

Herzlich willkommen!

Abschlusstreffen Forschungsprojekt INSIDE – Einblicke und Ergebnisse



Gefördert durch:
 Bundesministerium
für Wirtschaft
und Klimaschutz
aufgrund eines Beschlusses
des Deutschen Bundestages

Eingereicht vom
Eingereicht vom

Projektträger Jülich
Forschungszentrum Jülich

Agenda

Start time	Topic	Speaker
08:30	Welcome, coffee, registration	
09:00	Welcome message, Video, Project overview	R. Baasch, E. Gaucher
09:20	Well-based data acquisition and analysis	P. Goblirsch, K. Thiemann
09:55	Seismic monitoring	J. Azzola
10:30	Geodetic monitoring	M. Westerhaus
11:05	Break	
11:20	Geothermal reservoir numerical modelling	E. Gaucher, A. Savvatis, R. Habibi
11:55	Reservoir Management System	K. Thiemann
12:30	Communication to the public	P. Goblirsch
12:45	Conclusion, outlook and discussion	G. Bergdolt
13:30	Lunch break	
<i>14:30</i>	<i>Non-public operator meeting</i>	



➤ MAIN OBJECTIVES

- To investigate induced seismicity and ground deformation associated with geothermal energy exploitation in the Munich area
- To apply innovative monitoring techniques, standard ones and compare results
- To propose a “Reservoir Management System”

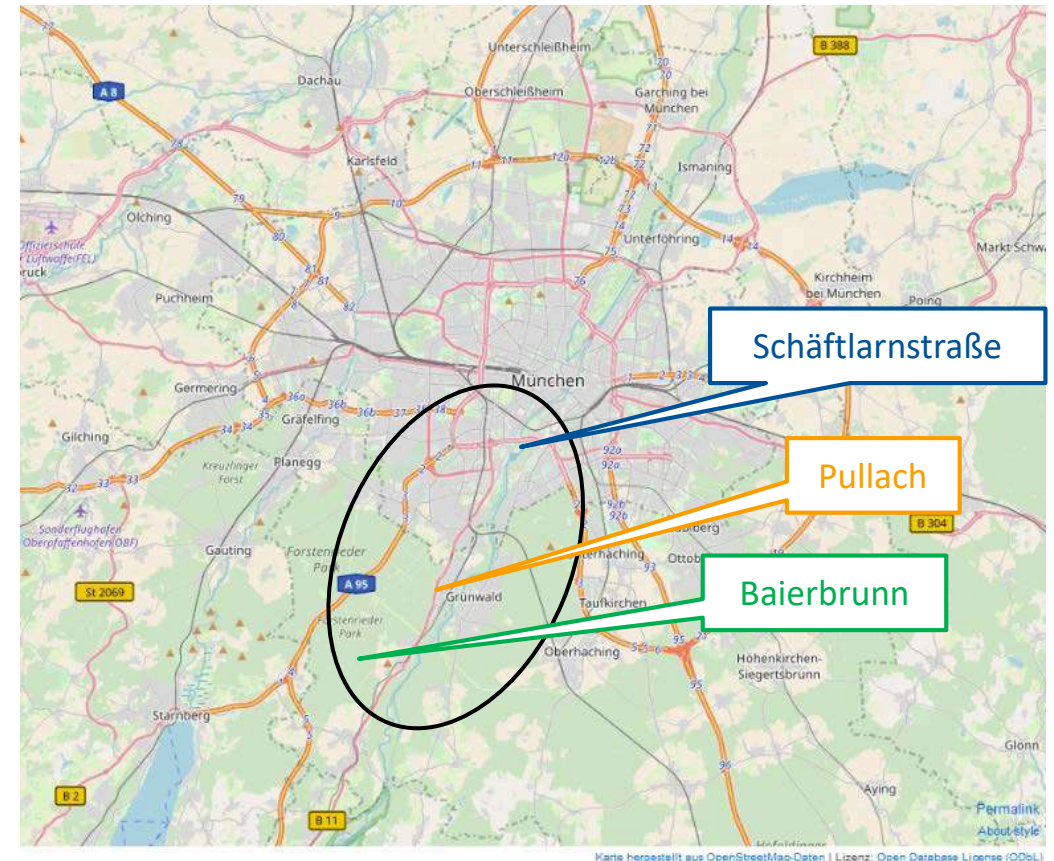
➤ THREE KEY PILLARS

- Data acquisition and processing
- Numerical modelling
- Integration

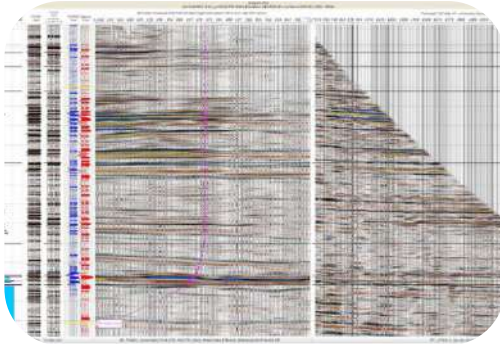
➤ *Partners:* IEP, SWM, KIT

➤ *Period:* 09.2019 – 05.2024

➤ *Initial budget:* 4.7 M€



Main topics



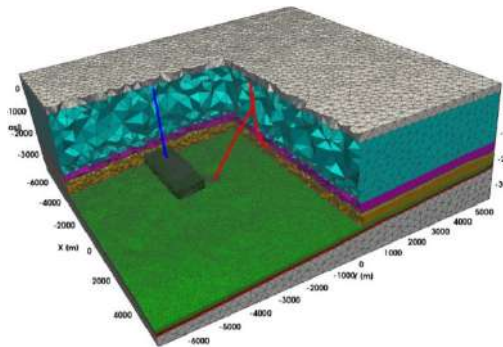
Well-based data
analysis



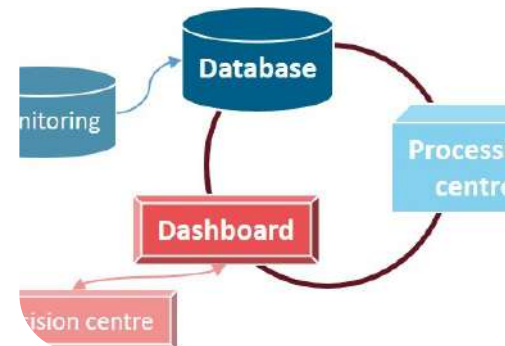
Seismic
monitoring



Geodetic
monitoring



Numerical reservoir
modelling



Reservoir Management
System



Communication
to public

Well-based data acquisition and analysis

➤ KEY QUESTIONS

- Can we improve the seismic velocity model?
- Can we get suitable petrophysical parameters?
- Can we calibrate numerical reservoir modelling?

➤ METHODOLOGY

- Running active seismic campaigns
 - Cross-well sparker test at Schäftlarnstraße, VSP at Pullach
- Gathering well log data for geomechanical characterization
- Core and sample analysis
 - Thermo-hydraulic properties, geomechanical properties
- Tracer test (in Schäftlarnstraße)



Seismic monitoring



➤ KEY QUESTIONS

- Can we build a reliable velocity model of the area?
- Can we observe induced seismicity in the project area?
- What is the most valuable monitoring approach in an urban environment?
- Can Distributed Acoustic Sensing (DAS) be used for seismic monitoring?

➤ METHODOLOGY

- Integrate data associated with seismic velocities
- Set-up of various observational means
 - 3C-seismometers, at surface, downhole, mini-array, DAS in well and at surface
- Passive seismic data recording
 - In continuous mode or during specific periods
 - Possibly real-time storage
- Comparison of results

➤ KEY QUESTIONS

- Can we see any uplift or subsidence in the project area?
- What is the most valuable monitoring approach?
- Can satellite-based measurements contribute to the determination of the zone of influence (Einwirkungsbereich)?

➤ METHODOLOGY

- Set-up of various observational means
 - GNSS, electronic corner reflectors (eCR)
- Processing of GNSS time series
- C-Band Radar-interferometric processing
 - Comparison with X-Band
- Comparison with levelling



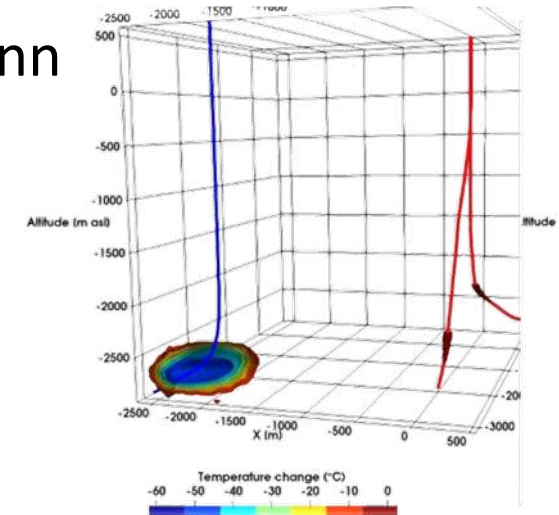
Numerical reservoir modelling

➤ KEY QUESTIONS

- Where to drill wells? Which well for injection/production?
- How pressure, temperature and stress vary in the reservoir in the course of the geothermal field exploitation?
- Can we propose/model induced seismicity during geothermal production?

➤ METHODOLOGY

- Build structural models of Schäftlarnstraße, Pullach and Baierbrunn
- Slip- and dilation tendency analyses of faults
- Long-term thermo-hydro-mechanical (THM) modelling
- Development of a coupled THM-Seismicity modelling tool



Reservoir Management System

➤ KEY QUESTIONS

- How the operator should react when critical “events” are observed or forecasted
- Can we create a system integrated in the operator’s “control room” to ease and accelerate decision taking?

➤ METHODOLOGY

- Propose a concept for a Reservoir Management System
- Integrate data
- Make a prototype and test it



➤ KEY QUESTIONS

- How could we achieve an increase of acceptance in public concerning seismicity and ground deformation possibly related to geothermal energy production?
- How do we communicate the results and learnings from INSIDE?

➤ METHODOLOGY

- Develop a communication strategy
- Implement actions of communication
- Evaluate actions of communication



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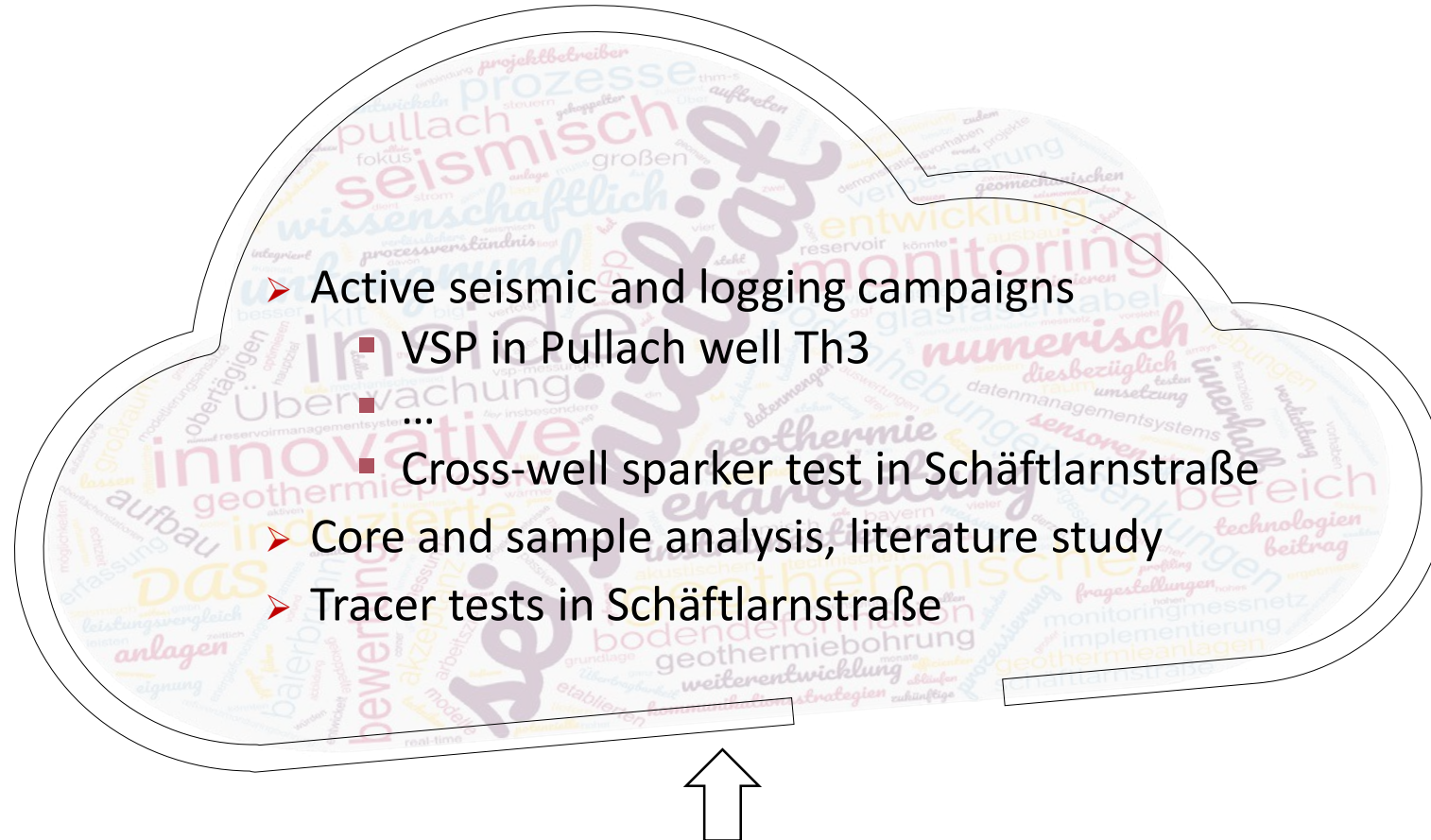
Well-based data acquisition and analyses



- Can we improve the seismic velocity model?
- Can we get suitable petrophysical parameters?
- Can we calibrate numerical reservoir modelling?

Peter Goblirsch, Johanna Zollner, Ralph Baasch, Katja Thiemann, Michael Meinecke, Kilian Beichel, Thorsten Hörbrand, Bernhard Betzl, Bernhard Köhl *et al.*

Overview of the well-based investigation campaigns



- Active seismic and logging campaigns
 - VSP in Pullach well Th3
 - ...
 - Cross-well sparker test in Schäftlarnstraße
- Core and sample analysis, literature study
- Tracer tests in Schäftlarnstraße

- Can we improve the seismic velocity model?
- Can we get suitable petrophysical parameters?
- Can we calibrate numerical reservoir modelling?

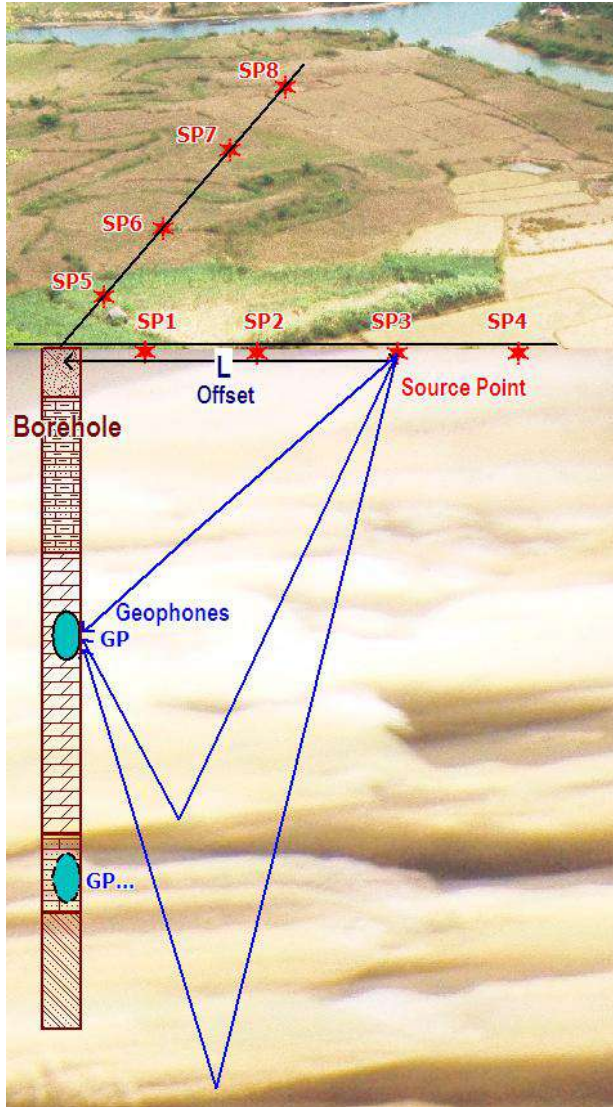
VSP Pullach Th3 (Vertical-Seismic-Profiling)



Erfolgreich durchgeführtes Bohrloch-Messprogramm an der Pullach Th3 im August '21:

- Messungen zur Sicherstellung der Befahrbarkeit und Integrität vor Durchführung VSP:
 - Multifinger-Befahrung (Check Befahrbarkeit und Zustand Casinge)
 - Segmented-Bond-Log (Zementgüte)
- **VSP- Messung (Vertical-Seismic-Profiling)**

VSP Pullach Th3 (Vertical-Seismic-Profiling)



- Seismische Messungen, zur Korrelation seismischer Daten aus klassischen Seismik Kampagnen, bei denen sich Empfänger und Sender an der Oberfläche befinden
- Sender an Oberfläche <-> Empfänger im Bohrloch
- Geophone nehmen Schallwellen in regelmäßigen Abständen im Bohrloch bis zur Endteufe auf
- Es entsteht ein vertikales seismisches Profil (Geschwindigkeitsmodell)

VSP Pullach Th3 (Vertical-Seismic-Profiling)



- Geofizyka Torun aus Polen
- Messdauer: ca. 15 Stunden
- Walk away / Multi-Offset Messung mit 3 Vibrationsfahrzeugen an 3 Anregungspunkten entlang des Bohrpfades Th3
- Auf Grund der Befahrbarkeitsmessungen wurde die Geofonkette (nur) bis 3010 Meter eingefahren (ca. Top Malm)
- Processing durch Geofizyka Torun
- Einbindung und Interpretation der Ergebnisse im Bezug auf vorhandene 3D-Seismik Daten durch Erdwerk

VSP Pullach Th3 (Vertical-Seismic-Profiling)

Number of depth levels	266 (3984 m to 9 m)
Receiver point interval	15 m
VSP-Tool	Multi-Level-Tool with 3C geophones, if possible, plus hydrophones for uncemented section and sections with poor quality of cementation
Horizontal distance of source point to well head	VP1: in 100 m to 150 m distance to the well head. VP2: 900 m to 1200 m distance to the well head VP3: > 2000 m distance to the well head The exact position (direction to well head) must take into account the fault system.
Seismic source	1 - 2 vibrators*
Frequency range of the sweep	3 - 120 Hz
Sample rate	1 ms
Record length	5 s

*3 Fahrzeuge für schnelleres Verfahren

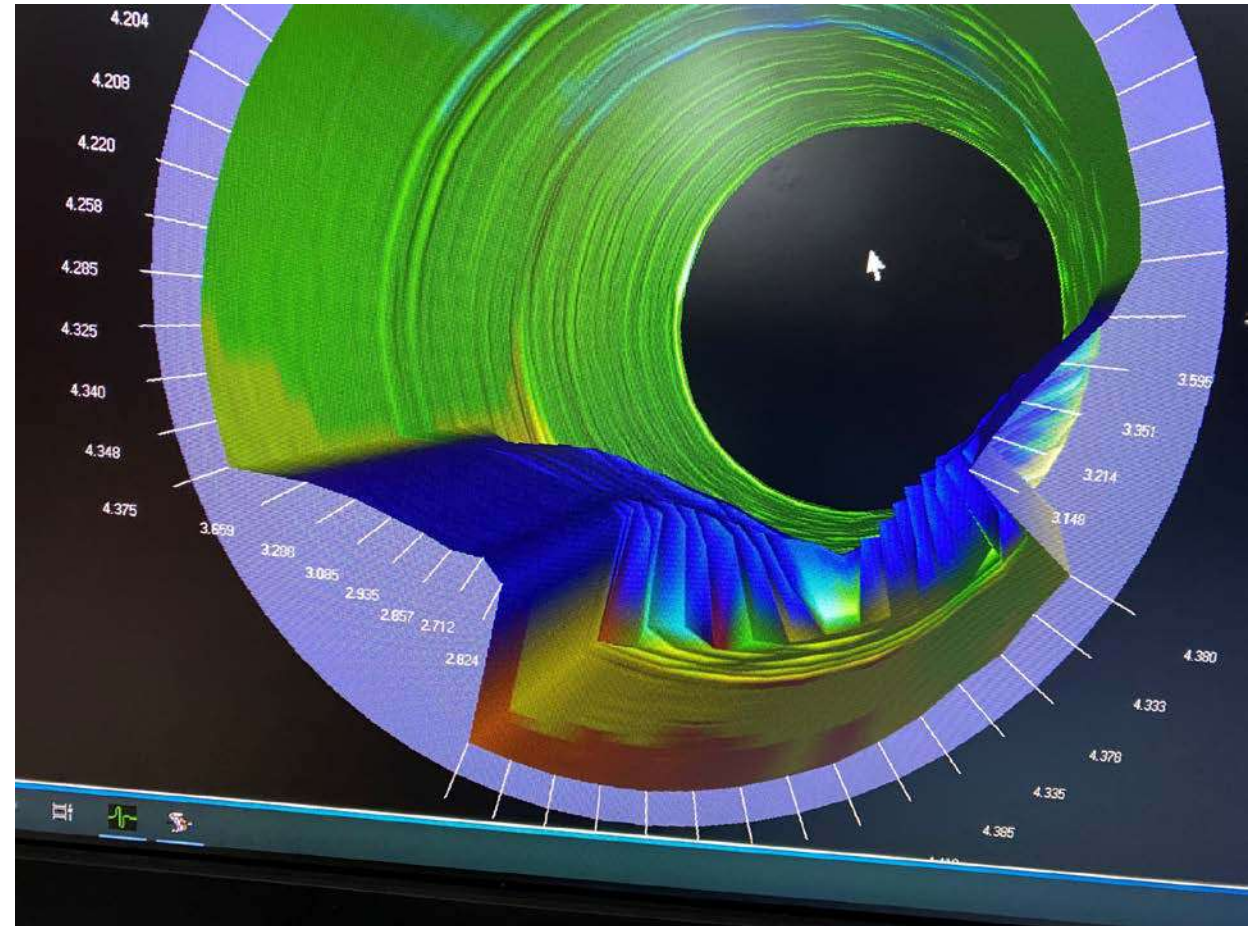
VSP Pullach Th3

Kombination Bohrlochmessungen



VSP Pullach Th3

Kombination Bohrlochmessungen



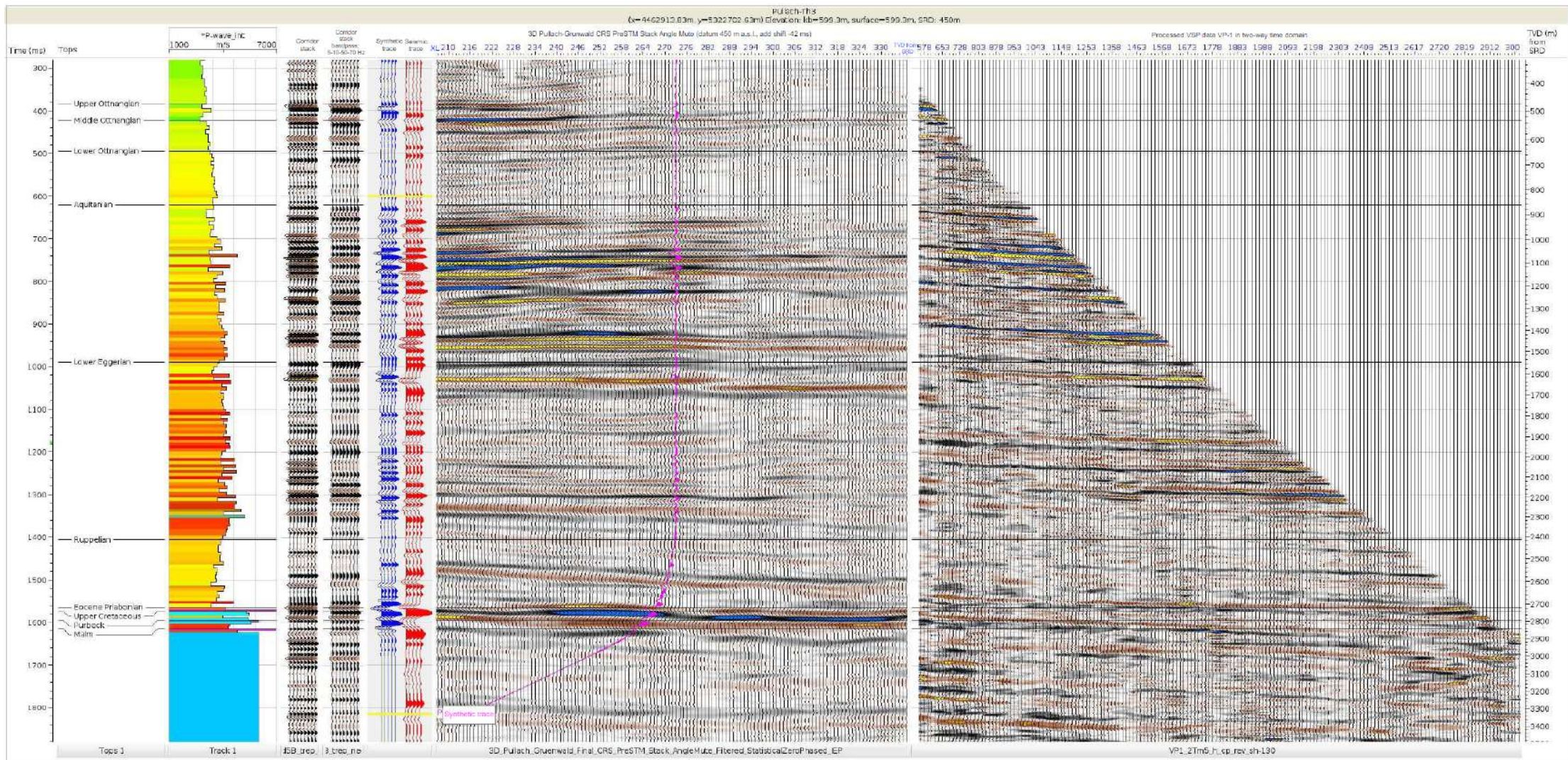
VSP Pullach Th3



VSP Pullach Th3

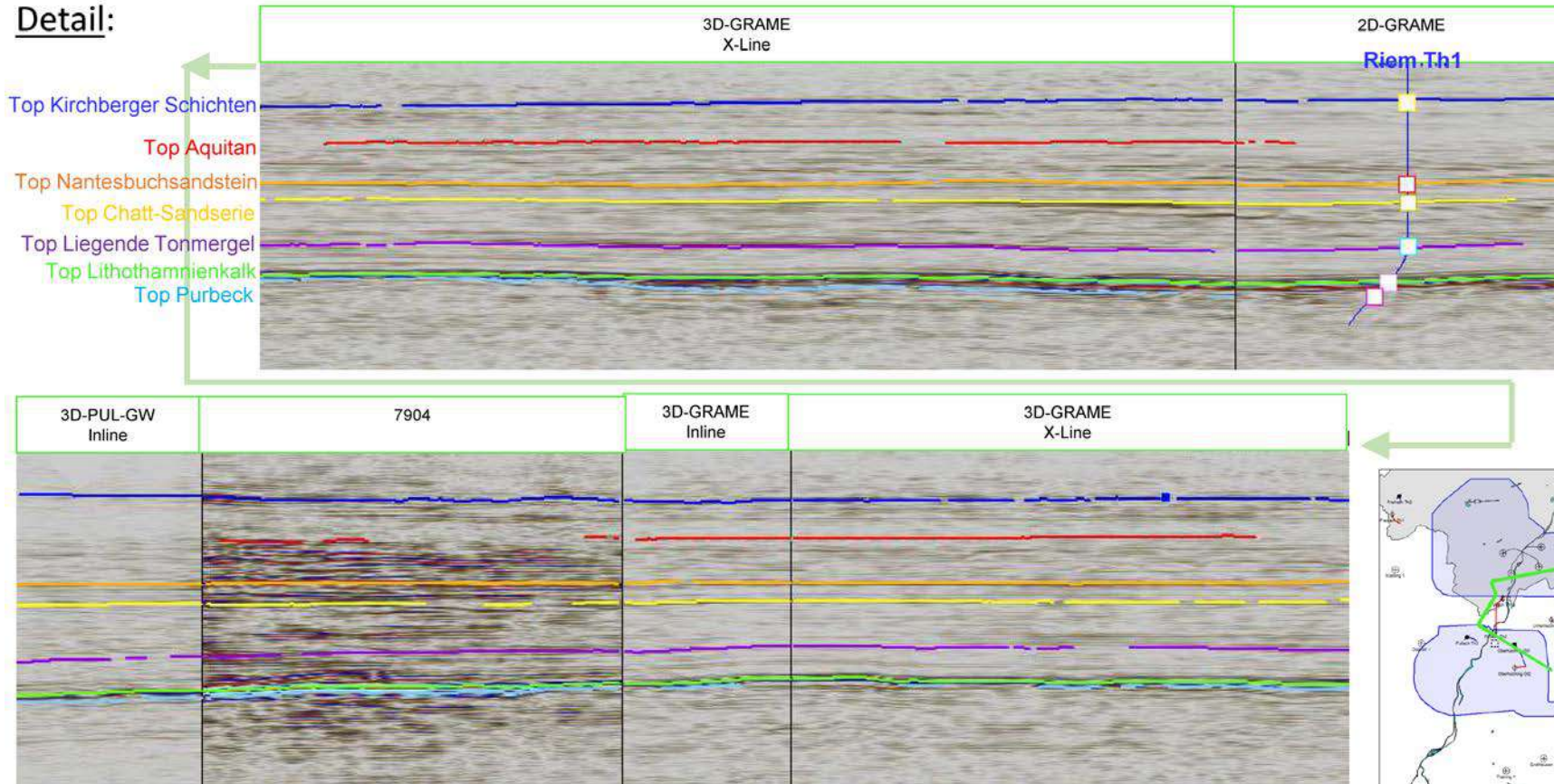


VSP Pullach Th3 Ergebnisse Welltie Geofizyka Torun



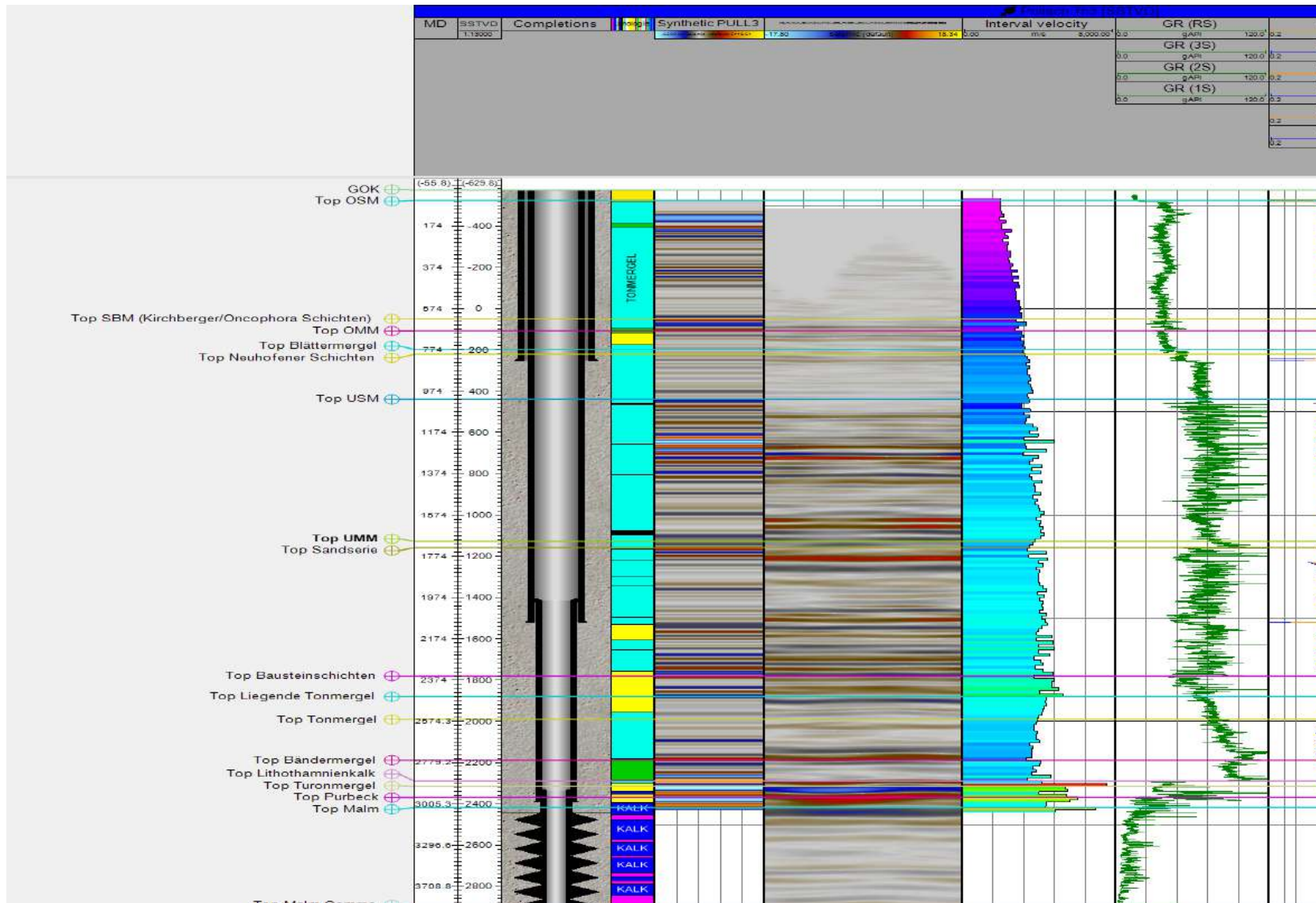
VSP Pullach Th3 Regionale Reflektorzuordnung

Detail:



Für die Reflektorzuordnung in der 3D-Seismik Pullach-Grünwald wurde ursprünglich eine synthetische seismische Linie von ebendieser 3D-Seismik über eine 2D-Seismik aus den 1970ern bis in die GRAMÉ 3D-Seismik gelegt. Durch die VSP-Messung in der Pullach Th3 kann die Reflektorzuordnung direkt innerhalb der 3D-Seismik Pullach-Grünwald durchgeführt werden.

VSP Pullach Th3 Welltie Erdwerk

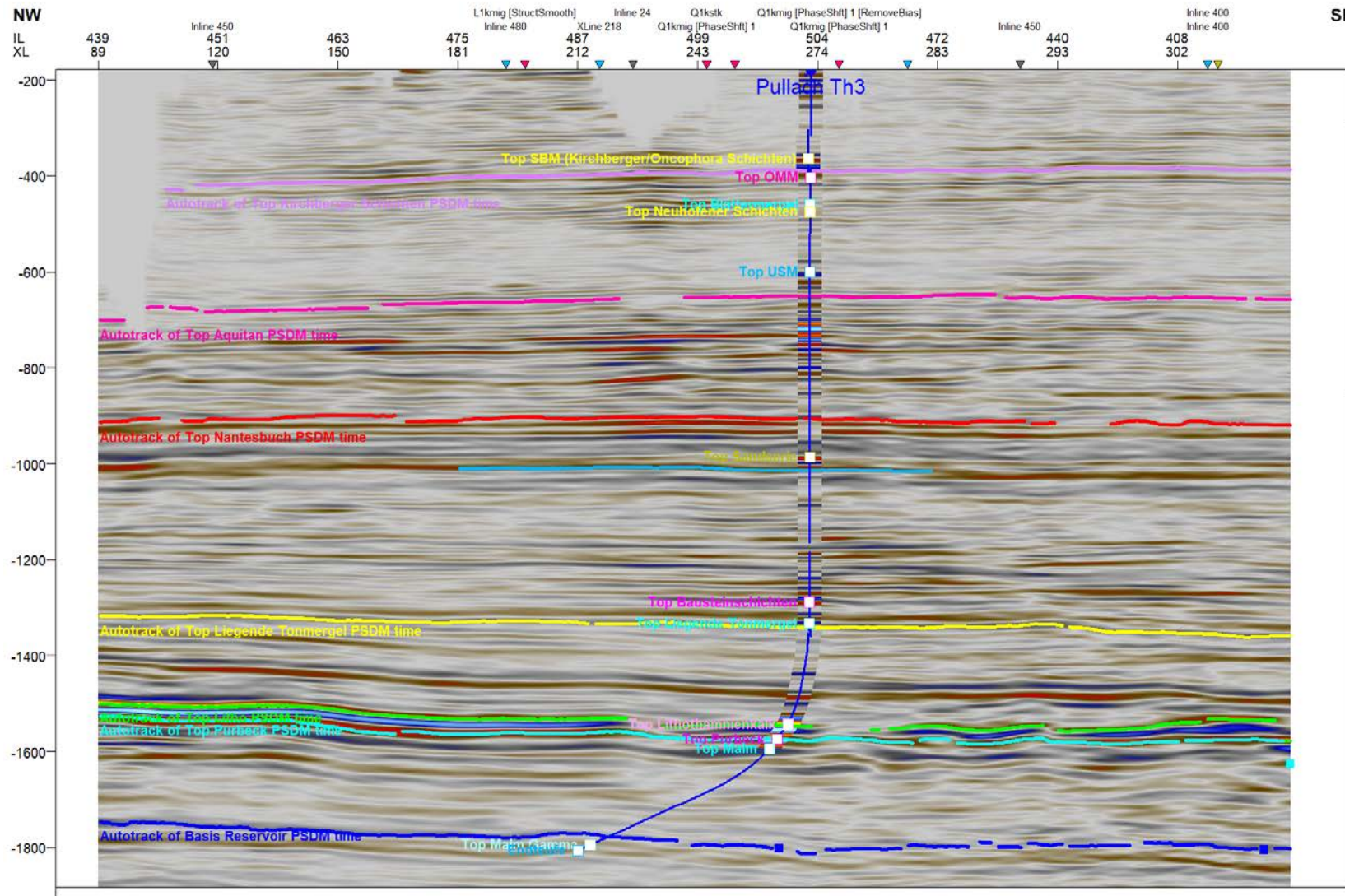


Aus der VSP-Messung wurde ein synthetisches Seismogramm erstellt. Dieses wurde allen existierenden Logs und der Stratigraphie aus der Bohrung Pullach Th3 gegenübergestellt und ausgewertet.

VSP Pullach Th3 Geomechanische Eigenschaften



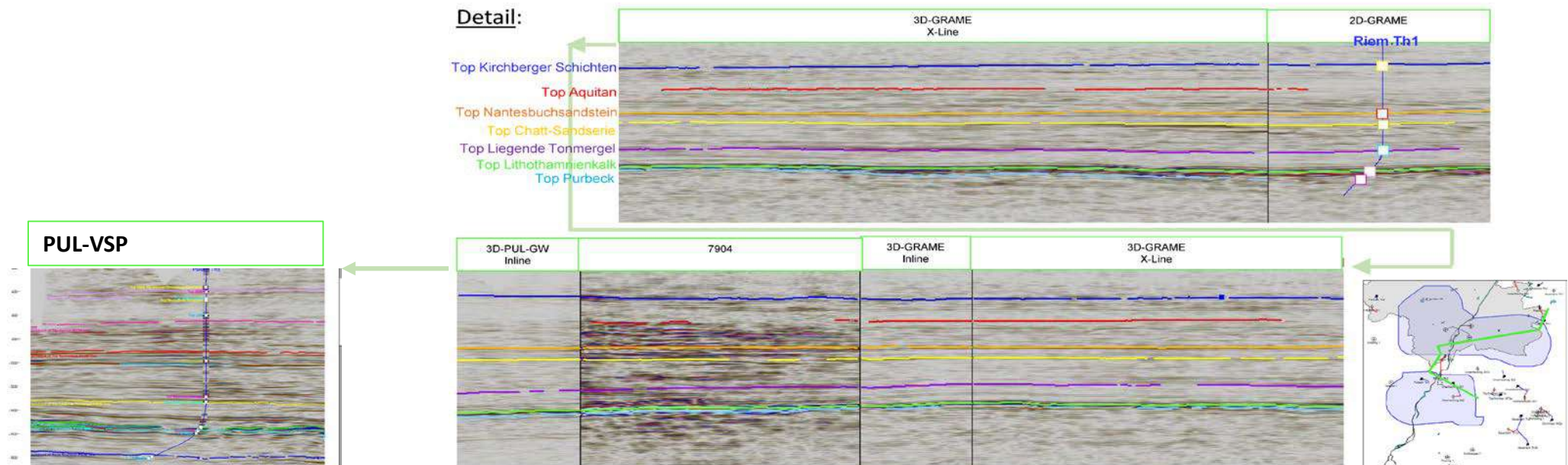
VSP Pullach Th3 Bewertung Reflektorzuordnung



- Bestätigung der Reflektorzuordnung für die Horizonte:
 - Top Liegende Tonmergel
 - Top Lithothamnienkalk
 - Top Purbeck
 - (Top Malm)
- **Keine Anpassung für das Reservoirmodell notwendig**

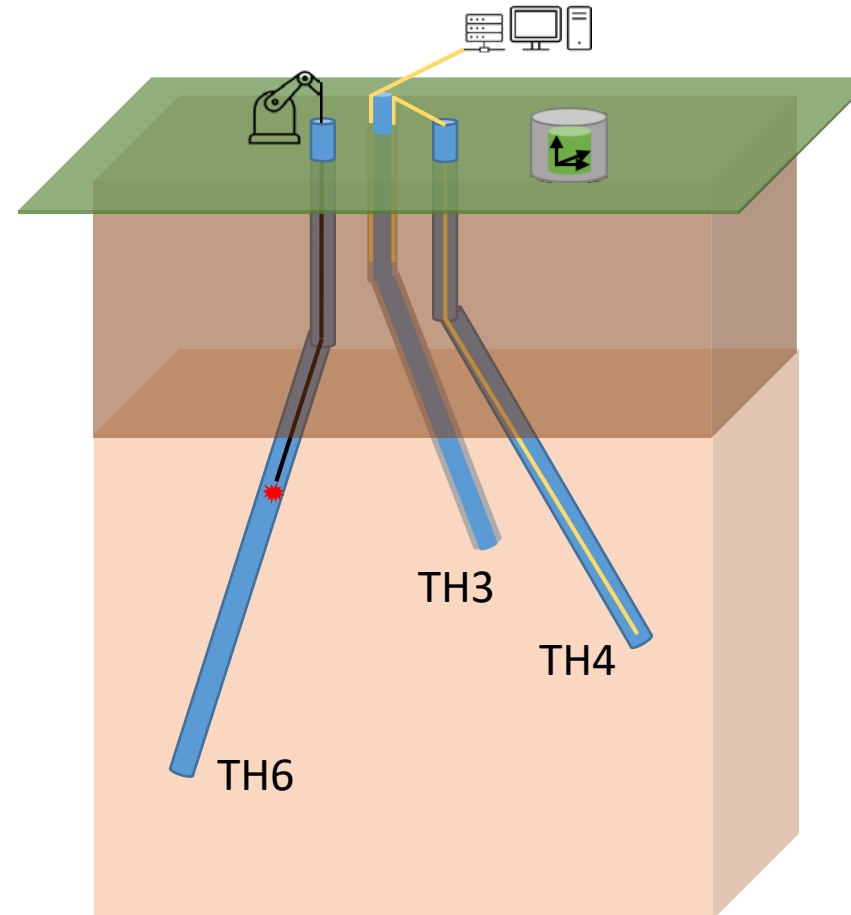
VSP Pullach Th3 Zusammenfassung

- Bohrlochintegrität Pullach Th3 festgestellt
- Geomechanische Daten für THM-Modelle
- **Bestätigung der Reflektorzuordnung** --> Die Modelle sind richtig und validiert.



Active seismic and logging campaigns

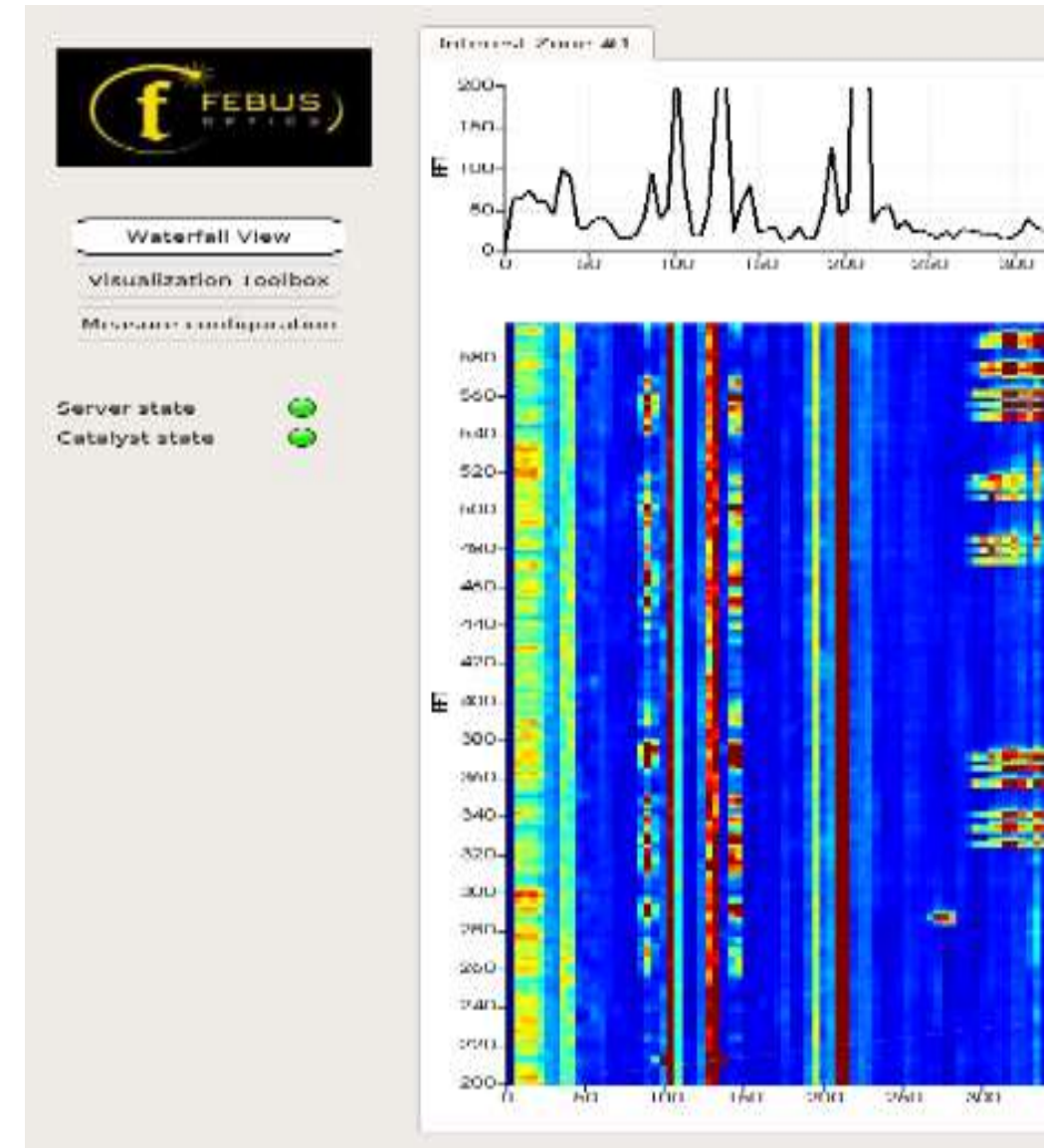
- Cross-well sparker test at Schäftlarnstraße geothermal site
 - Receivers: DAS well th3 and Th4
 - Objectives were
 - To improve velocity model to decrease event location errors
 - To improve reservoir imaging through tomography and finer interface resolution
 - To assess monitoring equipment



Sarker impulse probe from Avalon Sciences Ltd.
(Photo: Marcus Schlaf)

Active seismic and logging campaigns

- Results: No visible detection in the DAS signals
 - in the 1000 repeated shots and
 - in the post-processing (time and frequency domain, correlation analyses)



Core and sample analyses

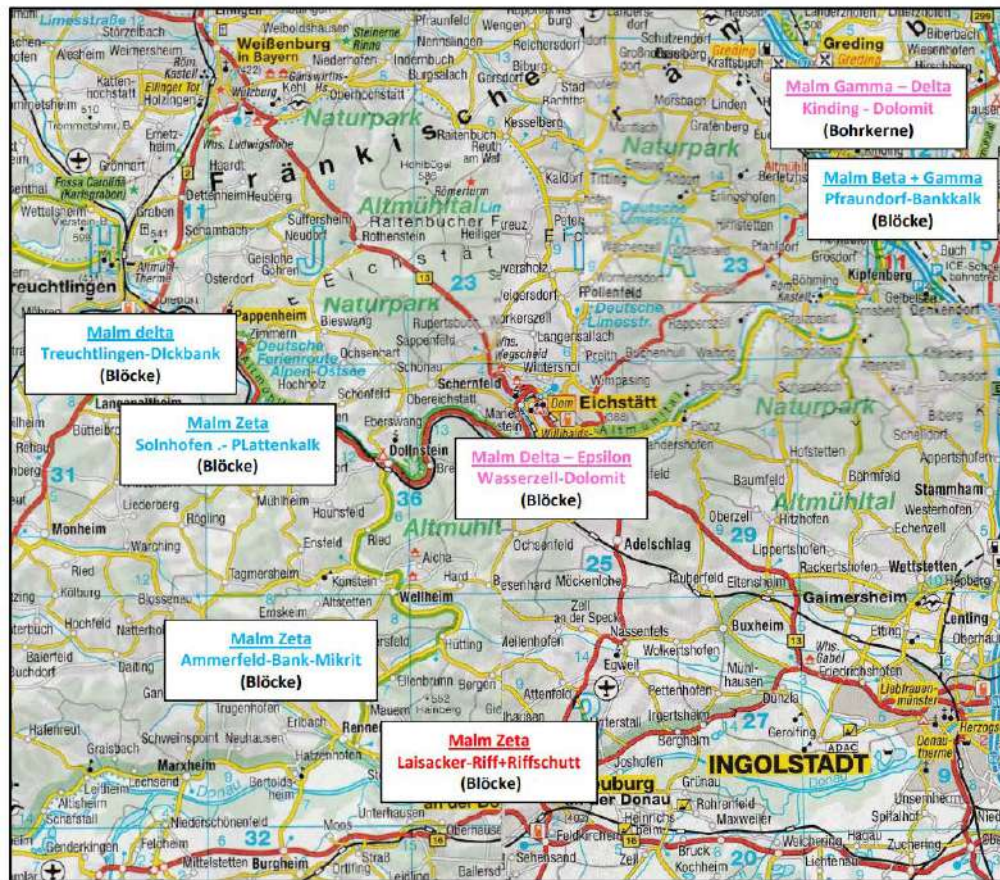
- Task: Model calibrations, determination of input parameters
- Data collection and evaluation for outcrop analogue samples
 - P- and S-wave velocity
 - Triaxial compressive strength, bulk density, elastic and deformation modulus, Poisson's ratio
 - Tensile strength, permeability, etc.
- Sampling from all facies classes and stratigraphic units in the Northern and Southern Franconian Jura
- Literature study on upscaling of parameters in analogue outcrop and geothermal reservoirs



Rock sample investigated in the rock laboratory of Ruhr University Bochum

Core and sample analyses

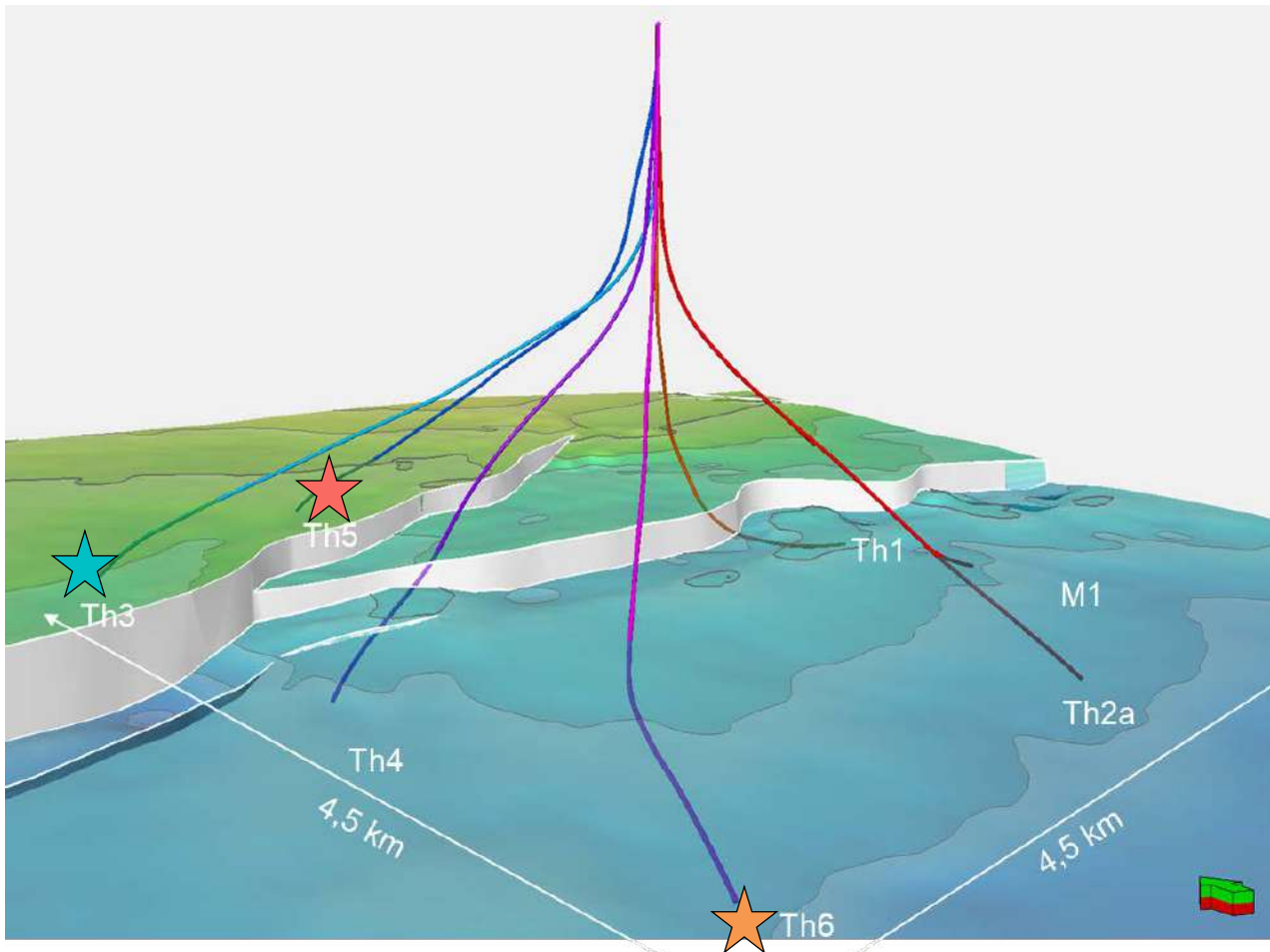
- Location maps of the outcrop analogs sampled in INSIDE from Malm Alpha to Zeta



