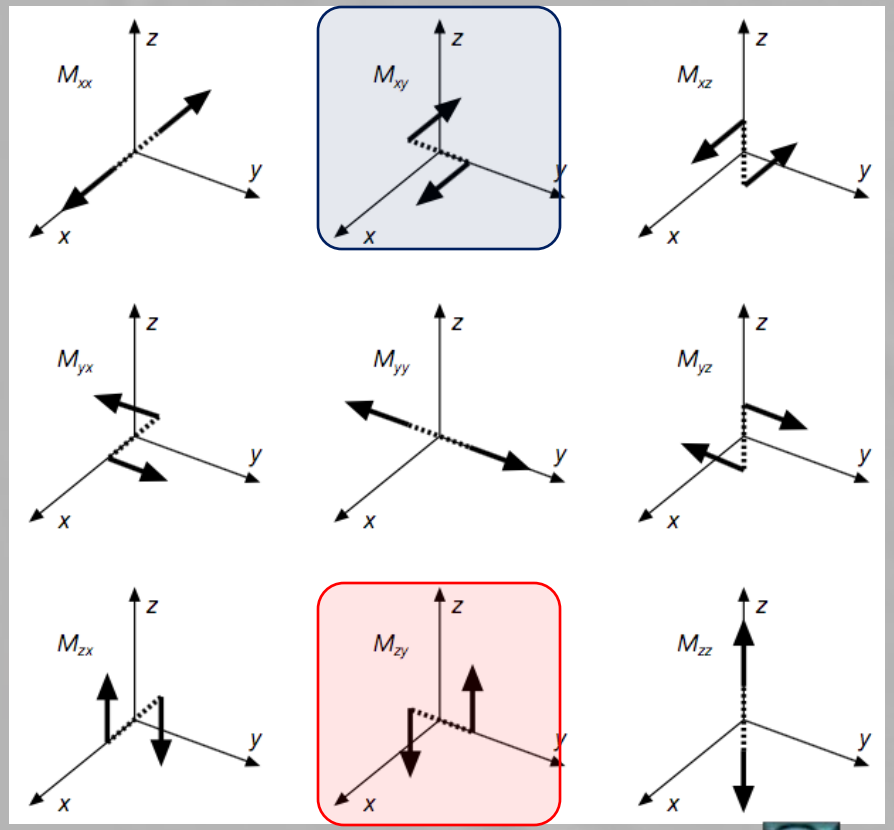


Geological model with the velocities of the P wave.
(Gonzalez de Lucio 2020)

Source

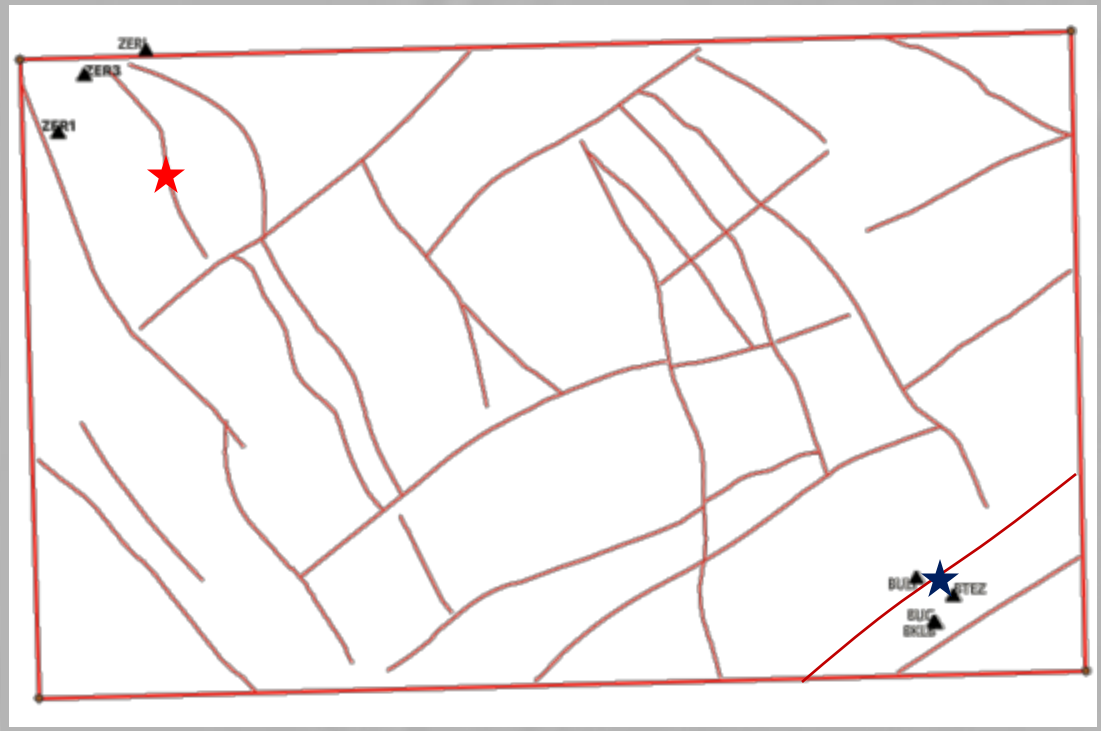
The source is related to the slip of a fault. The map is a view of the faults at the surface of the area.

The moment tensor is the mathematical description of the source. The components represent the geometry of faulting in the seismic events.



Components related to the cases. After Stein 2003.

Two cases are considered, first (red) based on the seismic events at the North-West of the area and the second (blue) for the hypothetical case of induced seismicity due to geothermal projects in the South-East.



Fault map of the area

Simulation of wave Propagation

Analyze of the seismic response with different sources.

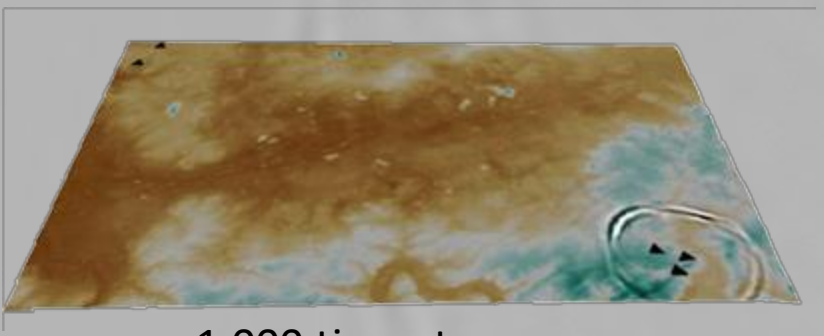
- The elastic model and the parameters for both simulations is the same.
- The source parameters change in orientation and location.

Elastic model	x	y	z
Number of grid points	1846	1121	316
Total		653,919,656	

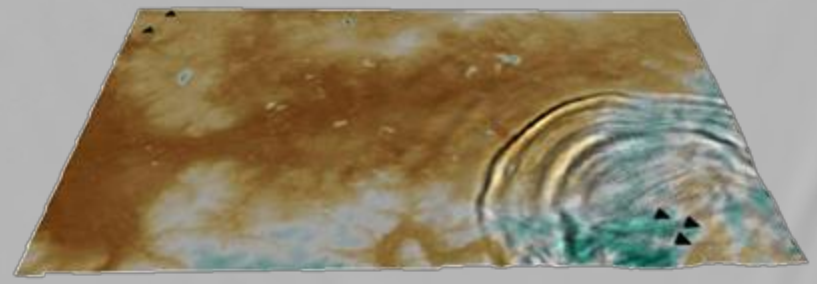
Parameters		Source	
Spacing	20 meters	Type	Double couple source
Frequency	2 Hz	Direction	North-South
Time step	.002 s	Depth	1900 m
Number of time steps	10, 000		

Wave propagation

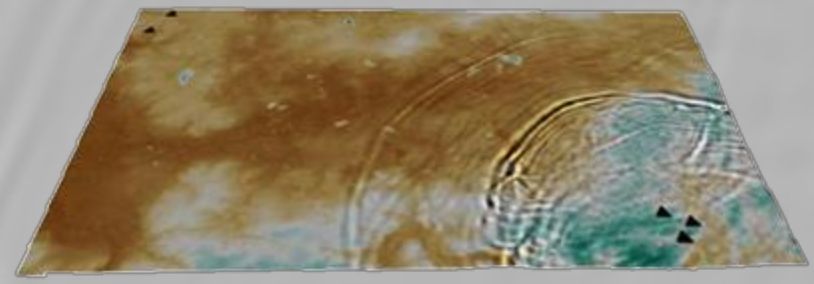
Snapshots every 2 seconds of the wave simulation visualize on the digital elevation model of the study area.