- Additional sample investigations were carried out from the quarries Sengenthal and Saal

Tracer tests in Schäftlarnstraße

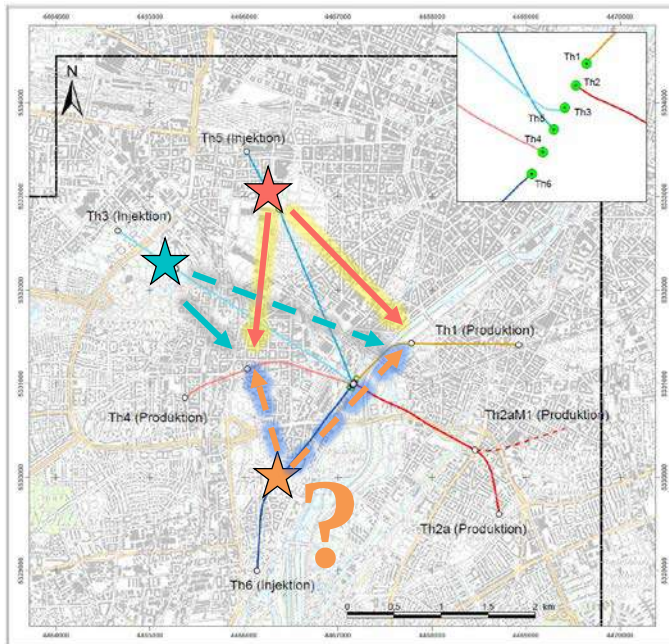
- Objective: Investigation of thermo-hydraulic properties for model calibration



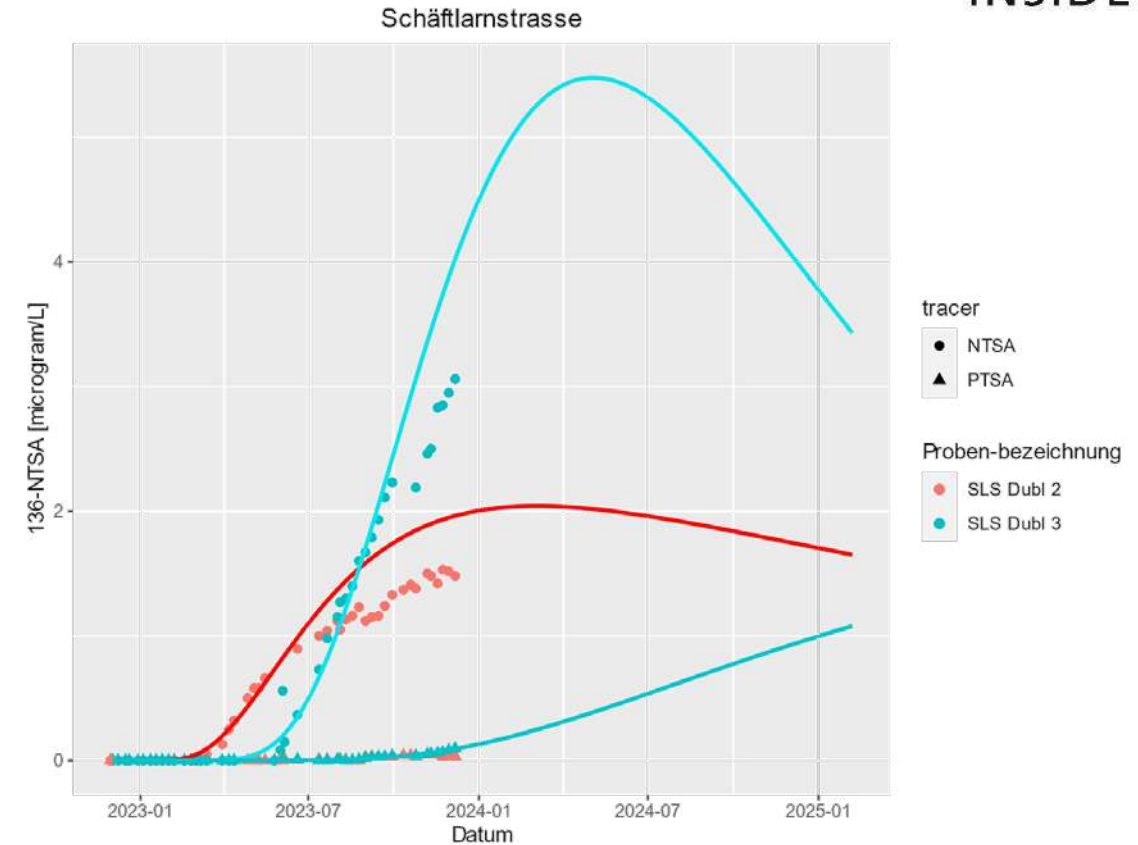
- ★ Th6, 24.11.2022:
 - ❑ Ca. 48 kg Uranin from planned 80 kg
 - ❑ Zugabe mittels Hochdruckpumpe gegen 14,5 barü
- ★ Th3, 24.11.2022:
 - ❑ 100 kg Pyren-1,3,6,8-tetrasulfonsäure Tetranatriumsalz Hydrat
 - ❑ No back-pressure
- ★ Th5, 25.11.2022:
 - ❑ Ca. 29.7 kg Naphthalin-1,3,6-Trisulfonsäure-Trisodiumsalz-Hydrat from planned 100 kg
 - ❑ Zugabe mittels Kreislumpumpe gegen 2,8-3,0 barü bei 121 kg/s

Tracer tests in Schäftlarnstraße

- First tracers detected
- Peak of the transmission curve not reached yet
- Mean residence time evaluation still very inaccurate
 - ❑ $t_0 = 700$ days (D3 / Th4 von Th5)
 - ❑ $t_0 = 2300$ days (D2 / Th1 von Th5)
 - ❑ $t_0 = ?$ (D3 / Th4 von Th3)



- ★ Th6, Uranin (24.11.2022)
- ★ Th3, Pyren-1,3,6,8-tetrasulfonsäure (24.11.2022)
- ★ Th5, Naphthalin-1,3,6-Trisulfonsäure-Trisodiumsalz-Hydrat (25.11.2022)



Conclusion & Outlook

➤ CONCLUSION

- Can we improve the seismic velocity model?
 - Successfully shown with the VSP-data
 - Not successful with the sparker test
- Can we get suitable petrophysical parameters?
 - Successfully shown with the VSP-data
- Can we calibrate numerical reservoir modelling?
 - Take over the static data as input parameters for modelling purpose

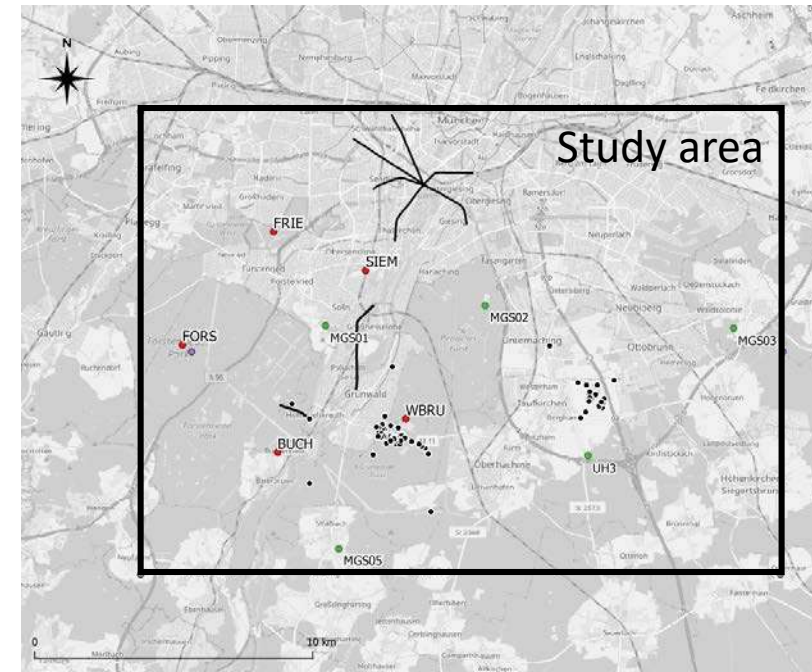
➤ OUTLOOK

- Tracer test: Further analysis of the thermal water
- Database available for future use

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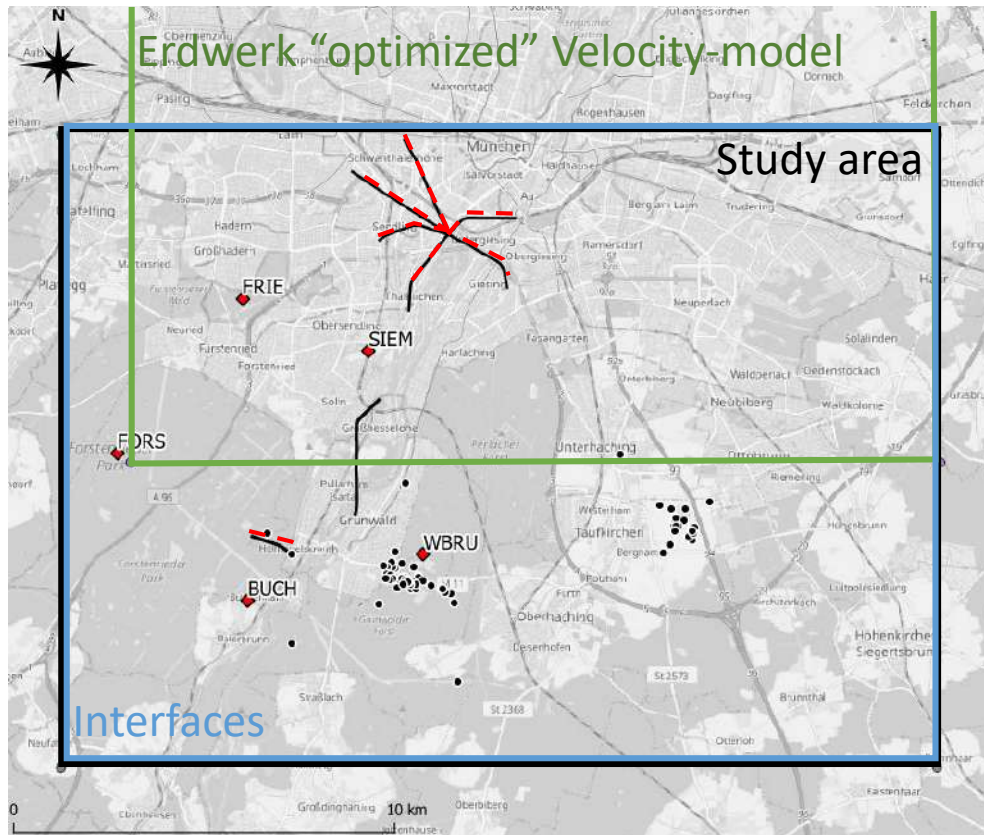
Seismic monitoring



- Can we build a reliable velocity model?
- Can we observe induced seismicity at Pullach or Schäftlarnstraße?
- What is the most valuable monitoring approach in an urban environment?
- Can Distributed Acoustic Sensing (DAS) be used for seismic monitoring?

Jérôme Azzola, Emmanuel Gaucher, Felix Bögelspacher, Bernhard Betzl, Martin Potten, Ralph Baasch, Michael Meinecke *et al.*

- Can we build a reliable velocity model for the study zone?
- Can we observe induced seismicity at Pullach or SLS?
- What is the most valuable monitoring approach in an urban environment?
- Can Distributed Acoustic Sensing (DAS) be used for seismic monitoring?



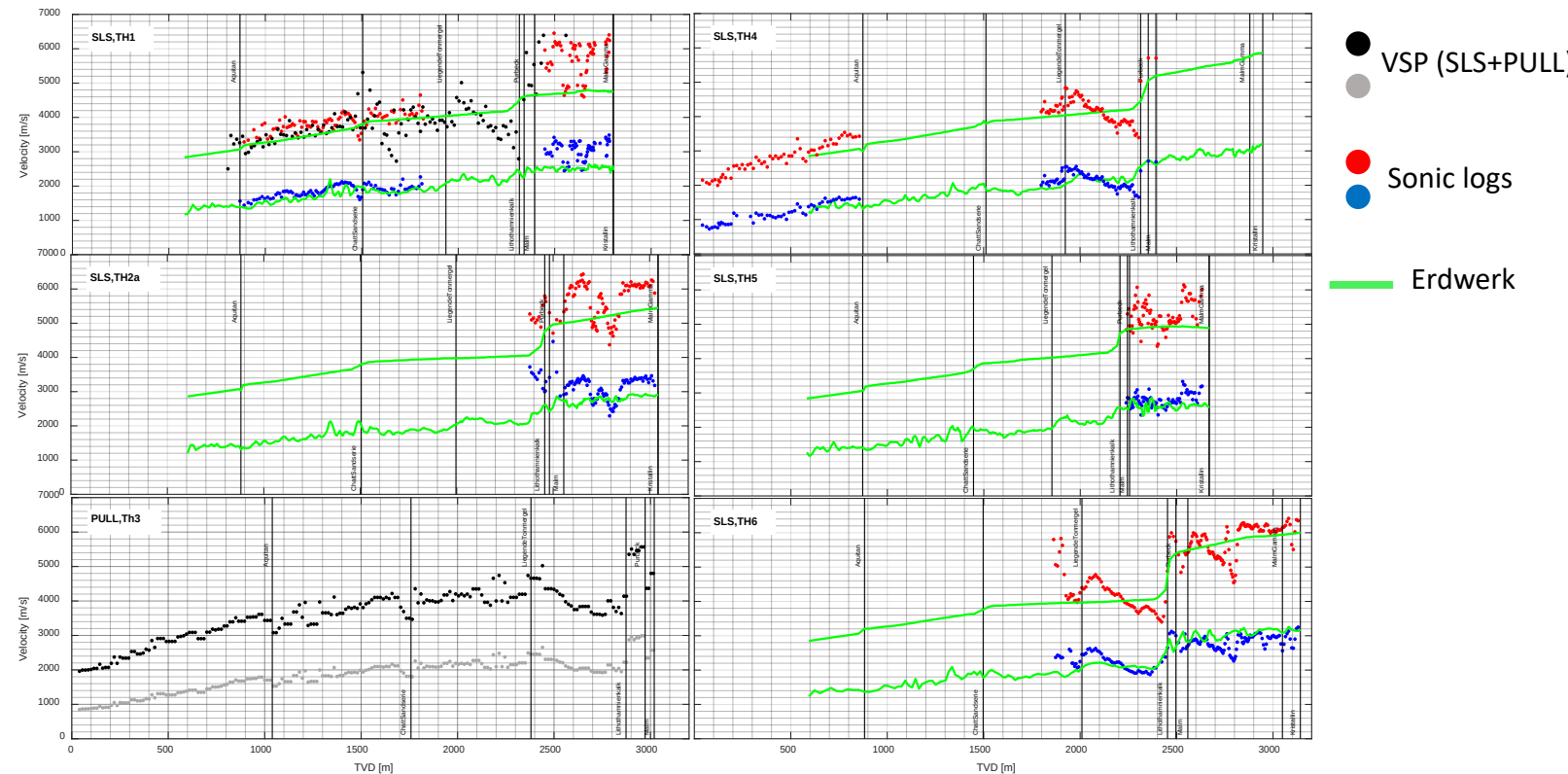
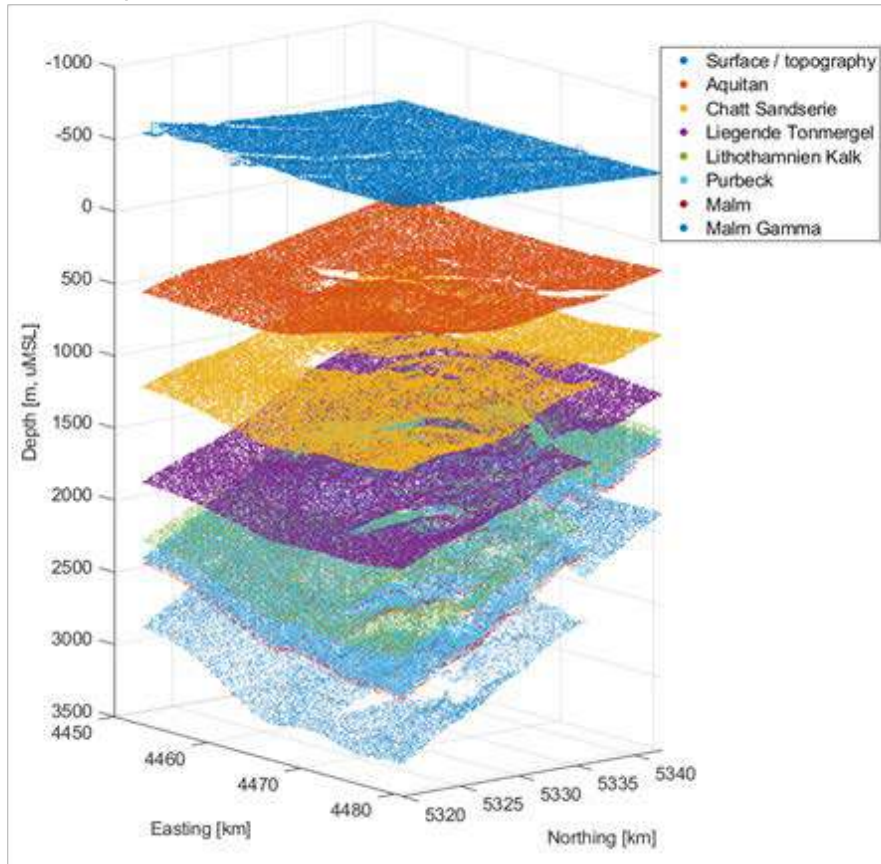
What data to address the question?

- Velocity model:
 - Structure: layer interfaces
 - Velocities: borehole measurements (VSP, sonic logs)
- >> *Challenge: necessary extra-/interpolation to fill the V-model volume*
- Test V-model, compare instruments, benchmark processing workflow:
 - Observed seismicity
 - Reported seismicity (Geophysical Observatory Fürstenfeldbruck)
[Tobias Megies, LMU]
- >> *Challenge: seismicity mainly to the east of the INSIDE network*

Can we build a reliable velocity model for the study zone?

Data to constraint the velocity model

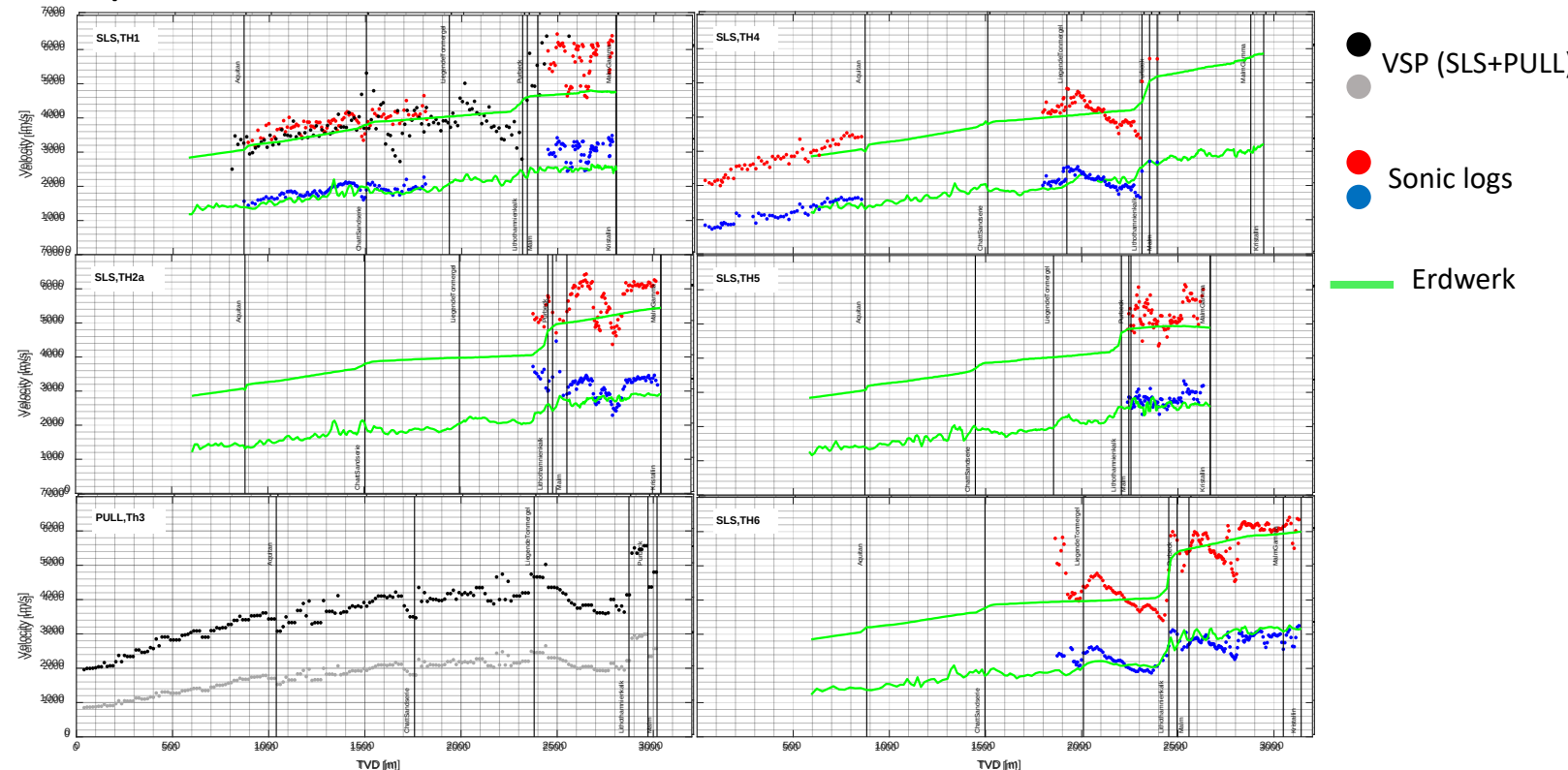
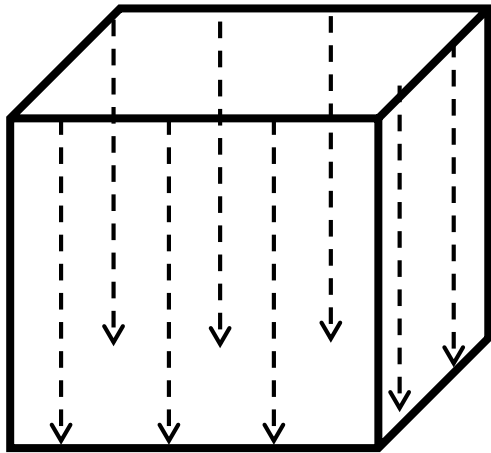
- Structure of the model: “Top” horizons, mapped over the study area (provided by Erdwerk)
- Spatial evolution of velocities: Borehole data (VSP, Sonic logs) and Erdwerk block



Can we build a reliable velocity model for the study zone?

Procedure to construct the model

- The interfaces between layers are defined by the horizons
- Velocities are fixed at each interface
- Velocities are linearly interpolated with depth

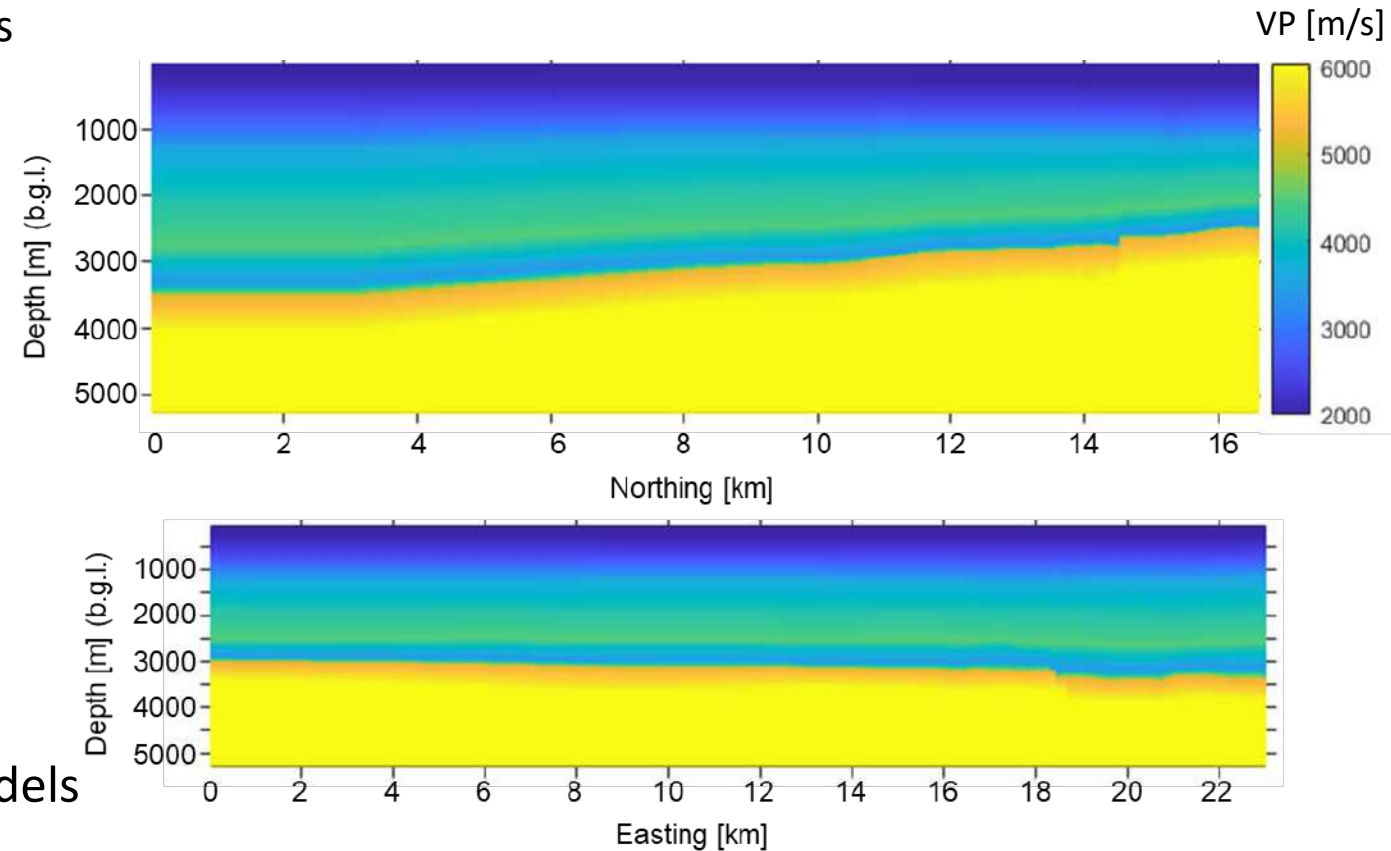
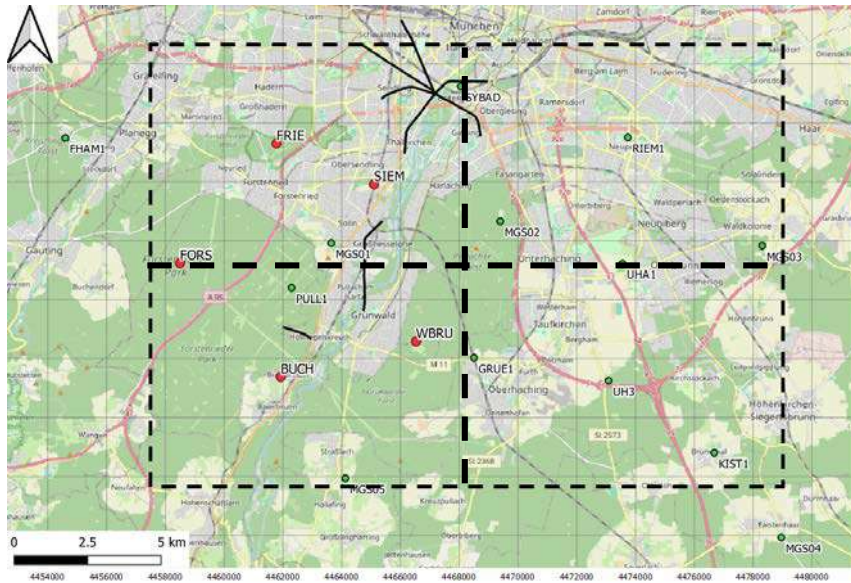


Fixed V_p , V_s  ...

Can we build a reliable velocity model for the study zone?

Test the “gradient” velocity model for south of Munich: location of detected seismic events

- Relatively small time residuals
- Results are relatively consistent with GOF epicenters
- Travel times are consistent with VSP travel times



Possible perspectives, towards more reliable models

- Refinement through passive tomography
- More observations, for more reliable interpolations, especially in deeper formations

Can we observe induced seismicity at Pullach?



Extending seismic monitoring capabilities to the west

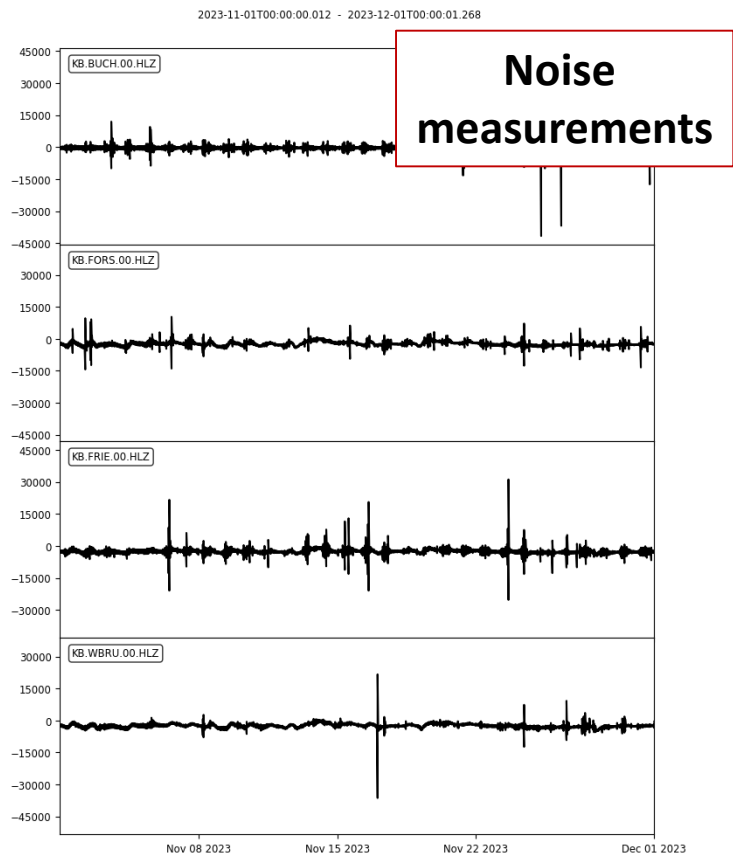
- Existing network, operated by GOF
- Five permanent “INSIDE” seismometers
 - Locations complement existing network
 - Used for event detection (STA / LTA + template analysis)
- INSIDE + local public stations of GOF
 - For event **location**



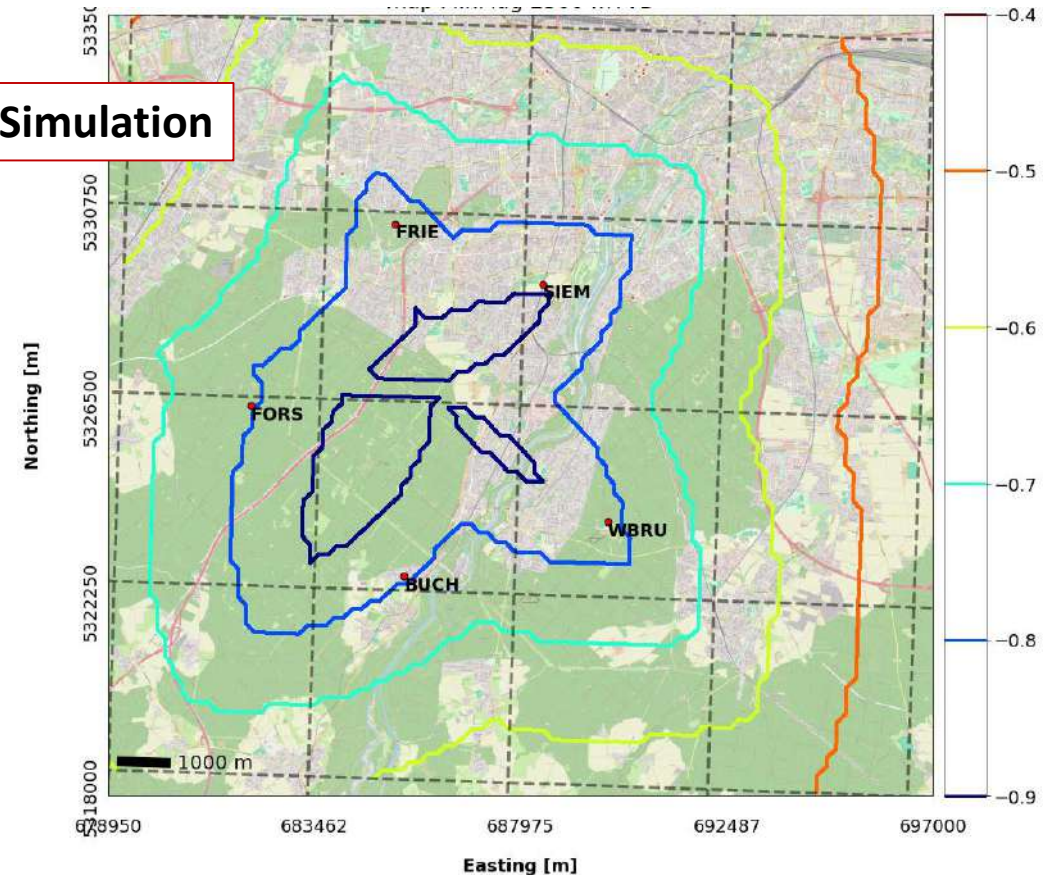
Can we observe induced seismicity at Pullach?

Noise measurements to infer the capabilities of the network

- Ground vibrations are acquired for one/multiple week(s)
- Estimation of the spatial evolution of minimum detectable magnitude at depth
- Here, for events at reservoir depth



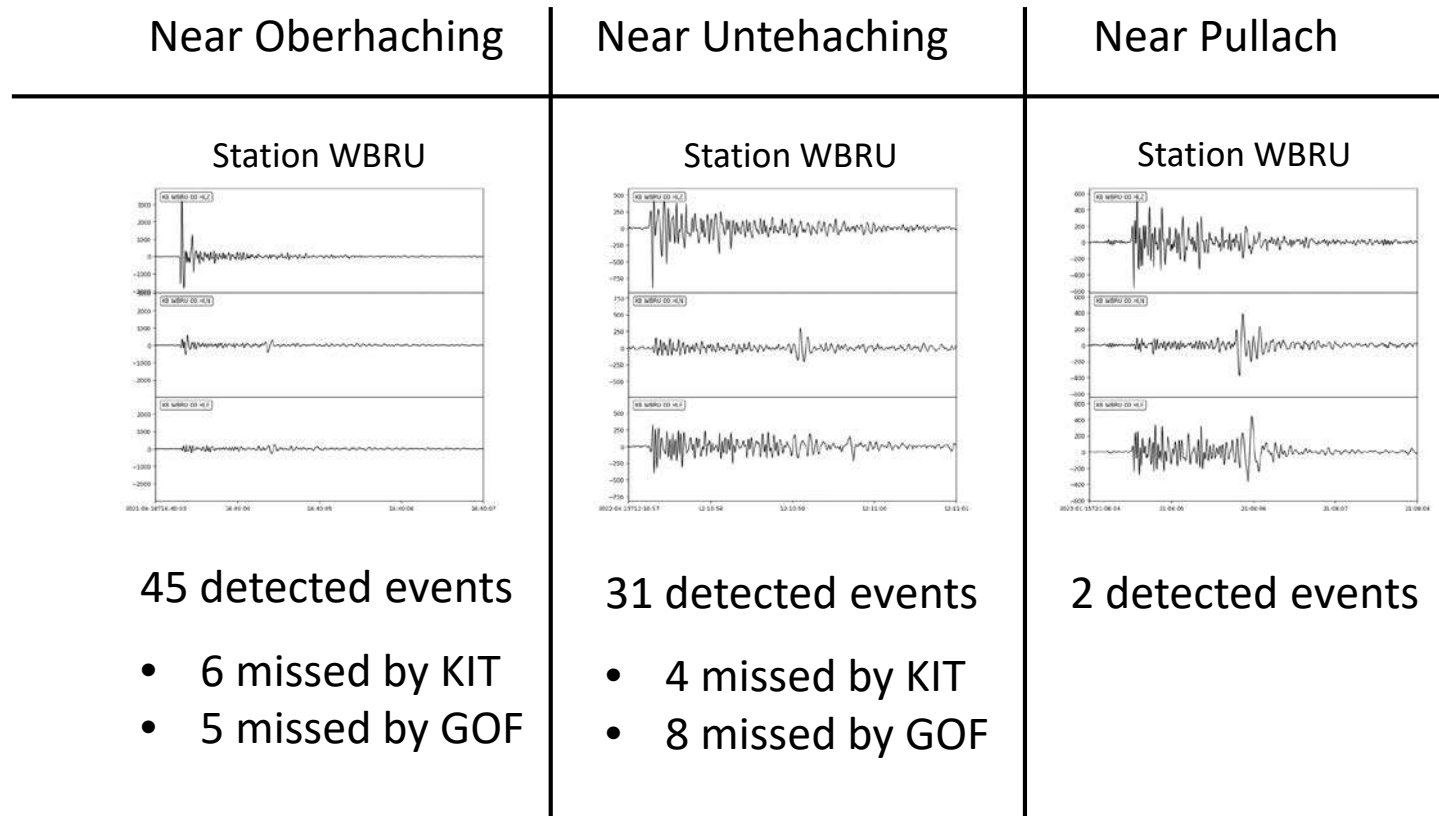
Simulation



Catalogue of seismic events from March 2021 to January 2024

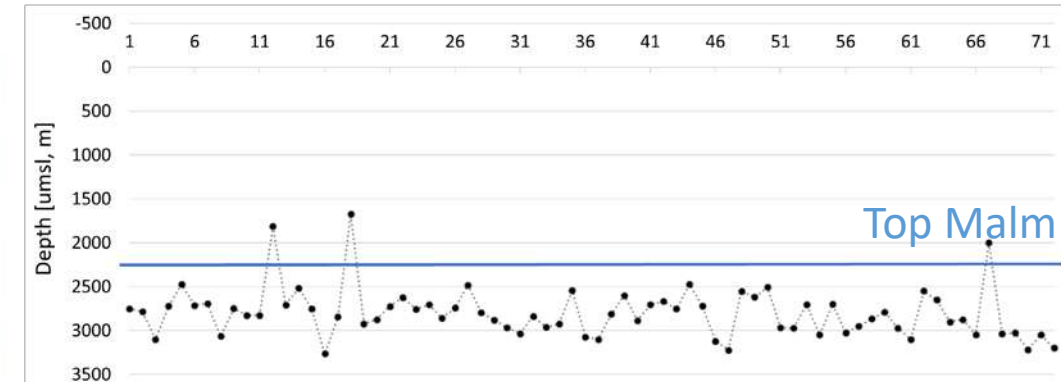
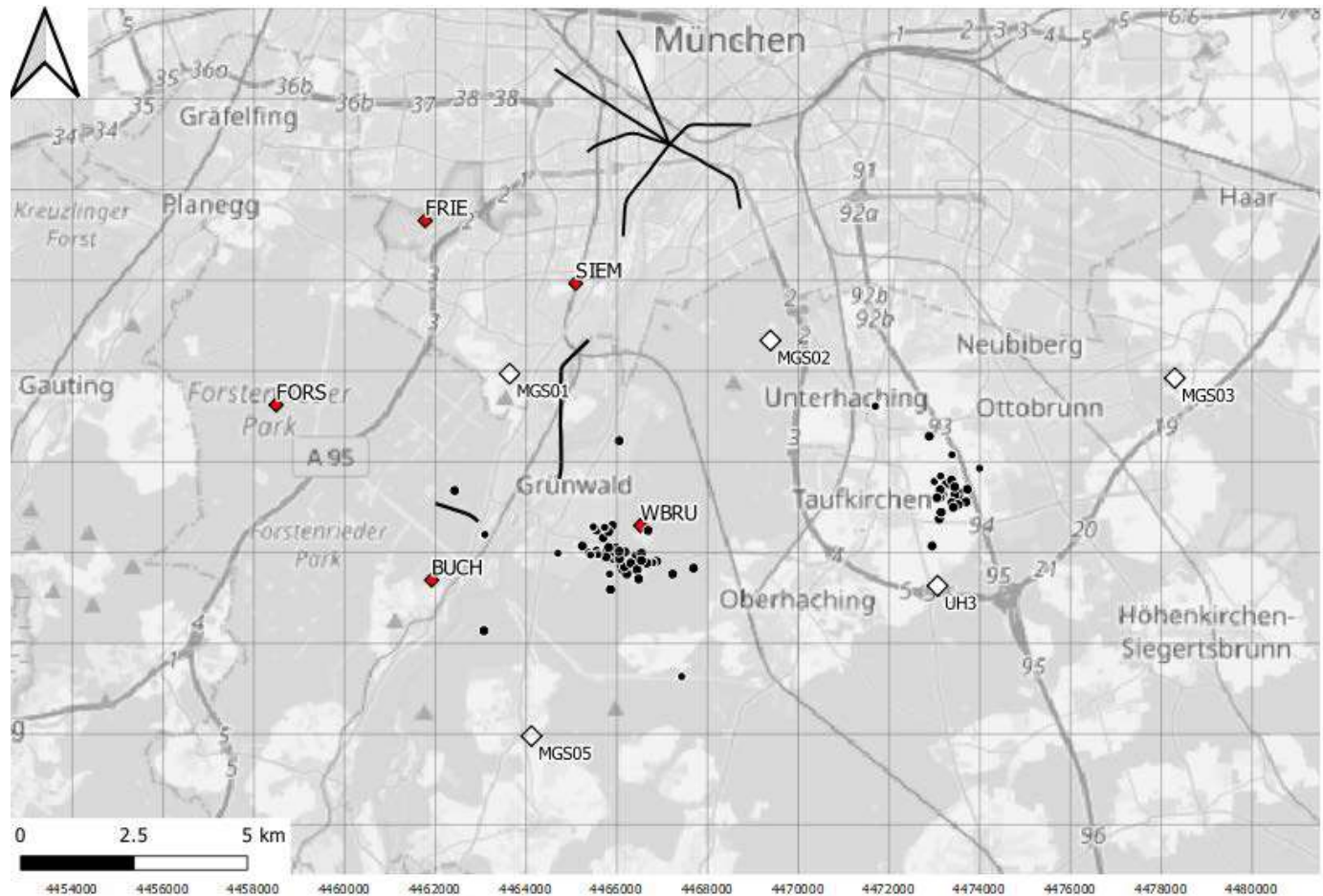
Seismic event detection

- 79 events detected, 3 main clusters
- Comparison with GOF / LMU catalogue (**only epicenters**)
- Catalogs are complementary



Catalogue of seismic events from March 2021 to January 2024

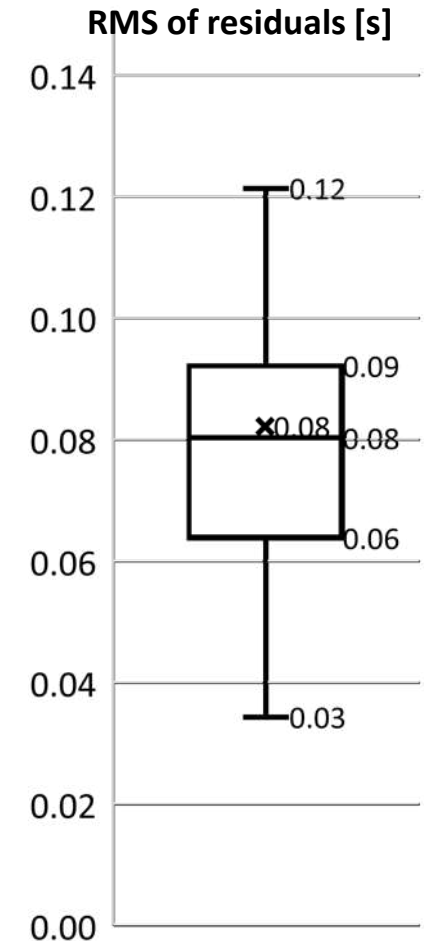
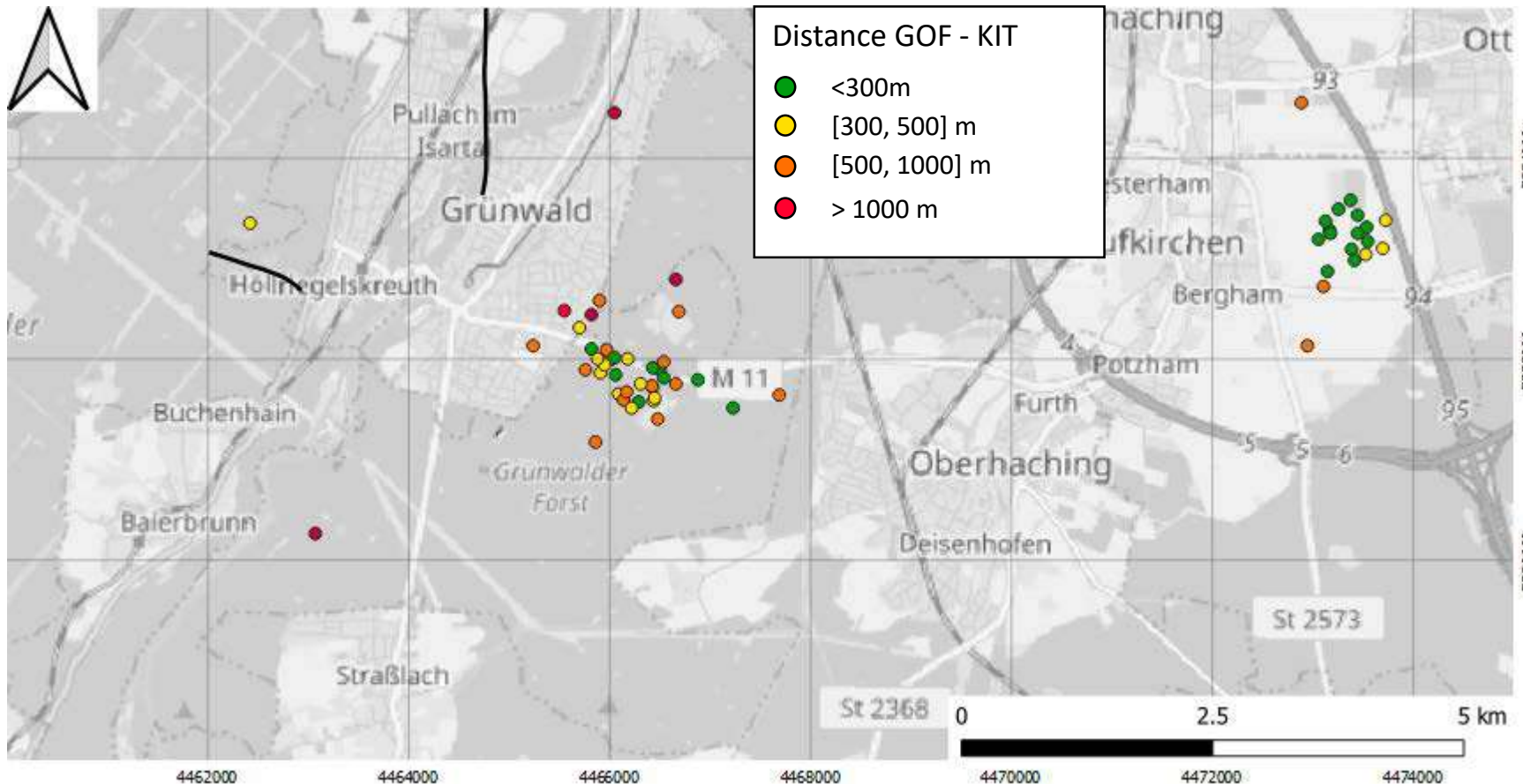
Seismic event location: using INSIDE and public BH stations in the workflow



Catalogue of seismic events from March 2021 to January 2024

Seismic event location: to test the developed velocity model

- Results are relatively consistent with GOF epicenters
- Relatively small time residuals



Can we observe induced seismicity at Pullach?

Observed vs simulated detection capabilities

- INSIDE network is working with sensitivity as expected
- INSIDE network can detect events with a magnitude down to -0.8 at the reservoir depth

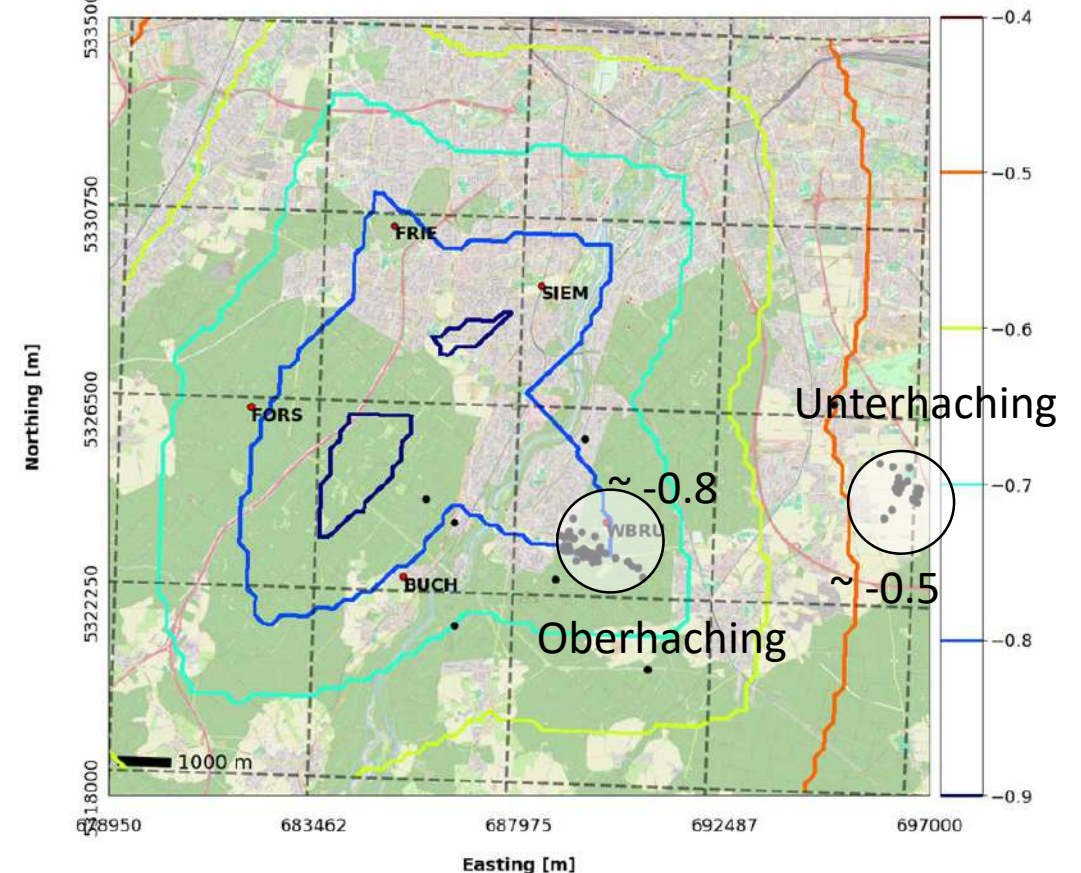
Observations

Min / max magnitudes per cluster

	Minimum	Maximum
Unterhaching	-0.55	1.6
Oberhaching	-0.75	0.8

Simulated detection capabilities

Minimum magnitude ; events at reservoir level

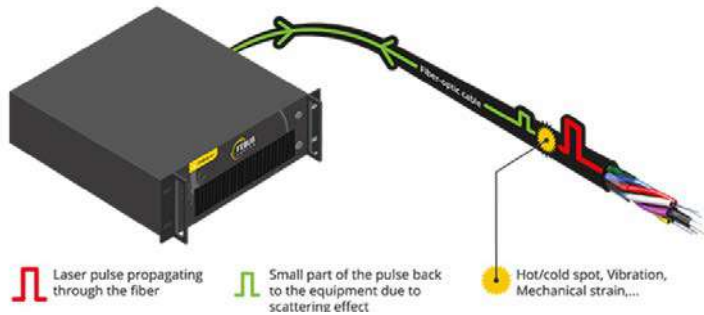


Most valuable monitoring approach in an urban environment?

A mix of different instrument types...

- Mini-array in Siemens Park
+ borehole seismometer
- DAS in BUCH
- Temporary DAS monitoring at SLS

... to compare monitoring capabilities



Distributed Acoustic Sensing (DAS)



Most valuable monitoring approach in an urban environment?