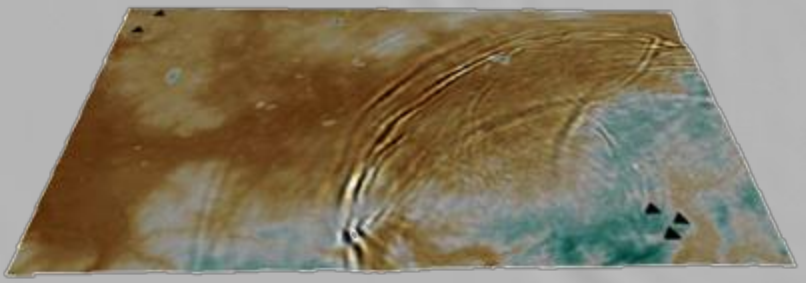
1,000 time steps
t=2s



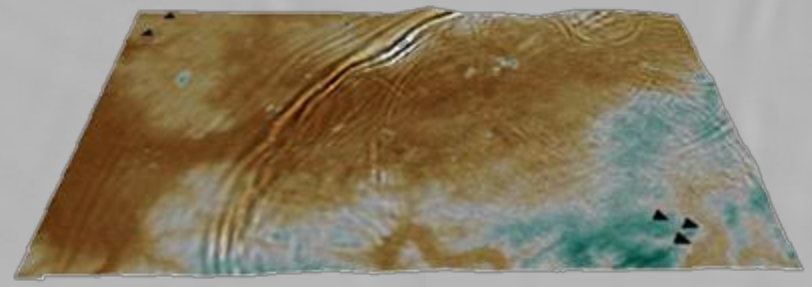
2,000 time steps
t=4s



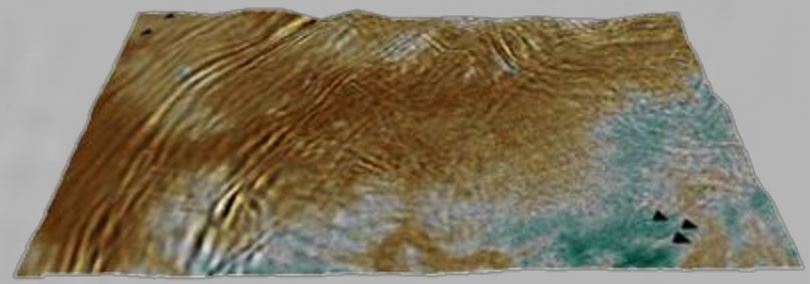
3,000 time steps
t=6s



4,000 time steps
t=8s



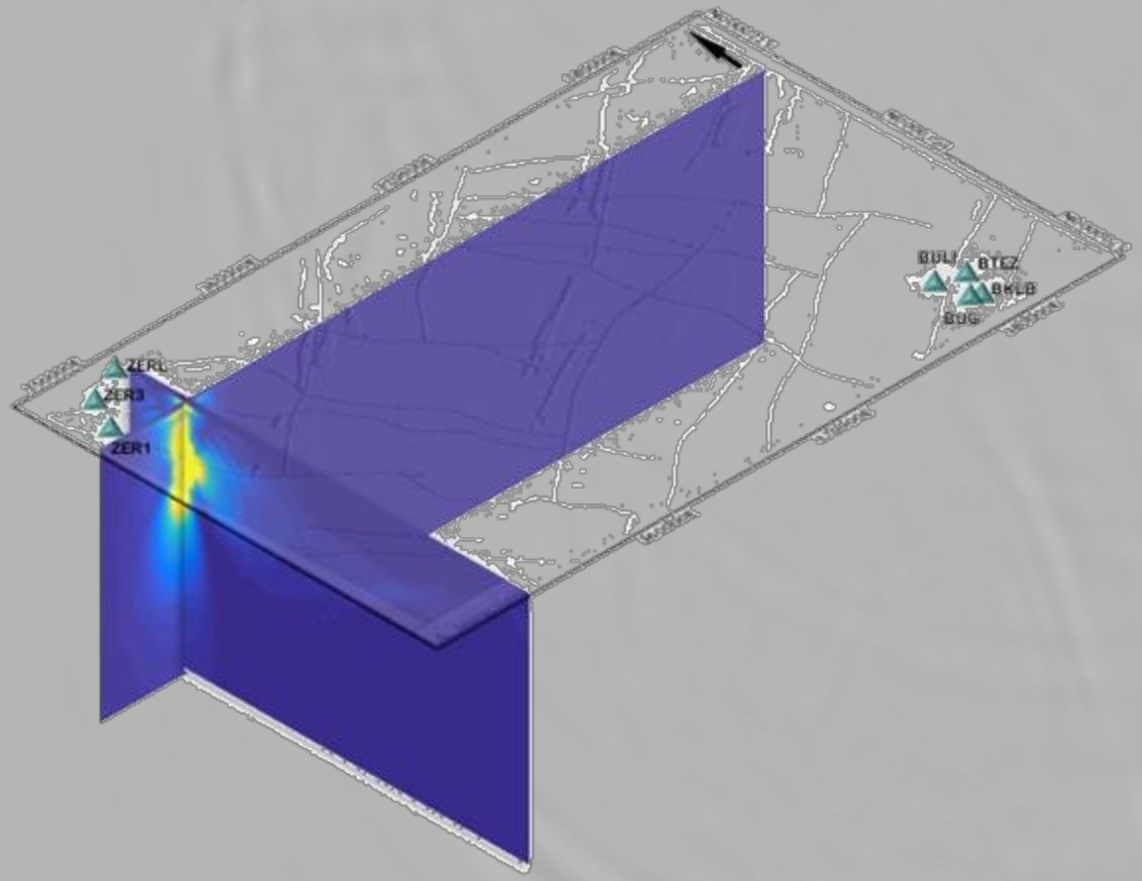
5,000 time steps
t=10s

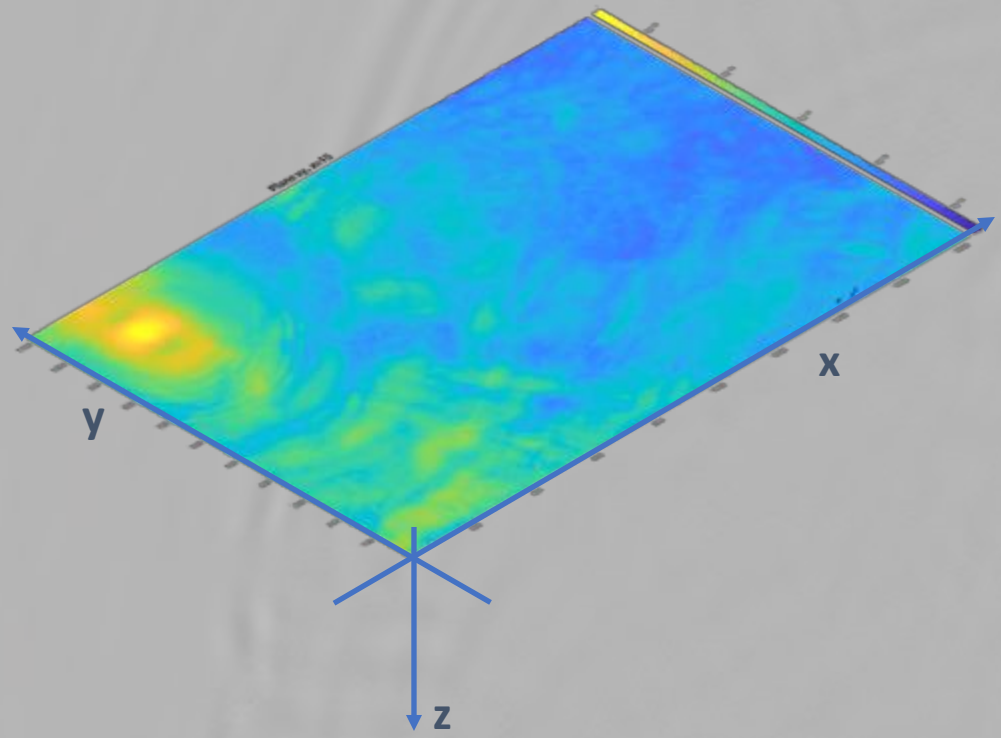


6,000 time steps
t=12s

Total energy density