Comparison of instruments / configuration

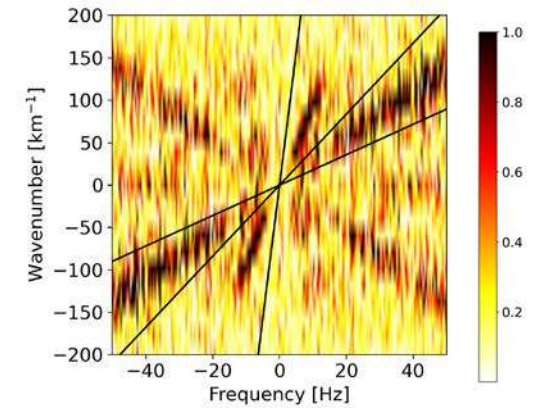
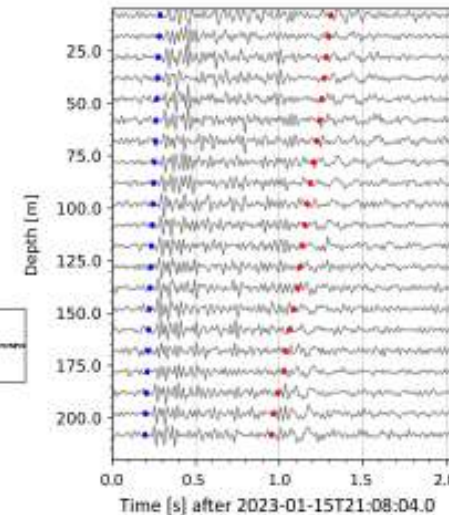
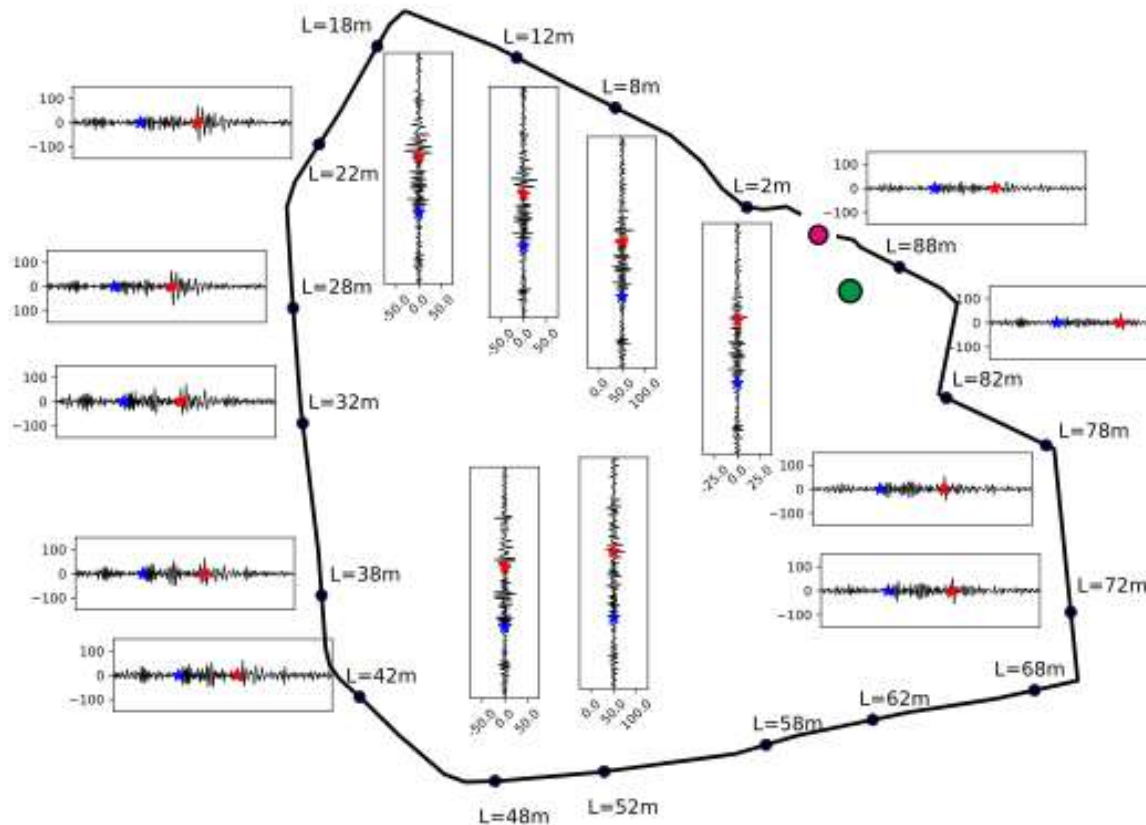
	Mini-array [Siemens Park]	DAS [Buchenhain and Schäftlarnstraße]
Pros	• Increase of SNR after stacking (beamforming) → Higher SNR than downhole seism. SIEM • Array processing, to describe • Seismic events: back azimuth, slowness • Subsurface: from ambient field methods → Back azimuths are mostly consistent with seismic catalogue	• Large number of sensing points to apply methods from array seismology • DAS in well: • Sensitivity to detection • Automatic picking, event description (magnitude, stress drop) → Results are mostly consistent with seismic catalogue • Buchenhain configuration to overcome 1D sensitivity, with multiple sensing azimuths: • Array processing, to describe > Seismic events: back azimuth, incidence and slowness > Subsurface: from ambient field methods → Location of event was demonstrated from Buchenhain DAS station
Cons	• Long permitting procedure • High maintenance requirements • Not suitable on a long-term basis...	• Buchenhain: aperture of the array limits beamforming capacities • Relatively low SNR • High data flows, high costs • Fairly recent technology, less established, requiring expertise (recording parameters, data types, ...)

Can Distributed Acoustic Sensing (DAS) be used for seismic monitoring?

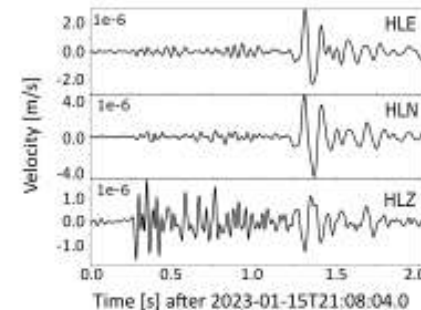
→ Experience from the Buchenhain station

Seismic event location with single DAS station

- Horizontal components (~90 m surface loop, with different azimuths) + vertical components (250 m well)
- Example of the seismic event near PULL TH3 from January 15, 2023



t-d to f-k

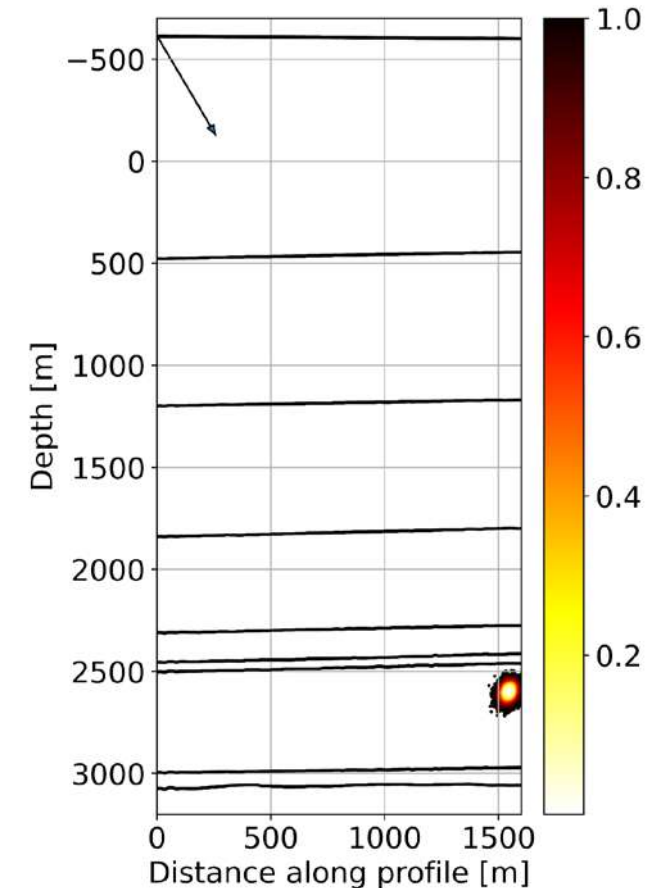
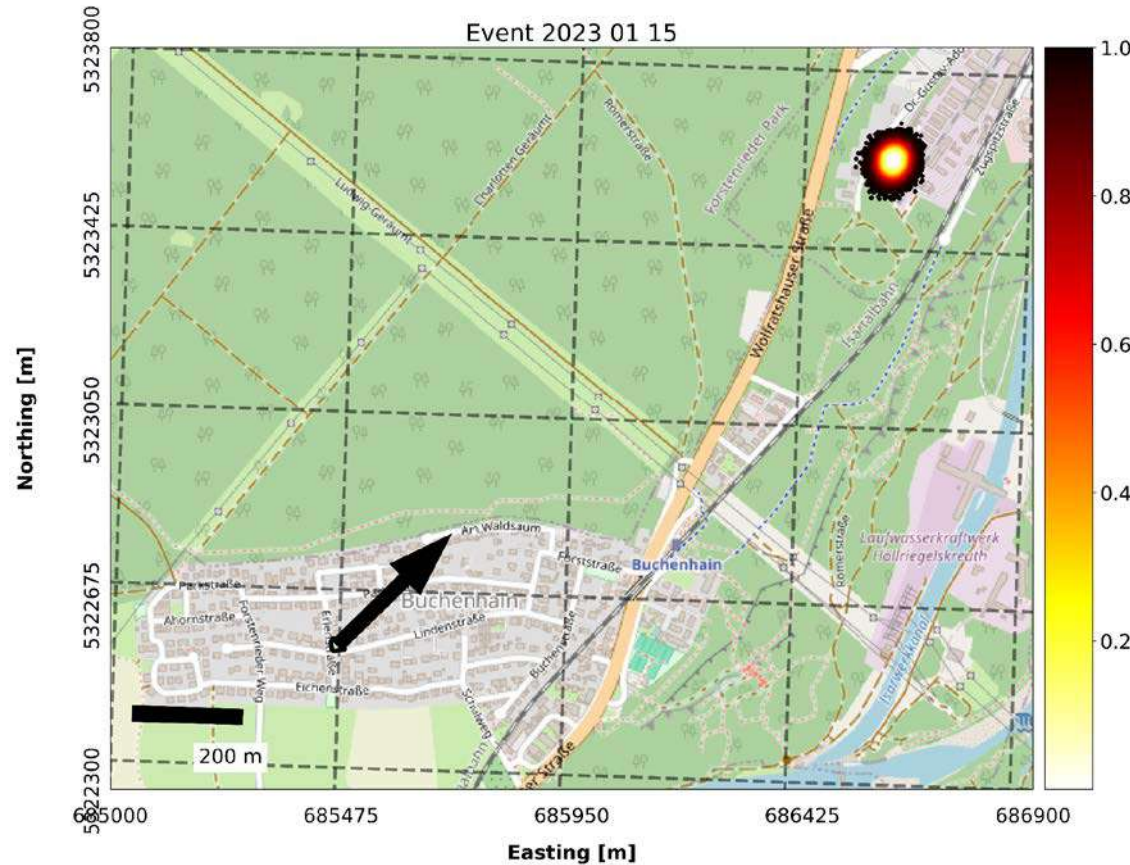


Can Distributed Acoustic Sensing (DAS) be used for seismic monitoring?

→ Experience from the Buchenhain station

Seismic event location with single DAS station

- Combining surface loop (back azimuth) + monitoring borehole (incidence)
- Location by seismometer network / DAS station are compatible

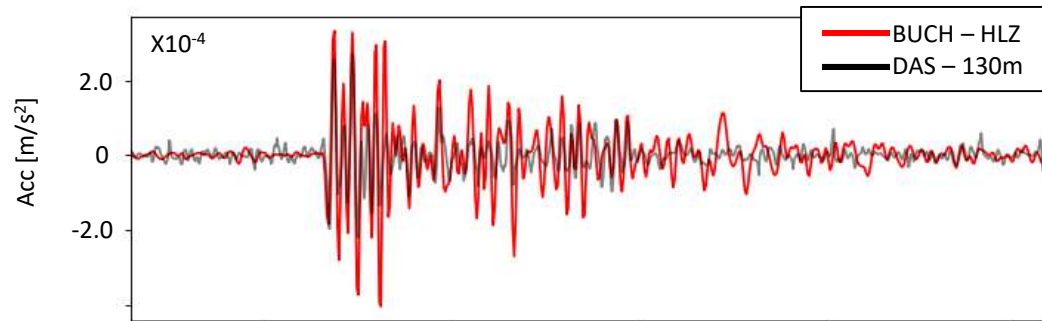
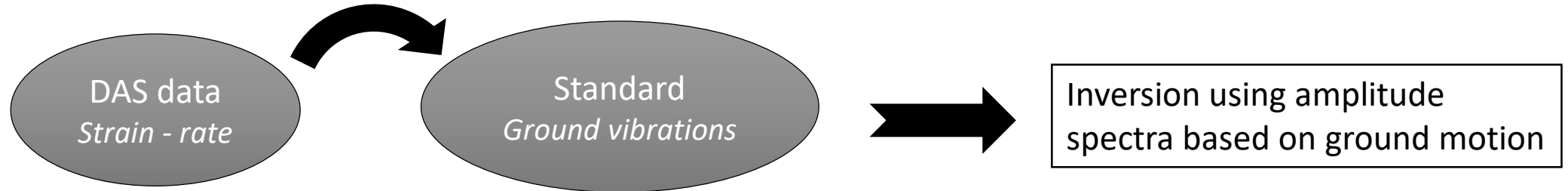


Can Distributed Acoustic Sensing (DAS) be used for seismic monitoring?

→ Experience from the Buchenhain station

Magnitude estimation: from strain-rate to ground motion (e.g. velocity acceleration)

- To apply well-established methods
- Allows to check that converted DAS data reliably represent ground motion



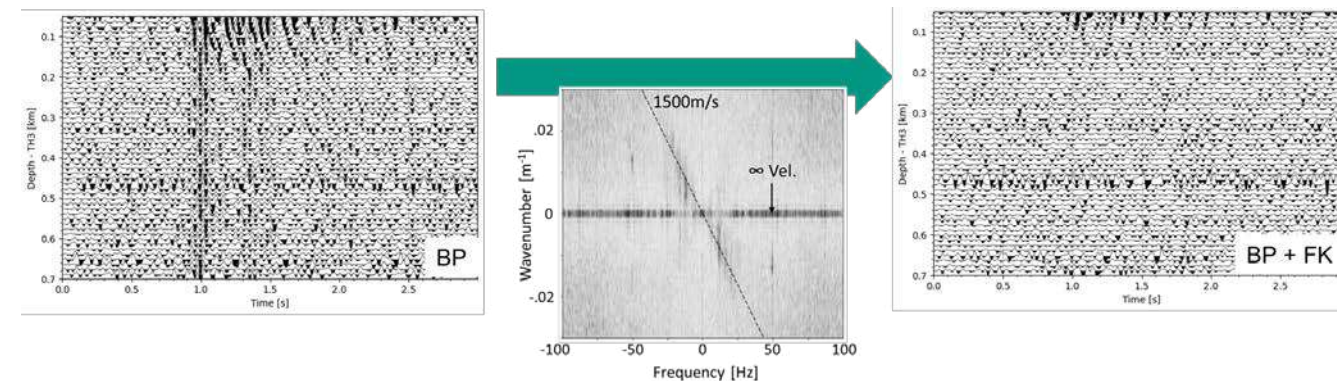
- DAS provides accurate magnitude estimates, given the fit between DAS and BUCH waveforms
- DAS- and seismometer data are compatible and can be combined in mixed networks

Can Distributed Acoustic Sensing (DAS) be used for seismic monitoring?

→ Experience from 6-month DAS monitoring at SLS

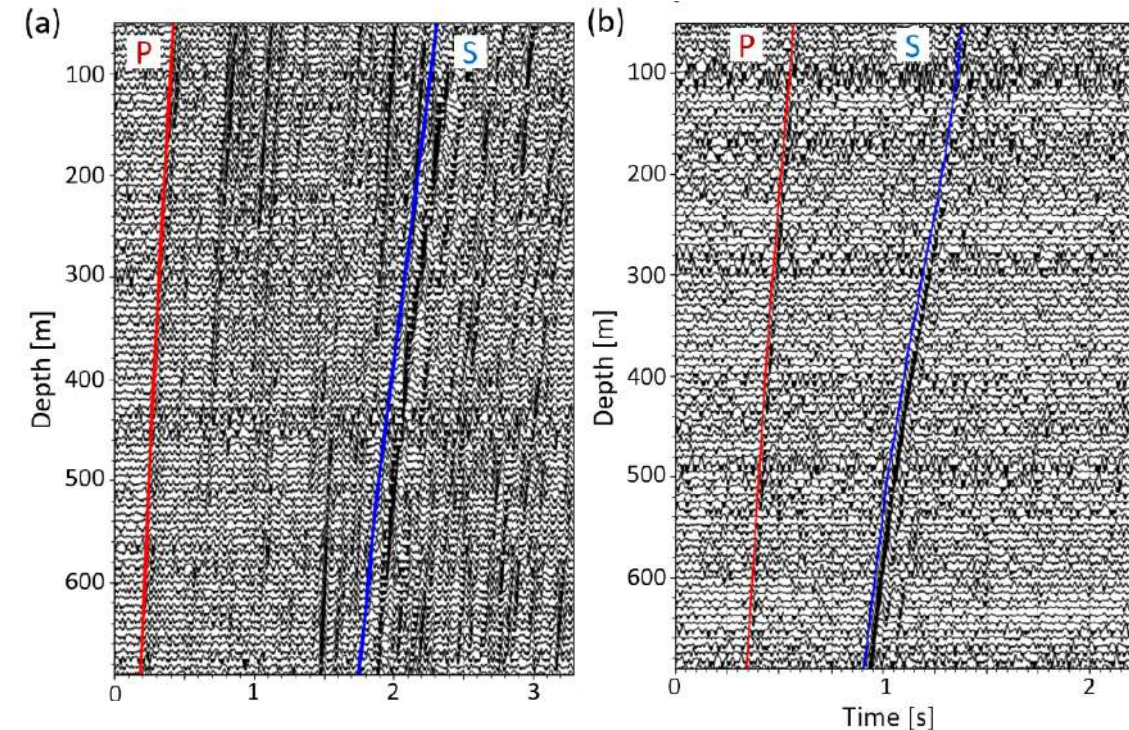
Seismic event detection from behind the casing of a flowing well (Azzola et al., 2023)

- Array processing for advanced de-noising (filtering in f-k domain)
- Increased sensitivity: April 9, 2022 event over DAS TH3 cable but only visible on 1 nearby seismometer



Seismic event description (Azzola and Gaucher, 2024, in review)

- Picking of arrival-times
- Moment magnitude / stress drop from DAS

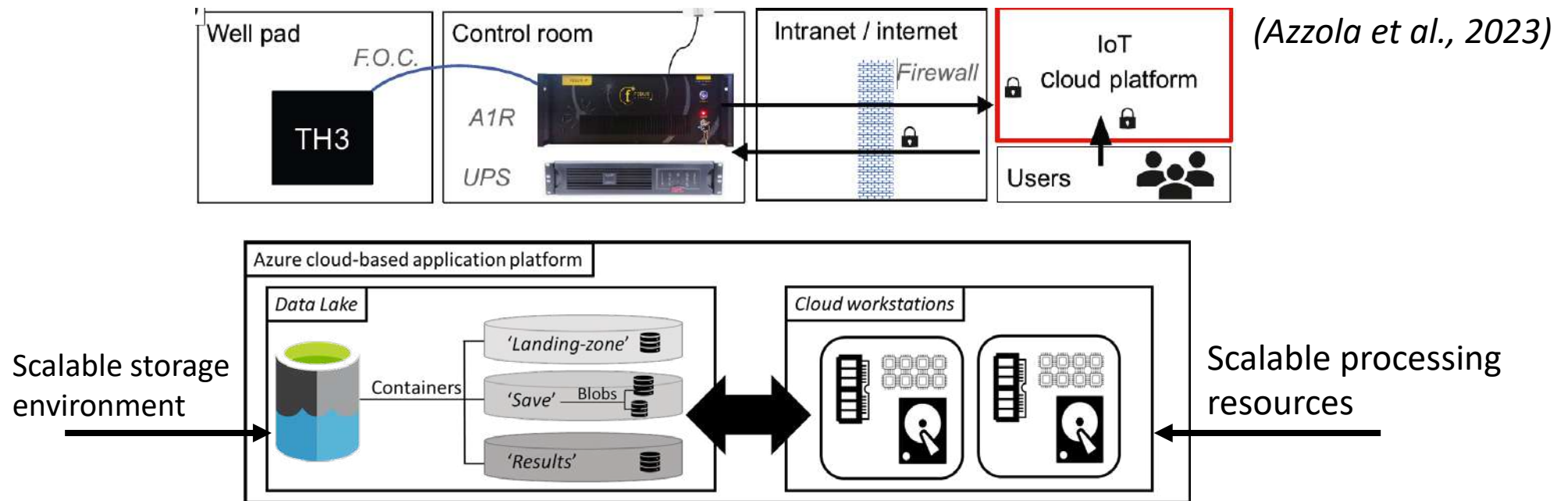


Can Distributed Acoustic Sensing (DAS) be used for seismic monitoring?

→ Experience from 6-month DAS monitoring at SLS

Data management: storage and processing of DAS data flows for monitoring is possible

- Automated acquisition and processing was implemented, with a view to real-time monitoring
- SWM cloud resources for storage and processing of data flow
- Towards a Reservoir Management System (Katja)



Conclusion & Outlook

➤ CONCLUSION

- Using data gathered and recorded during INSIDE we could build a reliable velocity model in the zone of interest
- The INSIDE network is working well, can record M_L -0.8 events at the reservoir level, but almost no seismicity was observed below it for the last 3 years
- Seismic mini-array or borehole sensor?
- Distributed Acoustic Sensing (DAS) can be used for seismic monitoring

➤ OUTLOOK

- Further investigate the capabilities of the “3D-array DAS” at Buchenhain
- Implement automatic detection and data transfer from Buchenhain DAS station

Agenda

Start time	Topic	Speaker
08:30	Welcome, coffee, registration	
09:00	Welcome message, Video, Project overview	R. Baasch, E. Gaucher
09:20	Well-based data acquisition and analysis	P. Goblirsch, K. Thiemann
09:55	Seismic monitoring	J. Azzola
10:30	Geodetic monitoring	M. Westerhaus
11:05	Break	
11:20	Geothermal reservoir numerical modelling	E. Gaucher, A. Savvatis, R. Habibi
11:55	Reservoir Management System	K. Thiemann
12:30	Communication to the public	P. Goblirsch
12:45	Conclusion, outlook and discussion	G. Bergdolt
13:30	Lunch break	
14:30	<i>Non-public operator meeting</i>	

Geodetic Monitoring

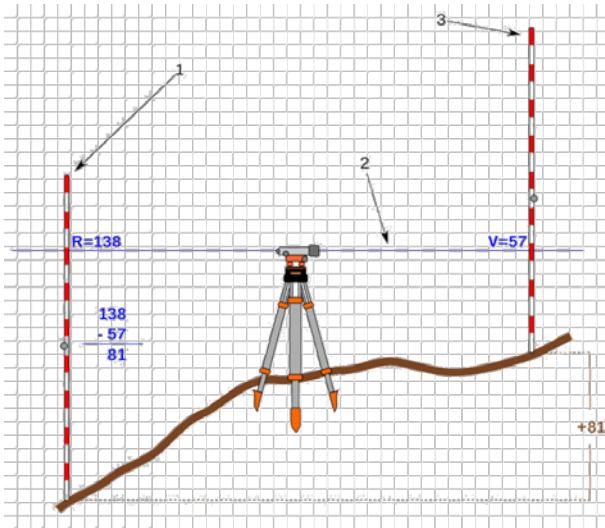


- Can we see any uplift or subsidence at Pullach or Schäftlarnstraße (SLS)?
- What is the most valuable monitoring approach?
- Can satellite-based measurements contribute to the determination of the zone of influence (Einwirkungsbereich)?

Malte Westerhaus, Bence Ambrus, Efthymios Tsantopolous, Chavosh Almassian, Alison Seidel, Markus Even, Ralph Baasch, Bernhard Betzl, Martin Potten *et al.*

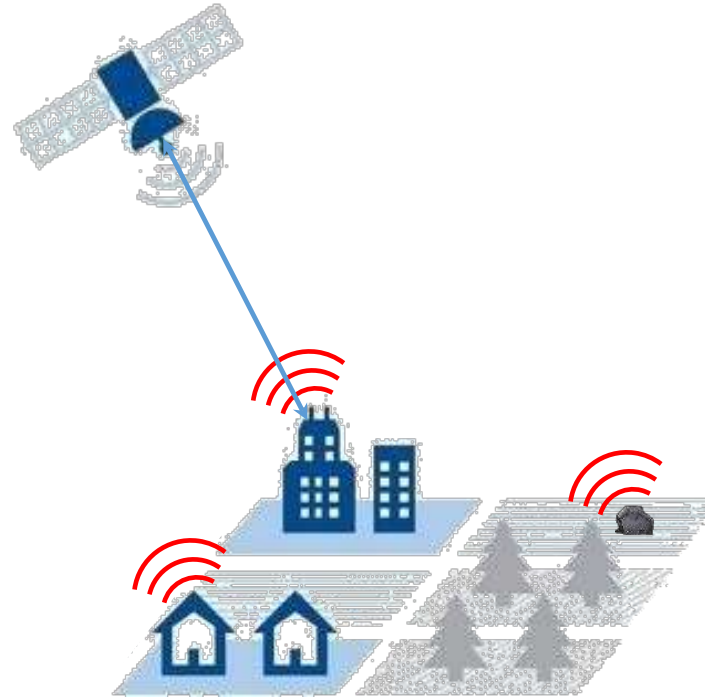
Components of the geodetic network

Precision Levelling



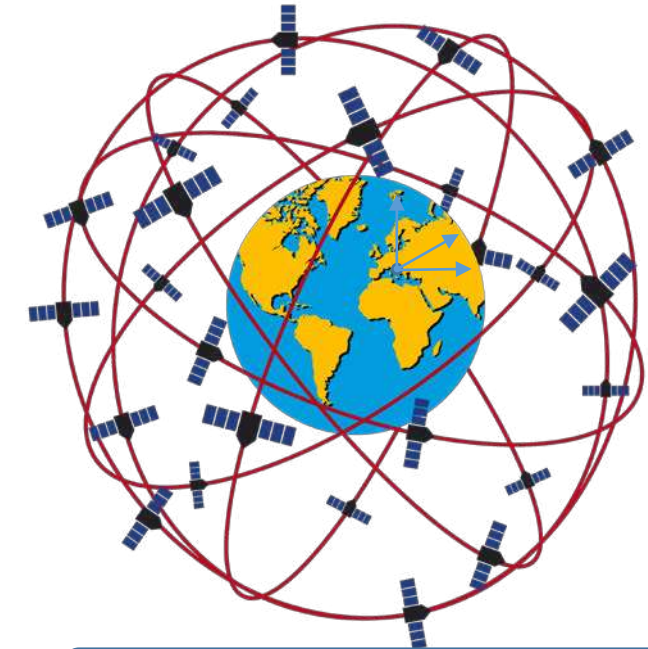
- Heights/height changes, 1-dim
- Precision heights: sub-mm
- Precision rates: < mm/a
- Nr. of marked points: ~135

Radar-Interferometry (InSAR)



- Slant range, 1-dim.
- Precision distance: 2 - 3 mm
- Precision rates: < mm/a
- Nr. of accepted points: ~ 52.000

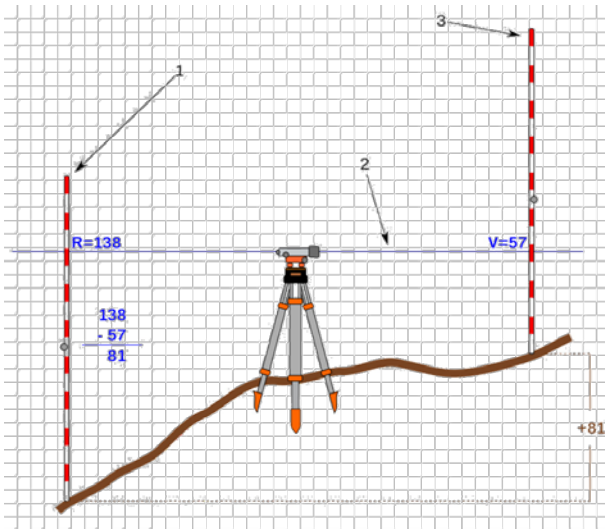
Global Navigation Satellite Systems (GNSS)



- Position/coordinates, 3-dim.
- Precision position: < 1 cm
- Precision rates: < mm/a
- Nr. of stations: 4

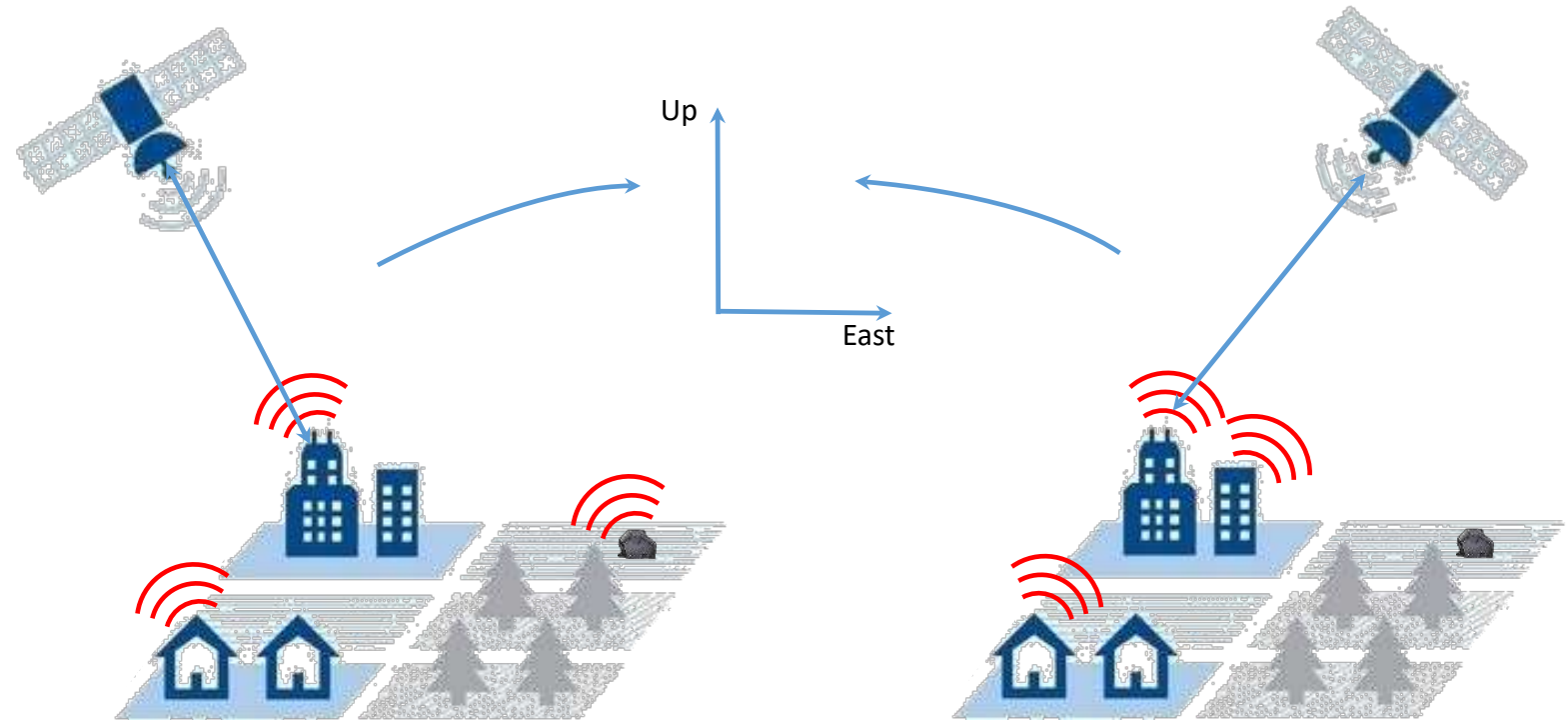
Components of the geodetic network

Precision Levelling



- Heights/height changes, 1-dim
- Precision heights: sub-mm
- Precision rates: $< \text{mm/a}$
- Nr. of marked points: ~ 135

Radar-Interferometry (InSAR)



- Slant range, 1-dim.
- Precision distance: 2 - 3 mm
- Precision rates: $< \text{mm/a}$
- Nr. of accepted points: ~ 52.000

Combination of radar images from ascending and descending orbits allows determination of vertical and EW-horizontal displacements.

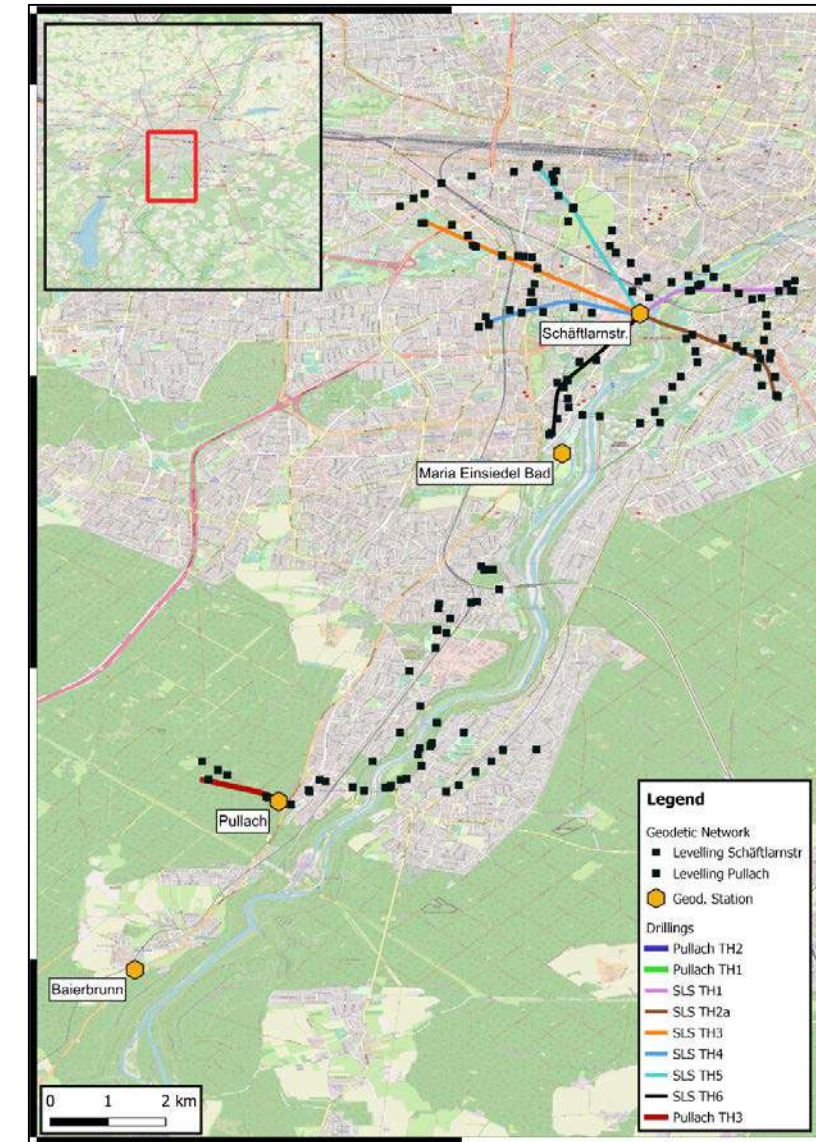
Components of the geodetic network

➤ WHY GNSS?

- Delivers full displacement vectors (northing, easting, up) in an absolute reference frame
 - Control of levelling reference point
- High temporal sampling rates (→ 1 sec)
 - Short term response in case of emergency

➤ RESEARCH QUESTIONS

- Performance of a network consisting of a fully equipped master station and three single frequency stations
- Performance of electronical corner reflectors
- **Integration of terrestrial and satellite-based methods in an urban environment.**



Components of the geodetic network

Pillar station



Baierbrunn

Pullach TH3



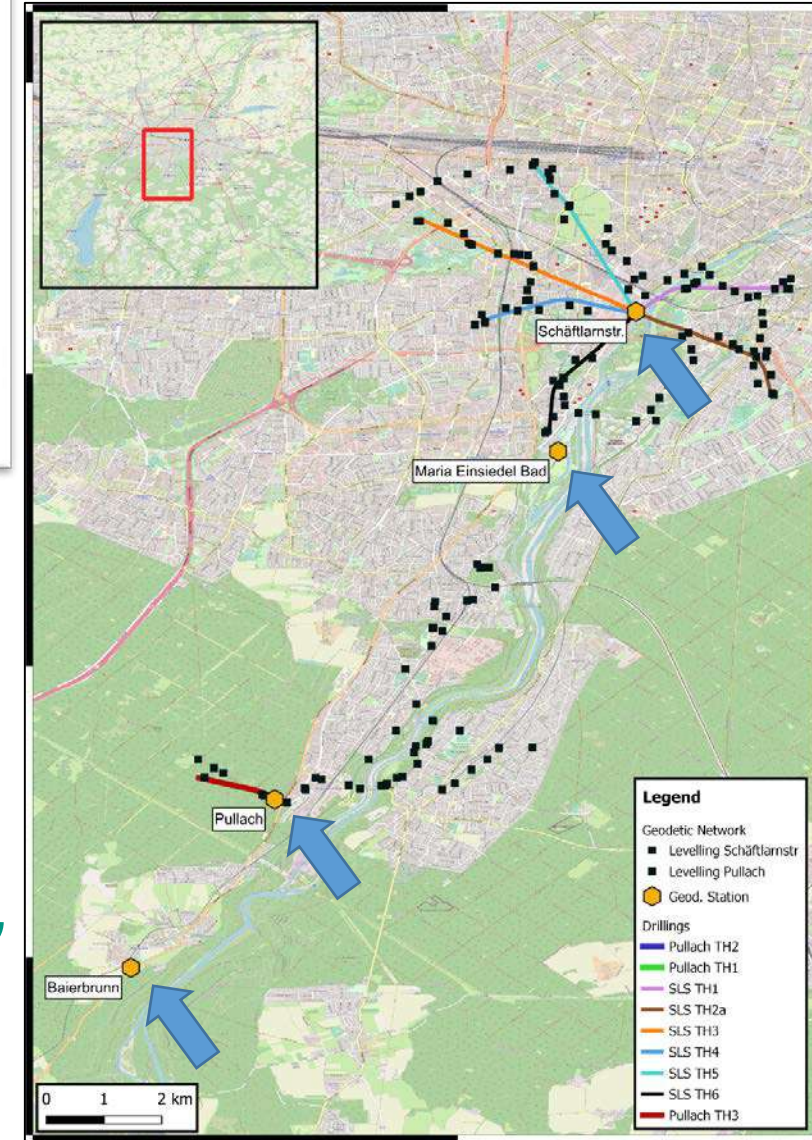
Maria-Einsiedel Bad



Schäftlarnstraße

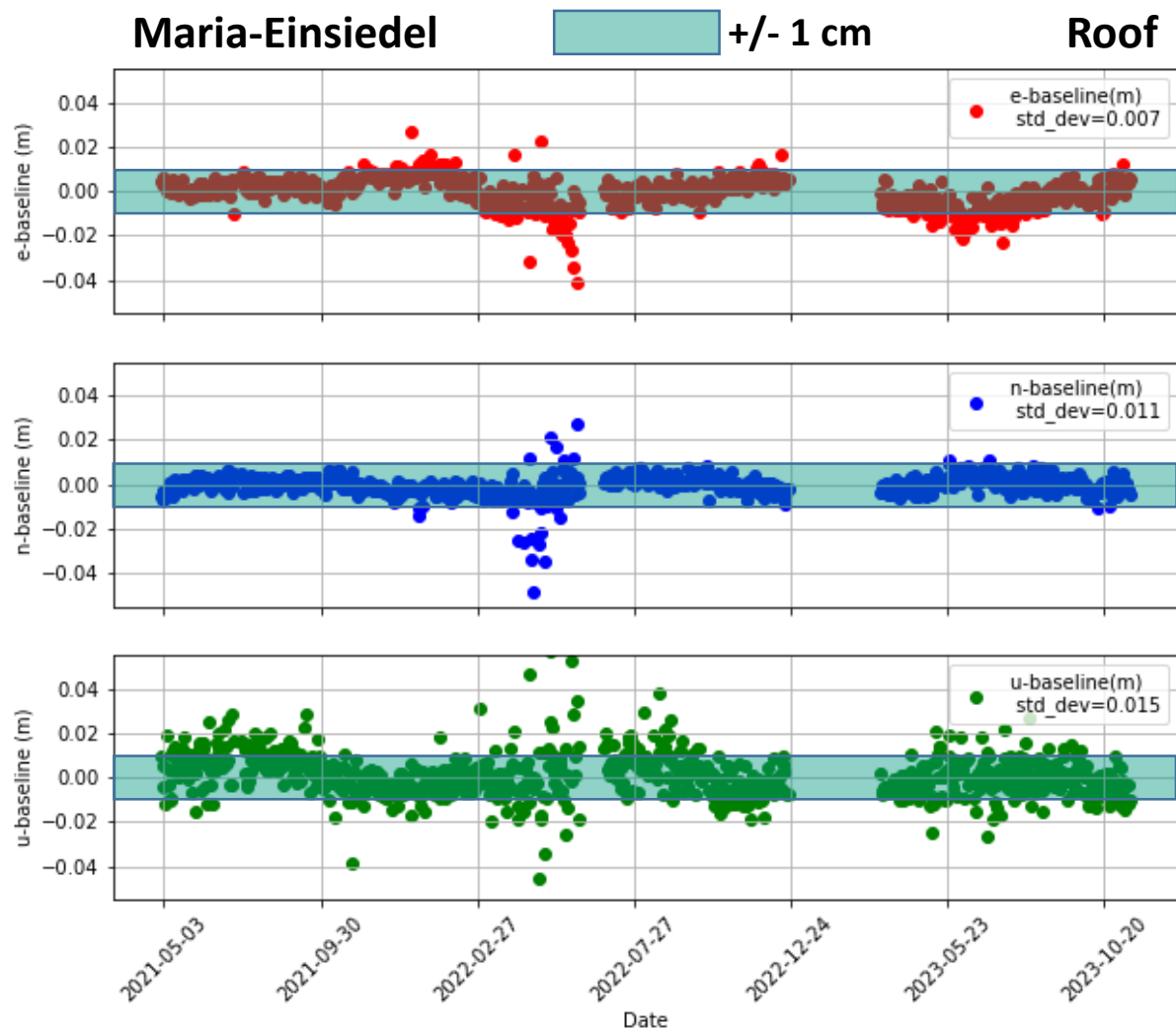


Roof stations

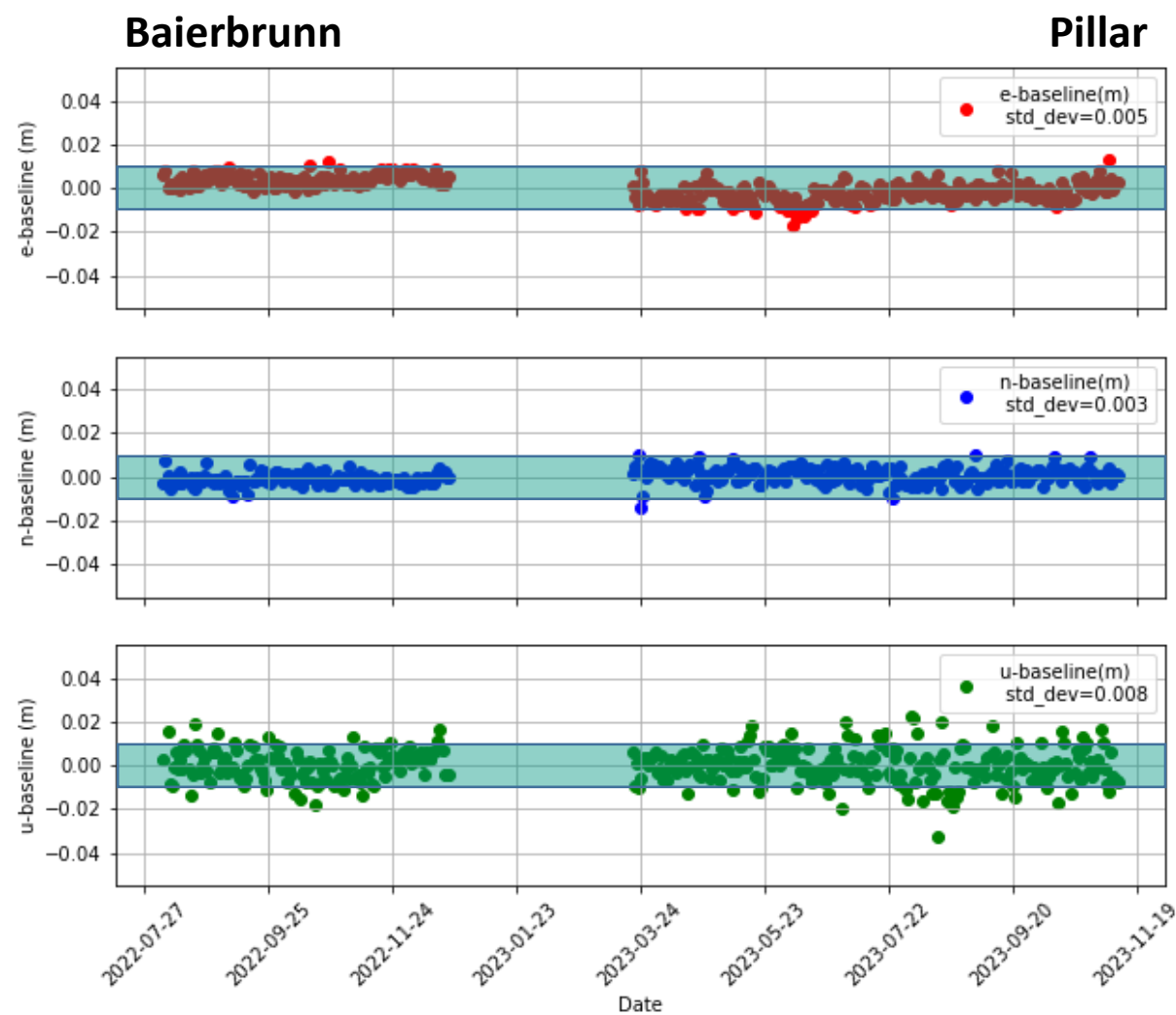


GNSS time series

GBAD station - Elevation angle 15° - Combined Filtering



GBAI station - Elevation angle 10° - Combined Filtering



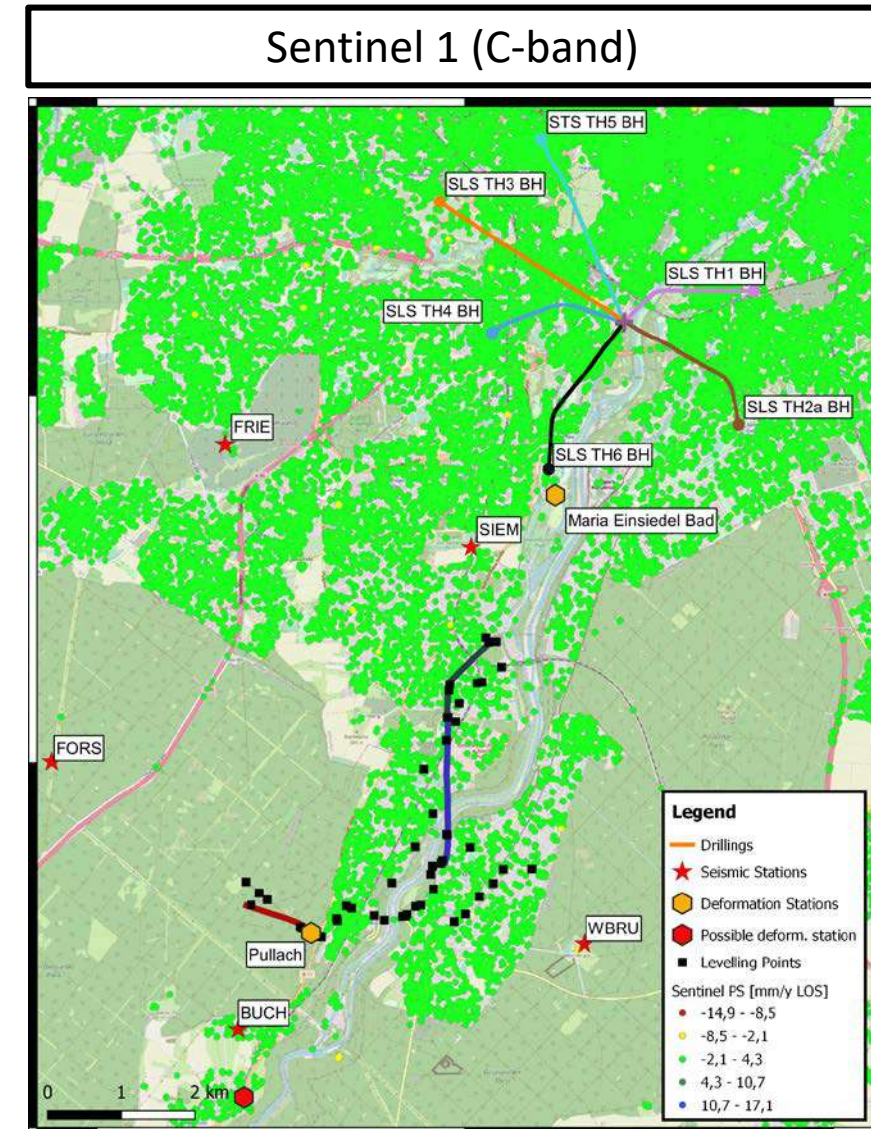
Components of the geodetic network

➤ WHY INSAR?

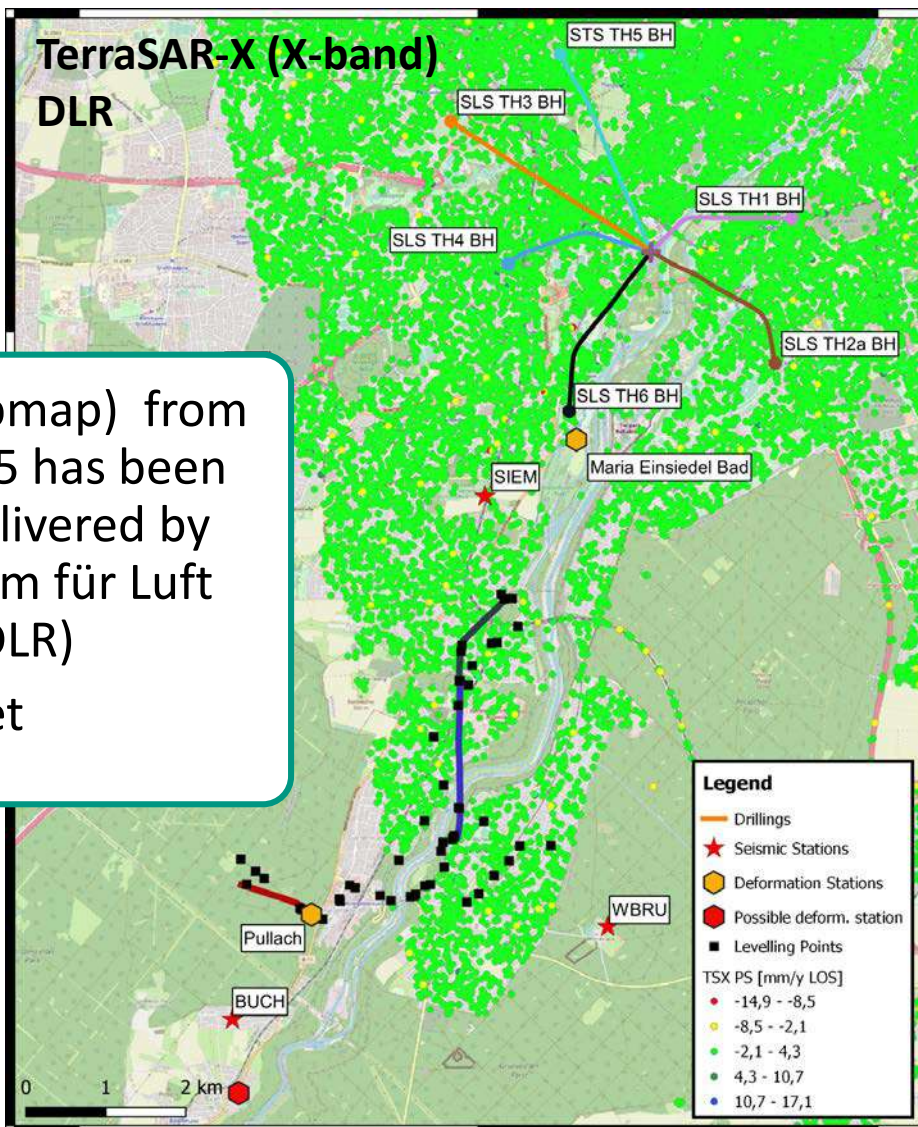
- High spatial density of measuring points (PS points)
 - map of surface displacements
- Delivers two displacement vectors (easting, up) from combination of two orbits

➤ RESEARCH QUESTIONS

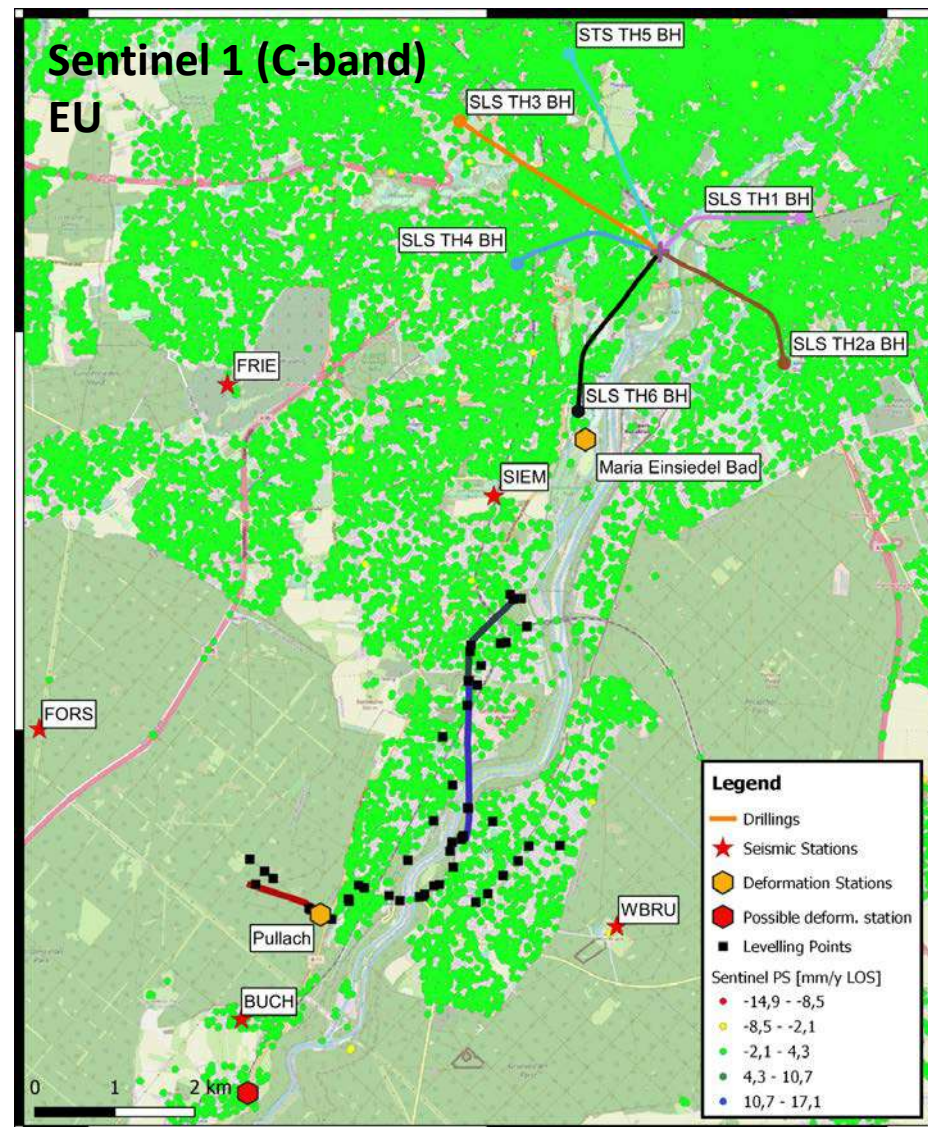
- Comparison of C-band and X-band data (Sentinel-1 versus TerraSAR-X)
- Performance of InSAR with respect to precision levelling in an urban area
- **Specifically: opportunities and limits of the ground motion services (BBD, EGMS) for geothermal monitoring**



Comparison C-Band vs. X-Band



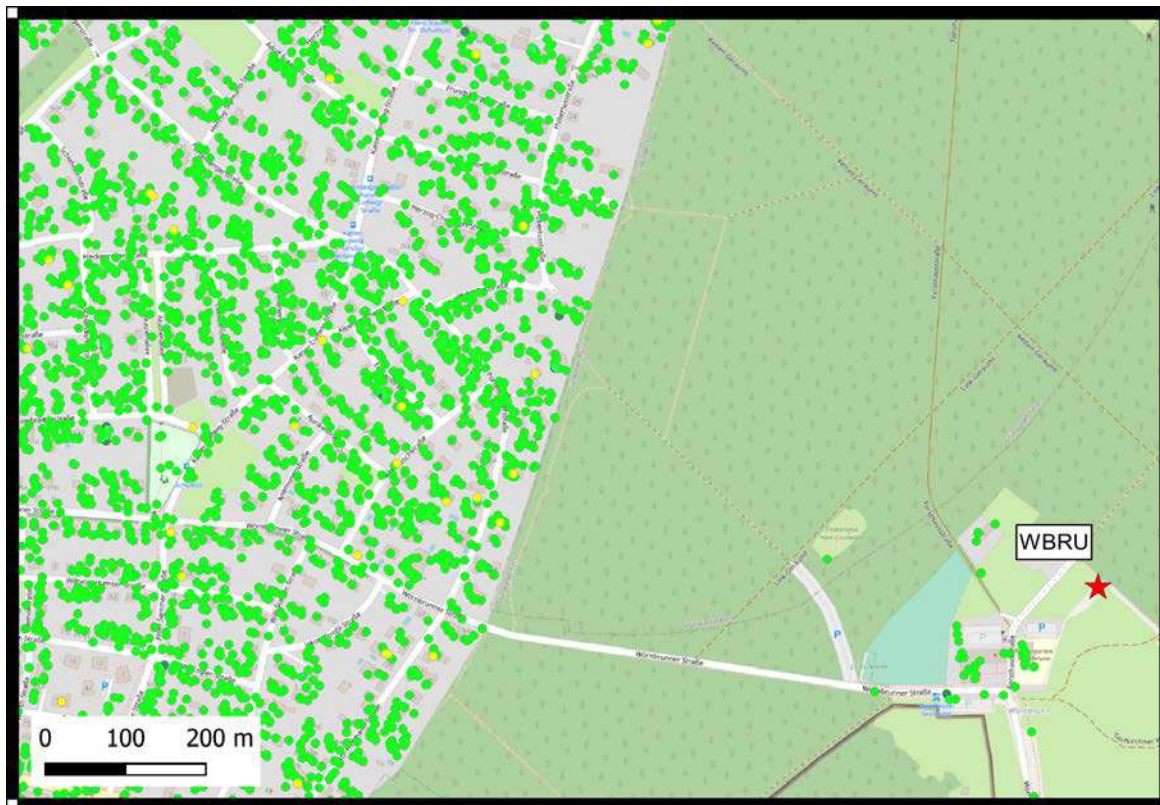
Terra-X data (stripmap) from ascending orbit 55 has been processed and delivered by Deutsches Zentrum für Luft und Raumfahrt (DLR)
Dr. Christian Minet



Comparison C-Band vs. X-Band

Nicht kostenfrei

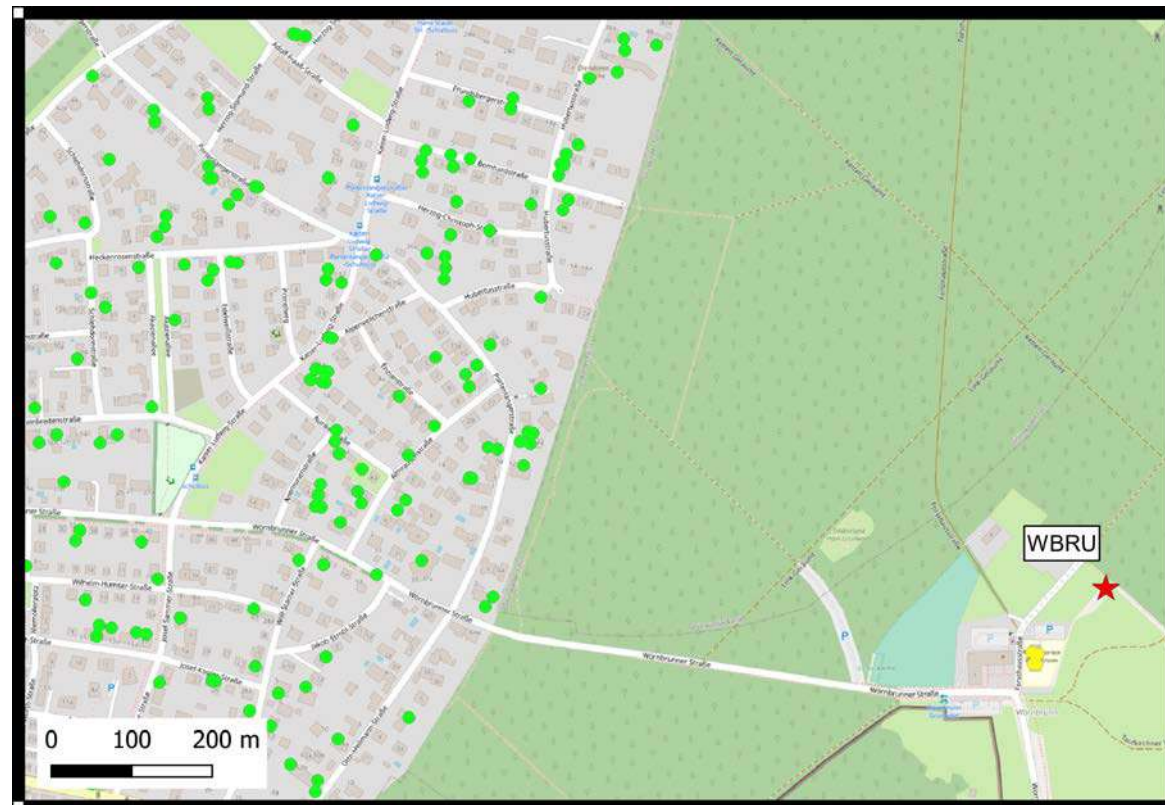
TerraSAR-X (X-band)



Räumliche Auflösung: 3 x 3 m

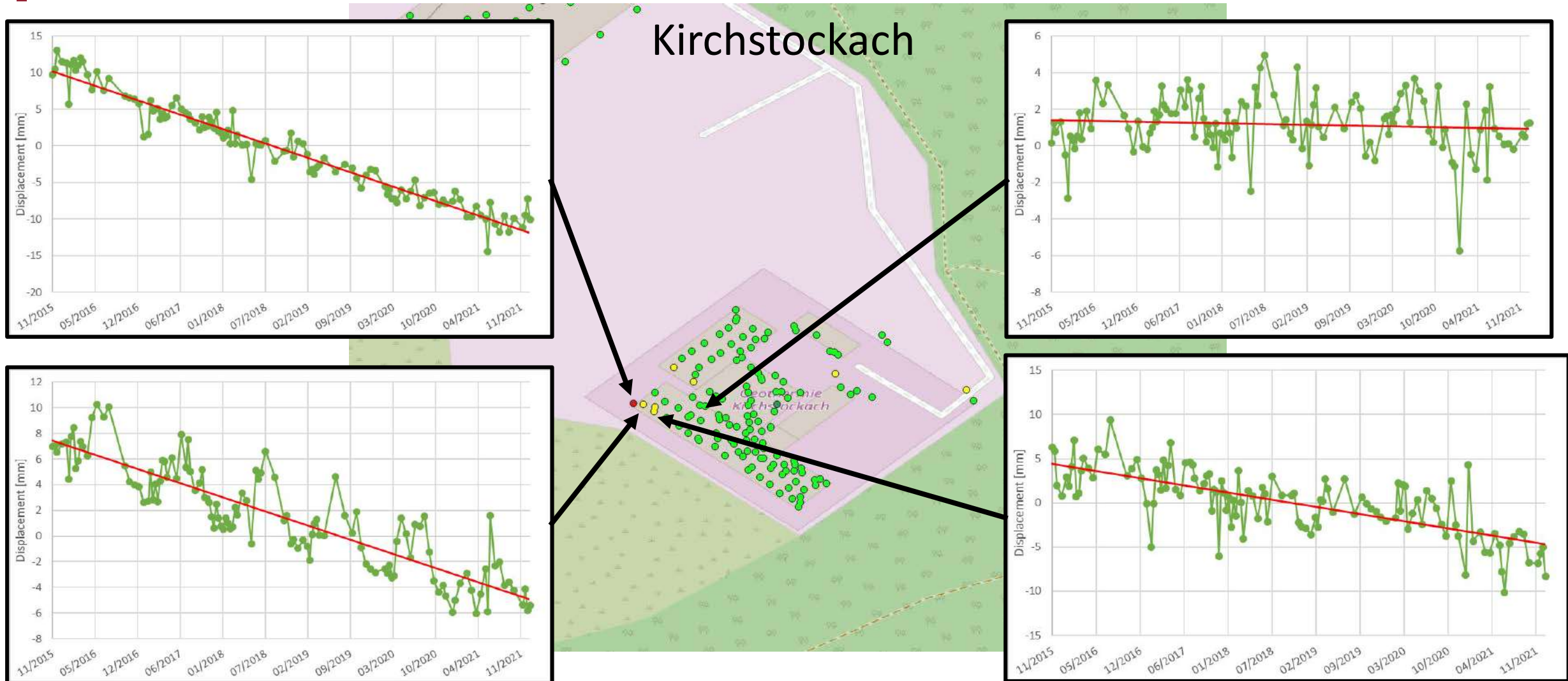
Kostenfrei

Sentinel 1 (C-band)

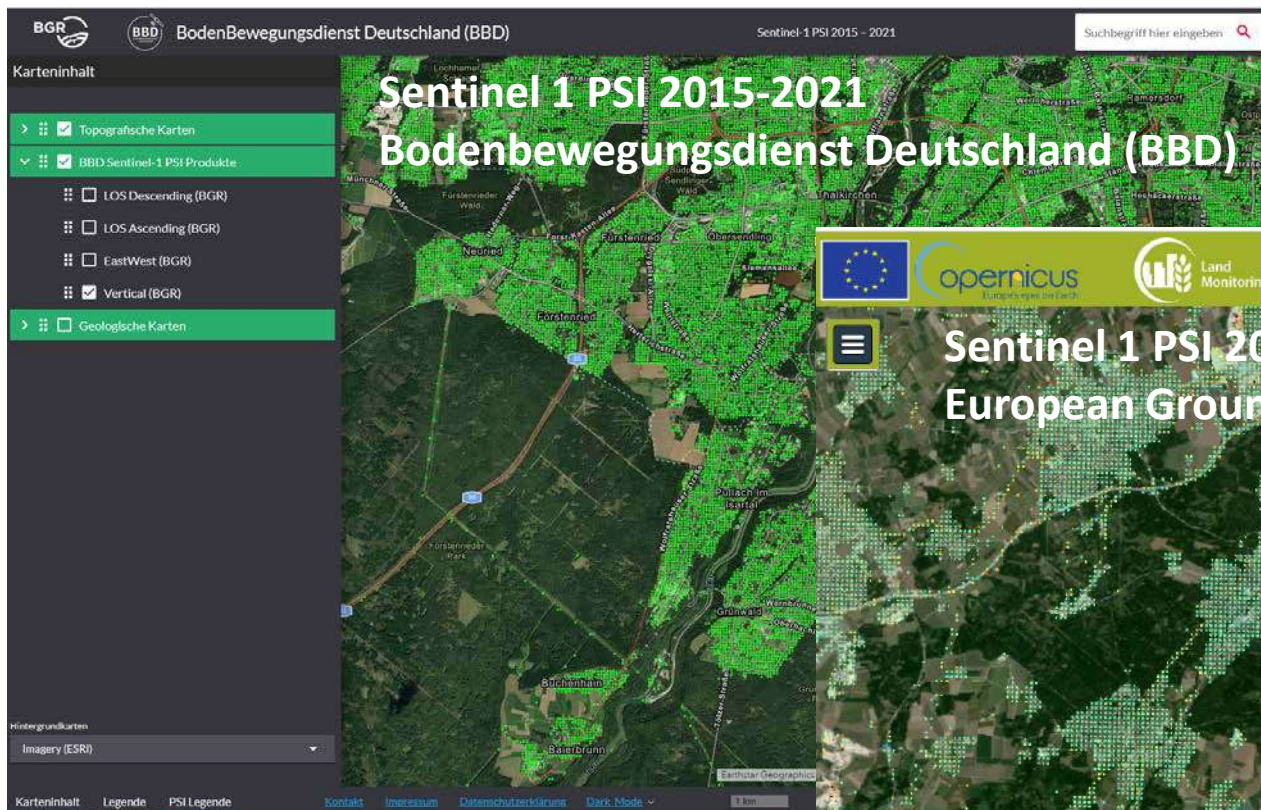


Räumliche Auflösung: 5 x 20 m
Ortho-Produkte (EGMS): Gitterabstand 100 m

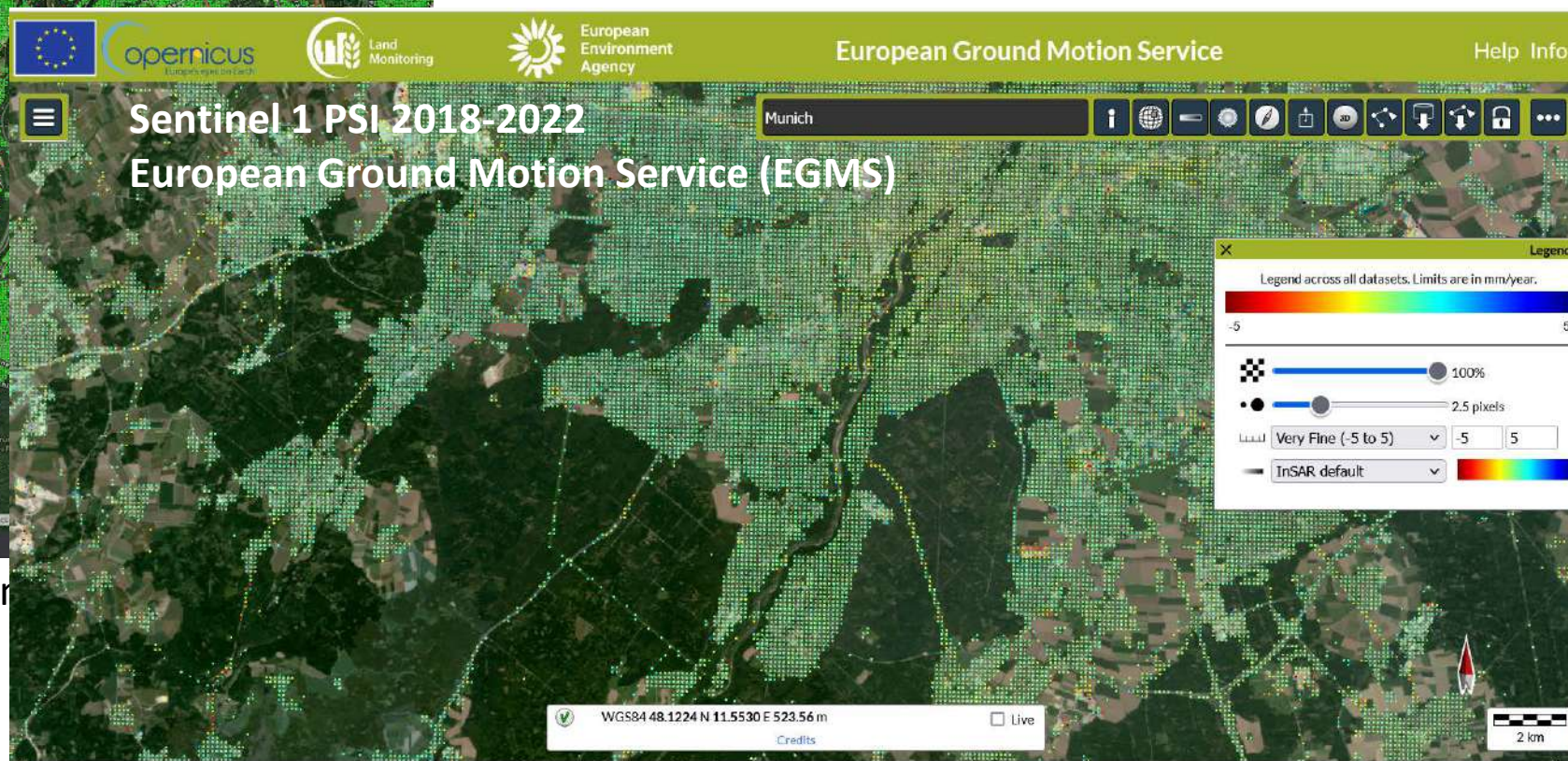
TSX Results (Examples)



Ground motion services



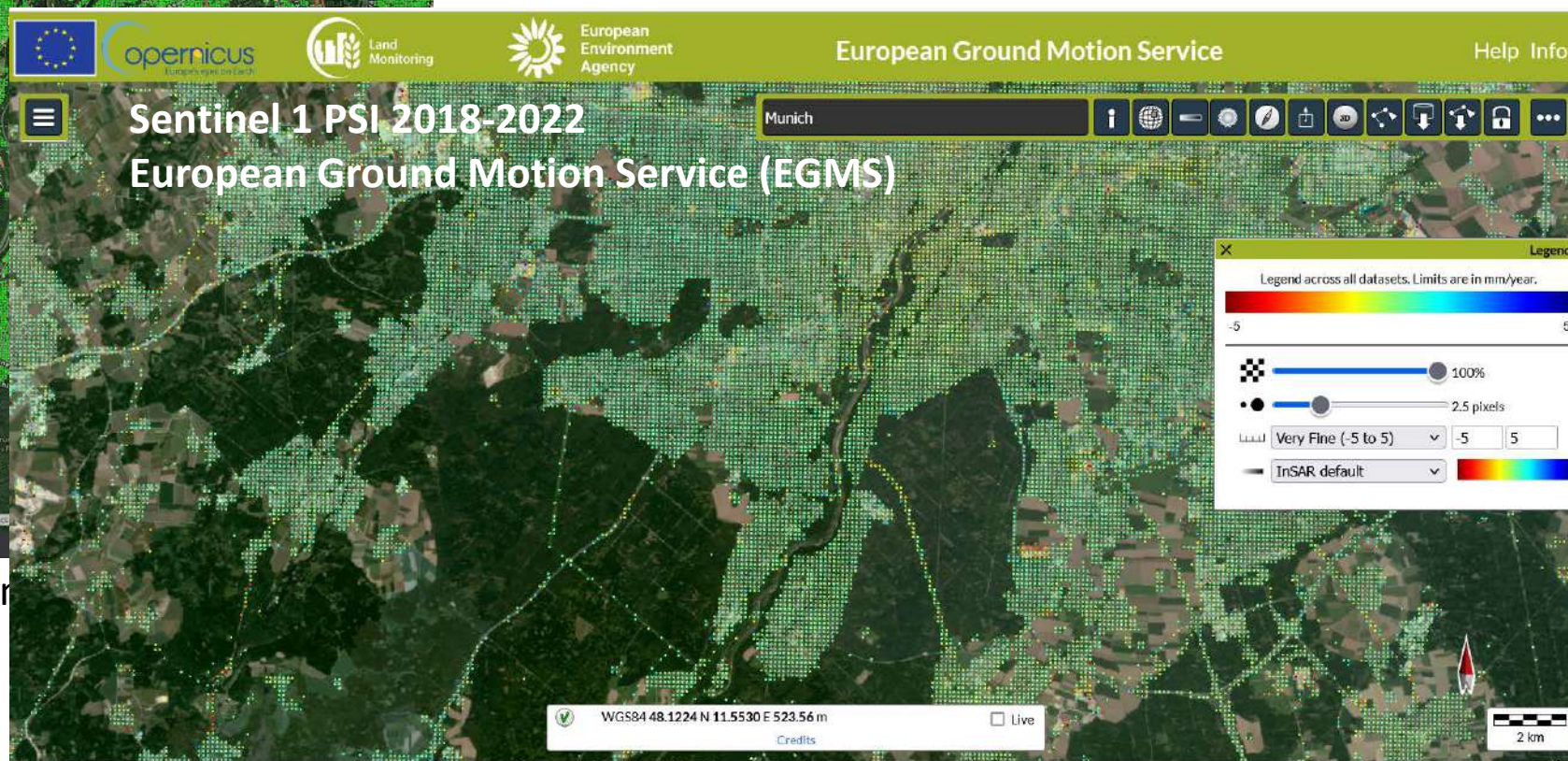
- Data freely available via Web-Browser
- Line of sight / vertical + EW horizontal components
- **Download: mean velocities, displacement time series**



➤ 1st release 2019, fully operative beginning

Data base: Sentinel 1a, 1b
C-band European SAR mission

➤ Operative since May 2022, freely available, no costs



- BBD /EGMS agree well within 2 mm
- Differences to ground truth (levelling): 2 – 3 mm

Data base: Sentinel 1a, 1b
C-band European SAR mission

- Operative since May 2022, freely available, no costs

Comparison levelling – InSAR: data base

LEVELLING CAMPAIGNS

Nivellements	2017	2018	2019	2020	2021	2022
Freiham (SWM)	08.11.			18.06.		13.04.
Riem (SWM)			04.09.	05.06.		11.04.
Ismaning (WVI)			21.03.	17.06.	20.04.	12.04. (tw)
Kirchstockach (SWM)			10.09.	28.09.		
Pullach (IEP)			12.09.	29.09.		
Schäftlarnstr. (SWM)					29.03.	09.03.

- Standard deviation: < 0.5 mm

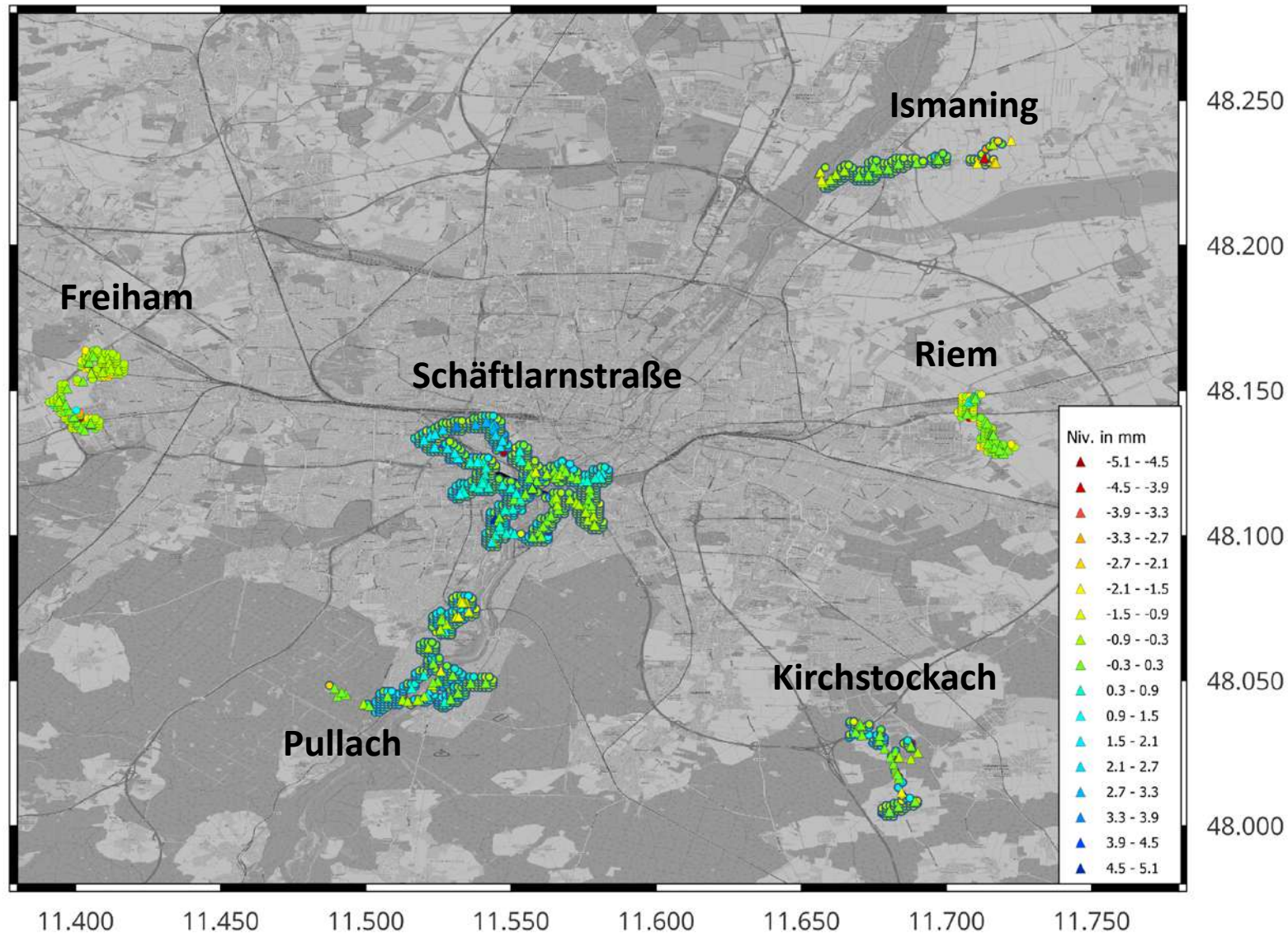
Height change rates

Height differences

PS-IN SAR TIME SERIES

- Actual release of the **European Ground Motion Service (EGMS)**
- Vertical component, time period 1/2018 – 12/2022
- KIT solution** based on a stack of 291 radar scenes, Sentinel 1a + 1b, 2 orbits
- Vertical component, time period 1/2019 – 12/2023
- Standard deviation: 2 – 3 mm in slant range, 1 mm in vertical/horizontal direction

Comparison InSAR – levelling: Overview

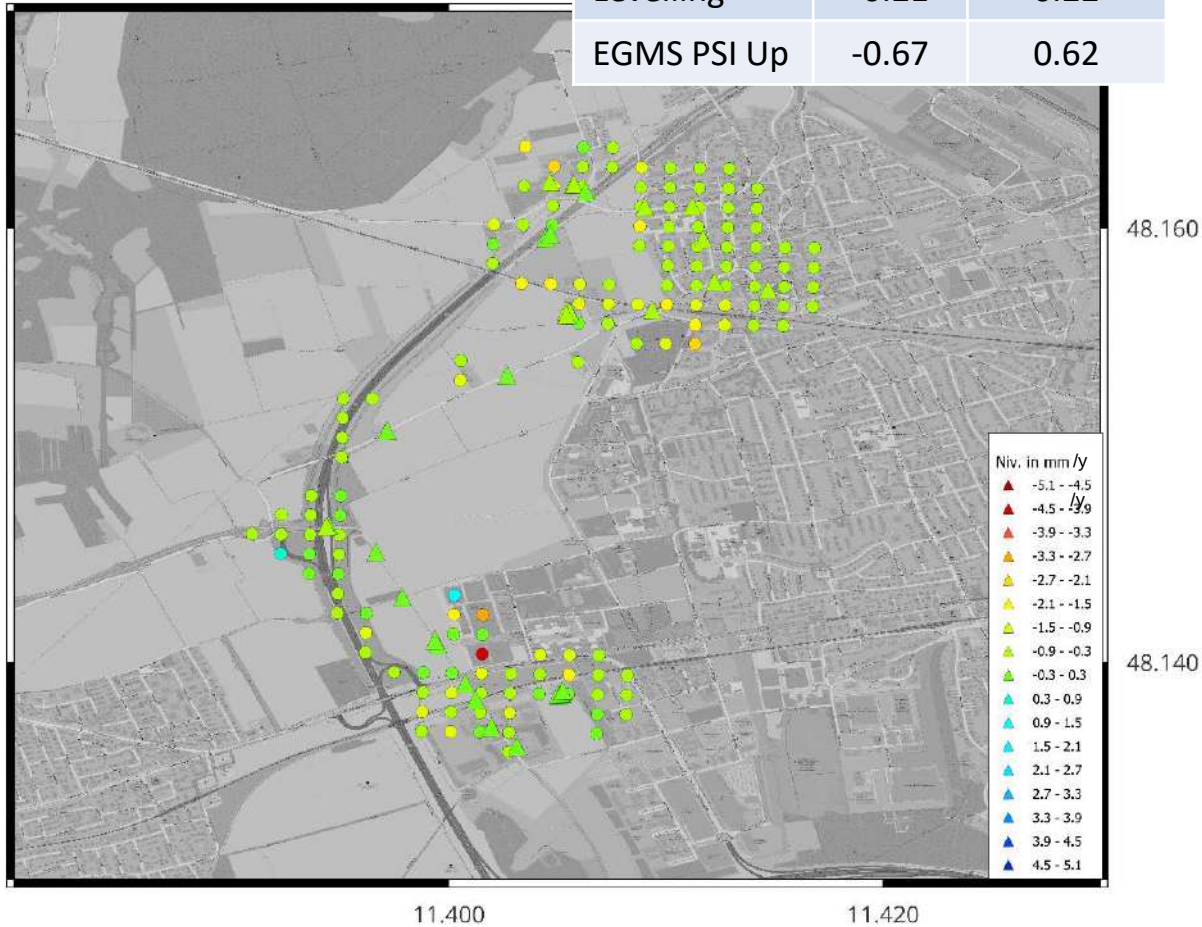


- Comparison of levelling results with EGMS InSAR data
- EGMS points up to a distance of 250 m from the levelling points are selected

Close-up: displacement rates

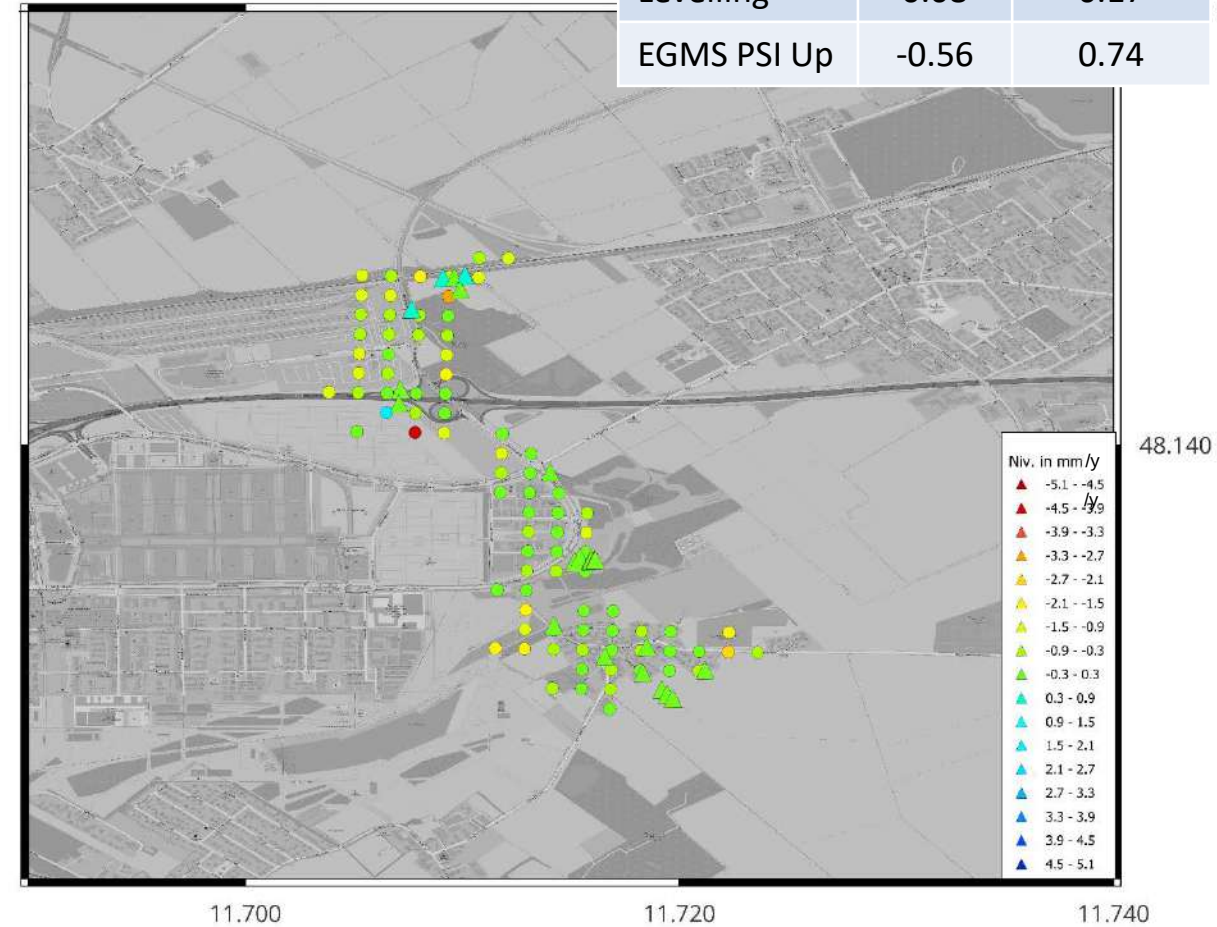
Freiham

Freiham	Mean mm/yr	Std. mm/yr
Levelling	-0.21	0.22
EGMS PSI Up	-0.67	0.62



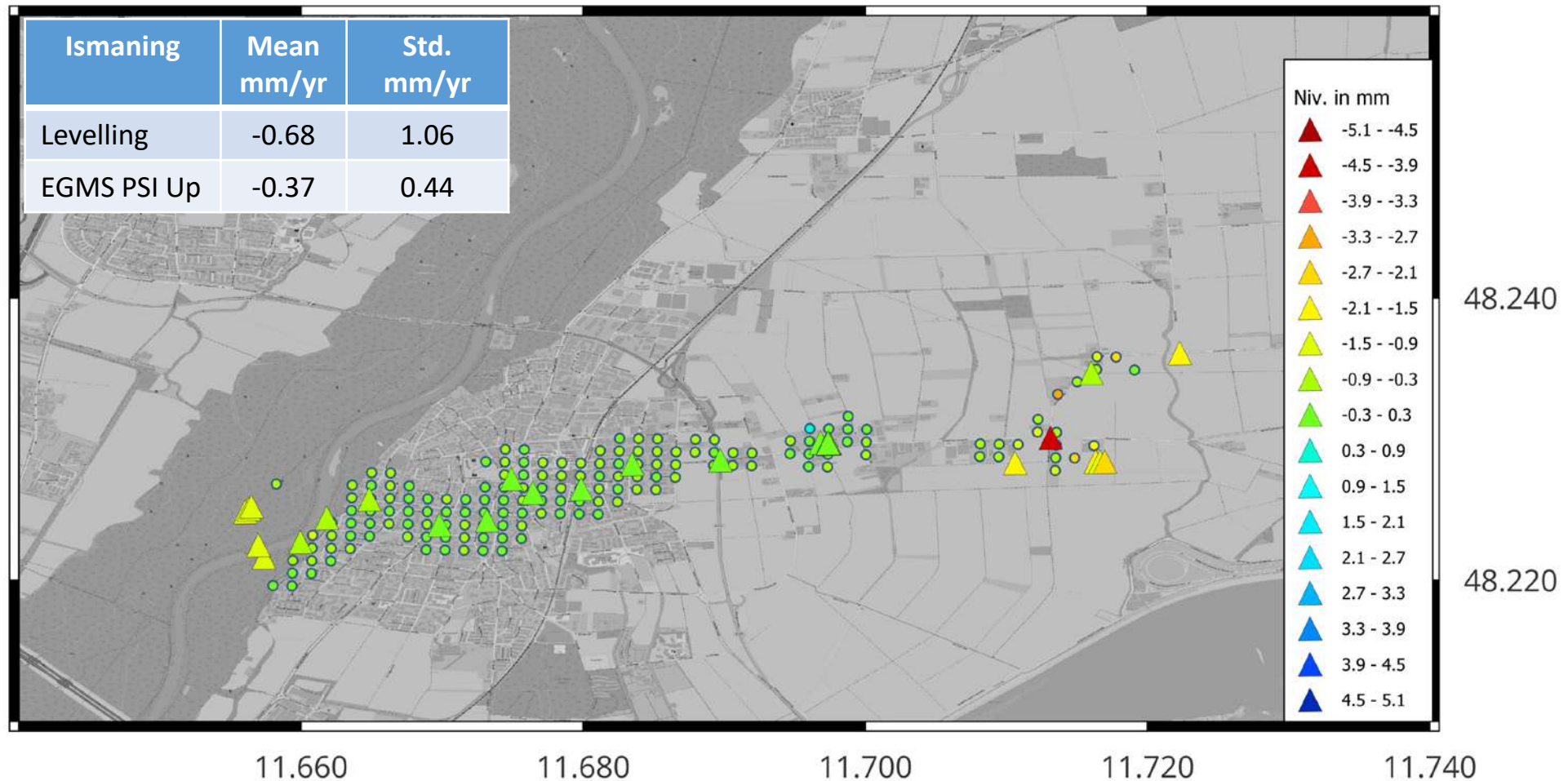
RIEM

Riem	Mean mm/yr	Std. mm/yr
Levelling	0.08	0.17
EGMS PSI Up	-0.56	0.74



Close-up: displacement rates

Ismaning

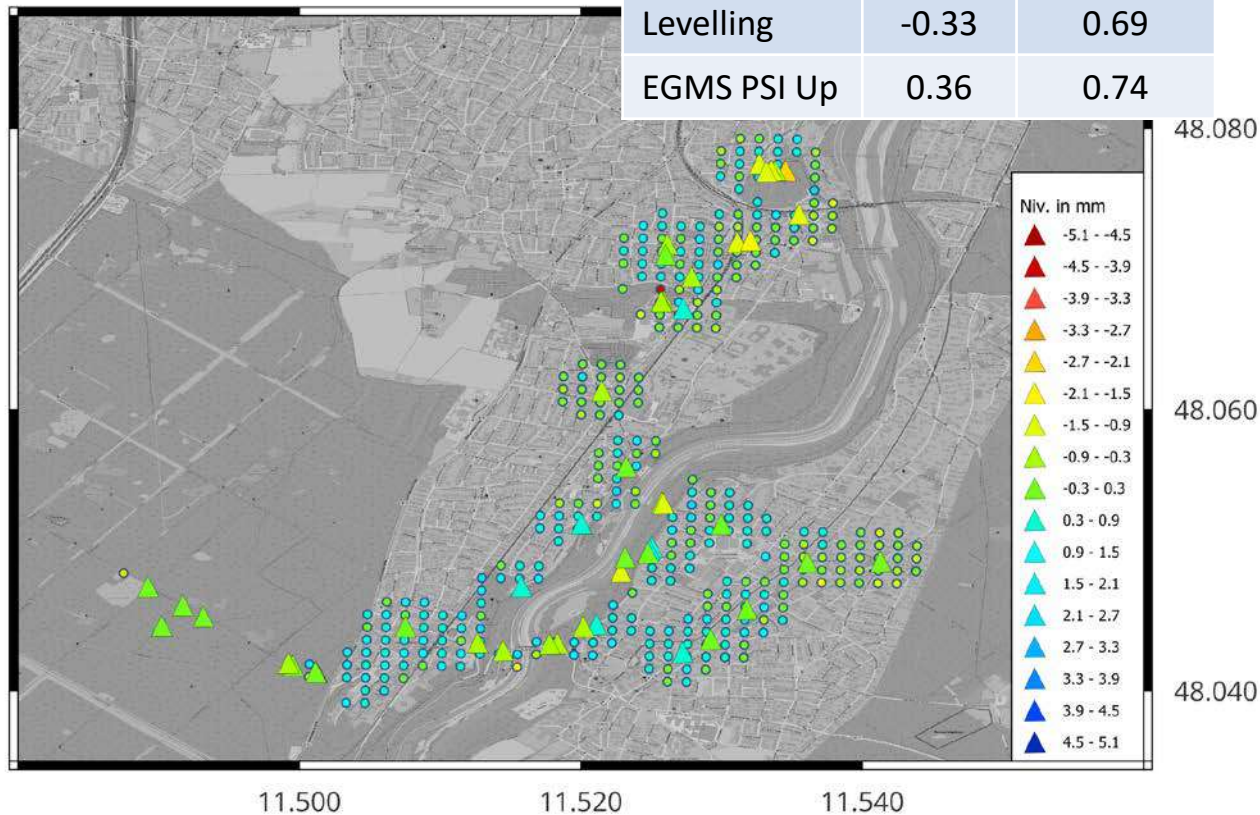


Close-up: displacement differences (1 year)

9/2020 – 9/2019

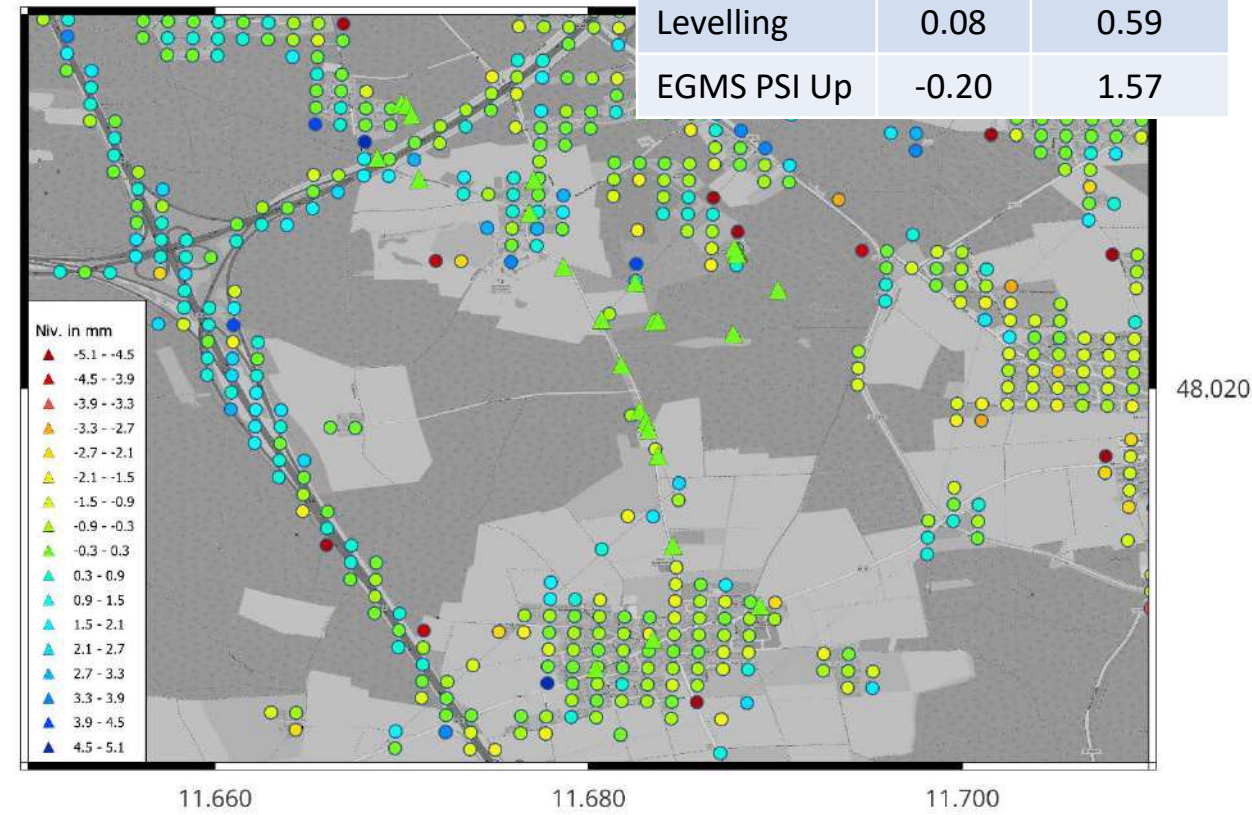
PULLACH

Pullach	Mean mm	Std. mm
Levelling	-0.33	0.69
EGMS PSI Up	0.36	0.74



KIRCHSTOCKACH

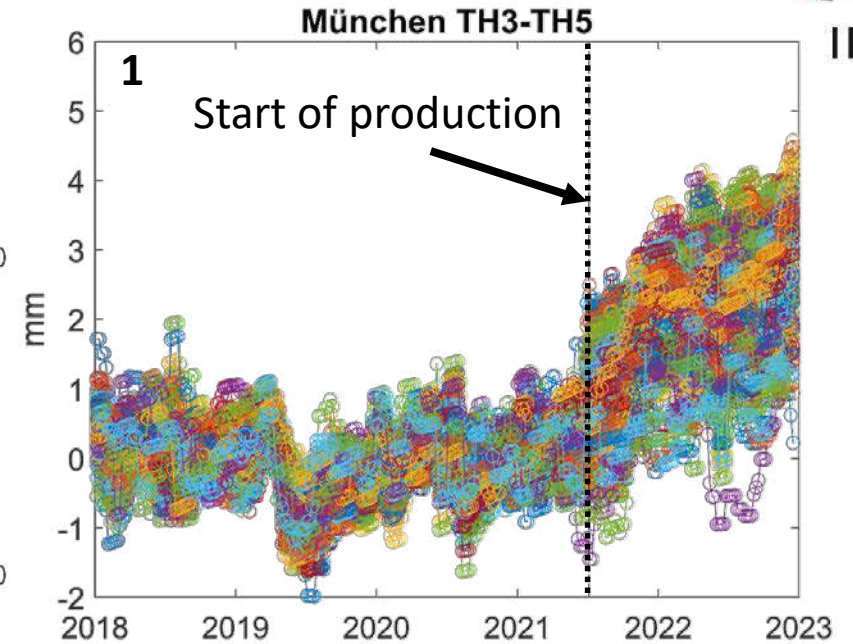
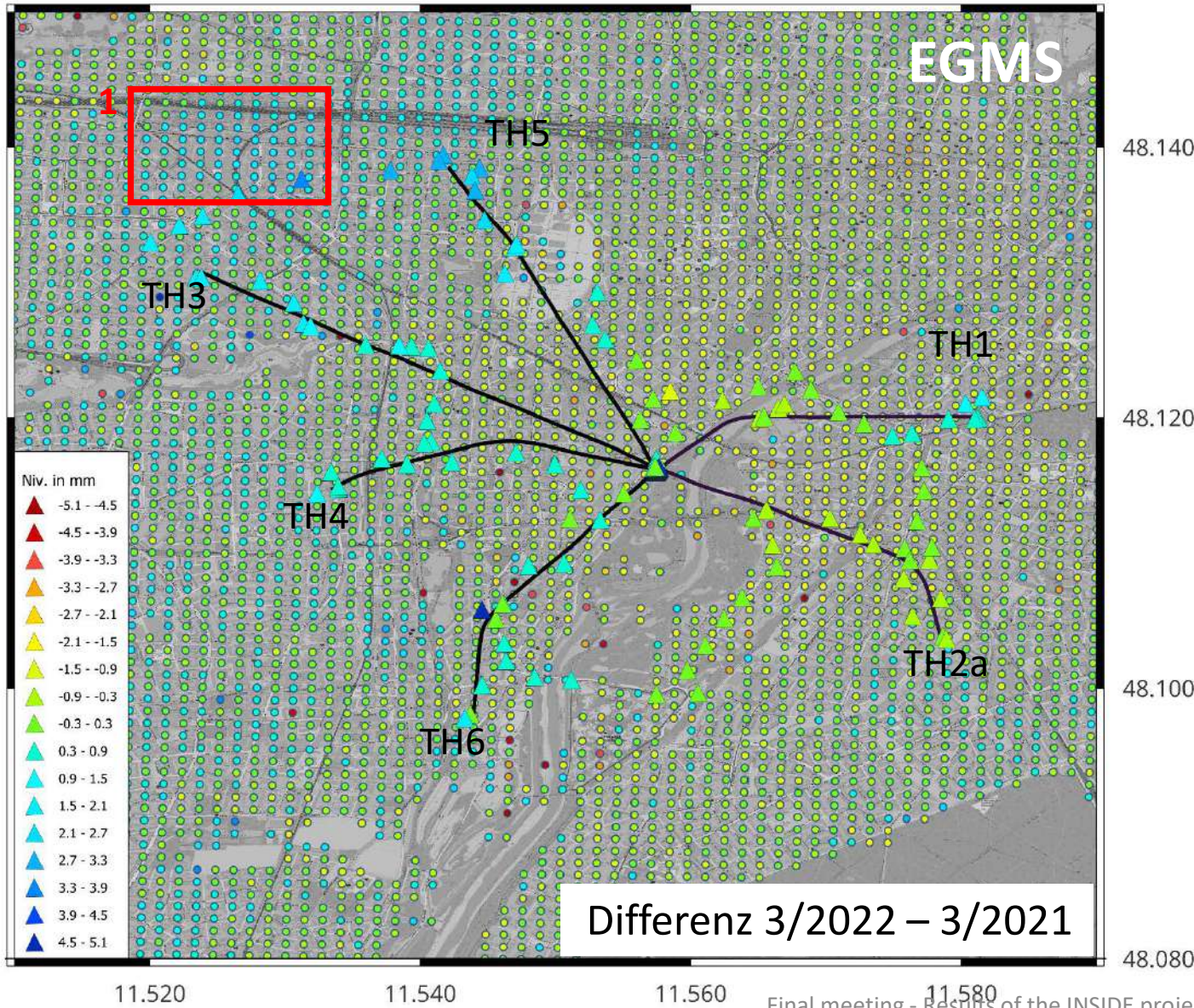
Kirchstockach	Mean mm	Std. mm
Levelling	0.08	0.59
EGMS PSI Up	-0.20	1.57