It characterizes the areas of greatest displacement and decrease in energy with the distance. It is calculated at every point and defined as the sum of stress times strains during the simulation time (Finger 2020).



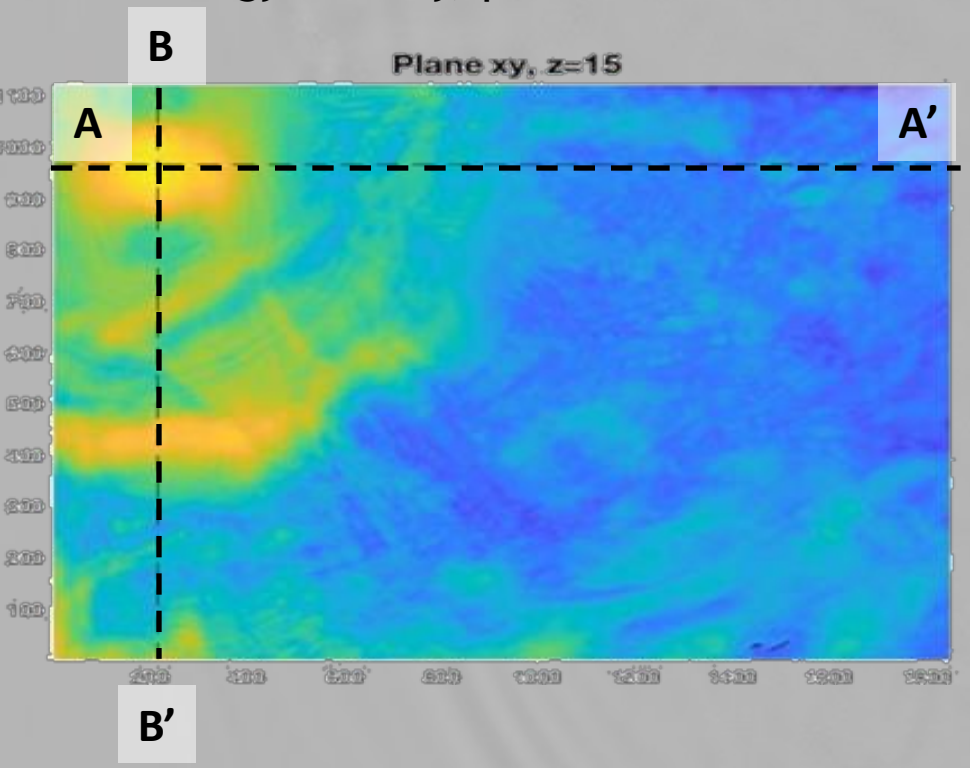


View of the total energy density volume at the surface after complete simulation, the warm colors are related to the higher energy.