Schäftlarnstraße



INSIDE



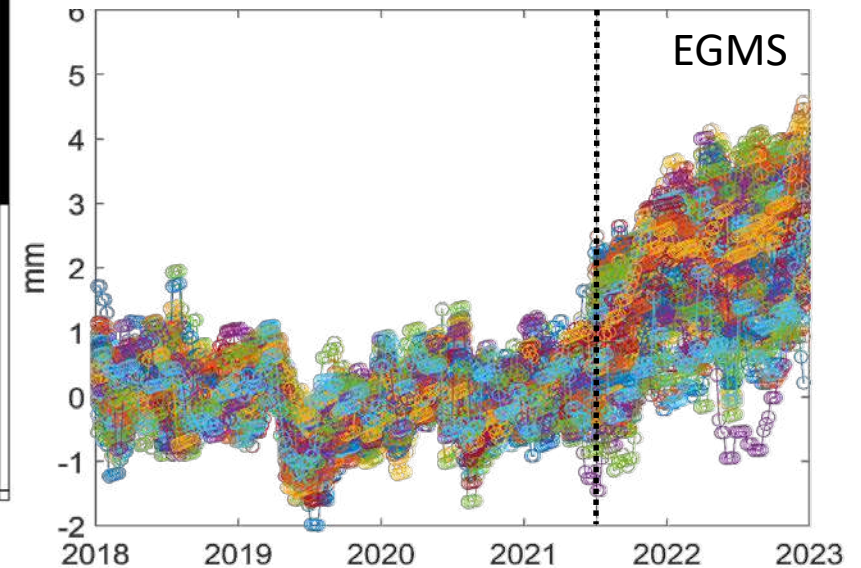
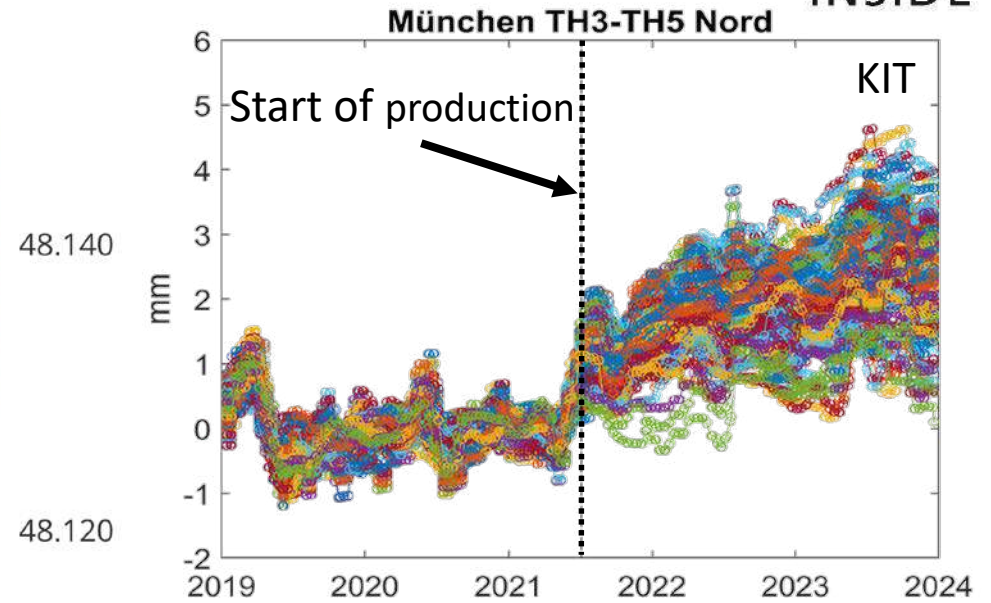
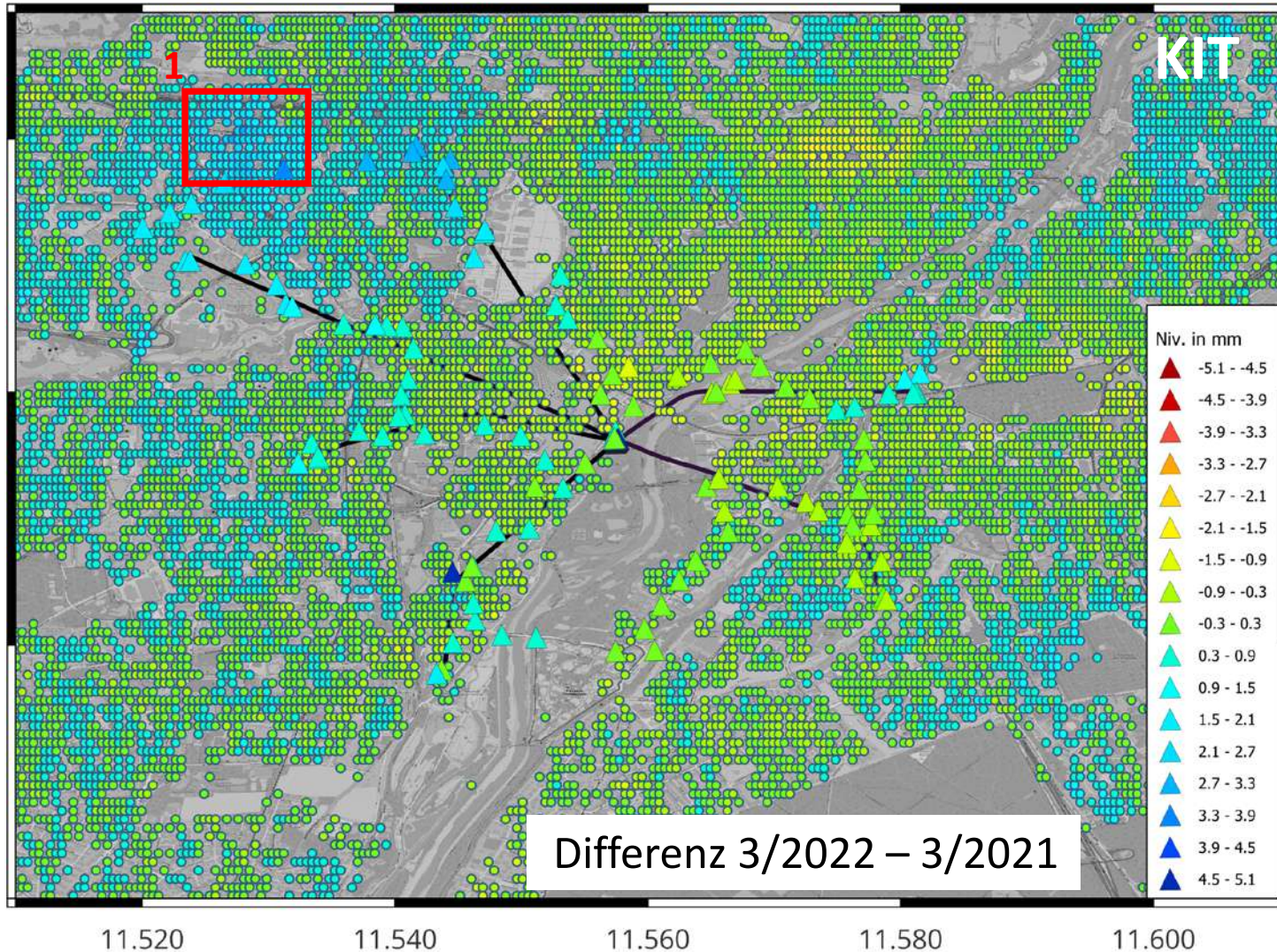
INSAR TIME SERIES:

- Mild low pass filtering
- Trend estimation 1/2018 – 6/2021; trend subtraction from whole series

Results of KIT data processing



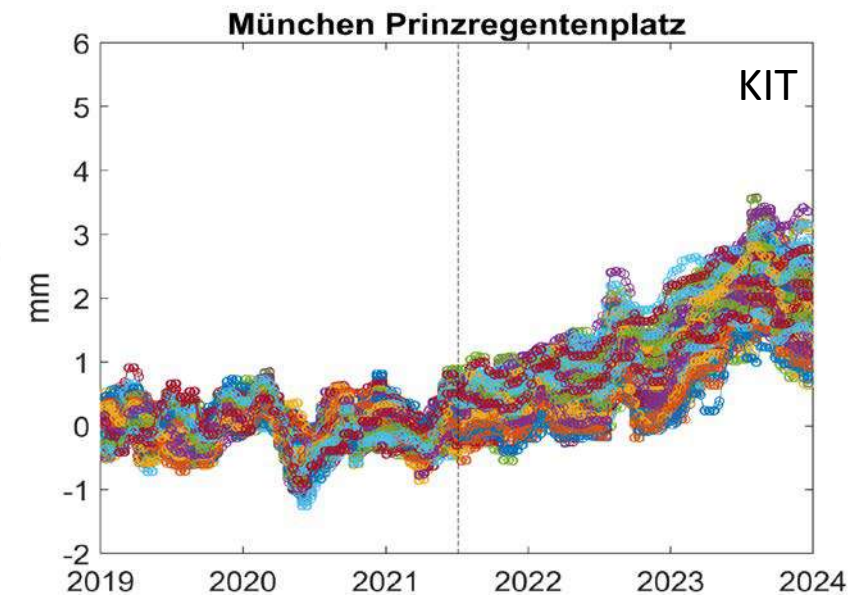
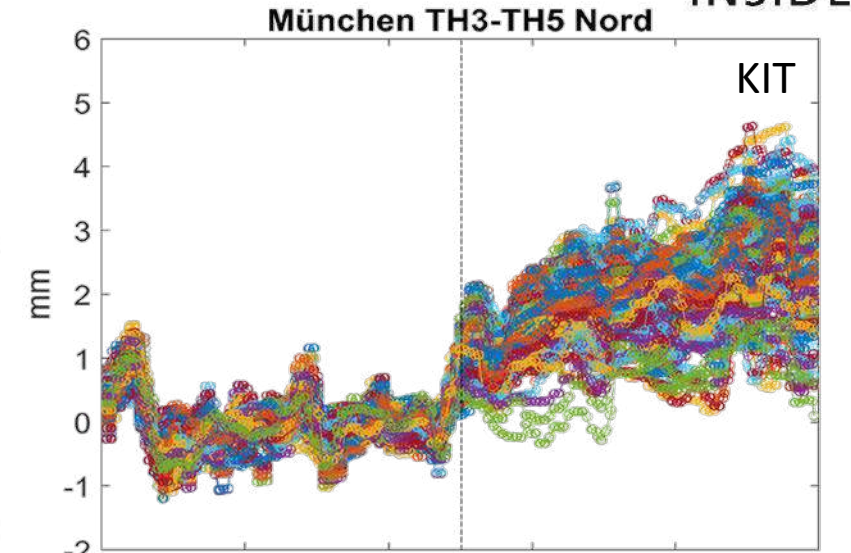
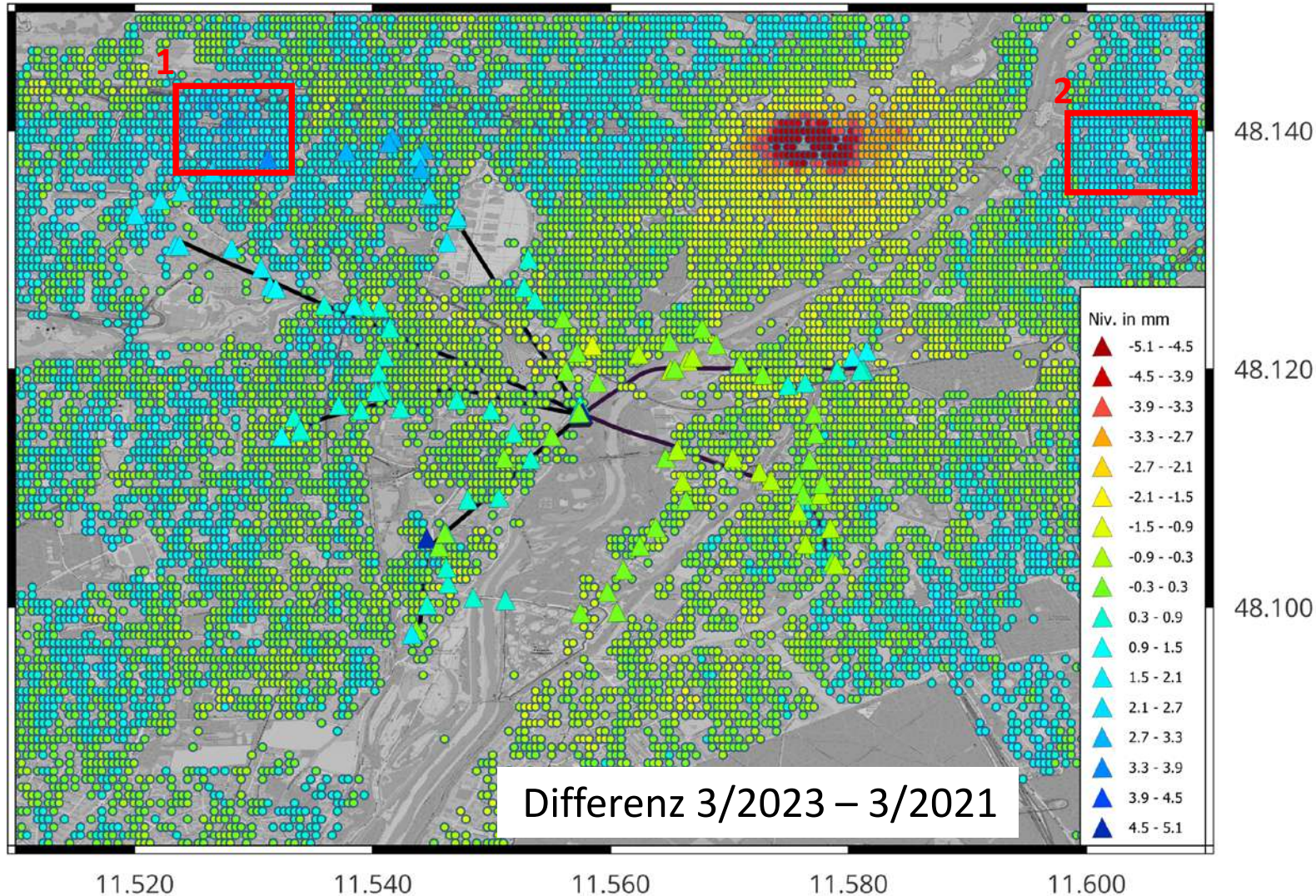
INSIDE



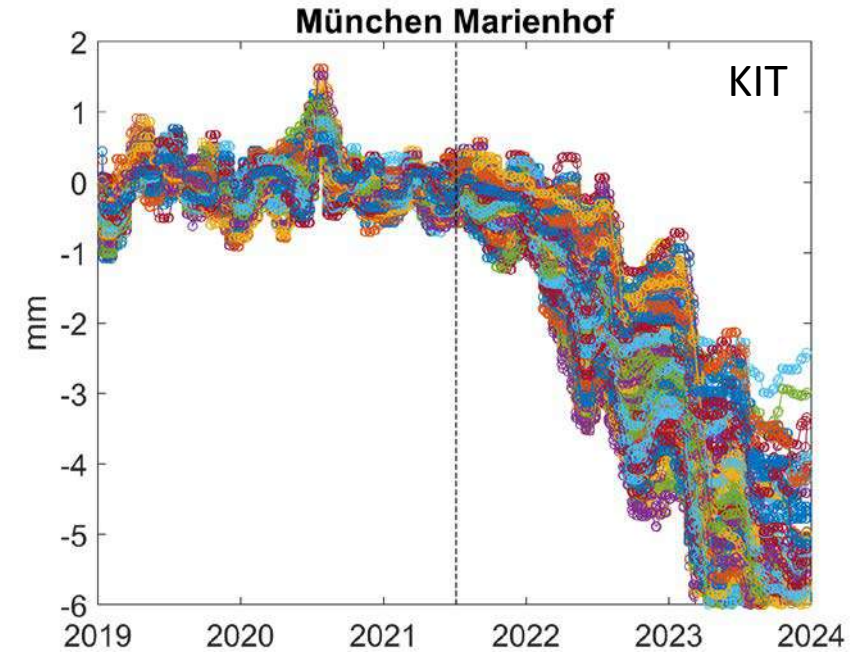
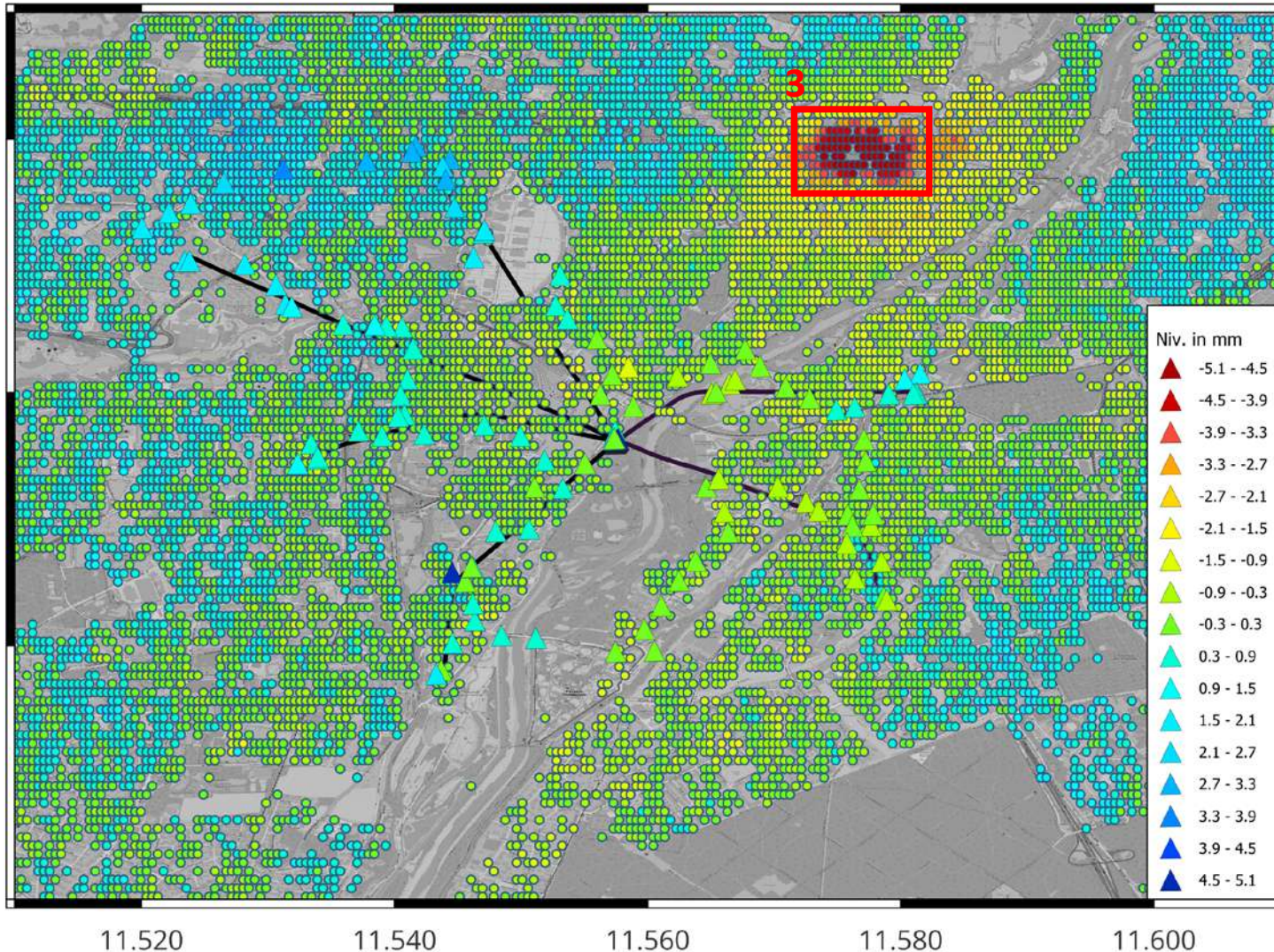
Height change 3/2023 – 3/2021



INSIDE

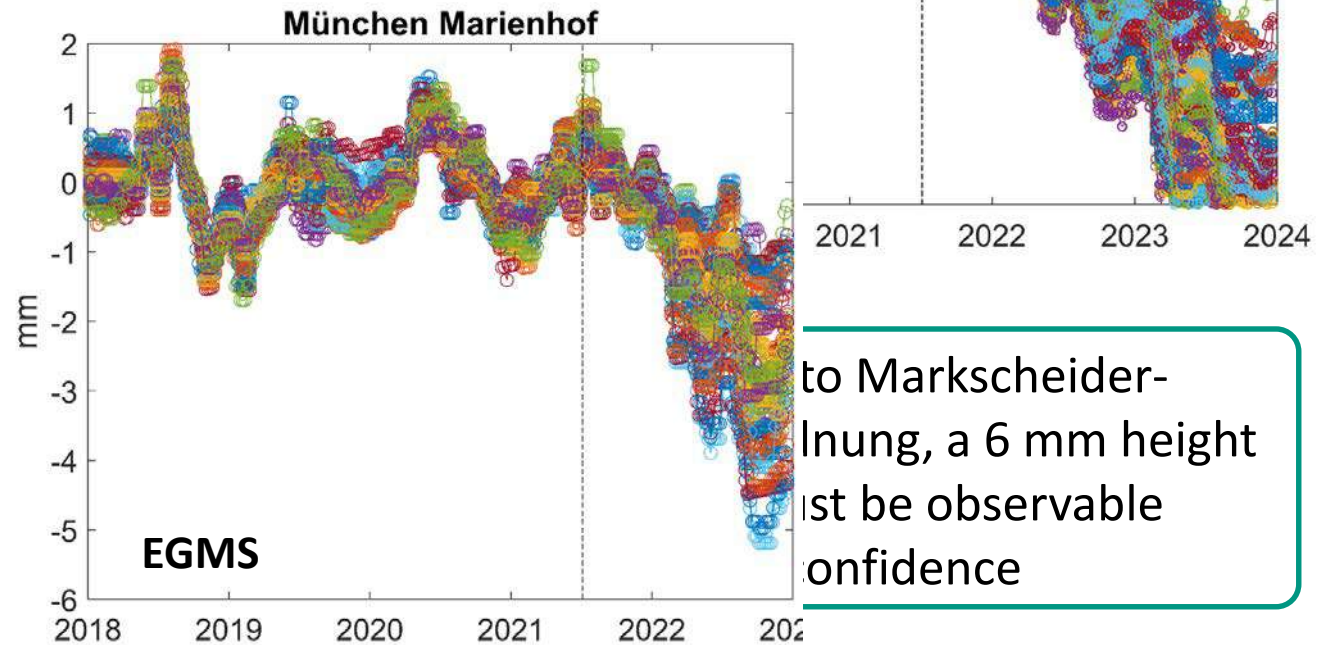
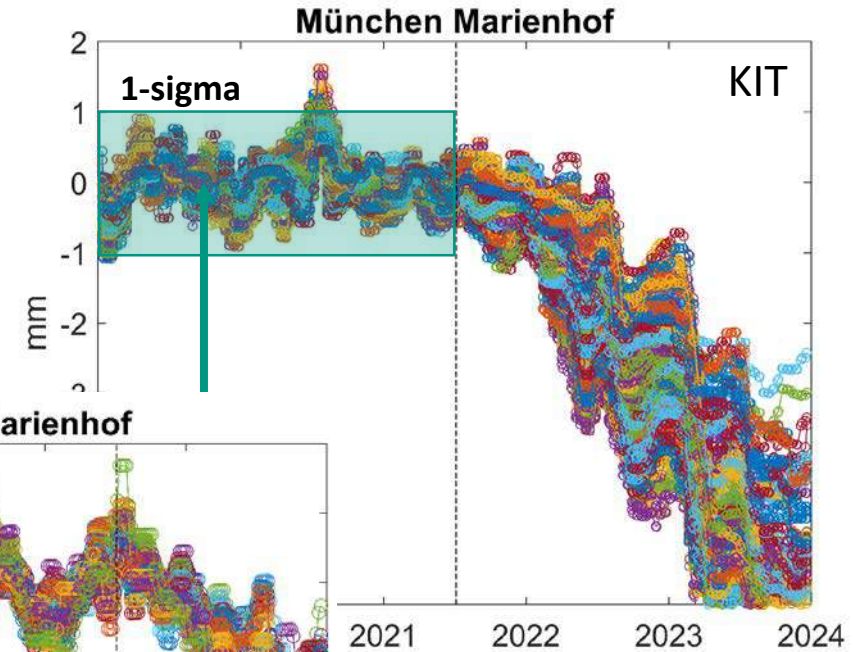
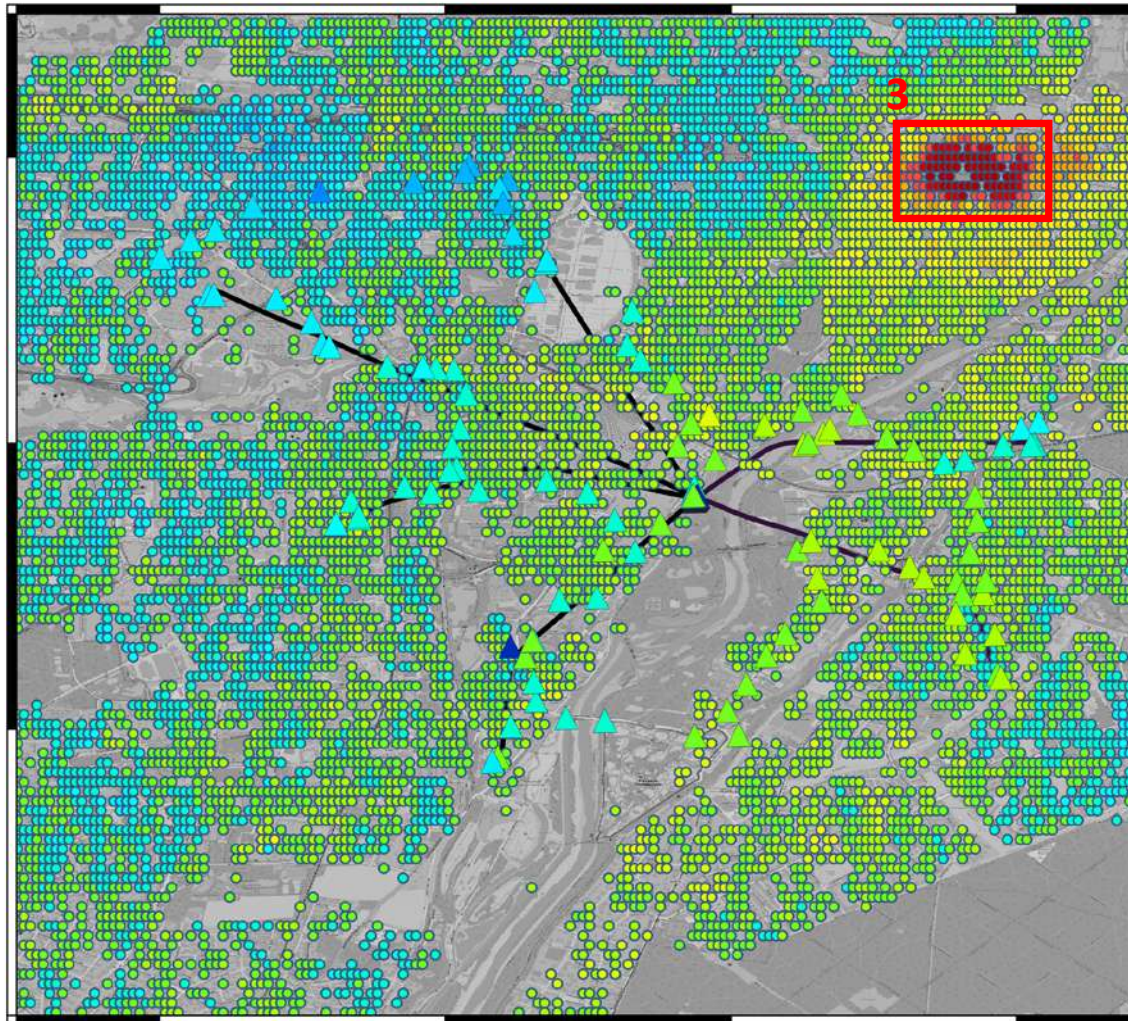


Other ground motion events



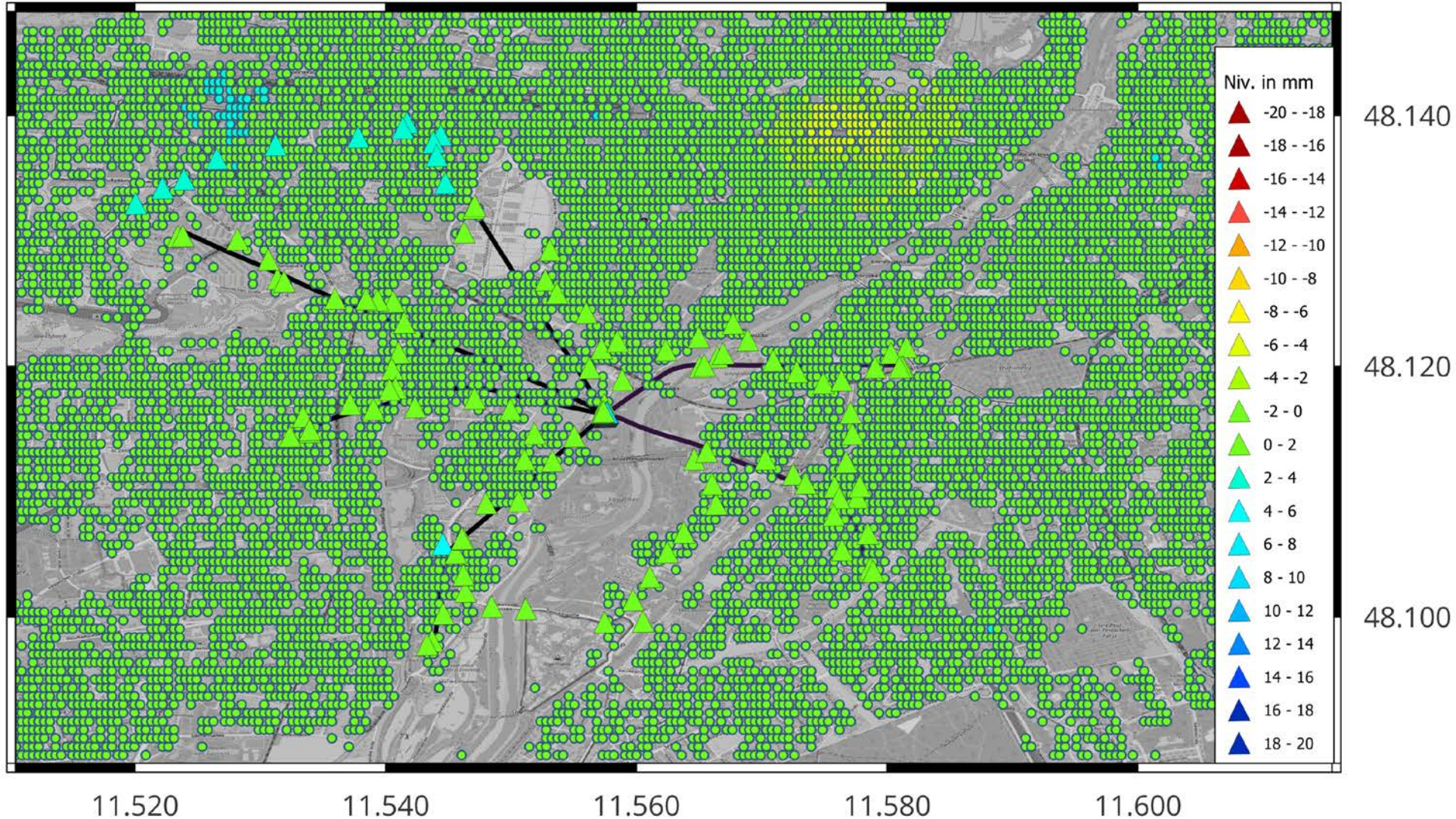
Coincidence in space/time with the construction work for the new S-Bahn underground station Marienhof.

Other ground motion events



to Markscheider-
Innung, a 6 mm height
ist be observable
onfidence

Height change 3/2023 – 3/2021



Scaled acc. to
MarkschBergV
Klasse III (20 mm)

Geodetic Monitoring – Conclusion

- What can the Ground Motion Services (BBD/EGMS) contribute to determine/monitor the zone of influence as well as the zero line of surface deformation?
 - **Fullfills the precision requirements** of the Markscheider-Bergverordnung
 - **Improved spatial resolution** → better overview about affected sensitive structures
 - **Improved temporal resolution** → assignment to production start / changes
 - **Cost reduction**
- Recommendation 1: Inclusion of EGMS ground motion maps into the Einwirkungsbereichs-Bergverordnung, improved monitoring schemes in line with a reduction of specified intervals for terrestrial geodetic measurement campaigns
- Recommendation 2: Inclusion of a permanent GNSS station in levelling lines for temporal control of geodetic (→ levelling) reference.

Pause

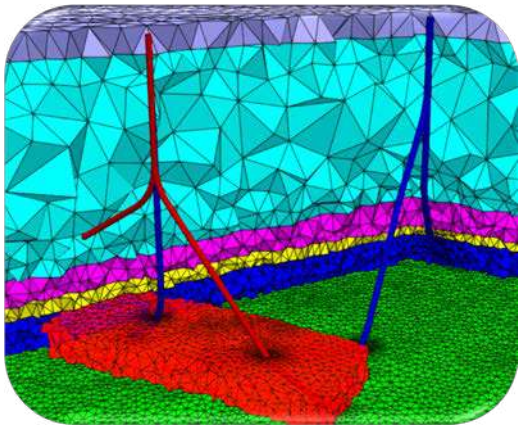
11:05 – 11:20



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<i>14:30</i>	<i>Non-public operator meeting</i>	

Geothermal reservoir numerical modelling



- Where to drill wells? Which well for injection/production?
- How pressure, temperature and stress vary in the reservoir in the course of the Pullach and Schäftlarnstraße geothermal field exploitation?
- Can we model induced seismicity during geothermal production?

Emmanuel Gaucher, Alexandros Savvatis, Rahim Habibi, Robert Egert *et al.*

Slip- and dilation tendency at Schäftlarnstr.

➤ What is the mechanical loading acting on faults prior to any operation?

➤ Normalized slip-tendency

$$ST = \frac{\tau - C}{\mu \cdot \sigma'_n}$$

Shear stress τ (indicated by a blue arrow pointing to the numerator term τ)
Cohesion C (indicated by a blue arrow pointing to the numerator term $-C$)
Friction coefficient μ (indicated by a blue arrow pointing to the denominator term μ)
Effective normal stress σ'_n (indicated by a blue arrow pointing to the denominator term σ'_n)

❑ EW: $C = 0$ MPa, $\mu = 0.6$

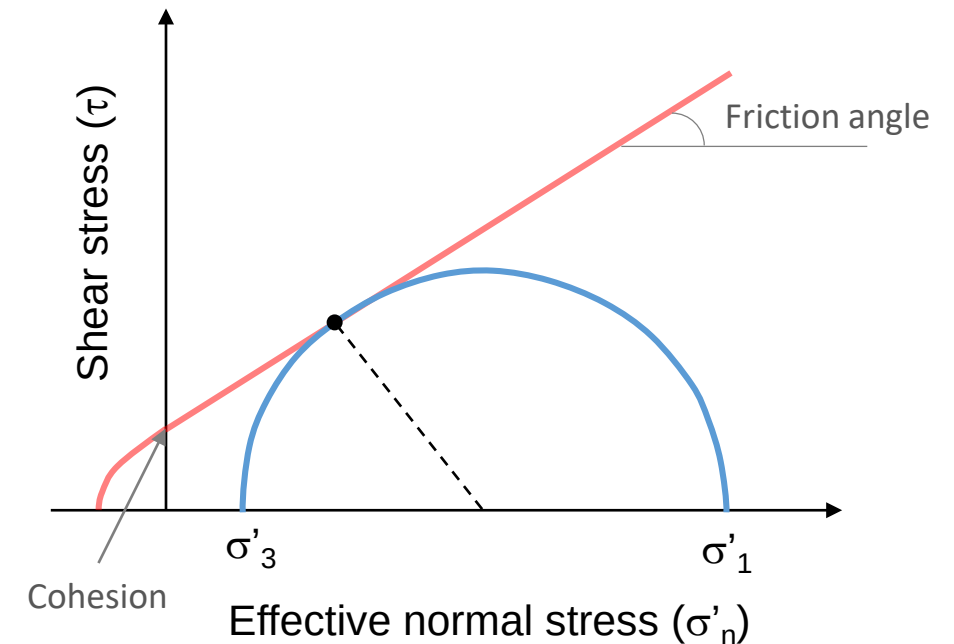
❑ KIT: $C = 3$ MPa, $\mu = 0.85$

➤ Dilation tendency

$$DT = \frac{\sigma_1 - \sigma_n}{\sigma_1 - \sigma_3}$$

Mohr-Coulomb failure criterion

$$\tau \geq C + \mu \cdot \sigma'_n$$



Slip- and dilation tendency at Schäftlarnstr.

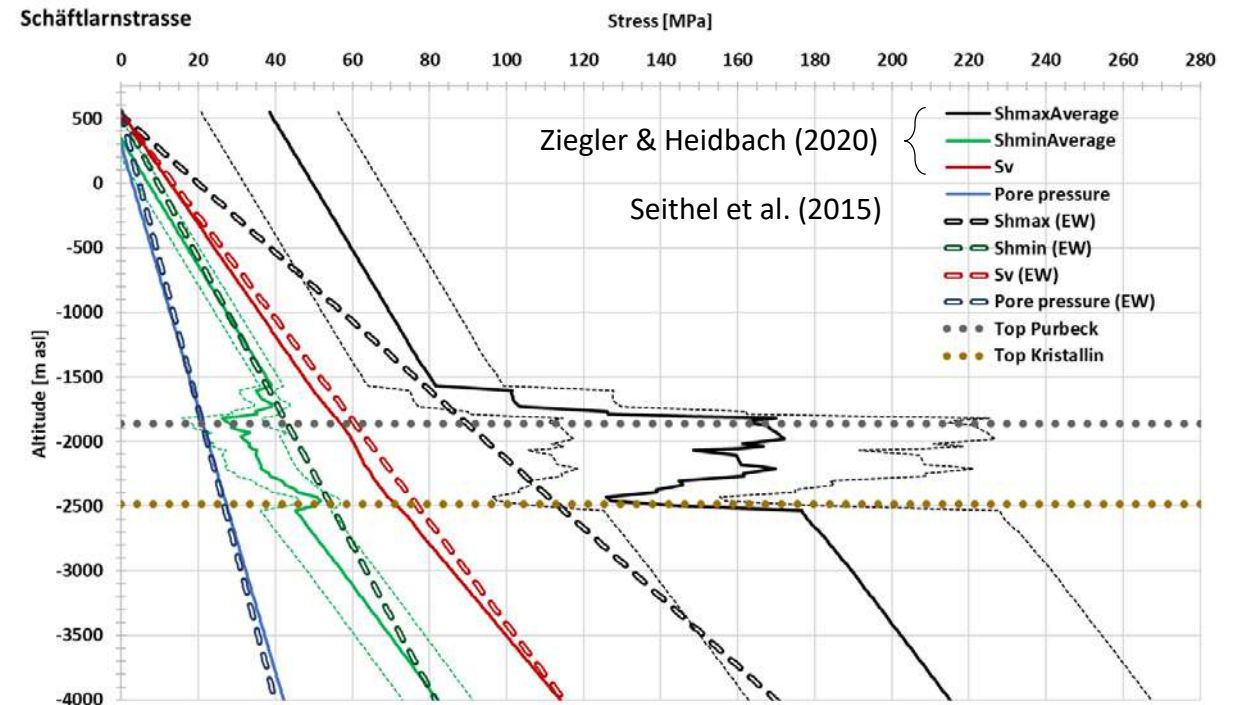
- What is the mechanical loading acting on faults prior to any operation?
- Normalized slip-tendency
- Stress field hypotheses
 - ❑ Strike-slip, $\sigma_1 = \sigma_{Hmax} \sim N0^\circ E$

$$ST = \frac{\tau - C}{\mu \cdot \sigma'_n}$$

- ❑ EW: $C = 0 \text{ MPa}$, $\mu = 0.6$
- ❑ KIT: $C = 3 \text{ MPa}$, $\mu = 0.85$

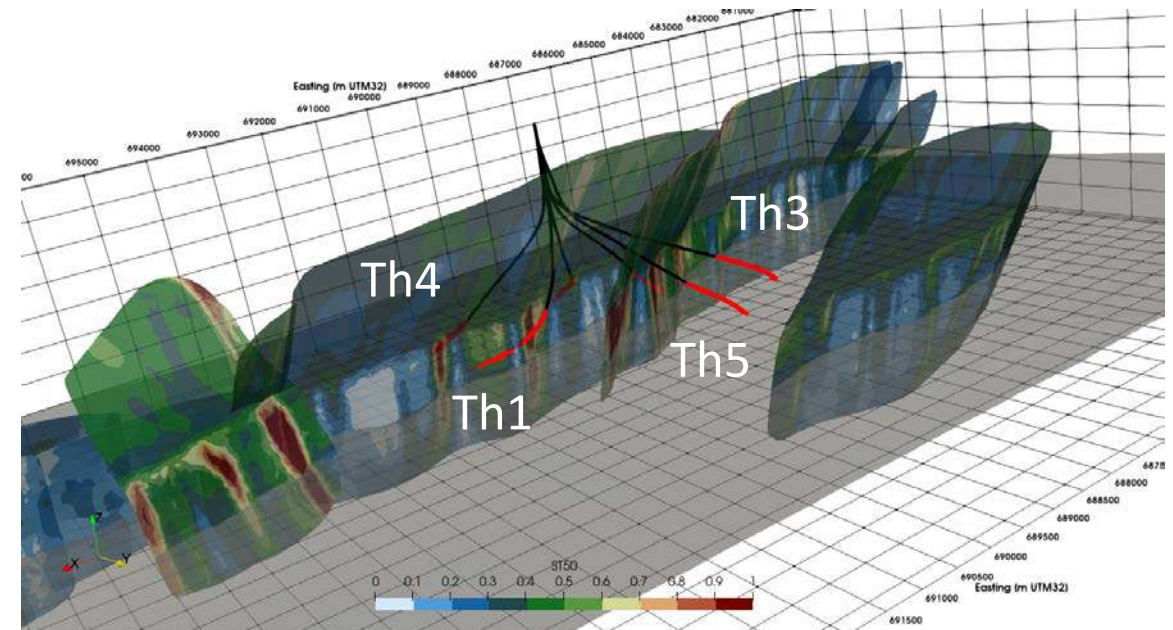
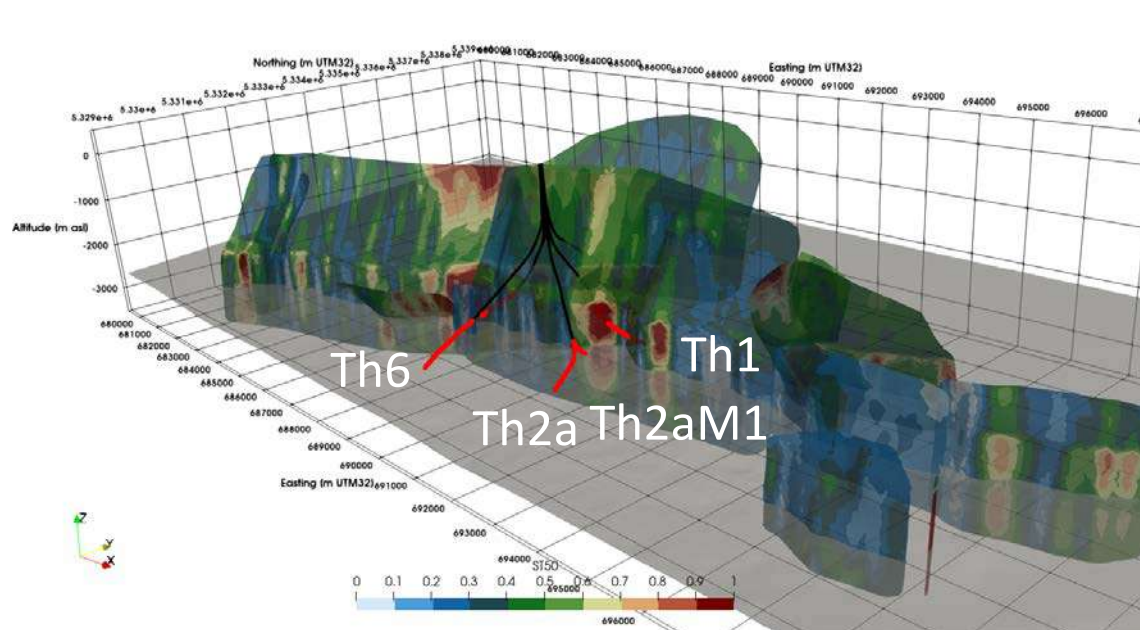
- Dilation tendency

$$DT = \frac{\sigma_1 - \sigma_n}{\sigma_1 - \sigma_3}$$



Normalized slip tendency at Schäftlarnstr.

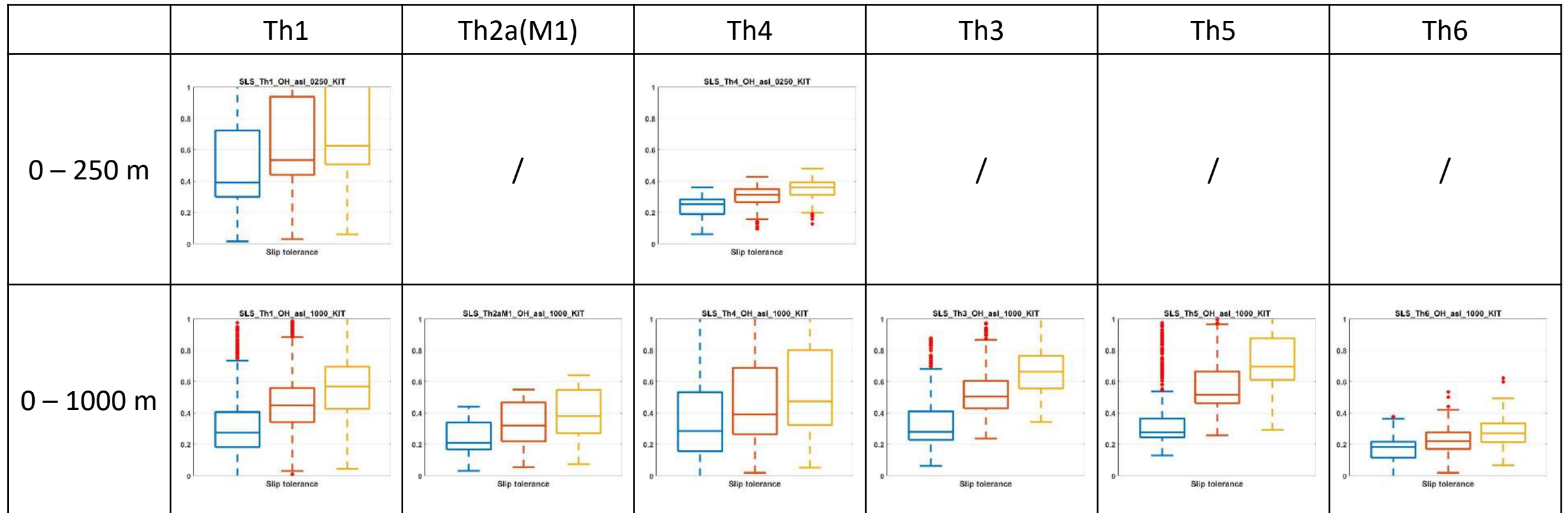
- 50% confidence level (variation of stress tensor amplitudes)



- “High” slip-tendency $\Leftrightarrow$ Production wells: Th1, Th2a/Th2aM1, Th4
- “Low” slip-tendency $\Leftrightarrow$ Injection wells: Th3, Th5, Th6

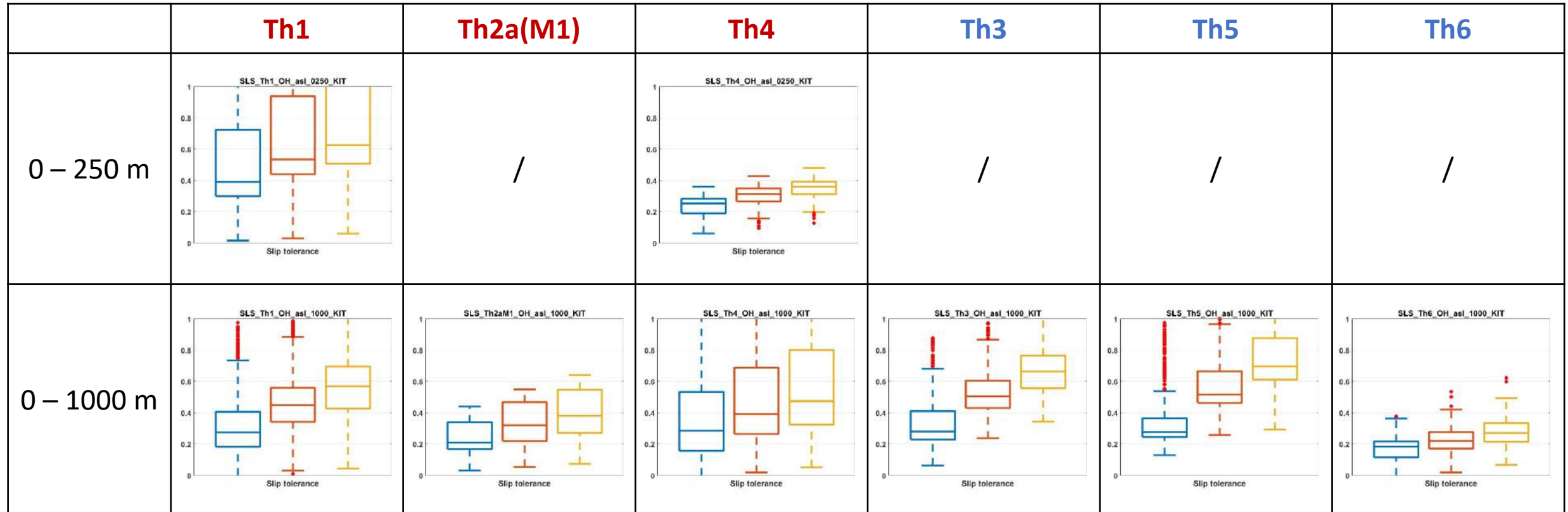
Fault surface exposure from well open-hole

- Look at slip tendency around the wells, how close to critical are the faults?



Confidence level: ■ 10% ■ 50% ■ 90%

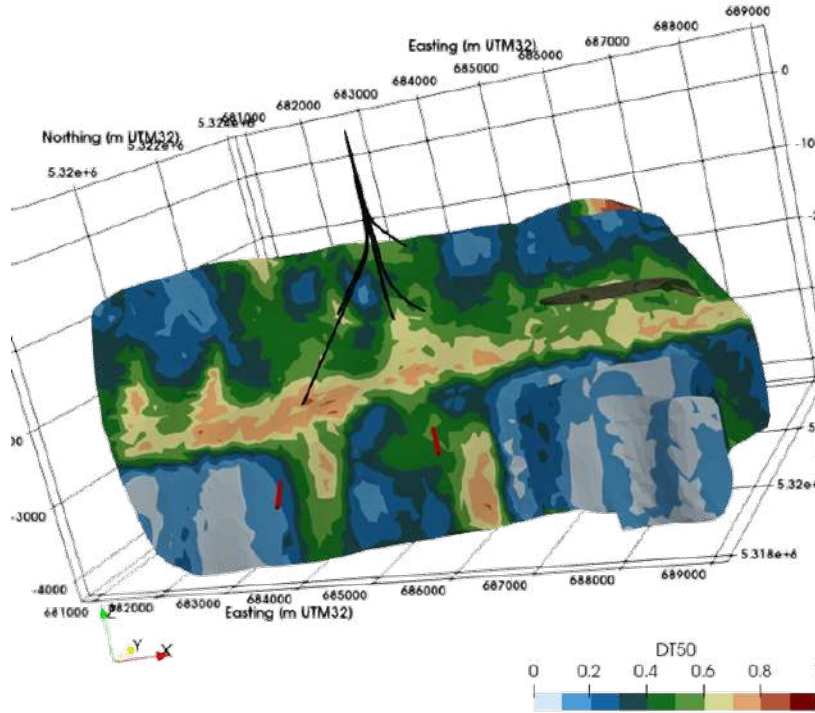
Fault surface exposure close to well



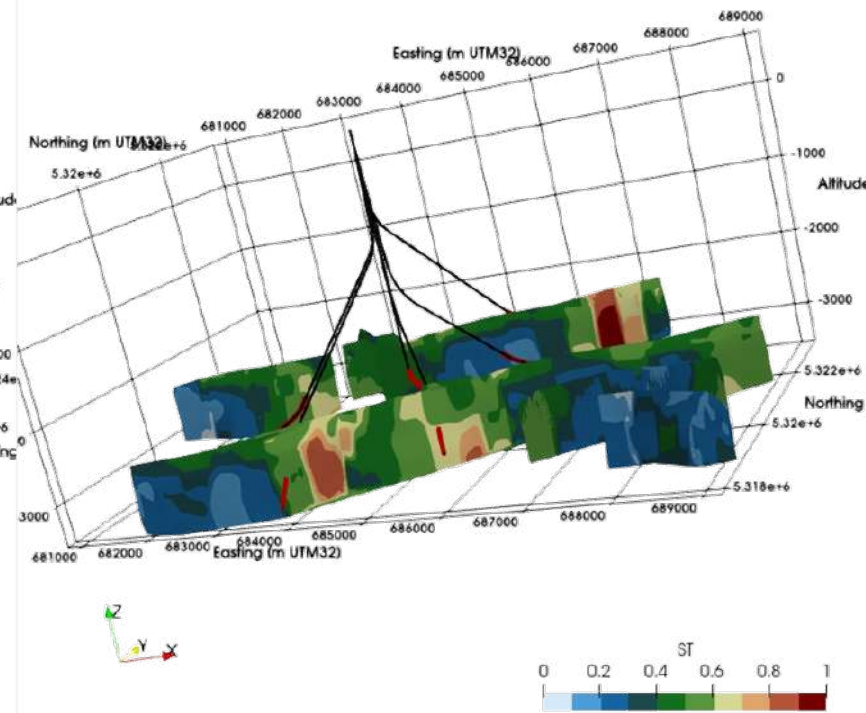
- “High” slip-tendency $\Leftrightarrow$ Production wells: **Th1, Th2a/Th2aM1, Th4**
- “Low” slip-tendency $\Leftrightarrow$ Injection wells: **Th3, Th5, Th6**

KIT vs Erdwerk: Comparison at Baierbrunn

KIT



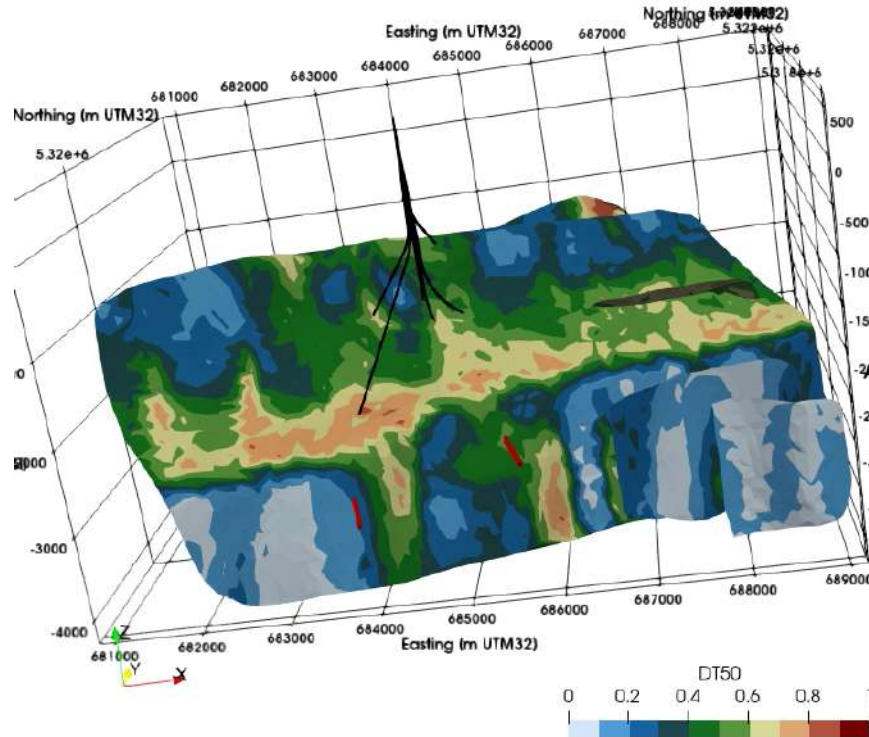
Erdwerk



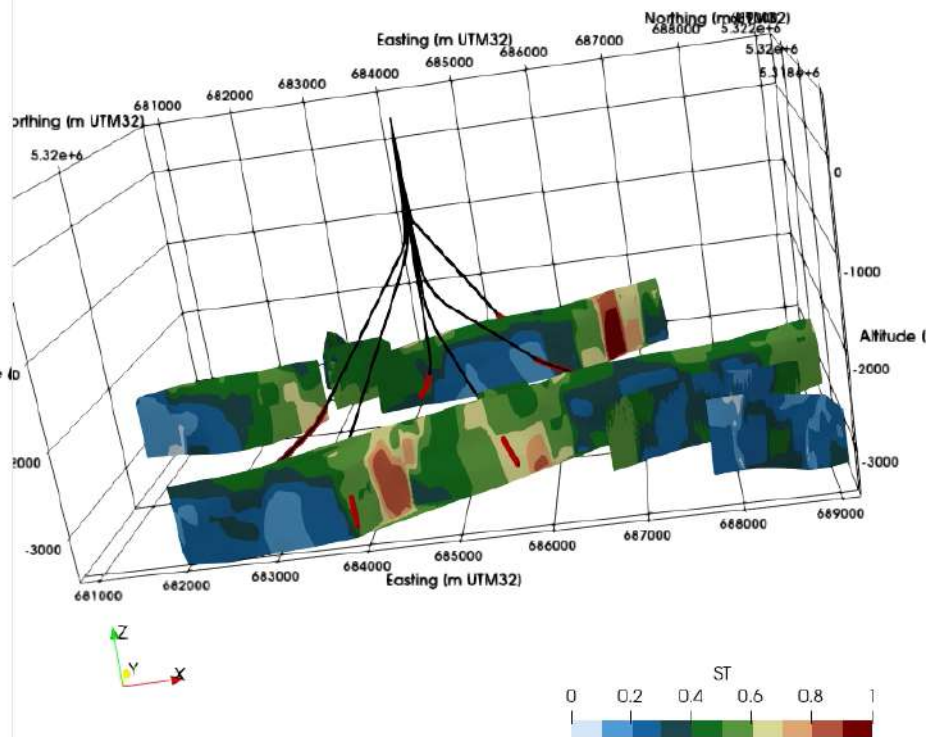
- Different stress field hypotheses and failure criteria lead to comparable “high”/“low” slip tendency areas ⇒ What is important are the critical zones rather than the absolute values
- The static analysis of slip-tendency should be extended to the life-time of the geothermal field exploitation ⇒ Dynamic analysis

KIT vs Erdwerk: Comparison at Baierbrunn

KIT

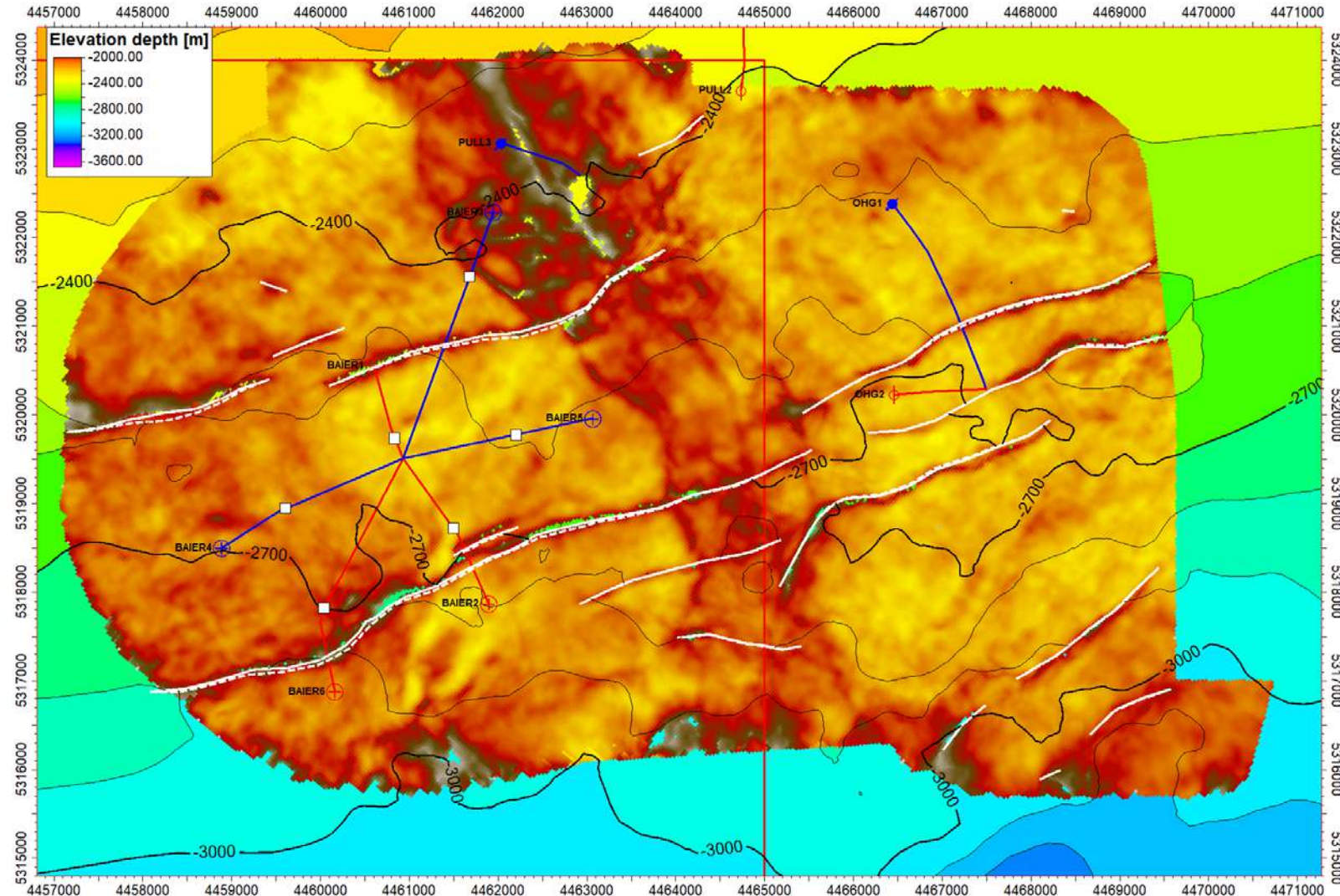


Erdwerk

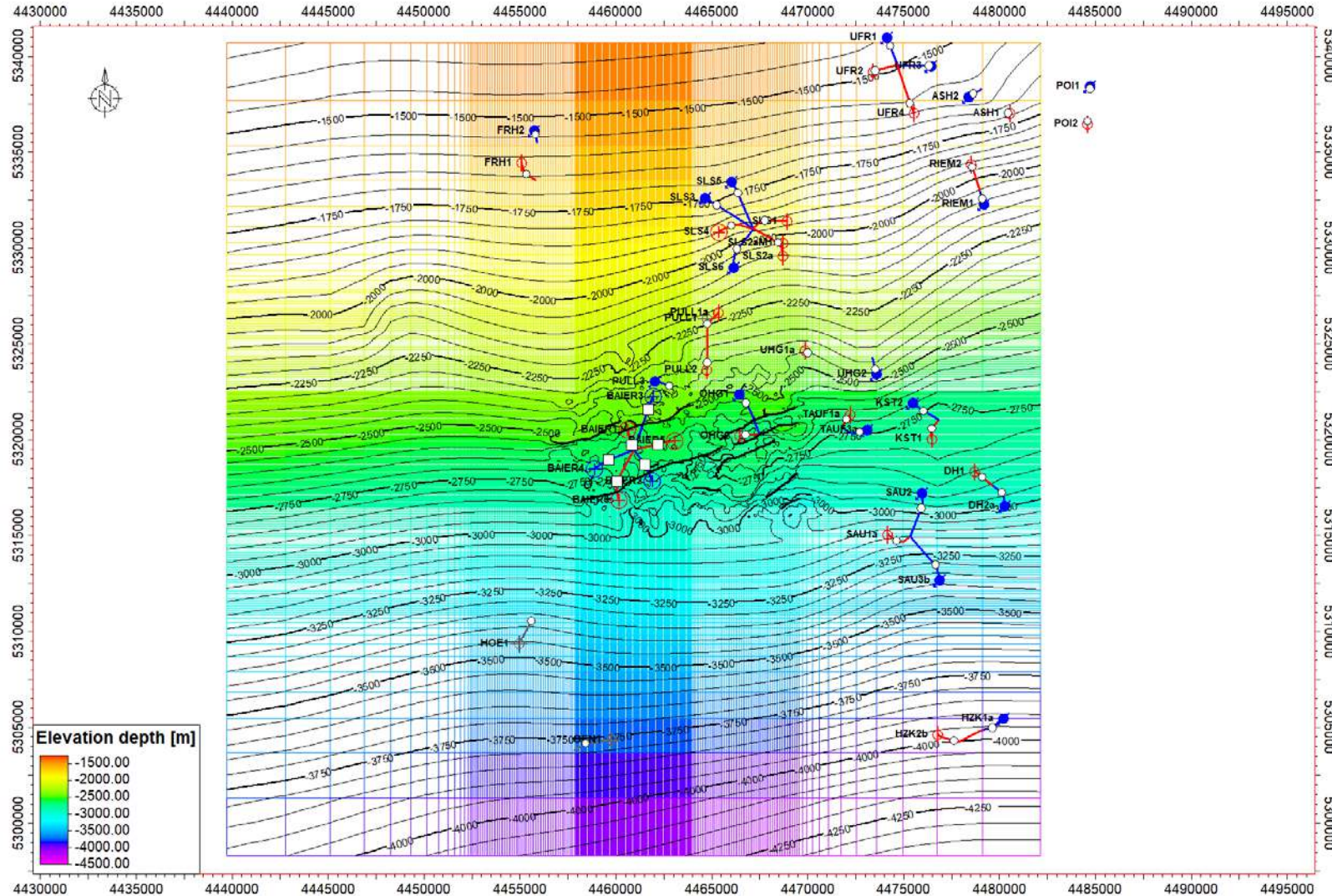


- Different stress field hypotheses and failure criteria lead to comparable “high”/“low” slip tendency areas ⇒ What is important are the critical zones rather than the absolute values
- The static analysis of slip-tendency should be extended to the life-time of the geothermal field exploitation ⇒ Dynamic analysis

Baierbrunn: Standard development with 6 wells

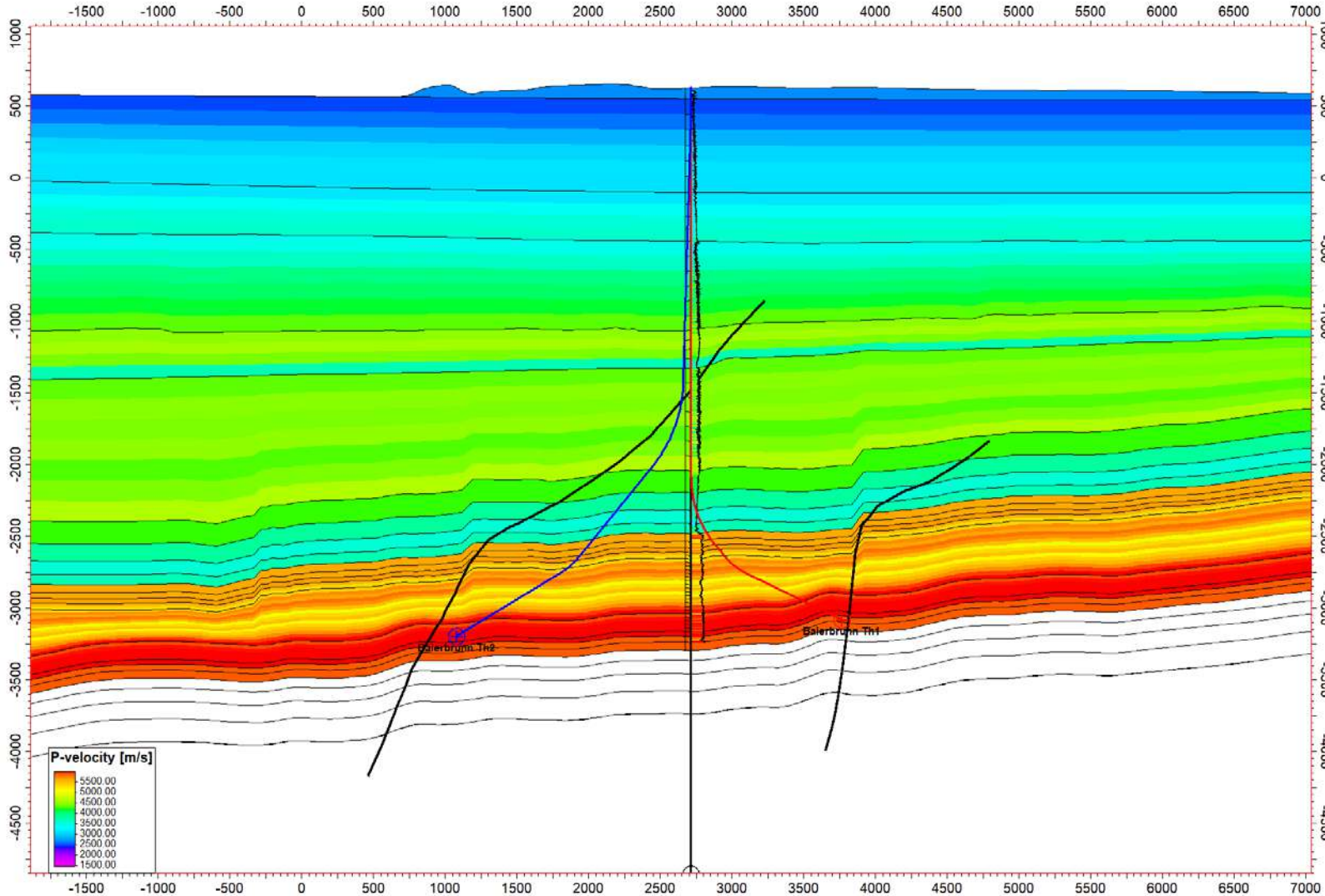


Simulation model – 2D grid (Top Malm)



- Simulation area 1797 km² (approx. 42.4 x 42.4 km²)
- Depth map: Top Malm in [m NN] with faults (black lines)
- Cell size of 40 m x 40 m in the core area and ~3000 m x 3000 m outside
- Together with the 81 layers of the model ⇒ grid with 6,469,632 (288 x 288 x 78) cells

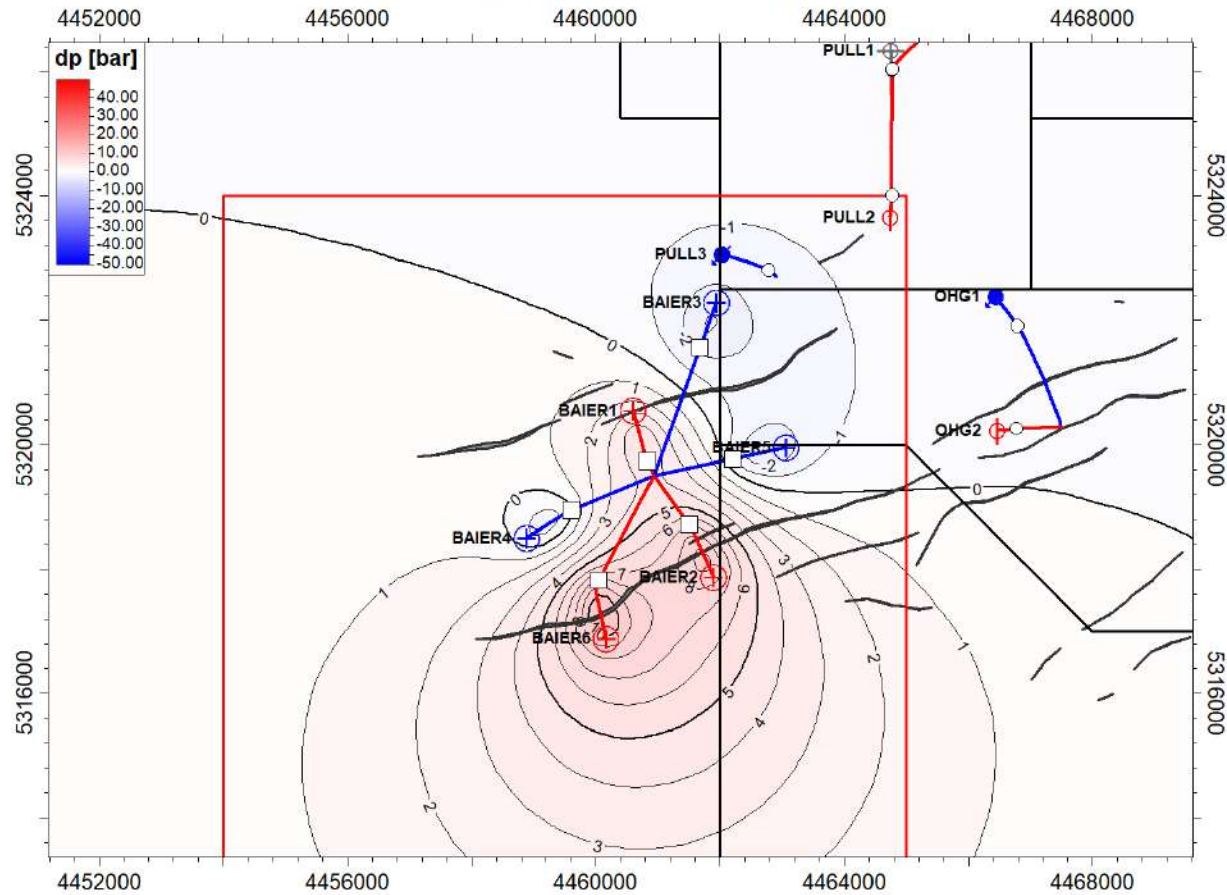
Simulation model – Upscaling the synthetic V_p log



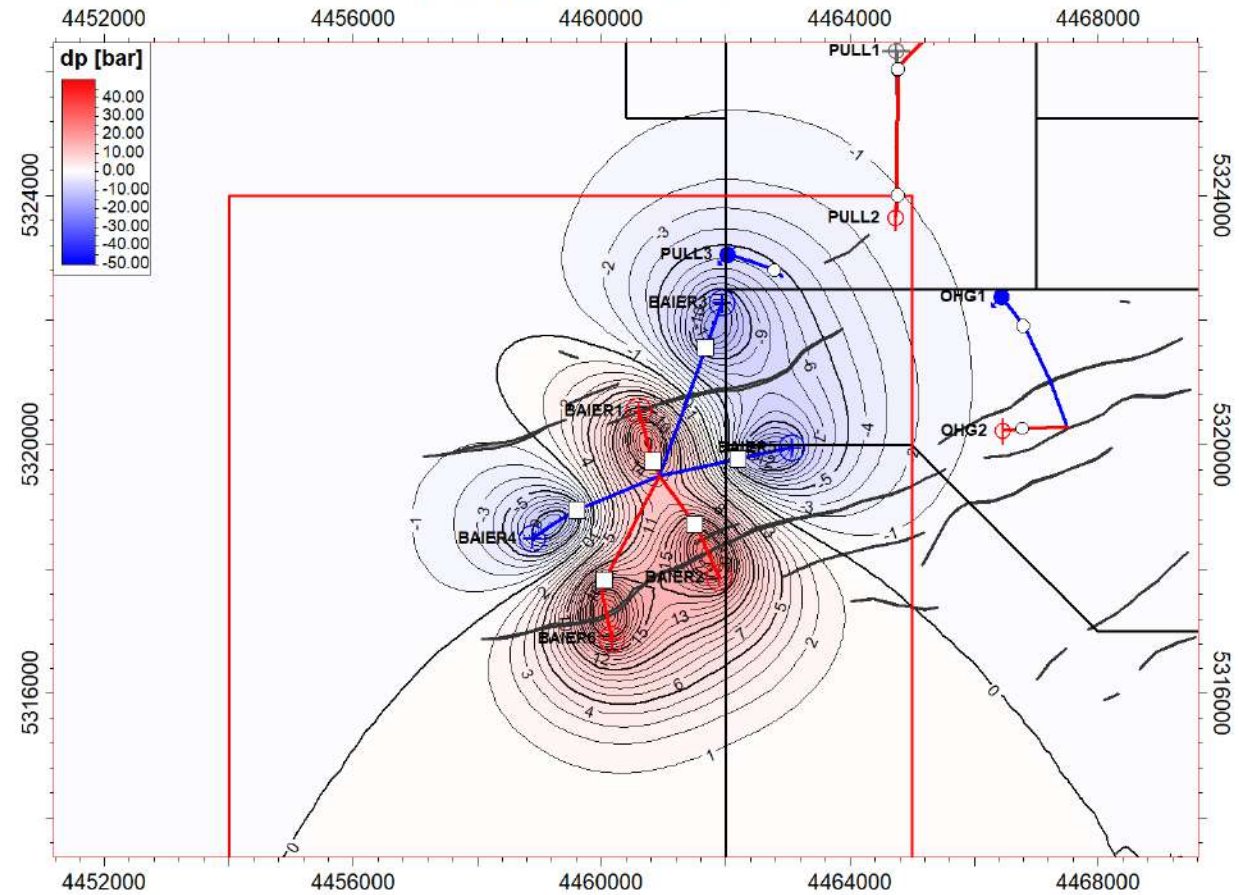
- North-South profile through a reference well
- Upscaled compressional wave velocities (V_p) of the geomechanical (THM) simulation model
- Projection of the faults and well trajectories Baierbrunn Th1 and Th2. (Projection does not conserve angles.)

TH simulation – Pressure changes after 50 years

P10 Transmissibilität / P50 RTG

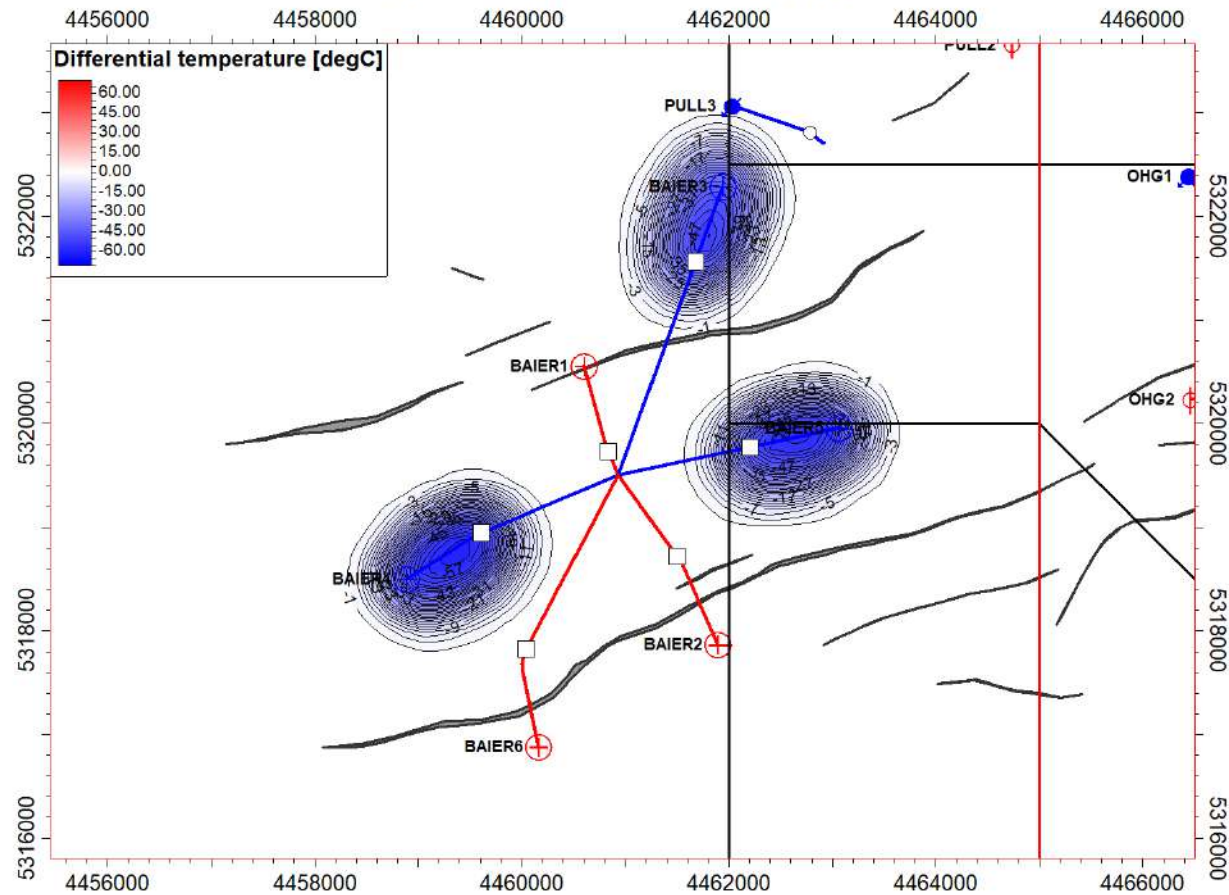


P90 Transmissibilität / P50 RTG

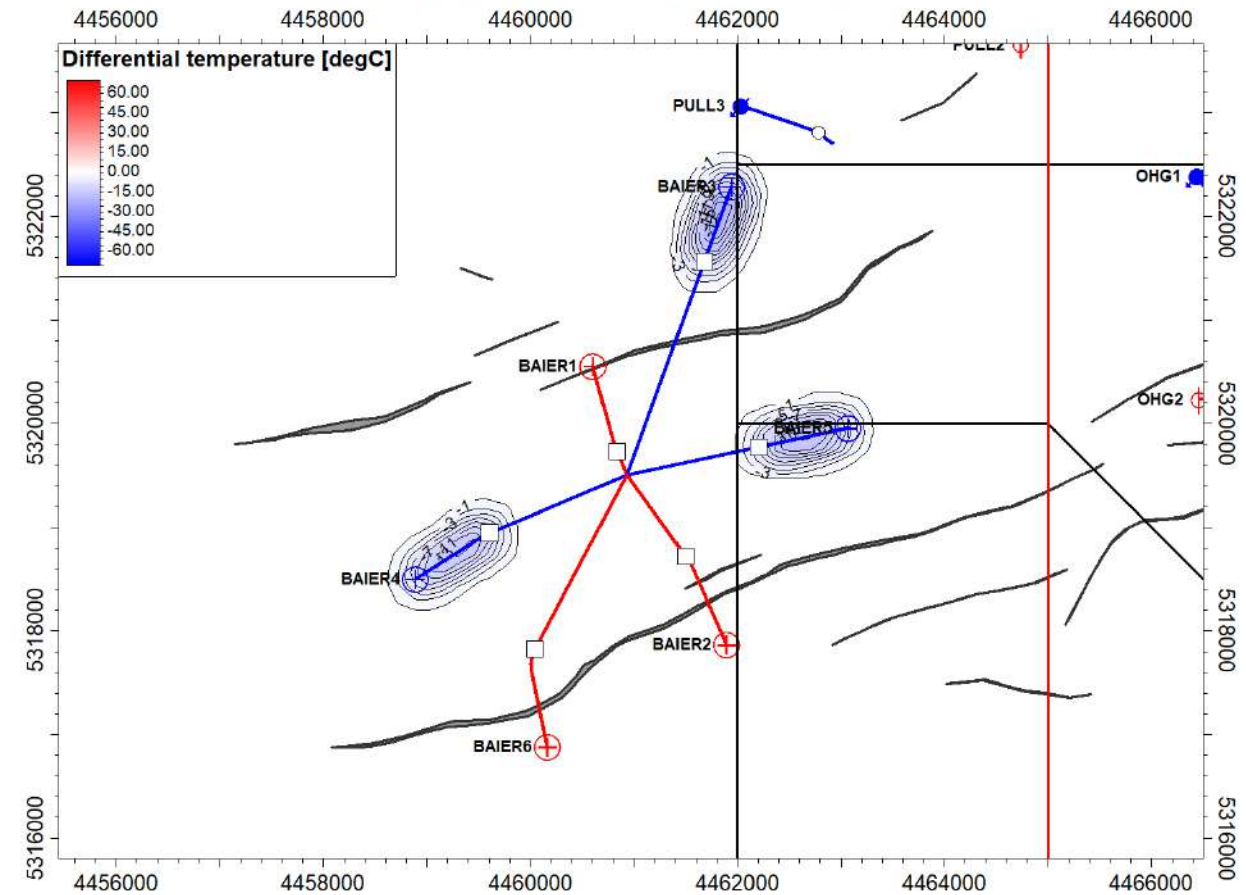


TH simulation – Temperature changes after 50 years

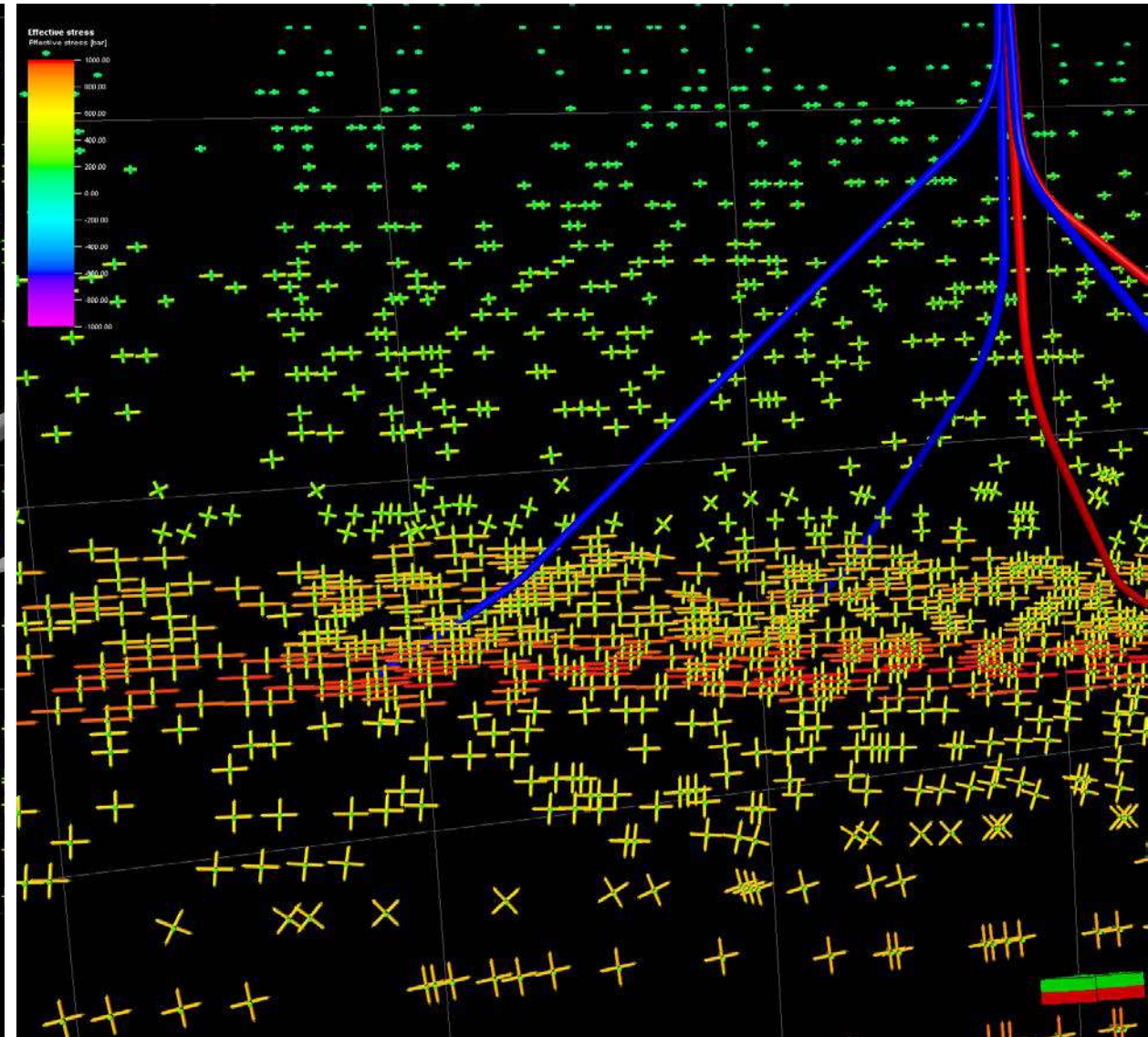
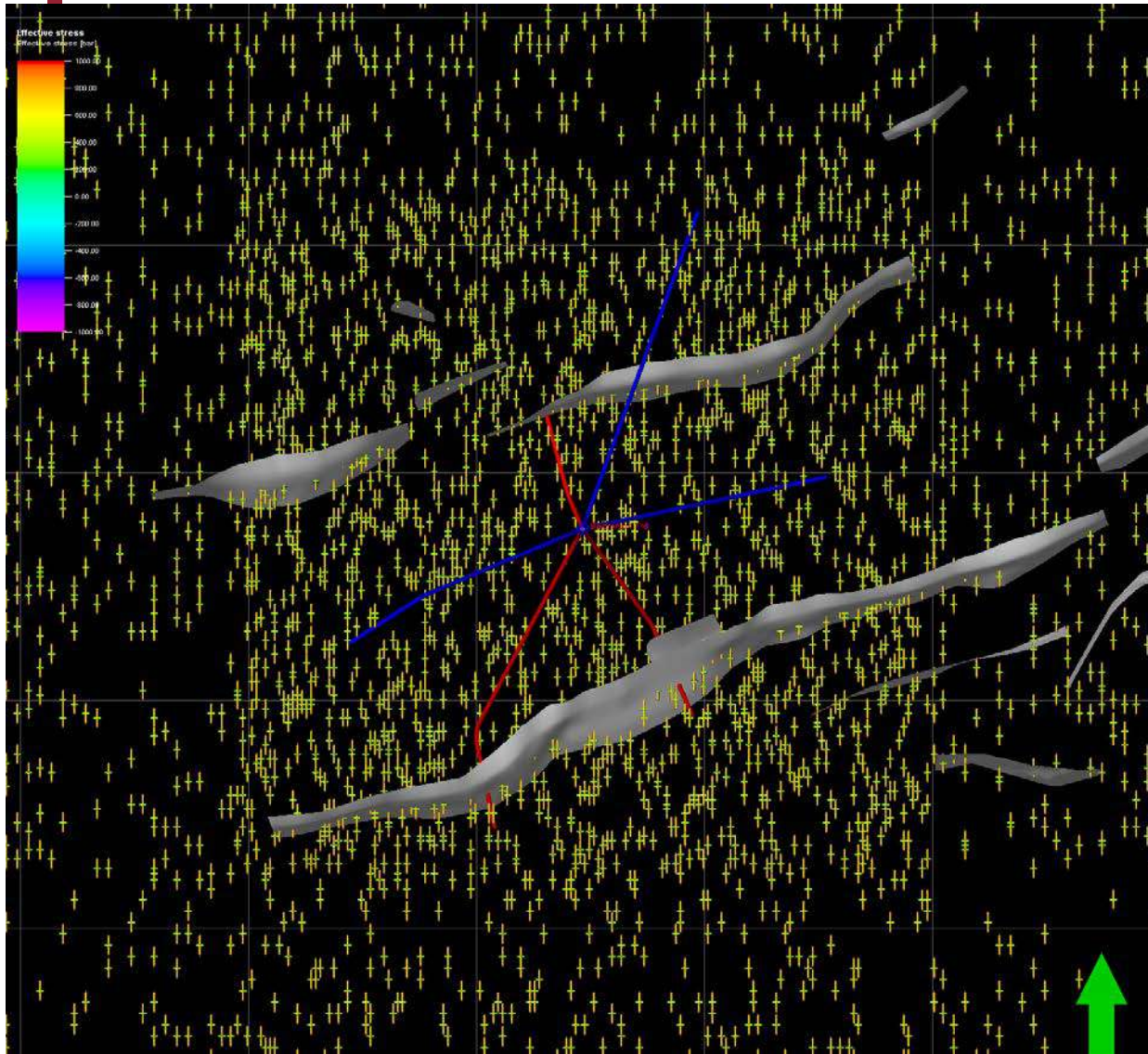
P10 Transmissibilität / P50 RTG



P90 Transmissibilität / P50 RTG

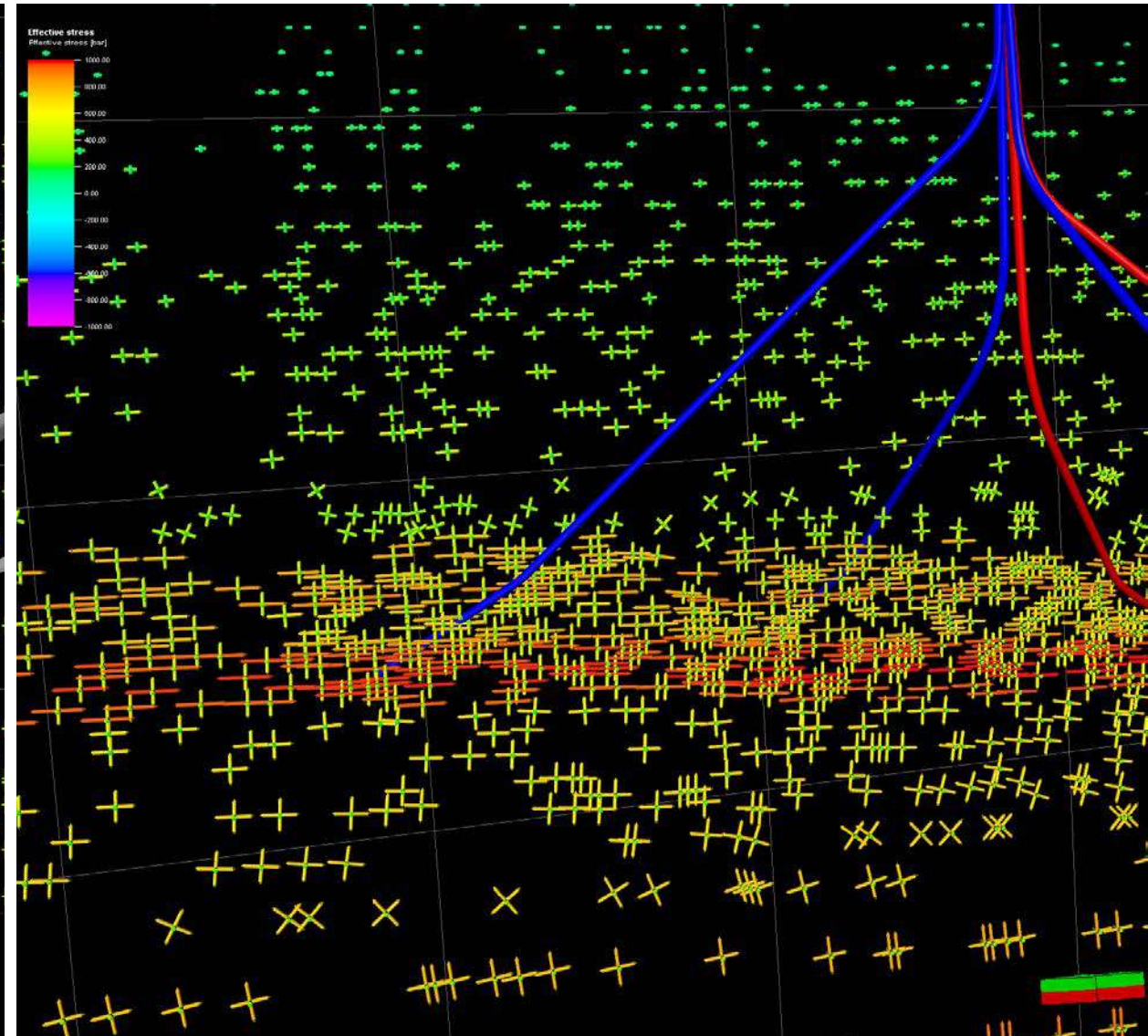
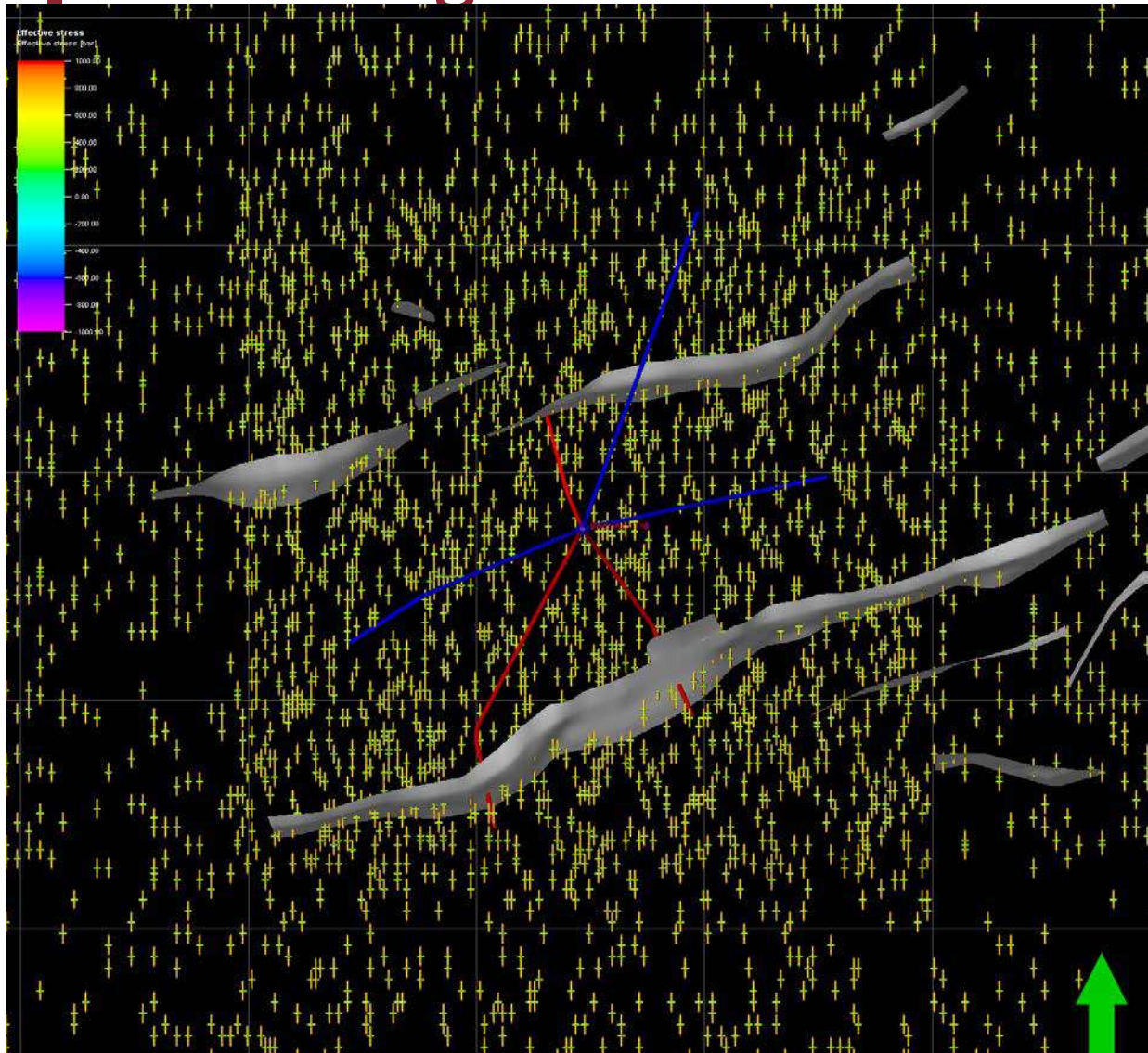


THM simulation – Stress tensor (Initial)

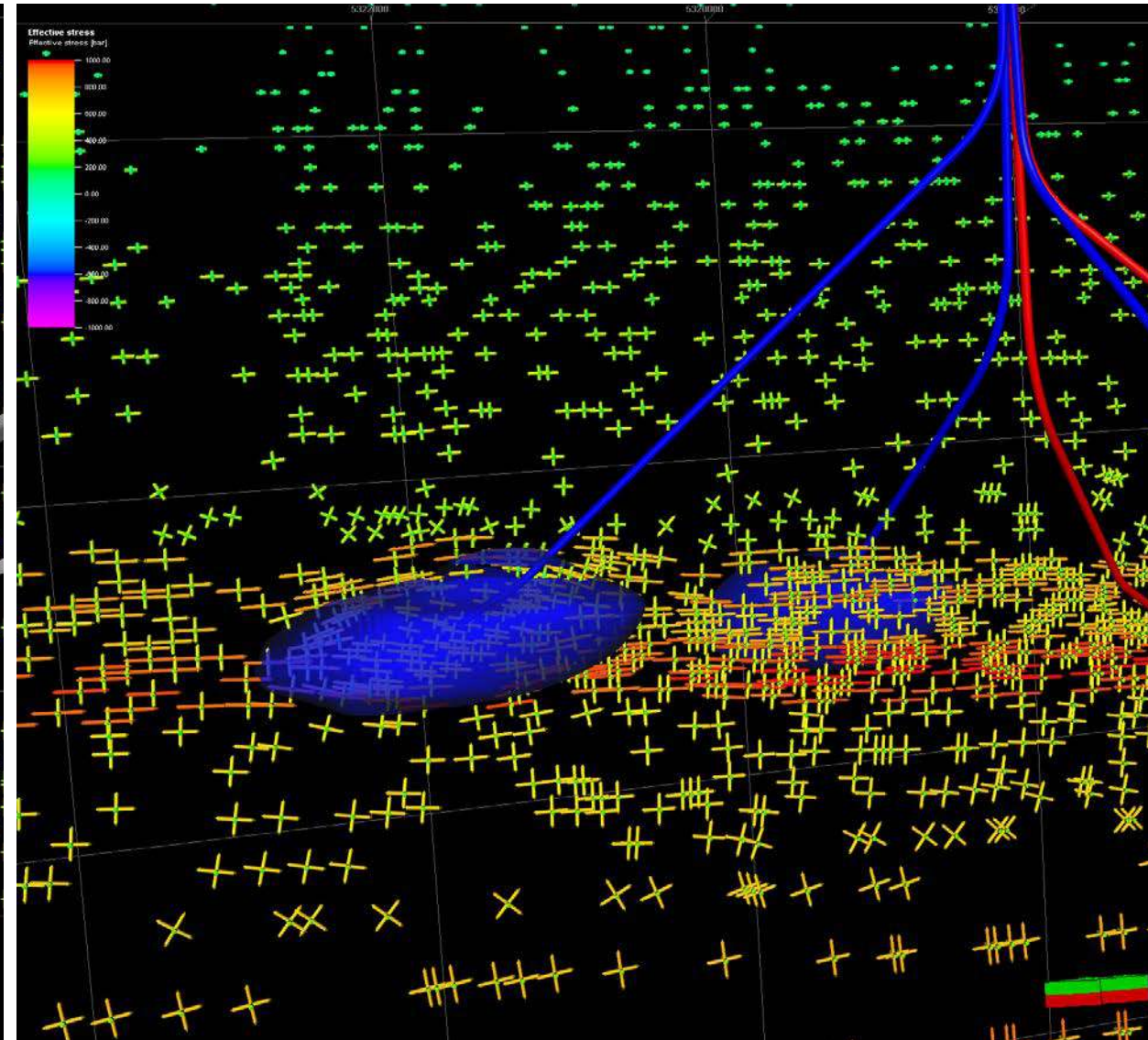
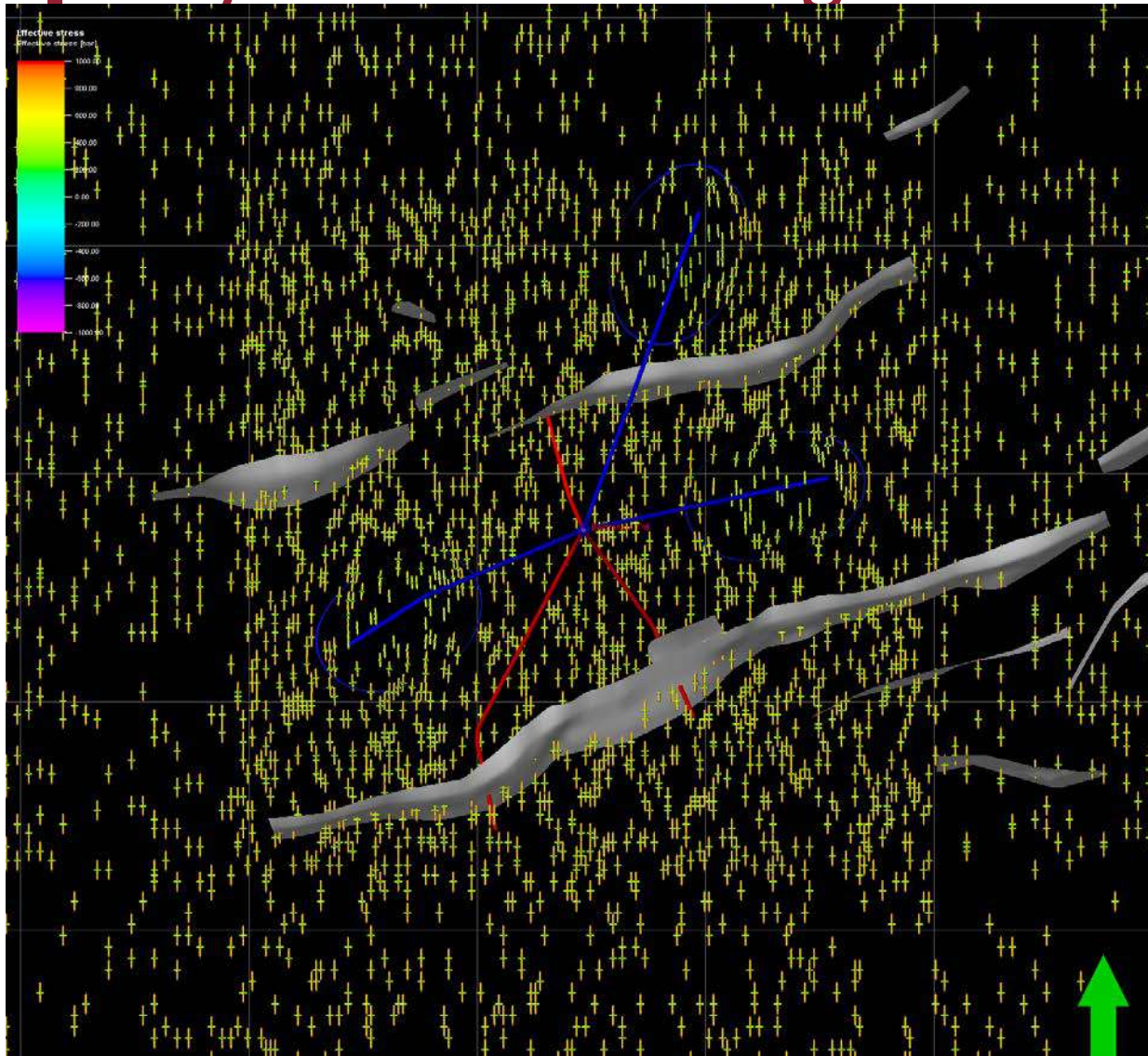