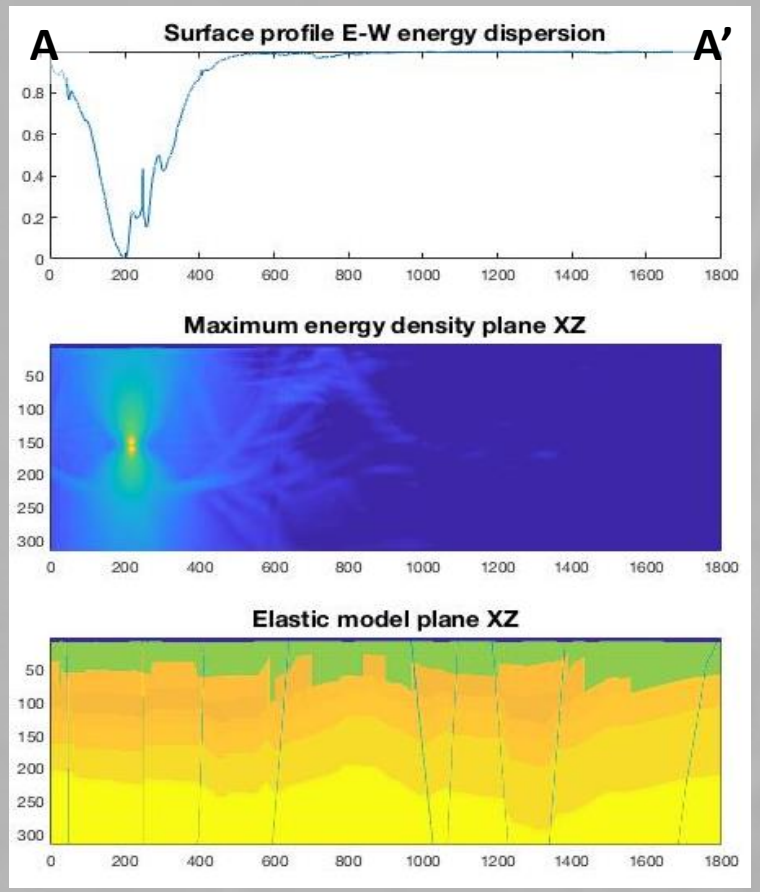
Profiles – Bottrop case

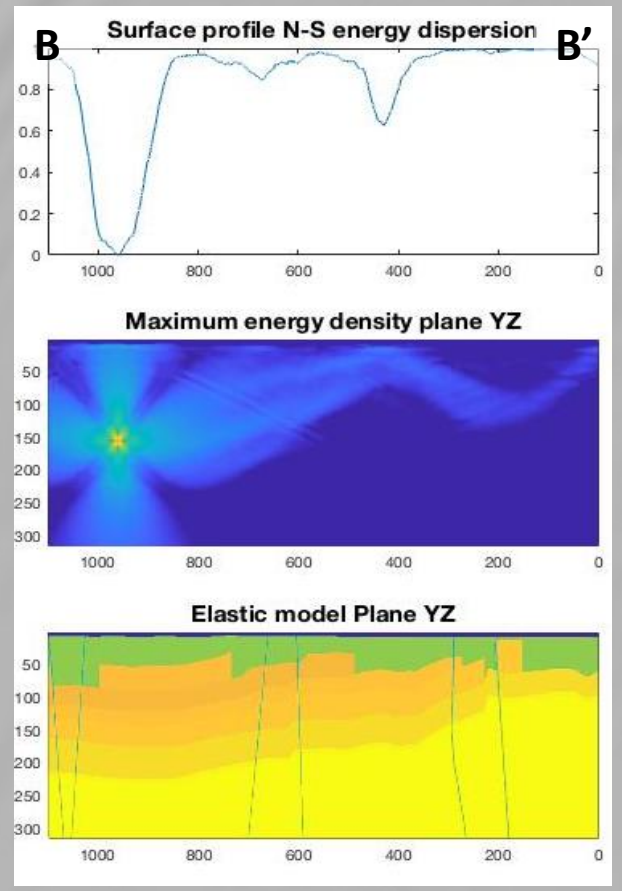
TOP: Profile that shows how decrease the maximum energy density with the distance.
Center: Section of the toal energy density volume, the reflected energy is visible.
Bottom: geological structure with the values of the elastic model, in this section the color are related with the density, warm colors are related with higher density.

Total energy density, plan view.



The dashed lines corresponds to the sections in plane x and y were the source are located.