THM Simulation – P90 log(kh), P50 RTG

No cooling



THM Simulation – P90 log(kh), P50 RTG 30 years with cooling

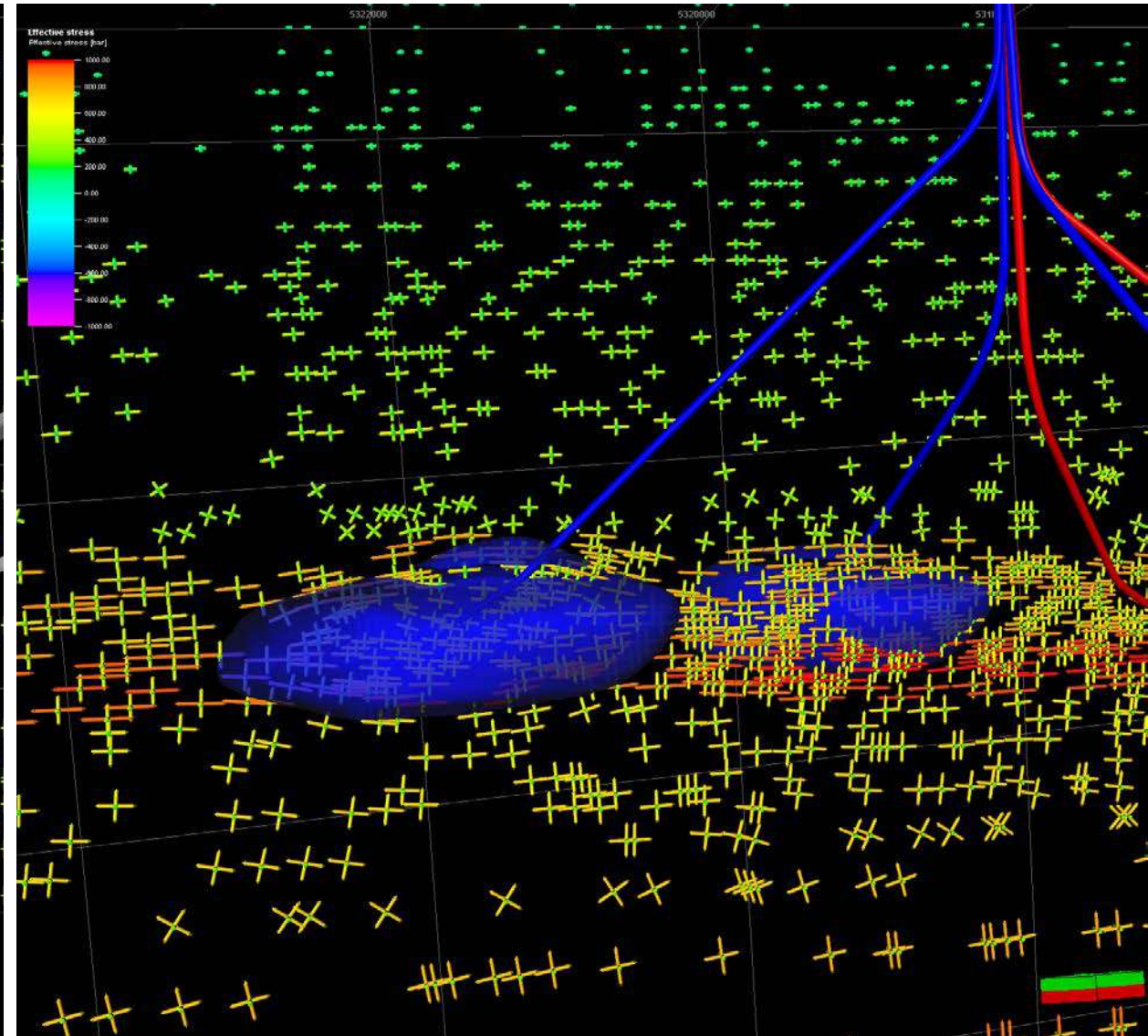
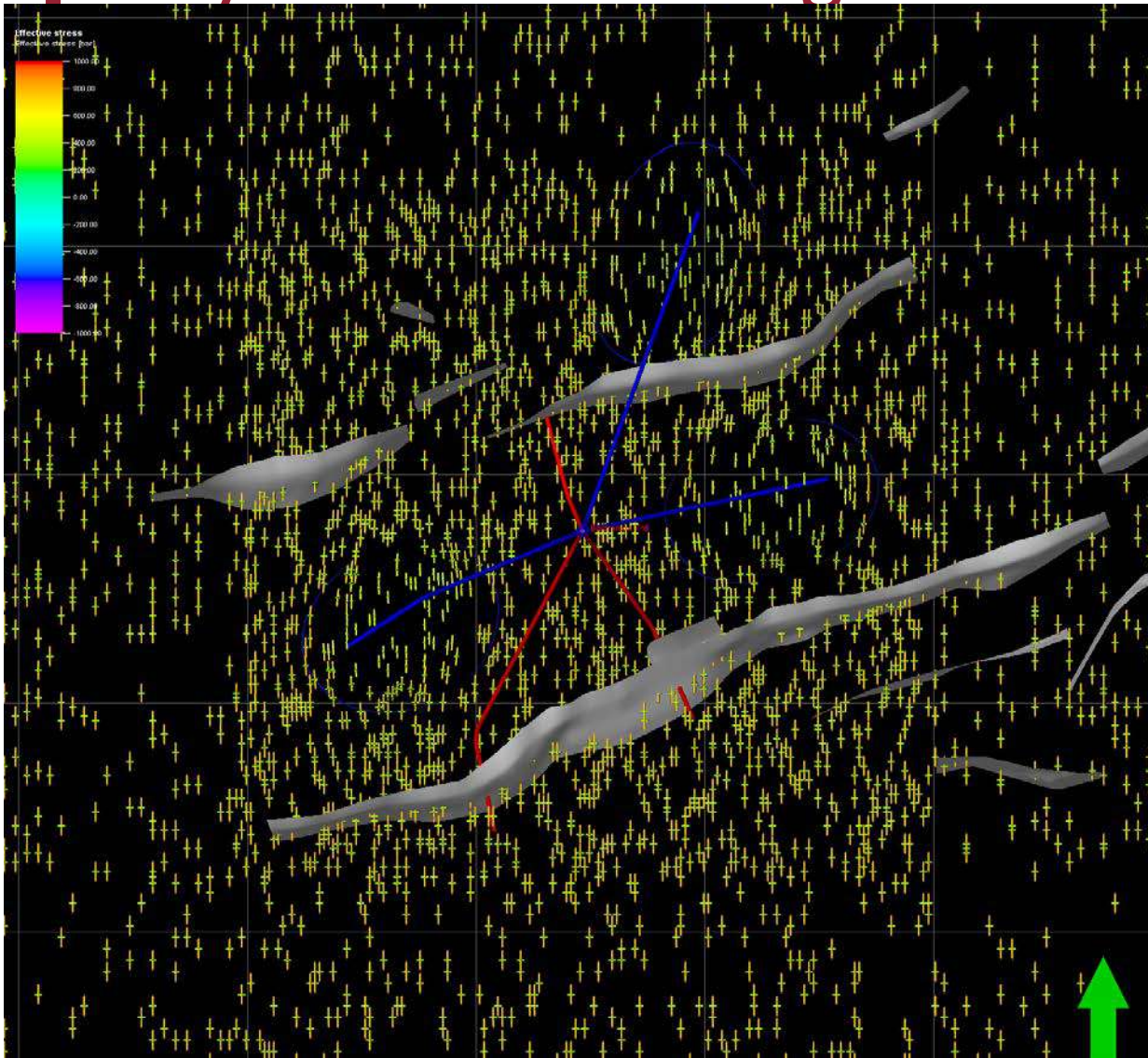


THM Simulation – P90 log(kh), P50 RTG

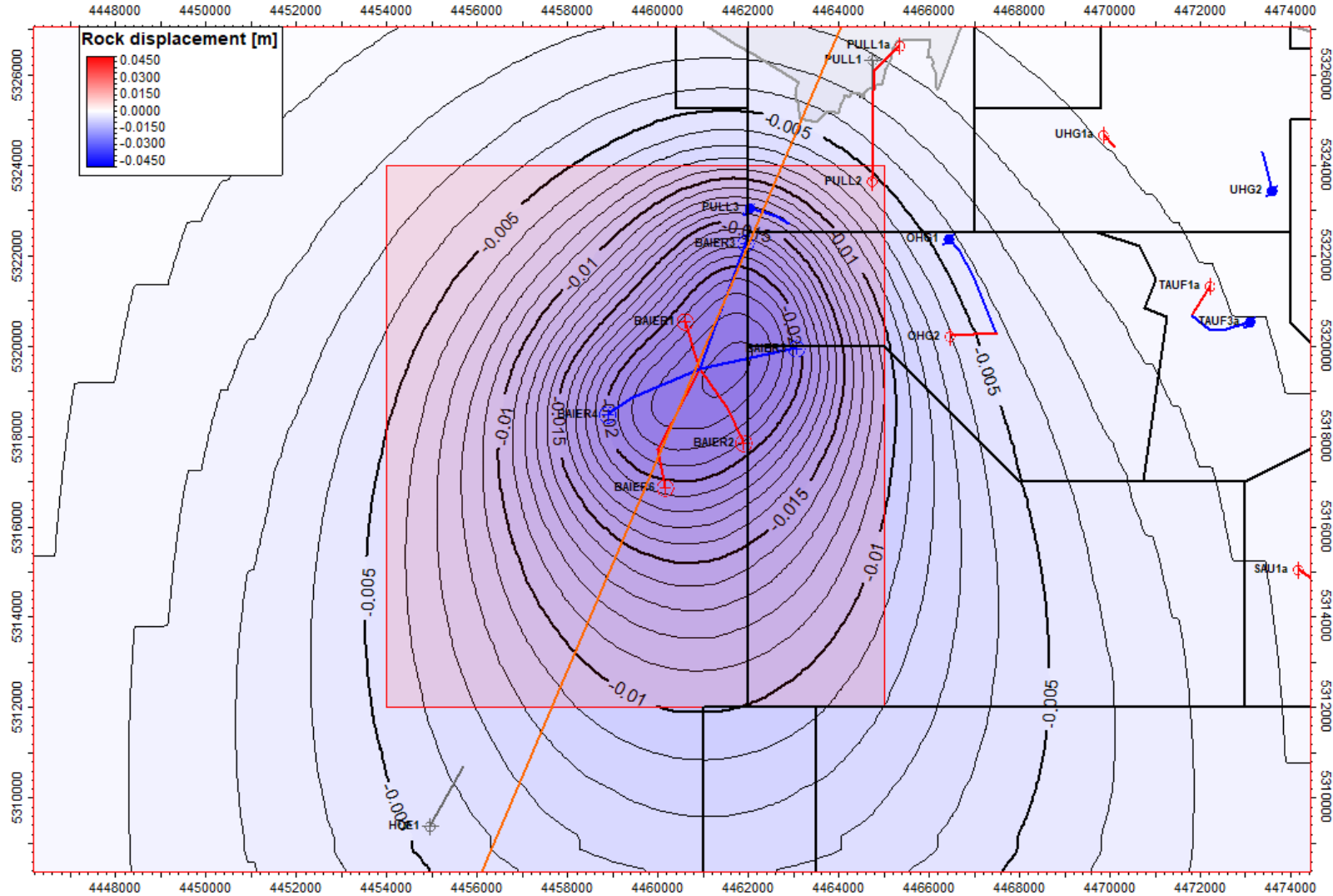
50 years with cooling



INSIDE

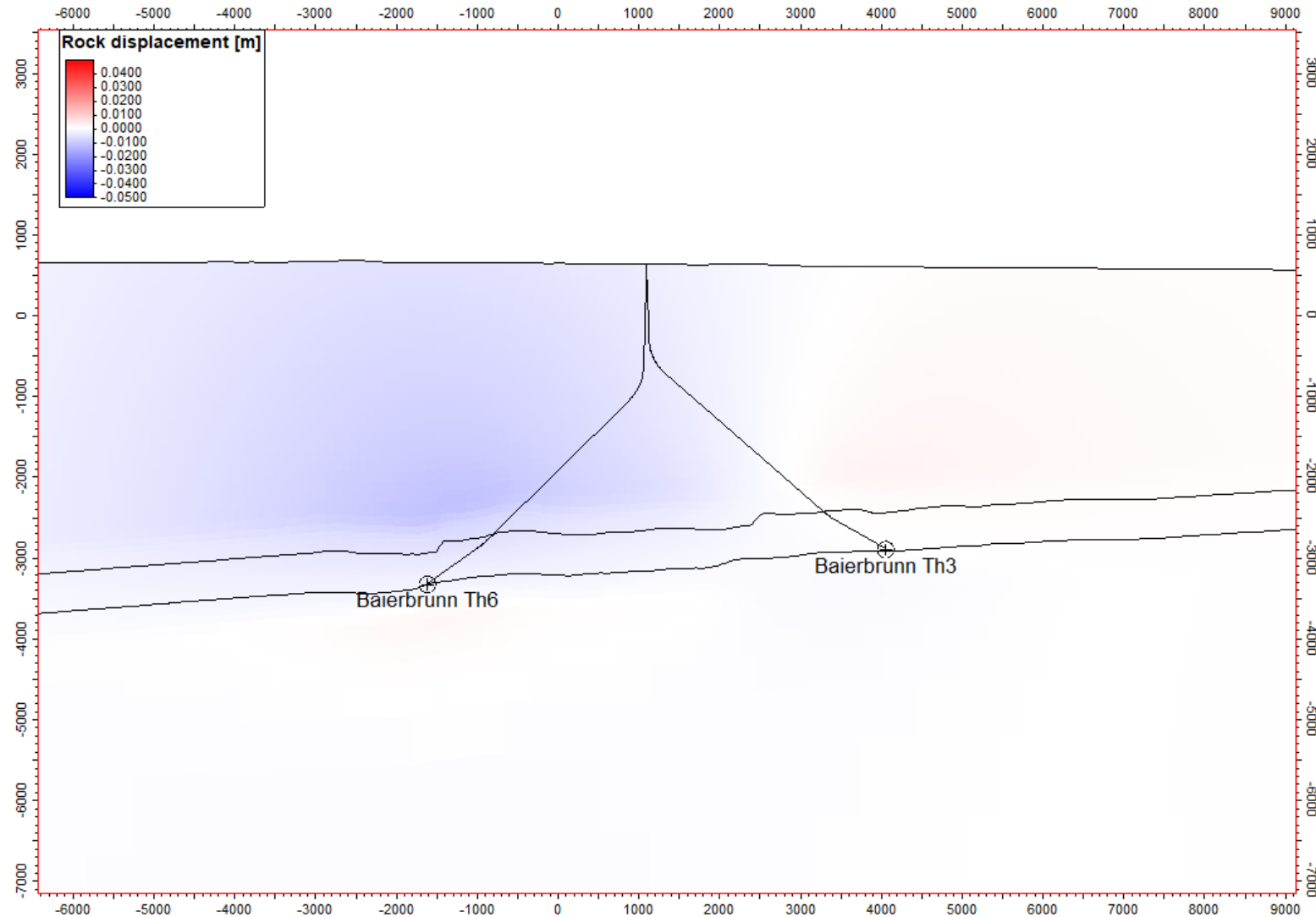


Ground displacement – Worst case scenario 50 years with cooling

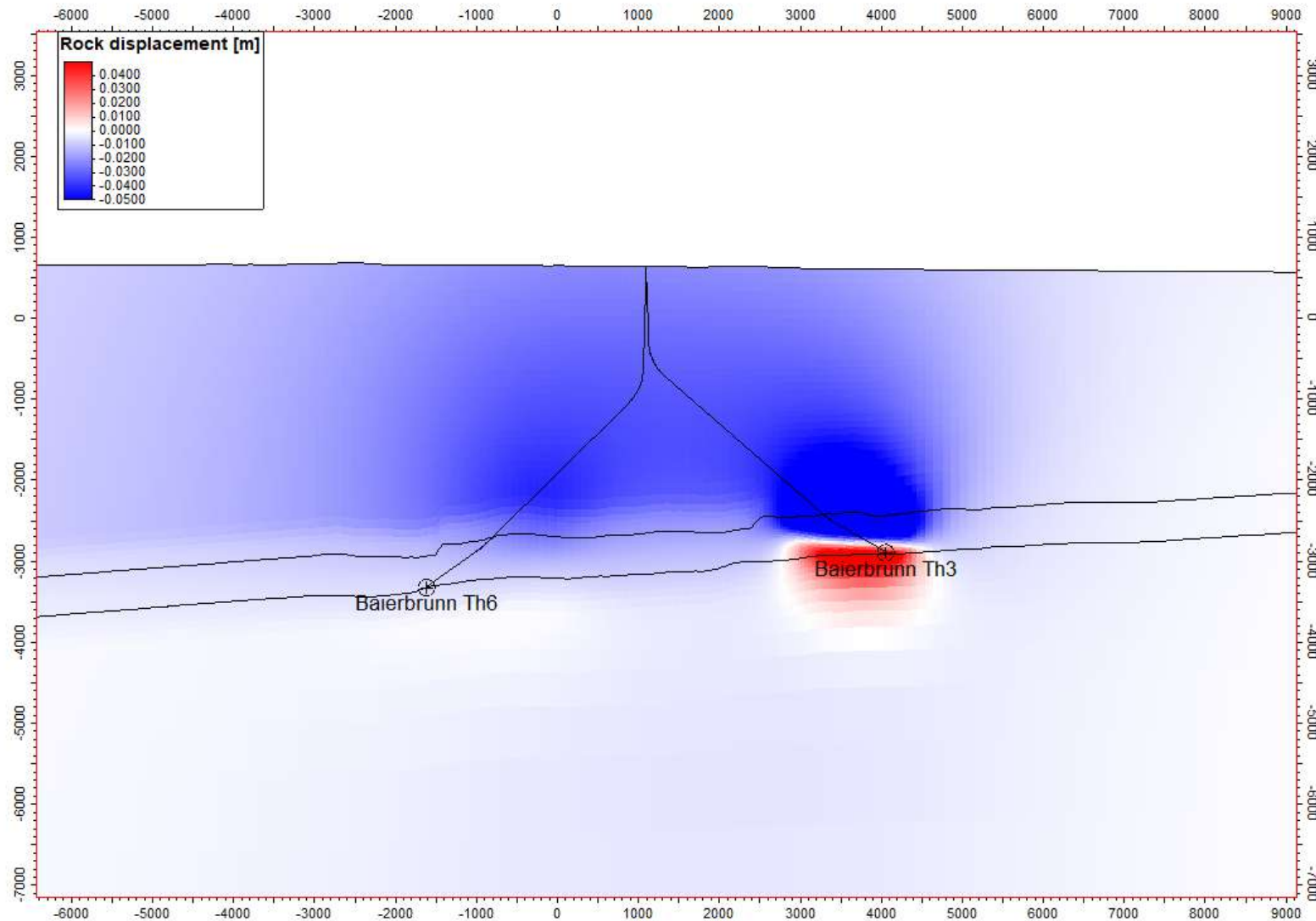


Ground displacement – Worst case scenario

50 years NO cooling



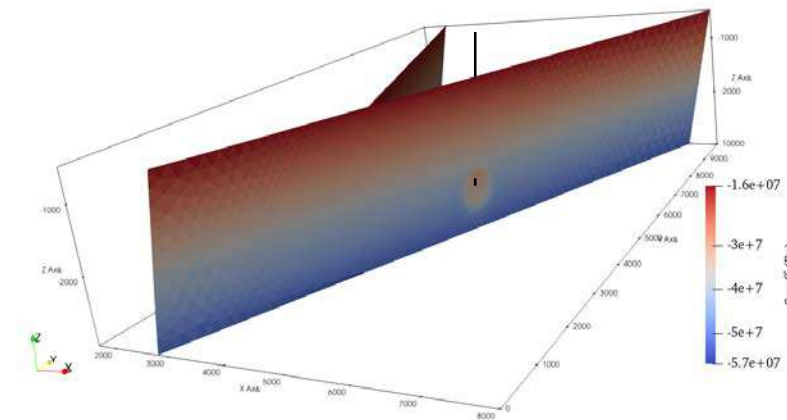
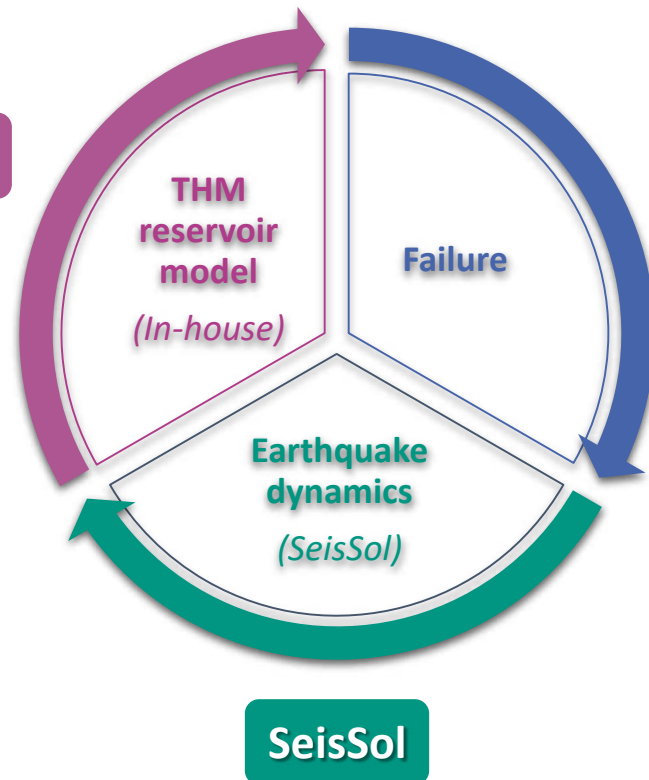
Ground displacement – Worst case scenario 50 years with cooling



Development of a coupled THM-Seismicity modelling tool

- **PROBLEMATICS:** Can we model induced seismicity during geothermal production?
- **CONCEPT**

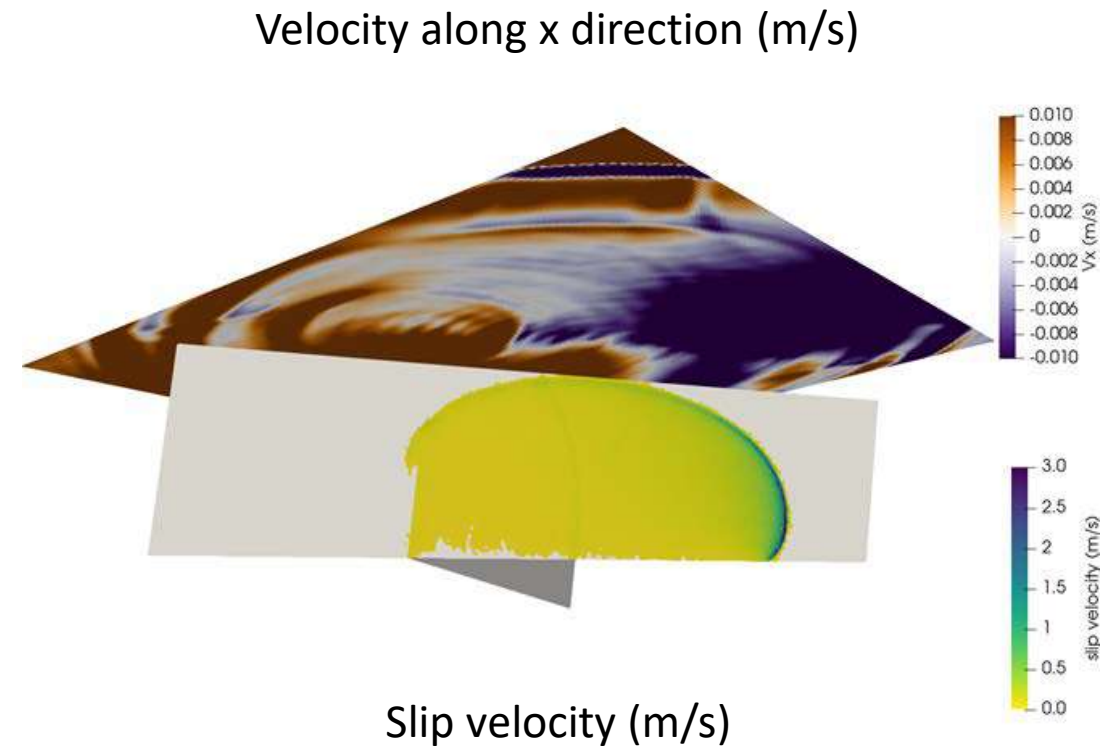
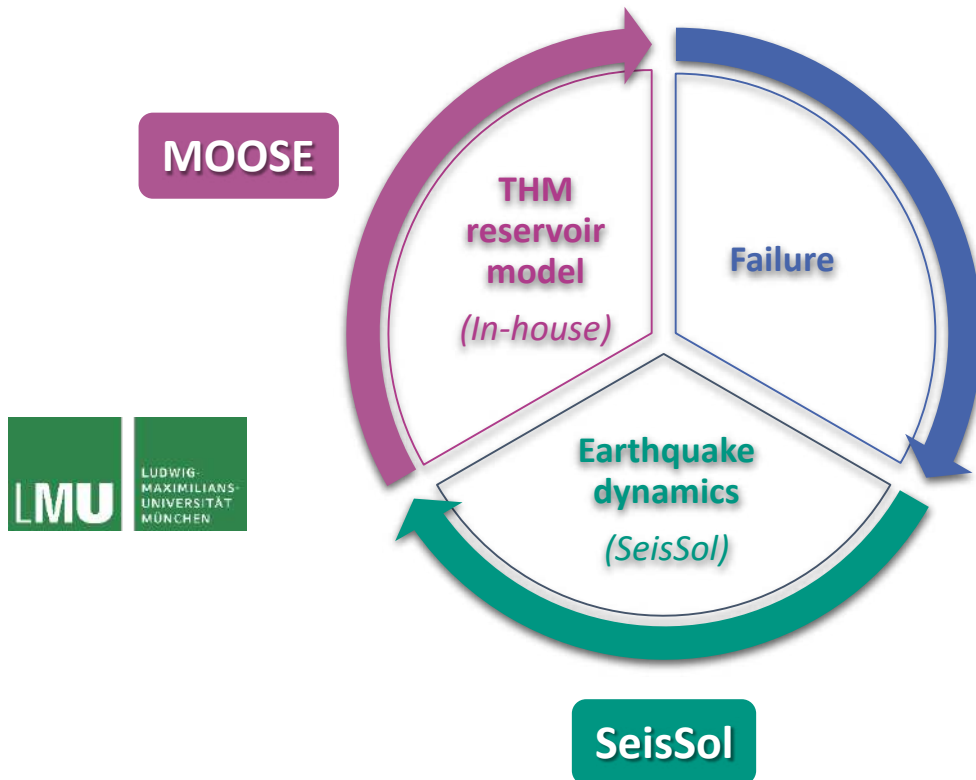
- Open-source Finite-Element codes
- MOOSE $\Leftrightarrow$ Fully coupled THM in saturated porous and fractured reservoir
- SeisSol $\Leftrightarrow$ Earthquake dynamic rupture simulation



Vertical Effective Stress

Development of a coupled THM-Seismicity modelling tool

- **PROBLEMATICS:** Can we model induced seismicity during geothermal production?
- **CONCEPT**



Open-source Finite-Element codes

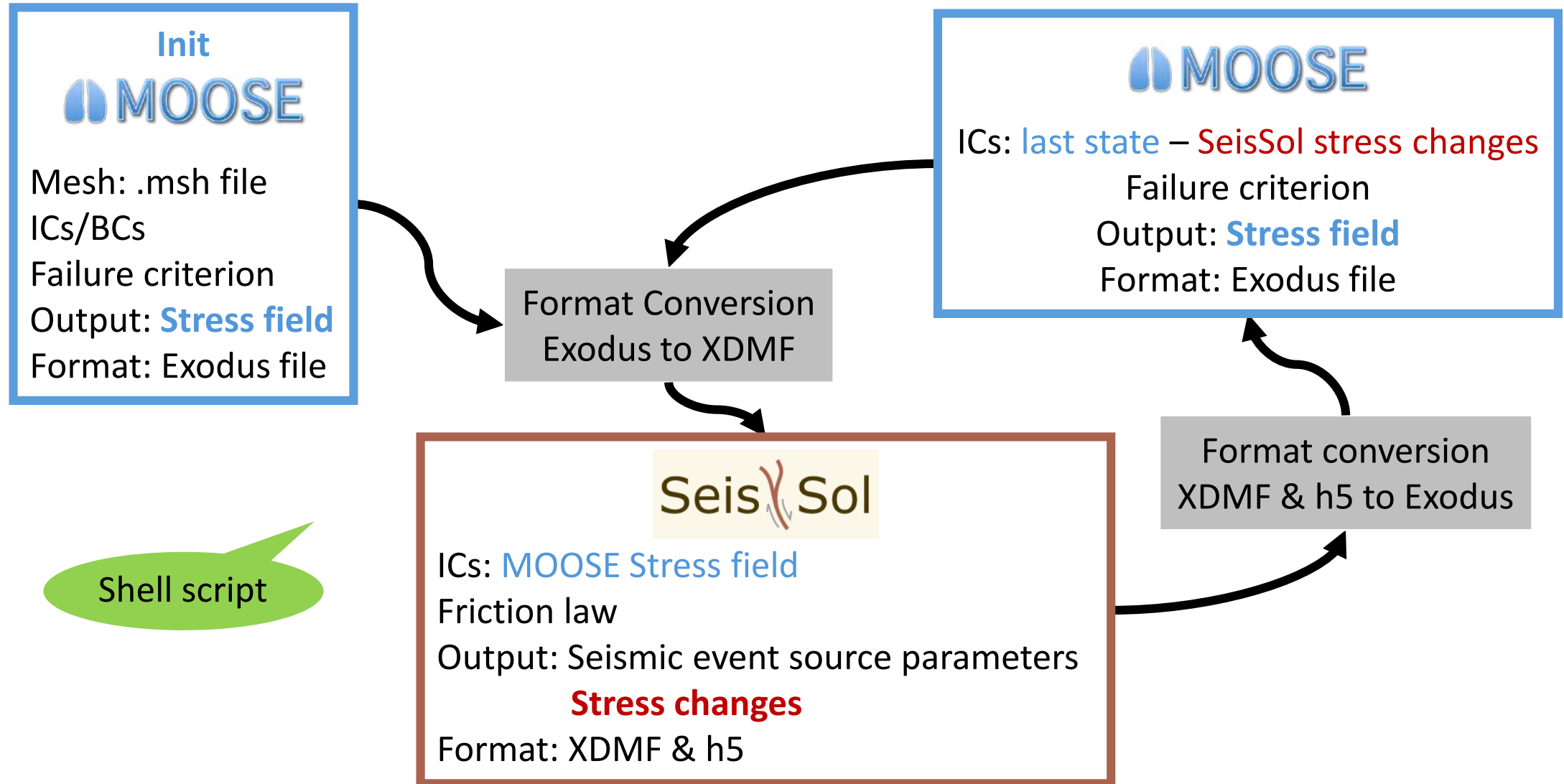
➤ MOOSE-based application

- ❑ Multiphysics Object-Oriented Simulation Environment
 - Dimension independent physics
 - Built-in mesh adaptivity
 - Continuous/discontinuous Galerkin FE
- ❑ In geothermal reservoir
 - T-H-M-solute transport problems
 - Lower-dimension features for wells and fractures
- ❑ Involved equations
 - Energy-balance: advection-diffusion equation for the transport of heat
 - Mass balance
 - Darcy's law
 - Change of porosity with P and T

➤ SeisSol

- ❑ Discontinuous Galerkin FE
- ❑ High-order numerical scheme: limited numerical dispersion
- ❑ High scalability, suitable for high-performance computing
- ❑ Complex fault geometries
- ❑ Versatile
 - 3D heterogeneous media
 - Various rheology (acoustic, (an)isotropic elastic, viscoelastic, viscoplastic, poroelastic)
- ❑ Involved equations
 - Friction law (rate-and-state, linear slip weakening, linear slip strengthening)
 - Seismic wave

Automation of workflow

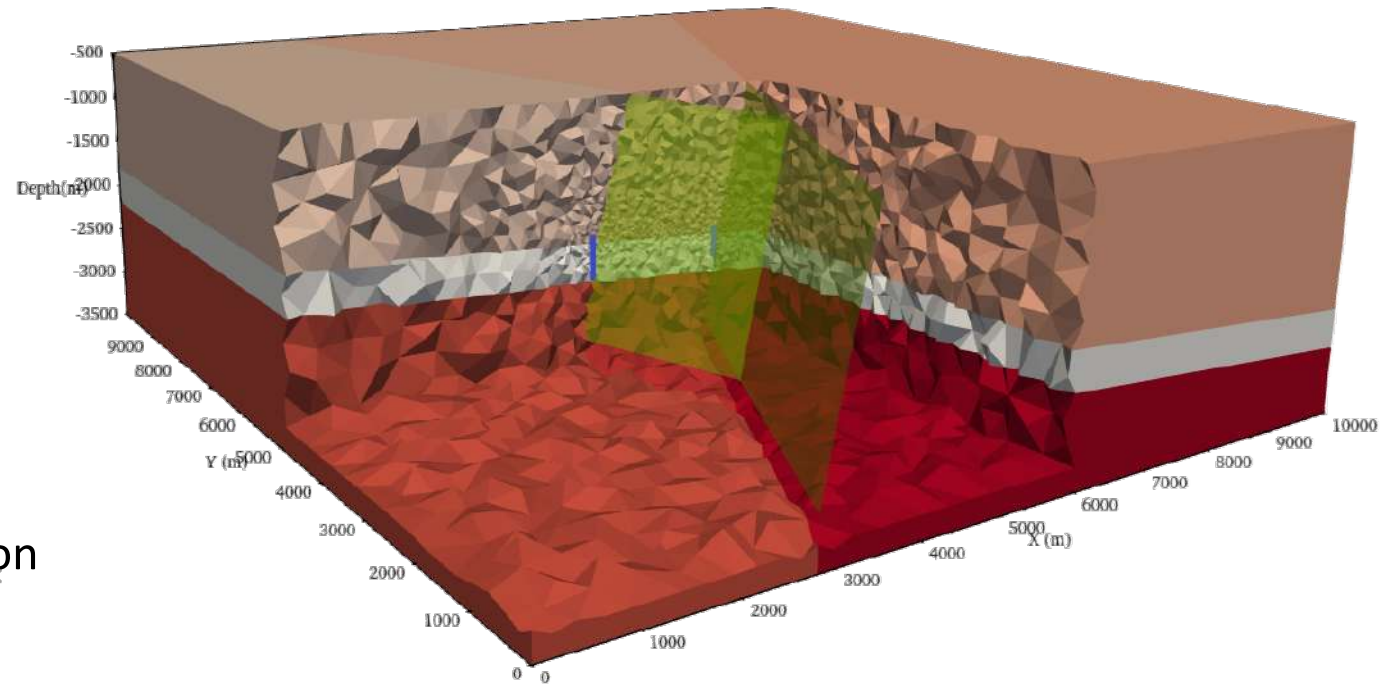


Some of the numerical challenges

- Working with a model of mixed-dimensions: from 0D (injection point) to 3D (matrix)
- Mixing continuous (Moose) and discontinuous (SeisSol) Galerkin FE
- Considering fault reactivation (element) and fault break (area)
- Finding the exact moment of failure
- Managing stress “shock” on and around fault after rupture

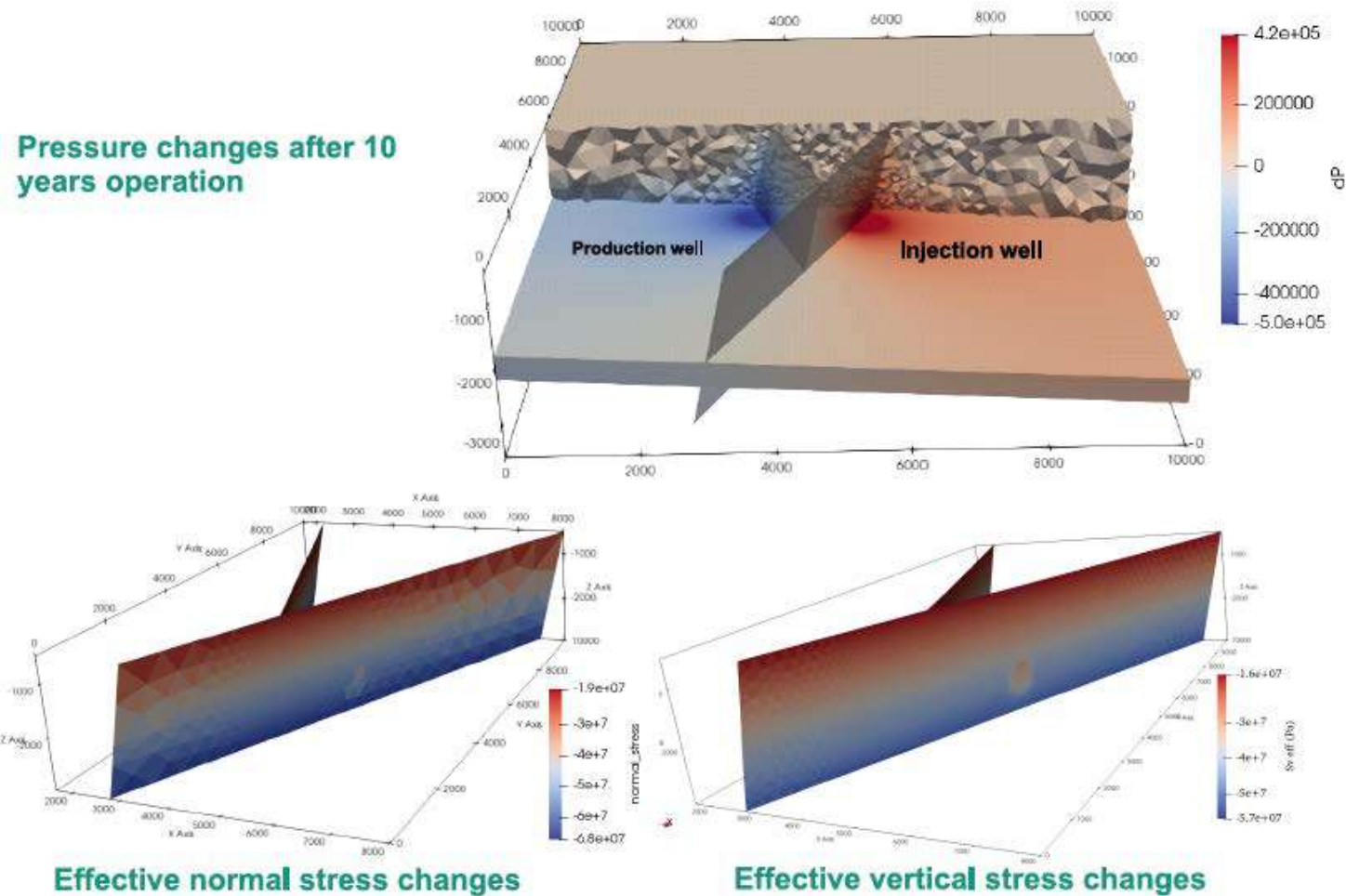
Synthetic case study

- Structural model
 - Simplified faulted reservoir
 - Two faults crossing “basement”, “reservoir” and “sediment” and intersecting each other
 - Faults dipping 70° to the west with different azimuths
 - 1 production well and 1 injection well crossing the faults
 - Well offset of 1500 m
- Finite-element mesh
 - GMSH software
 - $10 \times 10 \times 3.5 \text{ km}^3$
 - [500, 3500] m b.g.l.
 - 120.000 Elements
 - [10, 400] m mesh size
 - Refinement at wells and fault intersection



Prior to rupture

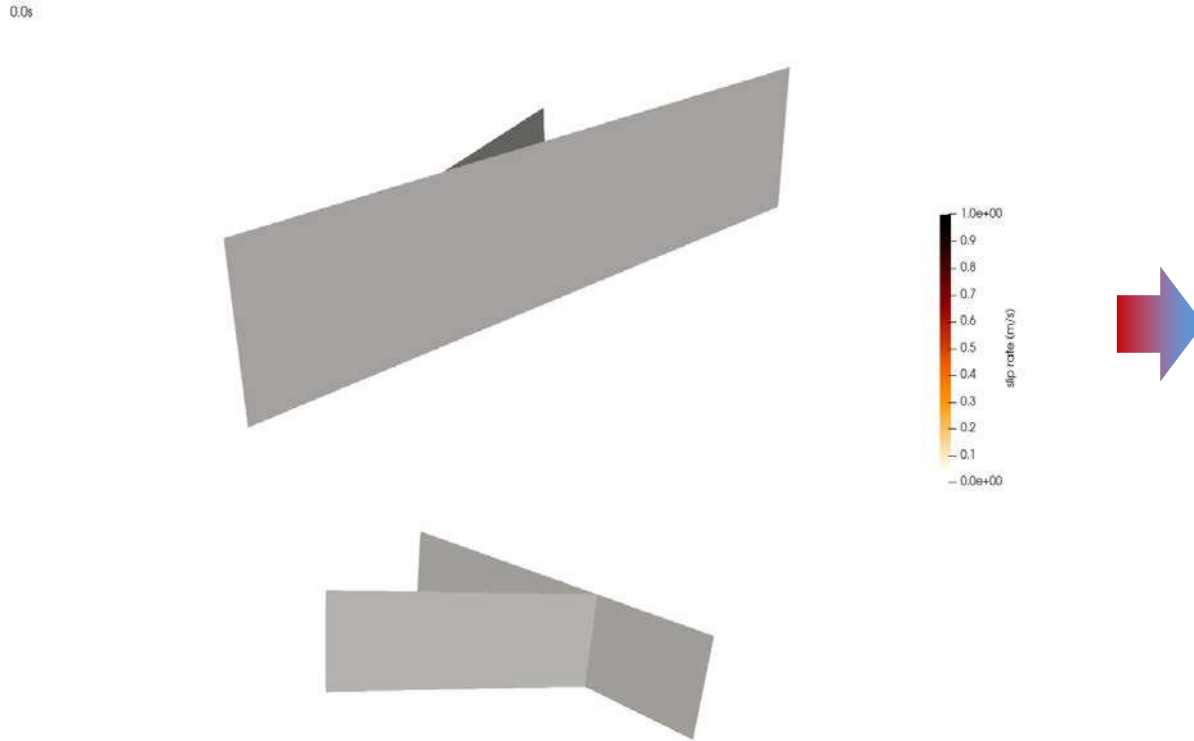
- Model is simulated and after ~10 years, failure criterion is met



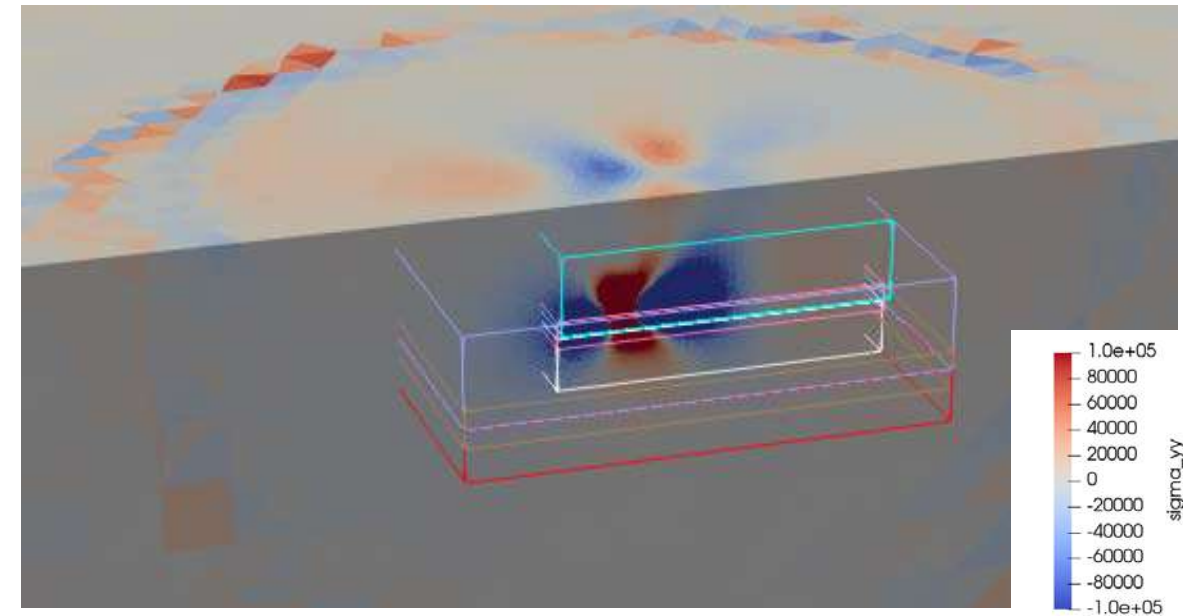
During and after rupture

➤ Linear slip weakening friction model

Slip rate (m/s)



Stress change (Pa)



Conclusion & Outlook

➤ CONCLUSION

- Static slip-tendency analysis highlight the most hazardous fault areas in terms of potential seismicity
 - Helps to design well trajectory and define well type (inj./prod.)
- Dynamic THM modelling
 - Highlights the role of the thermal effects close to the injection well
 - Can estimate ground deformation
 - Necessary for long-term hazard assessment
- THM-Seismicity
 - Coupling complex 3D THM reservoir models with SeisSol is demonstrated
 - The simulation of multiple seismic events during the life span of reservoir can be achieved
 - Coupling of two open-source codes triggered by a failure criterion

➤ OUTLOOK

- Continue with THM-Seismicity modelling
 - Better account for THM response to fault failure: poro/perm enhancement, heating during failure...
 - Apply concept to real field data

Agenda

Start time	Topic	Speaker
08:30	Welcome, coffee, registration	
09:00	Welcome message, Video, Project overview	R. Baasch, E. Gaucher
09:20	Well-based data acquisition and analysis	P. Goblirsch, K. Thiemann
09:55	Seismic monitoring	J. Azzola
10:30	Geodetic monitoring	M. Westerhaus
11:05	Break	
11:20	Geothermal reservoir numerical modelling	E. Gaucher, A. Savvatis, R. Habibi
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12:30	Communication to the public	P. Goblirsch
12:45	Conclusion, outlook and discussion	G. Bergdolt
13:30	Lunch break	
<i>14:30</i>	<i>Non-public operator meeting</i>	

Reservoir Management System concept



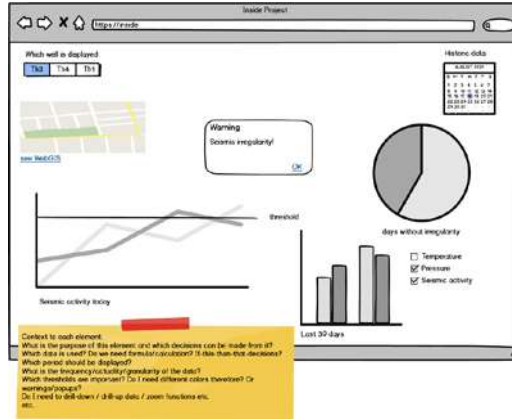
Pixabay (free for use)

- Proposal for the Reservoir Management System Concept
- Proposal for data management and integration
- Developed INSIDE prototype and test

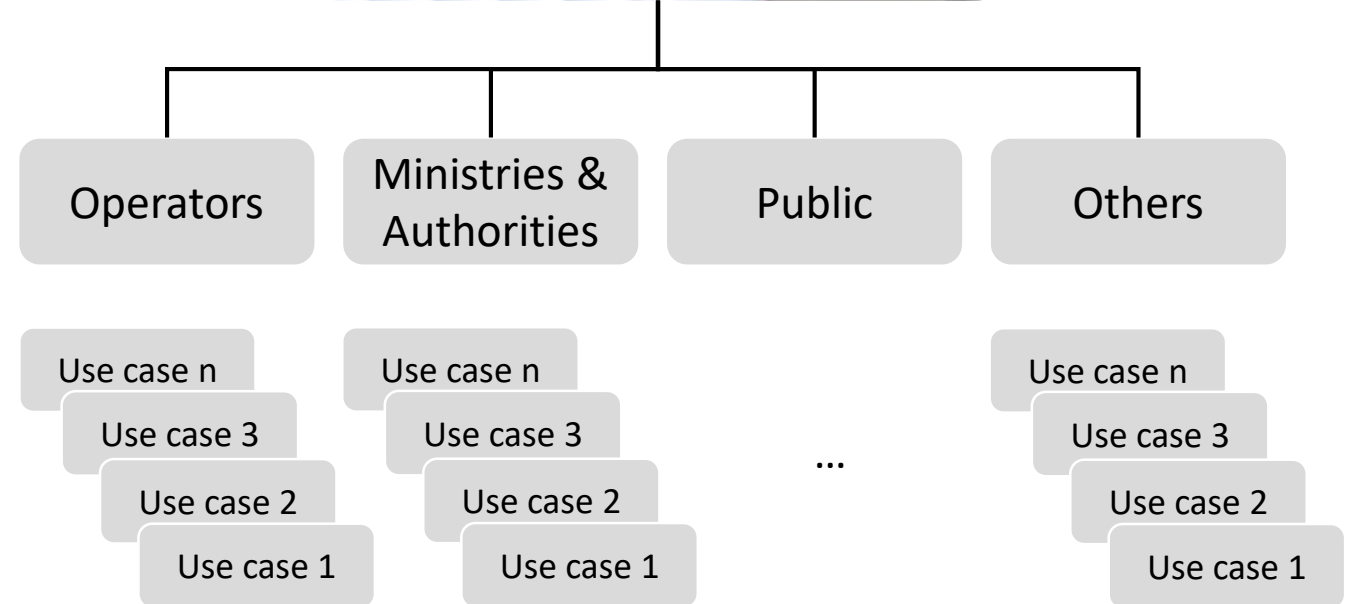
Katja Thiemann, Bettina Hille, Martin Klaus, Georg Aures, Maximilian Hansinger, Martin Potten, Peter Goblirsch, Ralph Baasch, Emmanuel Gaucher *et al.*

Reservoir Management System concept

MOTIVATIONS:



- Risk minimization in heat mining (e.g. induced seismicity, ground deformation)
- Optimized management, e.g. observing, planning, and controlling thermal-hydraulic interactions of the reservoir
- Safe and sustainable production operation



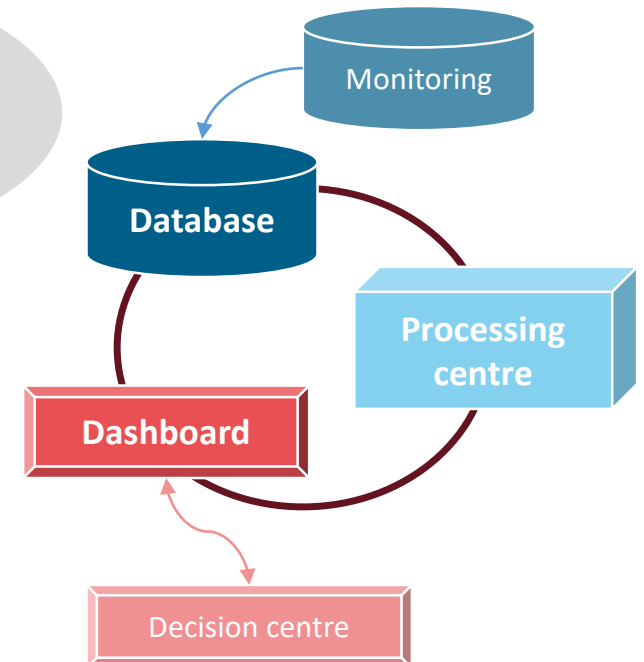
Reservoir Management System concept

➤ Task

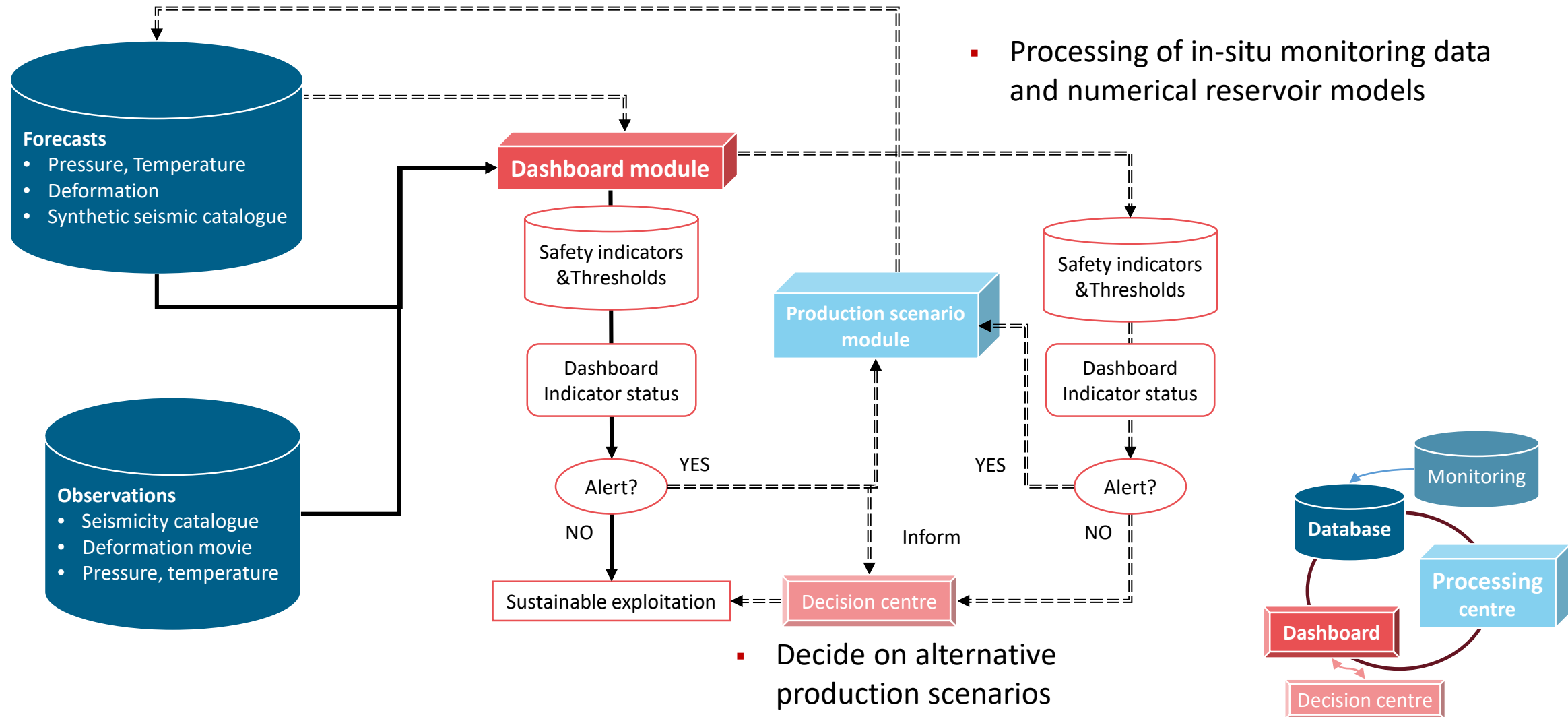
- Defining requirements and development of guidelines for establishing a dynamic RMS

Development of procedures for integrating the INSIDE results into a dynamic reservoir management system and for designing a technical setup in the control center

Possible operational recommendations

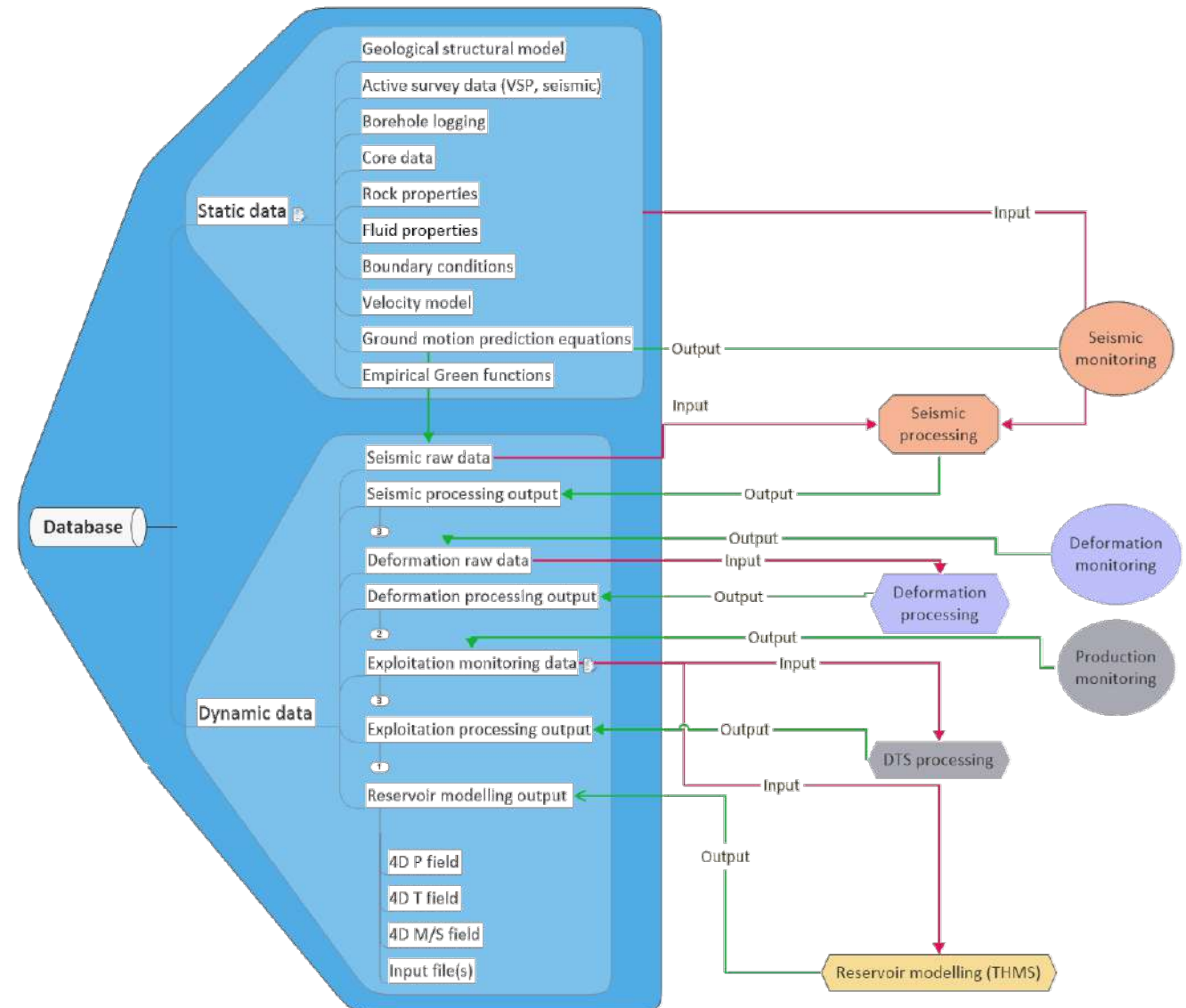
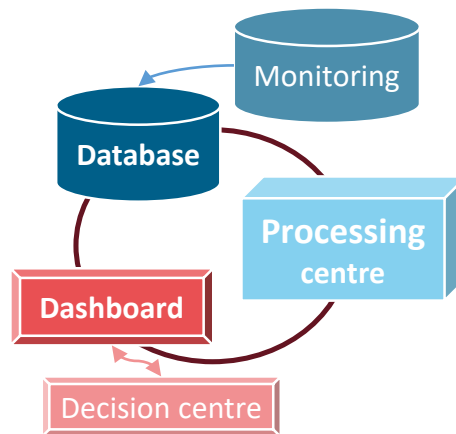


Reservoir Management System concept



Concept for data management and integration

- The reservoir management system modules communicate through the database



Concept for data management and integration

1. Analysis of hardware and software requirements, concept & design of data management

KEY QUESTIONS FOR THE DATA MANAGEMENT:

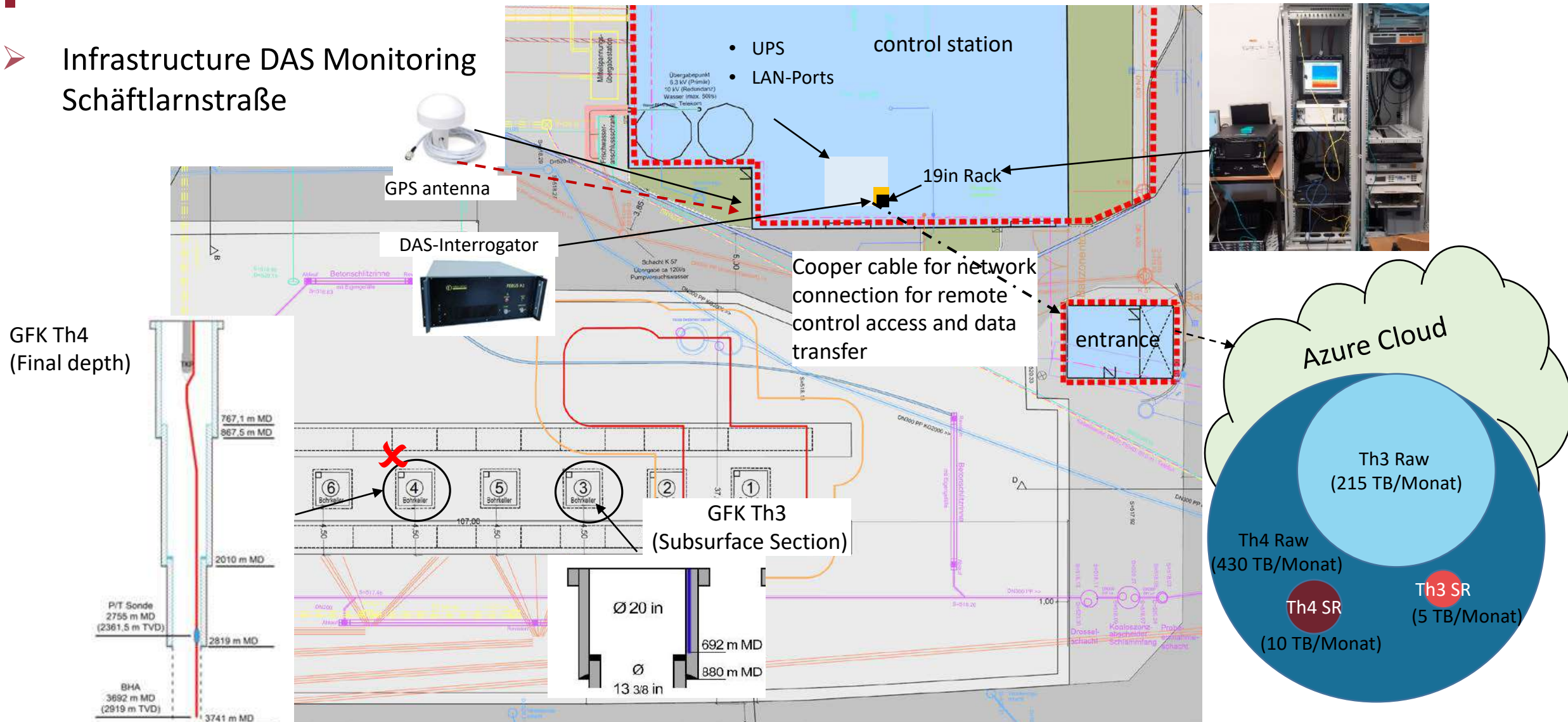
- Which technology and architecture to use for data storage?
- Who has access to the data?
- Data availability?
- Deployment of algorithms into production?
- Data handling?

2. Development of a data management system, implementation of shared access rights, data integration

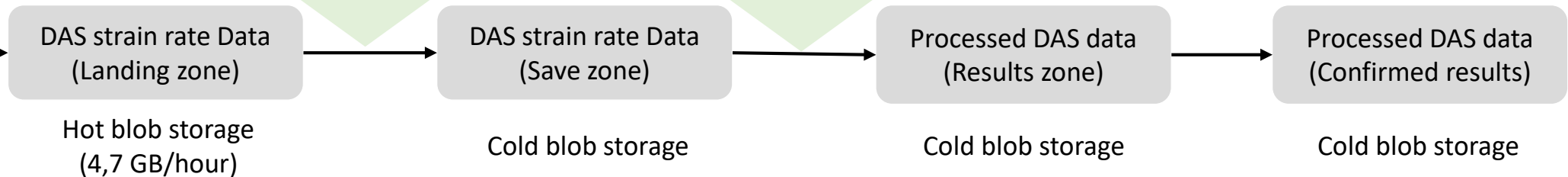
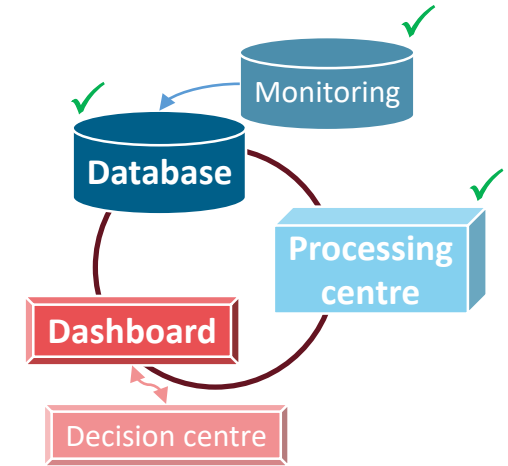
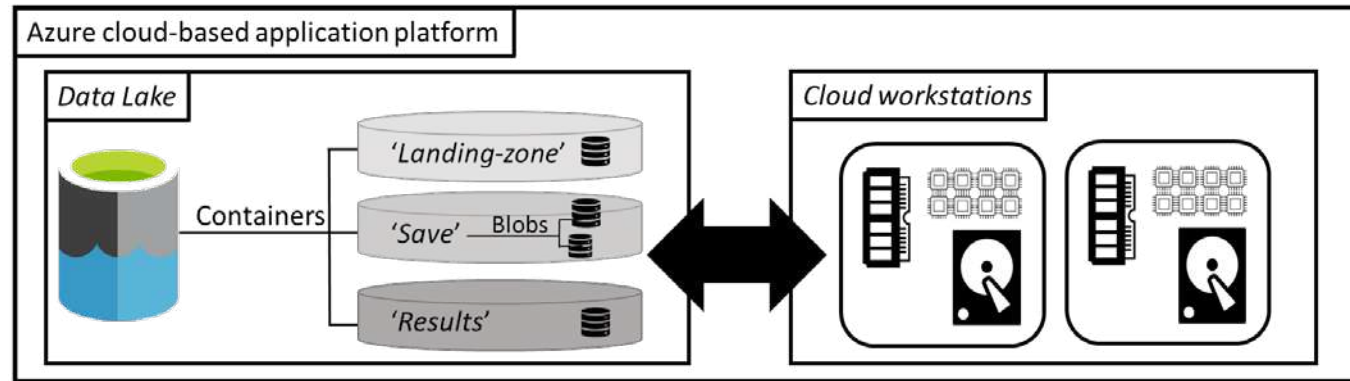
3. Designing a data management concept for long-term regional data acquisition, transmission, storage and analysis

Developed INSIDE prototype and system test

➤ Infrastructure DAS Monitoring Schäftlarnstraße



Developed INSIDE prototype and system test



Developed INSIDE prototype and system test

➤ INSIDE prototype dashboard developed in Jupyter notebook with synthetic data:

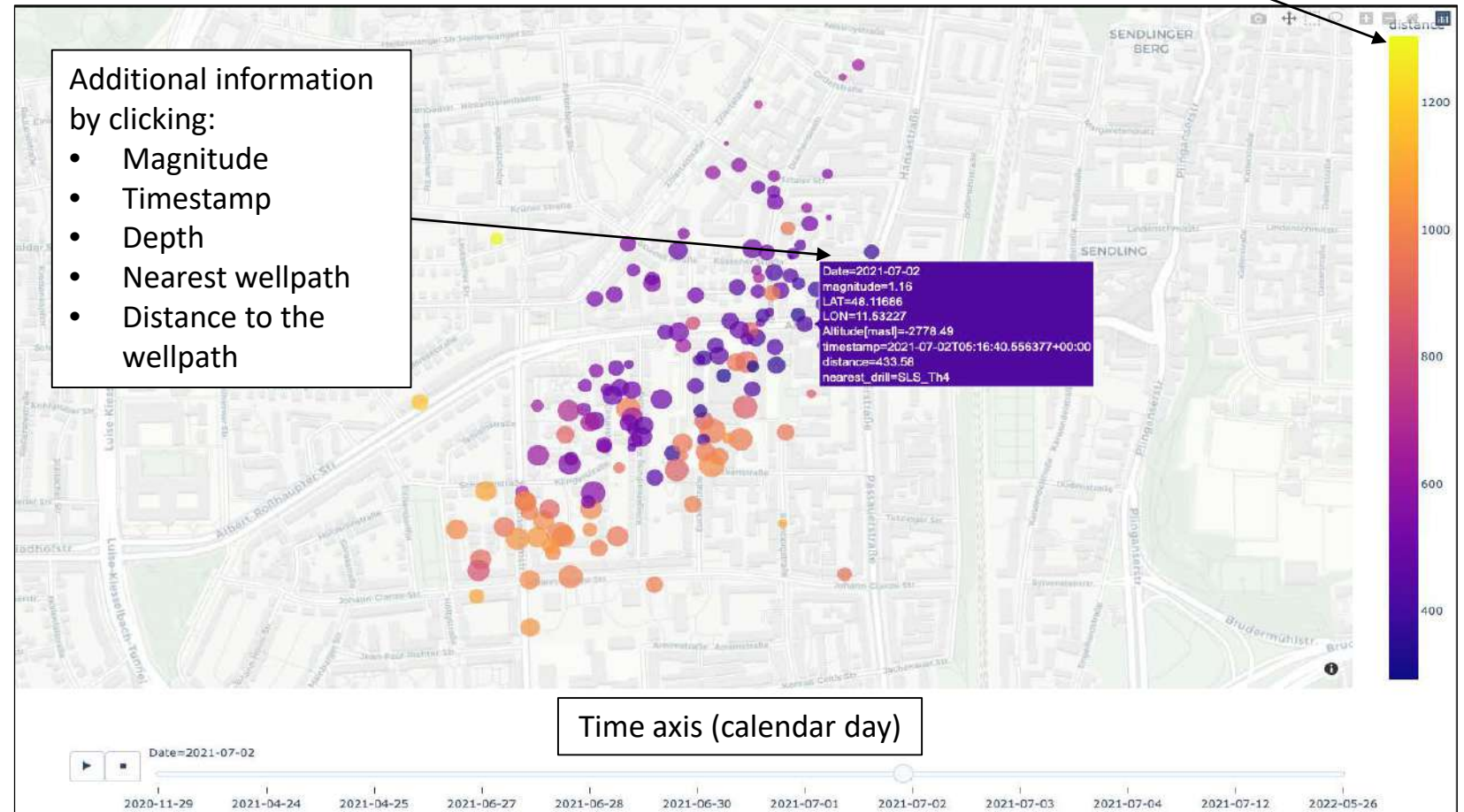
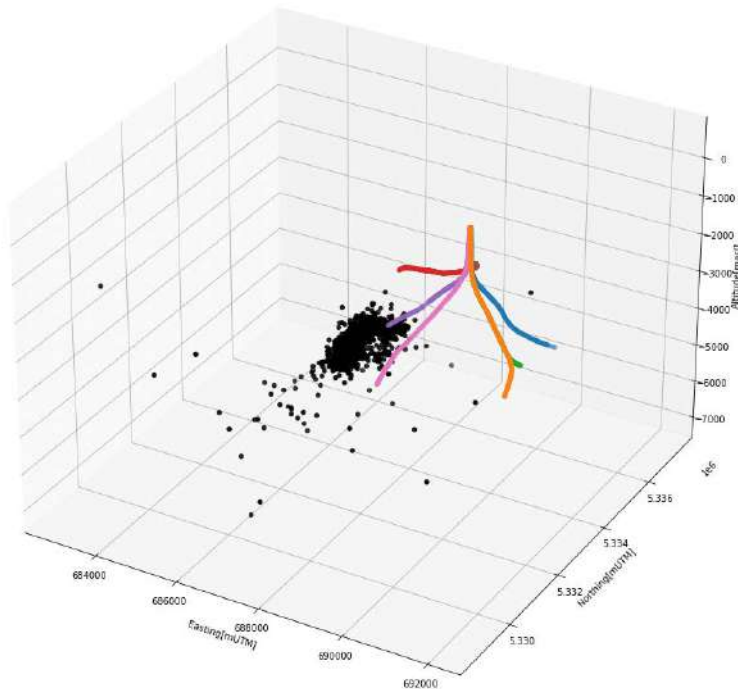
- No linking to data systems, models, analysis methods (Jupyter Notebook)
- No integration into live operation possible

Traffic light coding of the threshold values (magnitude level)



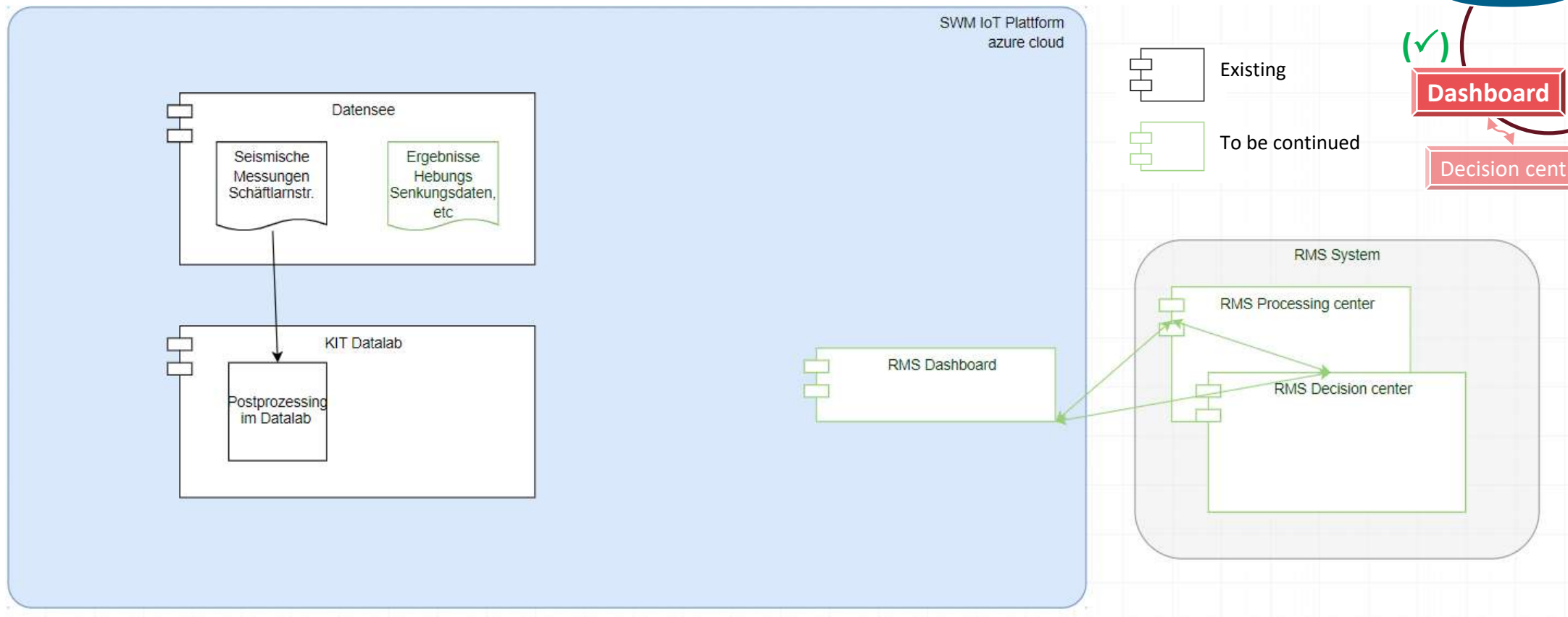
Developed INSIDE prototype and system test

- INSIDE prototype dashboard developed in Jupyter notebook with synthetic data:



Developed data management and integration

- Status quo of the developed INSIDE prototype Reservoir Management System and the data management



Developed data management and integration

✓
1. Analysis of hardware and software requirements, concept & design of data management

Concept for the scope "DAS Monitoring" is created.

- Data lake on the Azure cloud has been instantiated. Currently, no additional data repositories are planned in the data lake.
- Basic technical concept for implementing access rights is created. Data access for SWM and KIT has been provided.
- Concept for transferring data from the data lake including provision for the dashboard is developed

✓
2. Development of a data management system, implementation of shared access rights, data integration

- Concept development of data management for long-term, regional data acquisition, transfer, and storage via the DAS monitoring of Schäftlarnstraße.
- Usage concept for Data Lab was developed. DAS data evaluations were conducted in the KIT Data Lab environment → no real-time data evaluations

✓
3. Designing a data management concept for long-term regional data acquisition, transmission, storage and analysis

Conclusion & Outlook

➤ Task

- Defining requirements and development of guidelines for establishing a dynamic RMS → to be continued

Development of procedures for integrating the INSIDE results into a dynamic reservoir management system ✓

and for designing a technical setup in the control center ✗

Possible operational recommendations ✗



Operators

Others

SW/M

IE SP
INNOVATION ENERGY EFFICIENCY

KIT
Karlsruher Institut für Technologie

Use case 1: DAS-Monitoring¹
¹Feasibility study Schäftlarnstraße.
Cemented fiber optic cable in the first section of the Th3 borehole. No real-time evaluation has been conducted.

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Kommunikation

- Strategie
- Umsetzung
- Bewertung



Man kann nicht nicht
kommunizieren.

Paul Watzlawick

Peter Goblirsch, IEP GmbH

Peter Goblirsch, Ralph Baasch, Katja Thiemann, Doris Betzl, Jérôme Azzola, Emmanuel Gaucher *et al.*

➤ KEY QUESTIONS

- Wie kommunizieren wir die Ergebnisse aus dem Projekt INSIDE?
- Wie können wir die Akzeptanz in der Bevölkerung bezüglich induzierter Seismizität und Bodendeformation im möglichen Zusammenhang mit Tiefer Geothermie steigern?

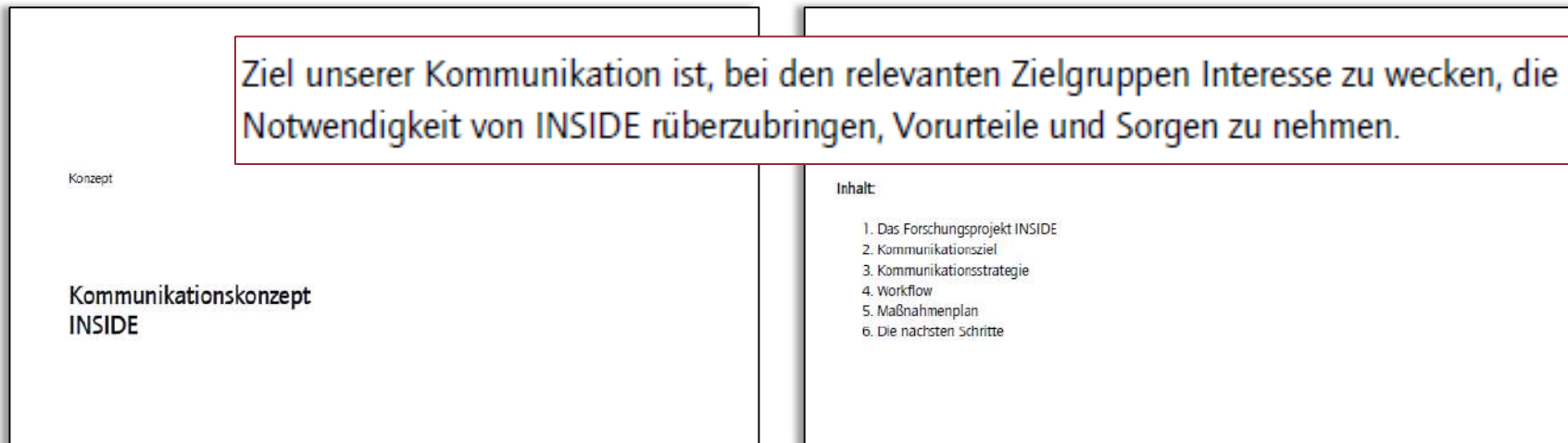


- AP 6.1: Entwicklung von Kommunikationskonzepten und einer -strategie zur Vermittlung der Forschungsergebnisse
- AP 6.2: Umsetzung der Kommunikationsstrategie
- AP 6.3: Bewertung der Kommunikationsstrategie
- AP 6.4: Wissenstransfer u.a. peer-reviewed Publikationen, wissenschaftliche Konferenzen, Workshops

Kommunikation – Strategie & Konzept

AP 6.1: Entwicklung von Kommunikationskonzepten und einer -strategie

Kernaussage: Im Molassebecken sind keine Schadboden, ausgelöst durch Tiefe Geothermie, zu erwarten. Kleine, meist kaum wahrnehmbare Erschütterungen könnten jedoch in Einzelfällen auftreten – denn jede Art der Energieerzeugung hat gewisse Nebenwirkungen auf unsere Umwelt. Trotzdem wollen wir mehr über die Prozesse und Wirkzusammenhänge im Untergrund verstehen, um die Akzeptanz in der Bevölkerung zur flächendeckenden Nutzung der Tiefen Geothermie zu steigern.



Kommunikationskonzept wurde durch alle Partner gemeinsam mit einer Marketing Agentur erstellt.

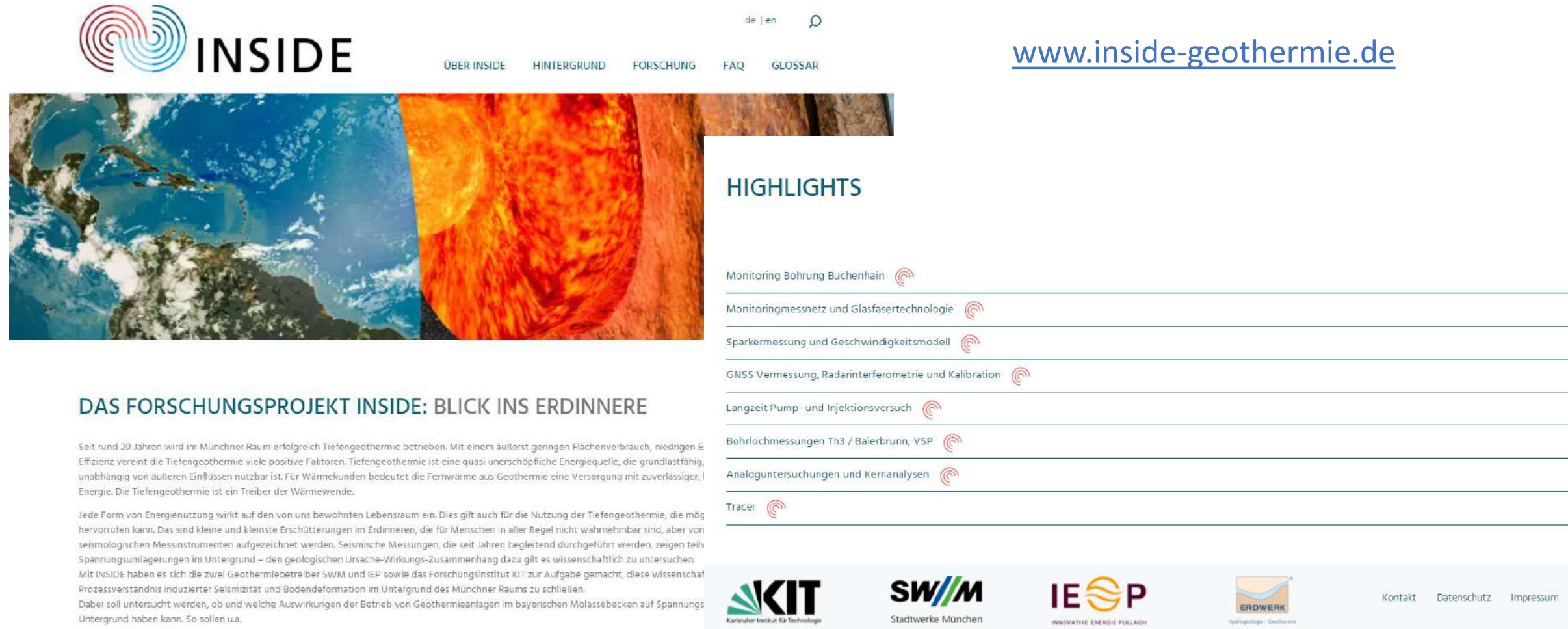
Maßnahmenplan Kommunikationskonzept:

- ❖ Website ✓
- ❖ Flyer ✓
- ❖ Presse- und Medienarbe ✓
- ❖ Reportage-Kurzfil ✓
- ❖ Erklärfilm ✓
- ❖ Bewertung der Kommunikationsstrategie ✓

Kommunikation – Website



Website: Online seit Frühjahr 2021



The screenshot shows the homepage of the INSIDE website. At the top left is the INSIDE logo. To its right are navigation links: ÜBER INSIDE, HINTERGRUND, FORSCHUNG, FAQ, and GLOSSAR. A language selector 'de | en' and a search icon are also present. Below the navigation is a large banner image split into two parts: the left part shows a satellite view of the Earth, and the right part shows a cross-section of the Earth's interior with a glowing orange-red core. Below the banner, the heading 'DAS FORSCHUNGSPROJEKT INSIDE: BLICK INS ERDINNERE' is followed by a paragraph of text. To the right of the text is a 'HIGHLIGHTS' section with a list of project activities, each preceded by a small circular icon. At the bottom of the page is a footer containing logos for KIT, SWM, IESP, and ERDWERK, along with links for Kontakt, Datenschutz, and Impressum.

INSIDE

ÜBER INSIDE HINTERGRUND FORSCHUNG FAQ GLOSSAR

de | en

www.inside-geothermie.de

HIGHLIGHTS

- Monitoring Bohrung Buchenhain
- Monitoringmessnetz und Glasfasertechnologie
- Sparkermessung und Geschwindigkeitsmodell
- GNSS Vermessung, Radarinterferometrie und Kalibration
- Langzeit Pump- und Injektionsversuch
- Bohrlochmessungen Th3 / Baierbrunn, VSP
- Analoguntersuchungen und Kernanalysen
- Tracer

DAS FORSCHUNGSPROJEKT INSIDE: BLICK INS ERDINNERE

Seit rund 20 Jahren wird im Münchner Raum erfolgreich Tiefengeothermie betrieben. Mit einem äußerst geringen Flächenverbrauch, niedrigen E Effizienz vereint die Tiefengeothermie viele positive Faktoren. Tiefengeothermie ist eine quasi unerschöpfliche Energiequelle, die grundlastfähig, unabhängig von äußeren Einflüssen nutzbar ist. Für Wärmekunden bedeutet die Fernwärme aus Geothermie eine Versorgung mit zuverlässiger, l Energie. Die Tiefengeothermie ist ein Treiber der Wärmewende.

Jede Form von Energienutzung wirkt auf den von uns bewohnten Lebensraum ein. Dies gilt auch für die Nutzung der Tiefengeothermie, die mög hervorrufen kann. Das sind kleine und kleinste Erschütterungen im Erdinneren, die für Menschen in aller Regel nicht wahrnehmbar sind, aber von seismologischen Messinstrumenten aufgezeichnet werden. Seismische Messungen, die seit Jahren begleitend durchgeführt werden, zeigen teilv Spannungsumlagerungen im Untergrund – den geologischen Ursache-Wirkungs-Zusammenhang dazu gilt es wissenschaftlich zu untersuchen. Mit INSIDE haben es sich die zwei Geothermiebetreiber SWM und IEP sowie das Forschungsinstitut KIT zur Aufgabe gemacht, diese wissenschaft Prozessverständnis induzierter Seismizität und Bodendeformation im Untergrund des Münchner Raums zu schließen. Dabei soll untersucht werden, ob und welche Auswirkungen der Betrieb von Geothermieanlagen im bayerischen Molassebecken auf Spannungs Untergrund haben kann. So sollen u.a.

KIT
Karlsruher Institut für Technologie

SWM
Stadtwerke München

IESP
INNOVATIVE ENERGIE PULLACH

ERDWERK
Hydrogeologie · Geothermie

Kontakt Datenschutz Impressum

Kommunikation – Auswertungen Website

Von **28.09.2020** bis 13.02.2024
haben **1.688 Besucher*innen**
61,36 Stunden auf der Website verbracht

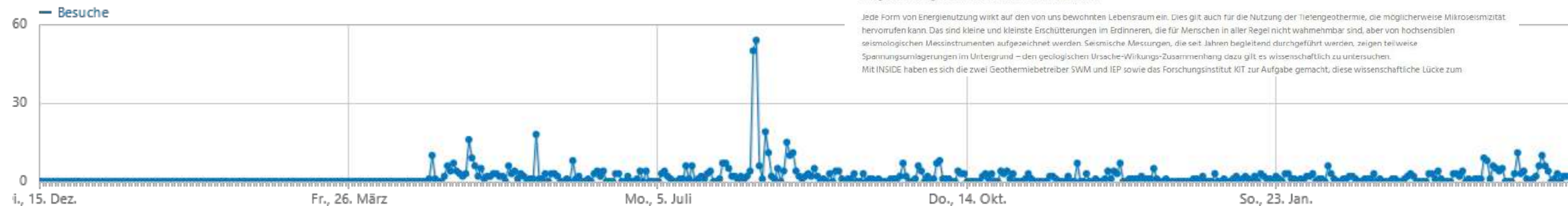


» Neuigkeiten im INSIDE Forschungsprojekt

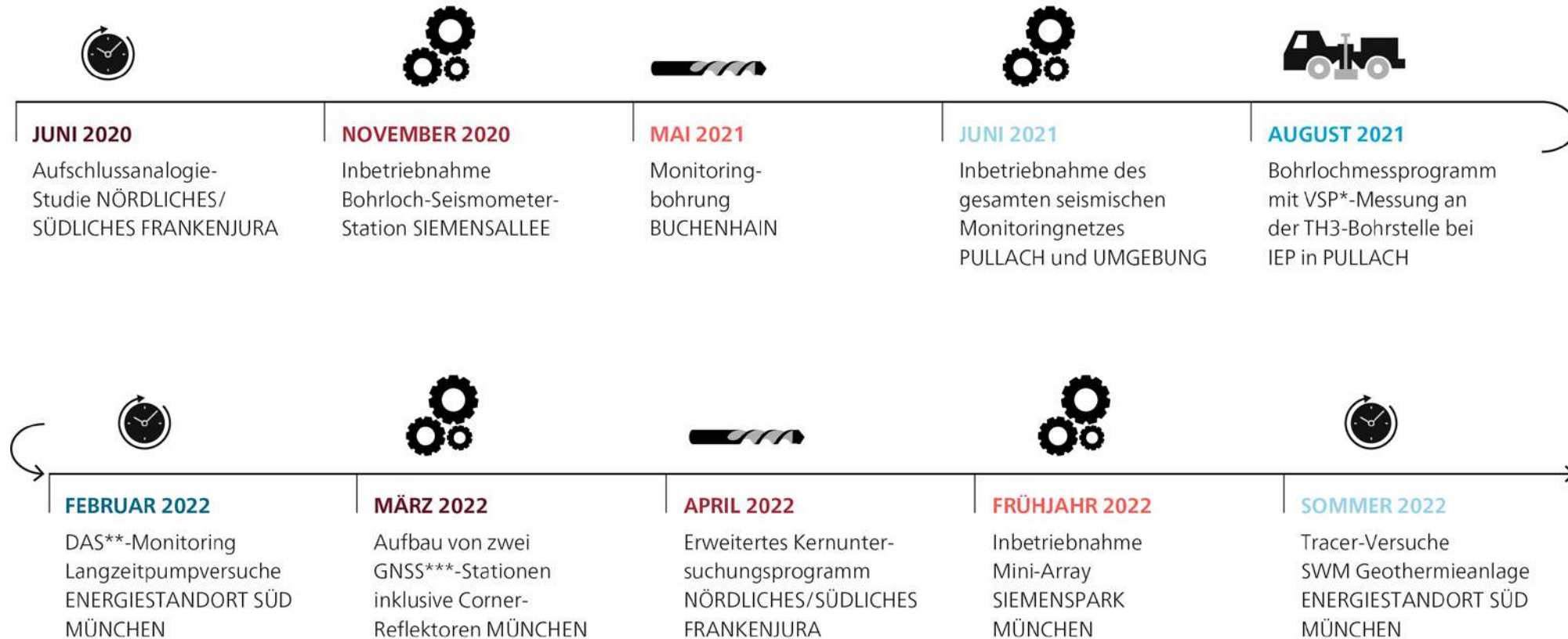
DAS FORSCHUNGSPROJEKT INSIDE: BLICK INS ERDINNERE

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Jede Form von Energienutzung wirkt auf den von uns bewohnten Lebensraum ein. Dies gilt auch für die Nutzung der Tiefengeothermie, die möglicherweise Mikroseismizität hervorrufen kann. Das sind kleine und kleinste Erschütterungen im Erdinneren, die für Menschen in aller Regel nicht wahrnehmbar sind, aber von hochsensiblen seismologischen Messinstrumenten aufgezeichnet werden. Seismische Messungen, die seit Jahren begleitend durchgeführt werden, zeigen teilweise Spannungsanlagerungen im Untergrund – den geologischen Ursache-Wirkungs-Zusammenhang dazu gilt es wissenschaftlich zu untersuchen. Mit INSIDE haben es sich die zwei Geothermiebetreiber SWM und IEP sowie das Forschungsinstitut KIT zur Aufgabe gemacht, diese wissenschaftliche Lücke zum



Kommunikation – Grafiken Website



* vertical seismic profiling

** DAS: Distributed Acoustic Sensing

*** GNSS: Globales Navigations-Satellitensystem

Die angegebenen Daten geben den Start der jeweiligen Maßnahmen an.

Kommunikation – Flyer

Flyer: Individuell wurden Wurfblätter für die Monitoringbohrung in Buchenhain designed.

INSIDE-FORSCHUNGSMETHODEN UND -FELDER

Seismische Messungen werden seit Jahren begleitend zu Geothermieforschungsprojekten durchgeführt – sie zeigen teilweise Spannungsumlagerungen im Untergrund. Die geologischen Ursache-Wirkungs-Zusammenhänge dazu gilt es jetzt wissenschaftlich zu untersuchen.

Mit INSIDE sollen kontinuierlich akustische Signale aus oberflächennahen seismischen Messnetzen sowie dem tieferen Untergrund aufgezeichnet werden, die auf mögliche Mikroseismizität hinweisen. Beobachtungsbohrungen liefern den Forschern ungestörte Schallsignale, die frei von Hintergrundgeräuschen erfasst werden können. Diese Daten werden dann in Beziehung gesetzt zu den Daten an den Oberflächenstationen.

IM EINZELNEN SOLL/EN MIT INSIDE

- Mikroseismizität räumlich und zeitlich hochauflösend aufgenommen und in 3D-geologischen Datensätzen verortet werden,
- mögliche Bodenhebungen und -senkungen im Millimeterbereich satellitengestützt gemessen und mit Feldmessungen kalibriert werden,
- ein Geschwindigkeitsmodell mit Hilfe von Messungen aufgebaut werden, das eine exakte Tiefenlokalisierung mikroseismischer Ereignisse zulässt und
- ein Reservoirmodell entwickelt werden, das noch besser verständlich macht, in welchem Kausalverhältnis die Art und Weise der Nutzung geothermischer Ressourcen zu den beobachteten Effekten steht.

SIE HABEN FRAGEN ODER WÜNSCHEN SICH VERTIEFENDE INFORMATIONEN?

Schreiben Sie uns eine E-Mail an:
info@inside-geothermie.de

oder besuchen Sie unsere Website:
www.inside-geothermie.de

DIE PROJEKTPARTNER

Innovative Energie für Pullach (IEP) GmbH



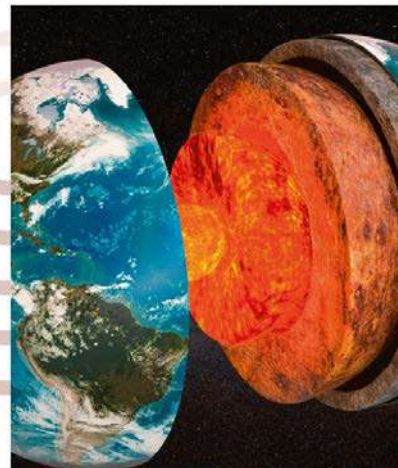
SWM – Stadtwerke München GmbH



KIT – Karlsruher Institut für Technologie



Das Forschungsprojekt INSIDE: Blick ins Erdinnere



WELCHES ZIEL VERFOLGT DAS FORSCHUNGSPROJEKT INSIDE?

Wir wollen noch besser verstehen, ob und wie die Nutzung von Geothermie in den Untergrund einwirken kann. Dies erforschen nun die Stadtwerke München (SWM) und die Innovative Energie für Pullach (IEP), unterstützt vom Forschungsinstitut KIT.

Der Raum München ist Deutschlands Geothermie-Hochburg. Als Energiequelle zu unseren Füßen liefert Tiefengeothermie seit rund 20 Jahren erneuerbare Wärmeenergie – jeden Tag, mit einem äußerst geringen Flächenverbrauch, niedrigen Emissionen und absolut zuverlässig. Tiefengeothermie ist eine quasi unerschöpfliche Energiequelle, die grundlastfähig, das heißt stabil und unabhängig von äußeren Einflüssen nutzbar ist. Für Wärmekunden bedeutet die Fernwärme aus Geothermie eine Versorgung mit zuverlässiger heimischer erneuerbarer Energie. Die Tiefengeothermie ist ein Treiber der Wärmewende.

Geothermie kann kleinste Erschütterungen im Erdinneren hervorrufen, die für uns Menschen in aller Regel nicht wahrnehmbar sind. Geowissenschaftler nennen dies „Mikroseismizität“. Feinste Messgeräte zeichnen diese Spannungsumlagerungen im Untergrund auf. Was dabei genau im Boden passiert, ist wissenschaftlich noch nicht hinreichend erforscht. Das Forschungsprojekt INSIDE will dies ändern. Die Projekt-Laufzeit beträgt vier Jahre.

WAS IST INSIDE?

INSIDE steht als Kurzform für die „Untersuchung von Induzierter Seismizität und BodenDeformation als Interferenzaspekte beim Betrieb von Geothermieranlagen im bayerischen Molassebecken“.

INSIDE hört im wahren Sinne des Wortes in den Boden hinein – feinste Messgeräte liefern dafür die notwendigen Daten, insbesondere über Monitoring-Netze und -Bohrungen.

INSIDE wird vom Bundesministerium für Wirtschaft und Energie über den Projektträger Jülich (PTJ) gefördert.

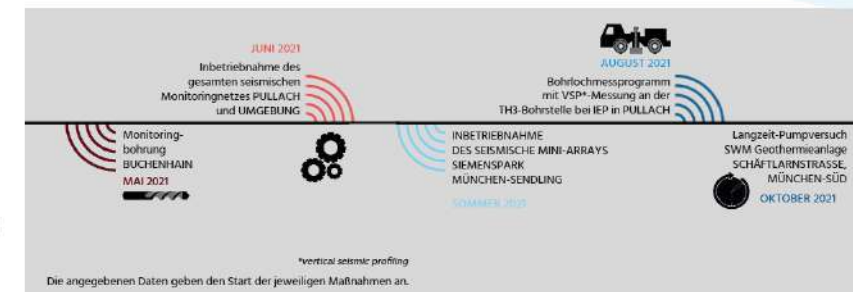
INSIDE-MEILENSTEINE

Die Grafik zeigt die Forschungs-Meilensteine im Jahr 2021. Die dabei gewonnenen Daten werden die beteiligten Wissenschaftlerinnen und Wissenschaftler dann in Folge aus.

ZITAT

„Mikroseismizität, wie es sie in Mitteleuropa immer wieder gibt, ist für Menschen in aller Regel nicht bis kaum wahrnehmbar. Aber sie ist da. Deshalb wollen wir genau wissen, ob und wie sie durch geothermische Aktivitäten beeinflusst oder hervorgerufen wird. INSIDE „hört“ mit Messgeräten in den Boden hinein – wir erwarten uns davon wertvolle Erkenntnisse. Diese Erkenntnisse können dem Ziel der bayerischen Regierung, 25% des bayerischen Wärmebedarfs bis 2050 aus Geothermie zu decken, nur nutzen.“

Michael Meinecke, Stadtwerke München



Kommunikation – Pressemitteilungen

Presse und Medienarbeit:

- Artikel im Isaranzeiger zur Monitoring-Bohrung Buchenhain
- Artikel im Isaranzeiger zur VSP-Messung und BLM an der Pullach Th3
- BR – Radio Beiträge und „Leschs Kosmos“
- Pressemitteilung zu INSIDE Projekt auf SWM Presseseite und SWM Medienverteiler



SWM Tarife & Angebote Service & Beratung Unternehmen Magazin Kontakt Meine SWM

GEMEINSCHAFTLICHES GEOTHERMIE-FORSCHUNGSPROJEKT

Geothermie-Forschung: INSIDE horcht ins Erdinnere

12.04.2022 | Wie wirkt sich die Nutzung von Geothermie im Untergrund aus? Gibt es kurzfristige, dauerhafte oder auch nur minimale Veränderungen? Diesen Fragen geht das mehrjährige Forschungsprojekt INSIDE auf den Grund, in dem die Geothermie-Betreiber SWM und Innovative Energie für Pullach (IEP) mit dem Forschungsinstitut Karlsruher Institut für Technologie (KIT) zusammenarbeiten.

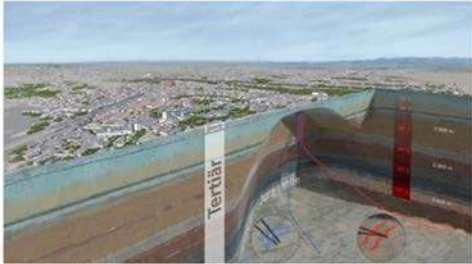
Glasfaserkabel liefern Echtzeit-Daten aus den Bohrungen

Das INSIDE-Projektteam sammelt mit teils erstmalig hierfür eingesetzter Technik umfangreiche Daten über die Vorgänge in der südbayerischen Molasse. Ziel ist es, mehr über induzierte Mikrosensitivität und Boden deformation im Untergrund des Münchner Raums zu erfahren. Die Erkenntnisse über die geologischen und geomechanischen Gegebenheiten sind dann Grundlage dafür, dass Geothermieprojekte und -Anlagen künftig noch besser geplant und betrieben werden können.

Ein Forschungs-Ort ist die Geothermieanlage der SWM am Energiestandort Süd. Hier lauschen die Fachleute ganz tief in den Untergrund.

Ein wichtiger Meilenstein wurde jetzt erreicht, wie die Geophysikerin Katja Thiernann, INSIDE-Projektleiterin bei den SWM, erläutert: „Die Geothermieanlage in der Schäftlarnstraße läuft aktuell im Erprobungsbetrieb. Schon 2020, während der Bauphase, haben wir in einer 3.750 Meter langen Bohrung sowie in der zementierten Verrohrung einer weiteren Bohrung bis in über 700 Meter Tiefe Glasfaserkabel verlegt. Damit ist uns die permanente Datenübertragung und -auswertung aus diesen Bohrungen gelungen – eine Premiere bei der Messmethode, die in Fachkreisen für viel Aufmerksamkeit gesorgt hat.“

Querschnitt der Erdschichten



Vom Energiestandort Süd gehen drei doppelte Bohrungen (Doubletten) in die Tiefe.



Akustische Messungen im Thermalwasser-Reservoir

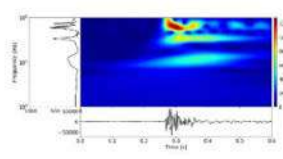
Die seismische Überwachung basiert auf der sogenannten „Distributed Acoustic Sensing“ (DAS) Technologie. Die Methode ermöglicht kontinuierliche akustische Messungen in Echtzeit über die gesamte Länge eines Glasfaserkabels. Die DAS-Daten werden einmal pro Stunde aus den Bohrungen in die SWM Cloud übertragen und können dort analysiert werden. Somit wird nahezu in Echtzeit ins Thermalwasser-Reservoir gehorcht. Minimale Ereignisse im Untergrund, die aus der gewohnten Frequenz fallen, können nach ihrer Ursache und Dauer untersucht werden.

Datenanalyse



Jérôme Azzola (links) analysiert mit einem Kollegen die Echtzeit-Daten aus der Geothermie-Bohrung in der Schäftlarnstraße.

Visualisierung



Ansicht eines Amplitudenspektrums aus der Bohrung am Energiestandort Süd.

© KIT

Film: Geothermie-Forschungsprojekt INSIDE



Kommunikation – Marketing-Kurzfilme

- Reportage Kurzfilm
- Erklärfilm

Die Story:

- ✓ Tiefengeothermie spielt eine zentrale Rolle für die Fernwärmeversorgung der nahen Zukunft im Raum München.
- ✓ Tiefengeothermie spielt eine zentrale Rolle in der Dekarbonisierung der Nah- und Fernwärme und ist ein Treiber der Wärmewende.
- ✓ Vorteile: erneuerbare Energie, klimaschonend, sicher, unerschöpflich, lokal, verlässliche Wärmeversorgung.
- ✓ Warum Forschung zu Geothermie? Um die Grundlagen für einen nachhaltigen, effizienten und sicheren Betrieb der perspektivisch wachsenden Zahl von Tiefengeothermie-Anlagen in der Region zu schaffen.



www.inside-geothermie.de

Kommunikation – Umsetzung Übersicht

Datum	Maßnahme
Oktober 2020	INSIDE Website konzipiert
23.04.2021	Dreharbeiten für einen Teaser an der Geothermie Schäftlarnstraße (GTH SLS) → Content von Baierbrunn und KIT Oktober 2021 wurde der Film auf der Homepage veröffentlicht.
Ende April 2021	Go-live der INSIDE-Homepage www.inside-geothermie.de
September 2021	Einrichtung Newsticker-Zeile auf der Website.
24.03.2022	Filmdreh mit KIT und SWM zum DAS-Monitoring GTH SLS und satellitengestützten Messtechnologie zum Deformationsmonoring. Veröffentlichung Video MünchenTV: 30.03.2022, SWM Youtube: 31.03.2022
1.4.2022	Pressemitteilung zu INSIDE Projekt auf SWM Presseseite und SWM Medienverteiler https://www.swm.de/presse : 01.04.2022, Verteiler der Pressemeldung auch über dpa bundesweit (~980 Abrufe), Veröffentlichung im Magazin-Bereich auf SWM Homepage: www.swm.de/magazin/energie/geothermie-forschung
April 2022	Socialmedia: Tweet zu INSIDE mit Link zum Video auf SWM Twitterkanal 1.4. (15.000 Follower), Post mit Video auf SWM Facebookkanal 3.4.2022, Thema im SWM Kundennewsletter April 2022 (26 T Empfänger).
April/Mai 2022	Erklärfilm zu INSIDE und zur Fernwärmewende am Bsp. Geothermie. Filmbeitrag wurde auf der INSIDE Homepage und dem SWM Youtube Kanal veröffentlicht.
27.09.2022	Dreh für „Leschs Kosmos“, Thema: „Energie nach 2022“ mit Schwerpunkt Geothermie mit Dreh Experten-Meeting INSIDE-Beteiligte SWM und KIT. Ausstrahlung von „Leschs Kosmos“: 08.11.2022
23.12.2022	BR „Radio Wissen“ Beitrag zur Tiefengeothermie und INSIDE mit Experteninterviews „Tiefe Geothermie – Energie der Zukunft?“ . INSIDE-Beteiligte SWM und IEP

- Three peer-reviewed papers
 - One published
 - Two under revision
- 21 conferences: abstracts, posters
 - Deutsche Geophysikalische Gesellschaft (DGG)
 - Deutscher Geothermie Kongress (DGK)
 - European Geothermal Workshop (EGW)
 - European Geothermal Congress (EGC)
 - European Geoscience Union (EGU)
 - European Association of Geoscientists & Engineers (EAGE)
 - American Geophysical Union (AGU)

Azzola et al. *Geothermal Energy* (2023) 11:30
<https://doi.org/10.1186/s40517-023-00272-4>

Geothermal Energy

RESEARCH

Open Access

Integration of distributed acoustic sensing for real-time seismic monitoring of a geothermal field

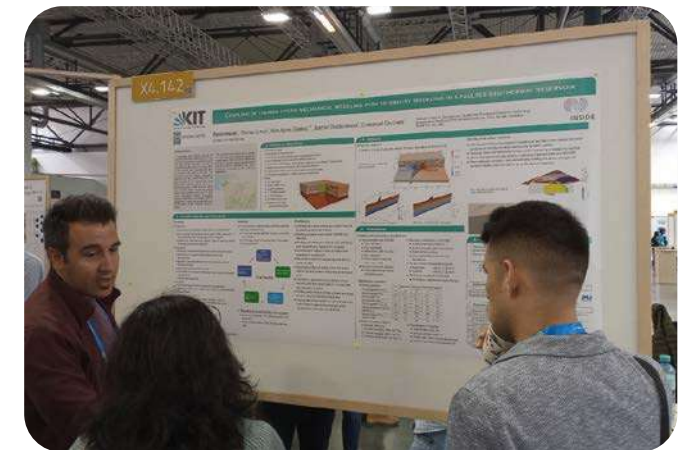
Jérôme Azzola^{1*}, Katja Thiemann² and Emmanuel Gaucher¹

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Geosciences (AGW), Karlsruhe
Institute of Technology (KIT),
Karlsruhe, Germany

Abstract

To accelerate the energy transition, the exploitation of deep geothermal reservoirs is becoming a priority to supply district heating networks in areas with high potential for geothermal applications. However, the sustainable development of the resource



Kommunikation – Bewertung

KEY QUESTIONS

- ❖ Wie kommunizieren wir die Ergebnisse aus dem Projekt INSIDE?
- ❖ Wie können wir die Akzeptanz in der Bevölkerung bezüglich induzierter Seismizität und Bodendeformation im möglichen Zusammenhang mit Tiefer Geothermie steigern?



BEWERTUNG & ZUSAMMENFASSUNG

- ❖ Wir haben umfassend über die verschiedensten Kanälen zum Projekt INSIDE, dessen Zweck und Ergebnisse erfolgreich berichtet, an wissenschaftliches- als auch an Laienpublikum.
- ❖ Wir haben durch verständliche Kommunikationsarten, wie Erklärfilme und Radiobeiträge, die Inhalte rund um INSIDE und die Tiefe Geothermie der Bevölkerung näher gebracht.
- ❖ Auf Grund der überwiegend positiven und verstärkten Wahrnehmung der Tiefen Geothermie in der Öffentlichkeit hat auch INSIDE in den letzten 5 Jahren einen wichtigen Beitrag zur Akzeptanz von Tiefer Geothermie geleistet.

Agenda

Start time	Topic	Speaker
08:30	Welcome, coffee, registration	
09:00	Welcome message, Video, Project overview	R. Baasch, E. Gaucher
09:20	Well-based data acquisition and analysis	P. Goblirsch, K. Thiemann
09:55	Seismic monitoring	J. Azzola
10:30	Geodetic monitoring	M. Westerhaus
11:05	Break	
11:20	Geothermal reservoir numerical modelling	E. Gaucher, A. Savvatis, R. Habibi
11:55	Reservoir Management System	K. Thiemann
12:30	Communication to the public	P. Goblirsch
12:45	Conclusion, outlook and discussion	G. Bergdolt
13:30	Lunch break	
<i>14:30</i>	<i>Non-public operator meeting</i>	

| Conclusion and outlook

Conclusion

- Sensitive seismic monitoring in Munich area is possible
- Distributed Acoustic Sensing can be a seismic monitoring component
- SAR interferometry can monitor ground deformation to a mm-scale resolution
- We could not observe significant microseismicity nor ground deformation in the INSIDE area
- The operator could process data and access monitoring results near real time
- Thermo-hydro-mechanical-seismicity modelling development will continue

Discussion

- Can SAR interferometry replace levelling measurements?
- How to design efficient seismic monitoring network across operators?
- How to better work as a team, i.e. all stakeholders?



Schön, dass Sie dabei waren!

Guten Appetit & viel Spaß beim Netzwerken!

Dokumente