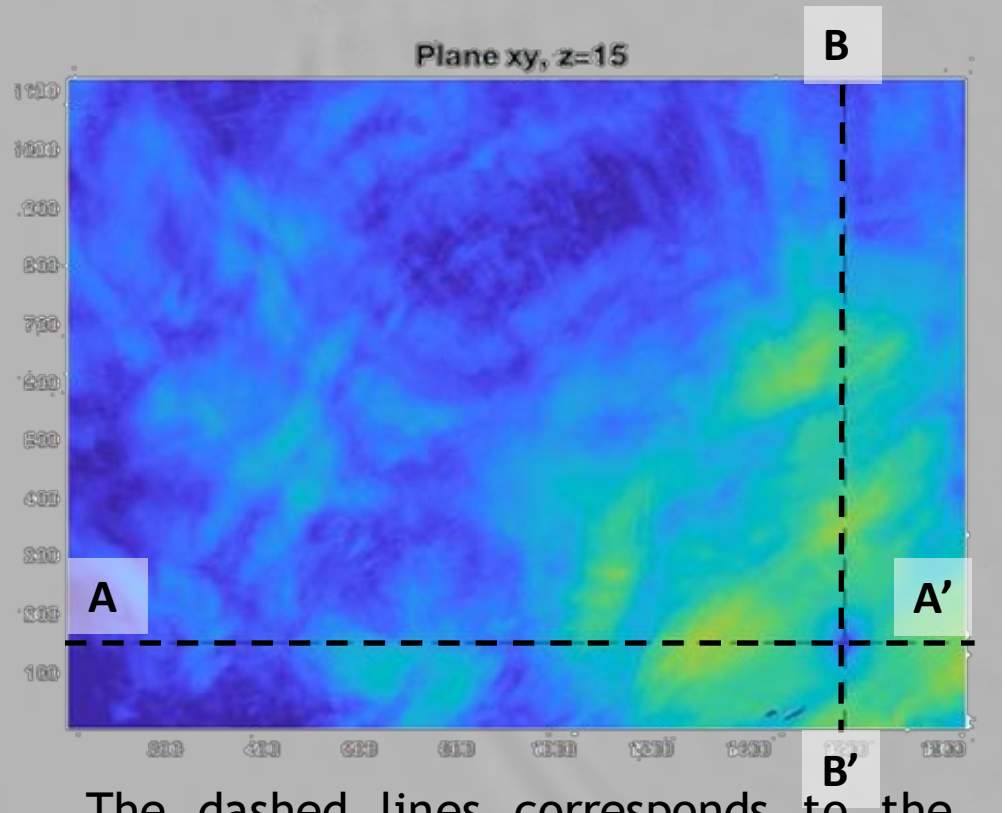


The profile shows a quickest decrease in the maximum energy density but in the profile N-S there is another peak related with high energy, it maches with the map view.

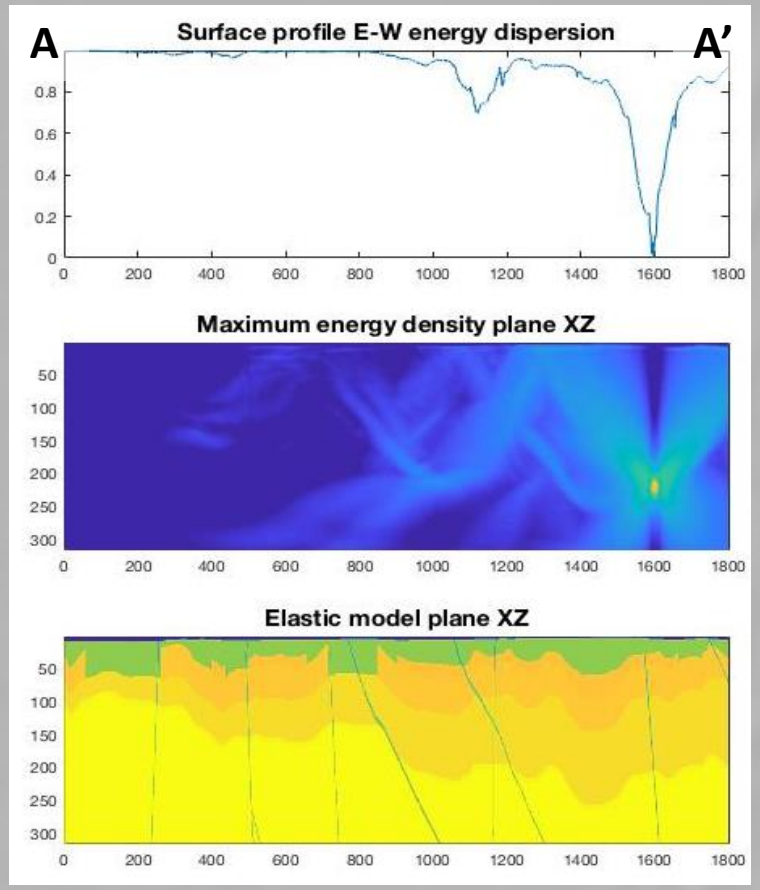
Profiles – Bochum case

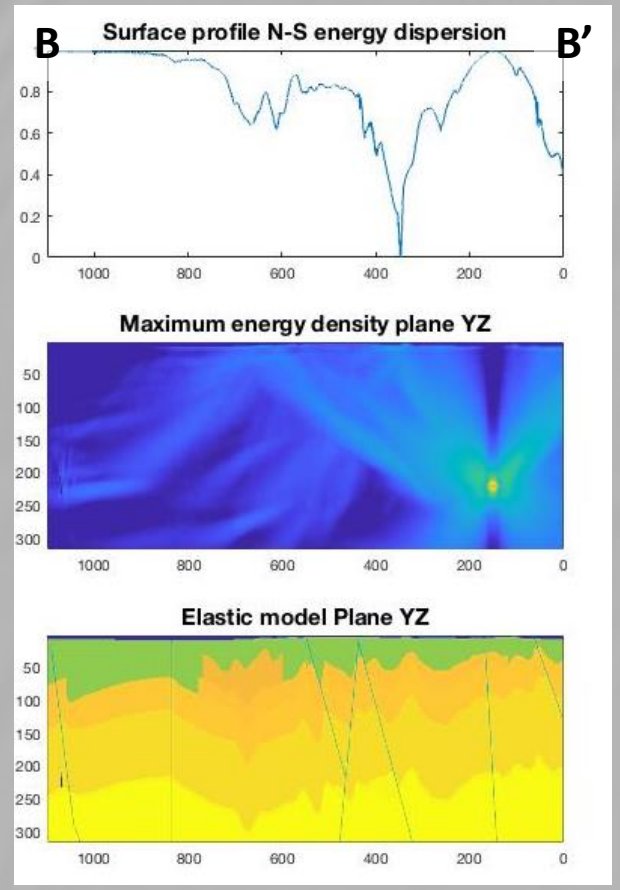
TOP: Profile that shows how decrease the maximum energy density with the distance.
Center: Section of the toal energy density volume, the reflected energy is visible.
Bottom: geological structure with the values of the elastic model, in this section the color are related with the density, warm colors are related with higher density.

Total energy density, plan view.



The dashed lines corresponds to the sections in plane x and y were the source are located.

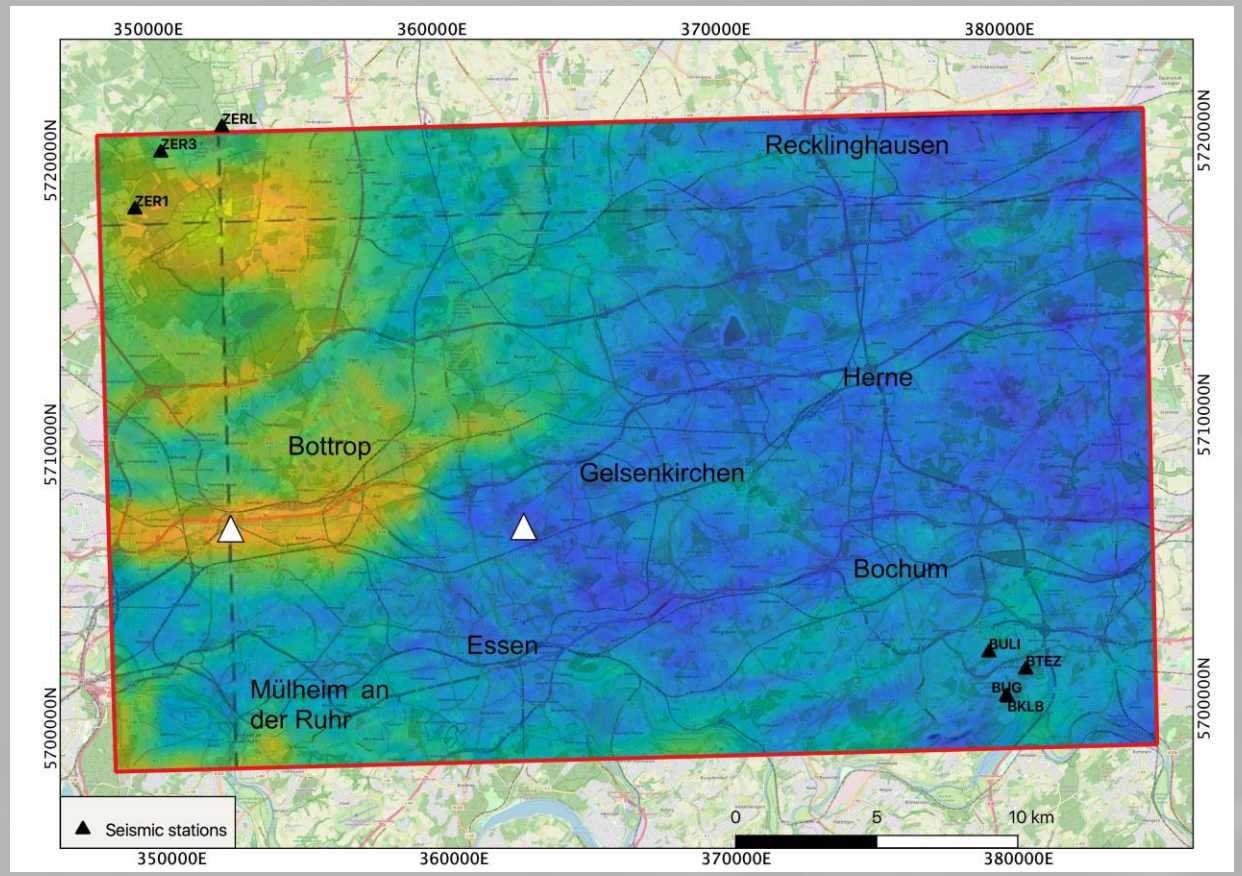


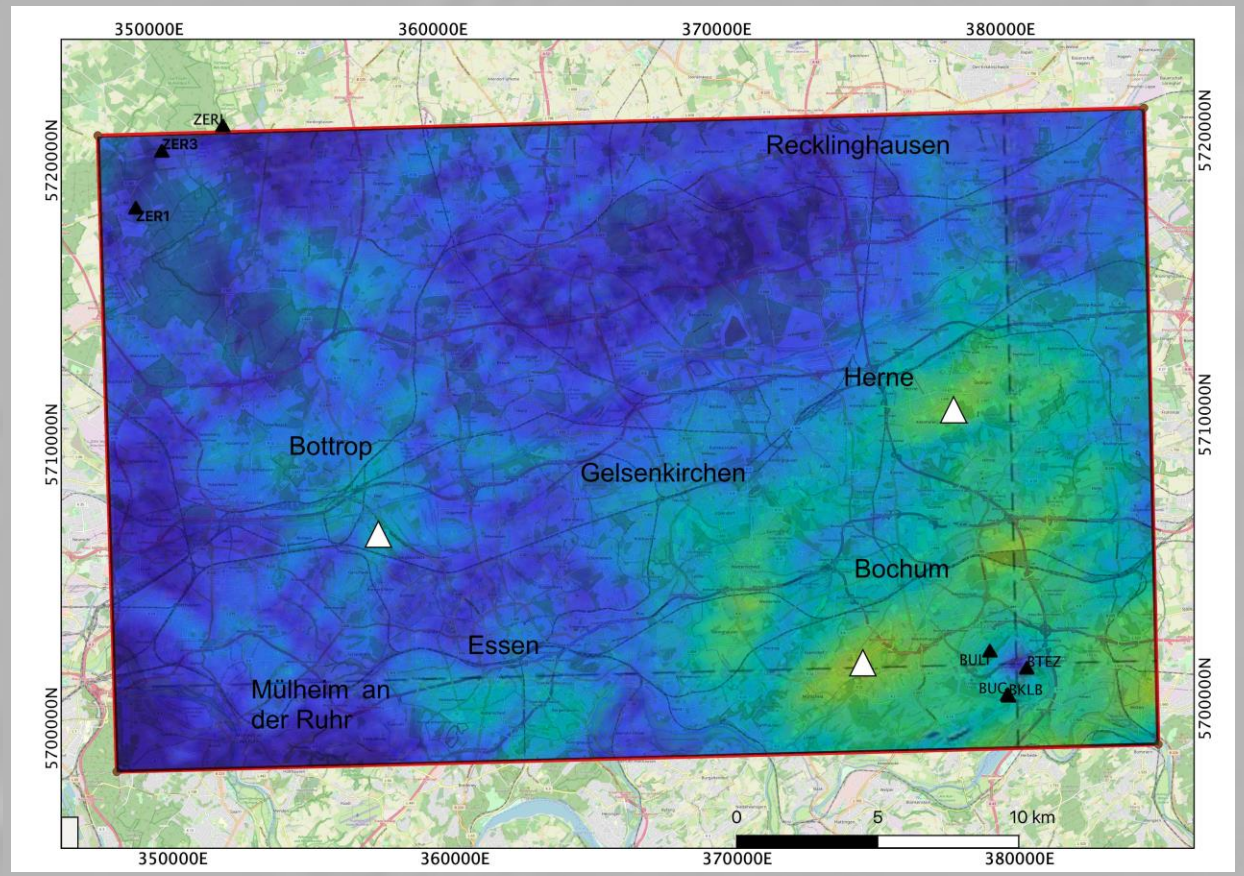


Proposal locations for seismic monitoring

Results from Bottrop (left) and Bochum (right) simulation with the map of the area to visualized the locations.

The locations are related with higher values and low, to be able to analyze the response in different zones.





Conclusion

- The areas with relatively high amplitudes of displacement correlated with structural features of the model.
- Applying the imaging condition of maximum energy density allows us to define zones with a potentially increased seismic risk that should be monitored more closely.

Literature

- **Finger C. and Saenger EH**. Sensitivity maps for time-reverse imaging: an accuracy study for the Los Humeros Geothermal Field (Mexico). Geophysical Journal International, 222(1):231-246, 04 2020. Go to article
- **Gonzalez de Lucio, G. D. L. A., Balcewicz, M., and Saenger, E. H.:** Establishing a 3D model for the Rhine-Ruhr region based on the geology and property distribution., EGU General Assembly 2020, Online, 4-8 May 2020, EGU2020-20592.Go to abstract
- **Saenger EH, Bohlen T.** Anisotropic and viscoelastic finite-difference modeling using the rotated staggered grid. Geophysics 2004;69(2):583-91. Go to article
- **Stein S, Wysession M**. An Introduction to Seismology, Earthquakes, and Earth Structure. Blackwell publishing 2003. Go to book
- **Saenger EH, Gold N, Shapiro SA**. Modeling the propagation of elastic waves using a modified finite-difference grid. Wave Motion 2000;31(1):77-92. Go to article