Improvement of predictive Quality for Final Repository Site Simulations through Optimal Data Acquisition and Smart Monitoring

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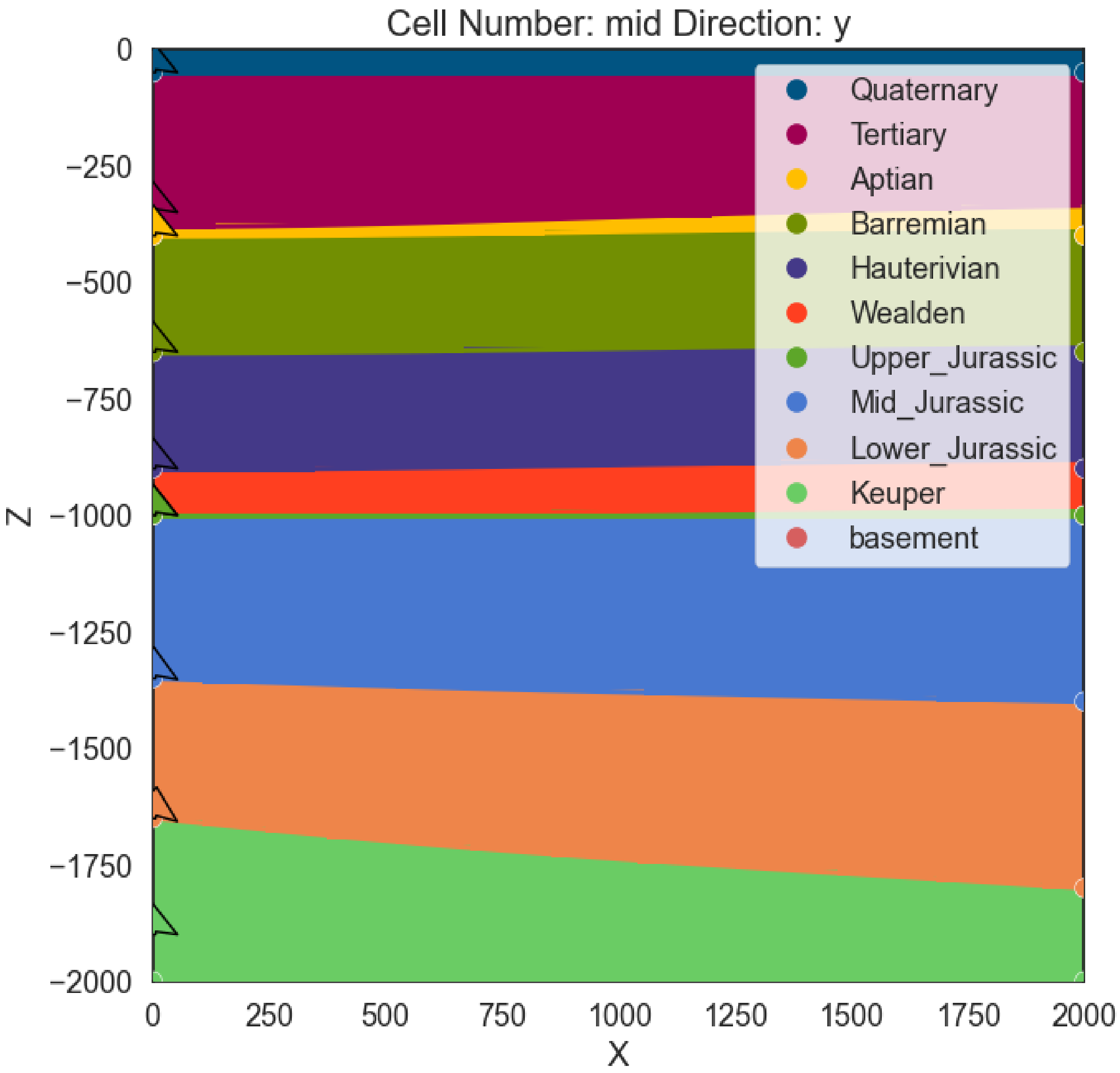
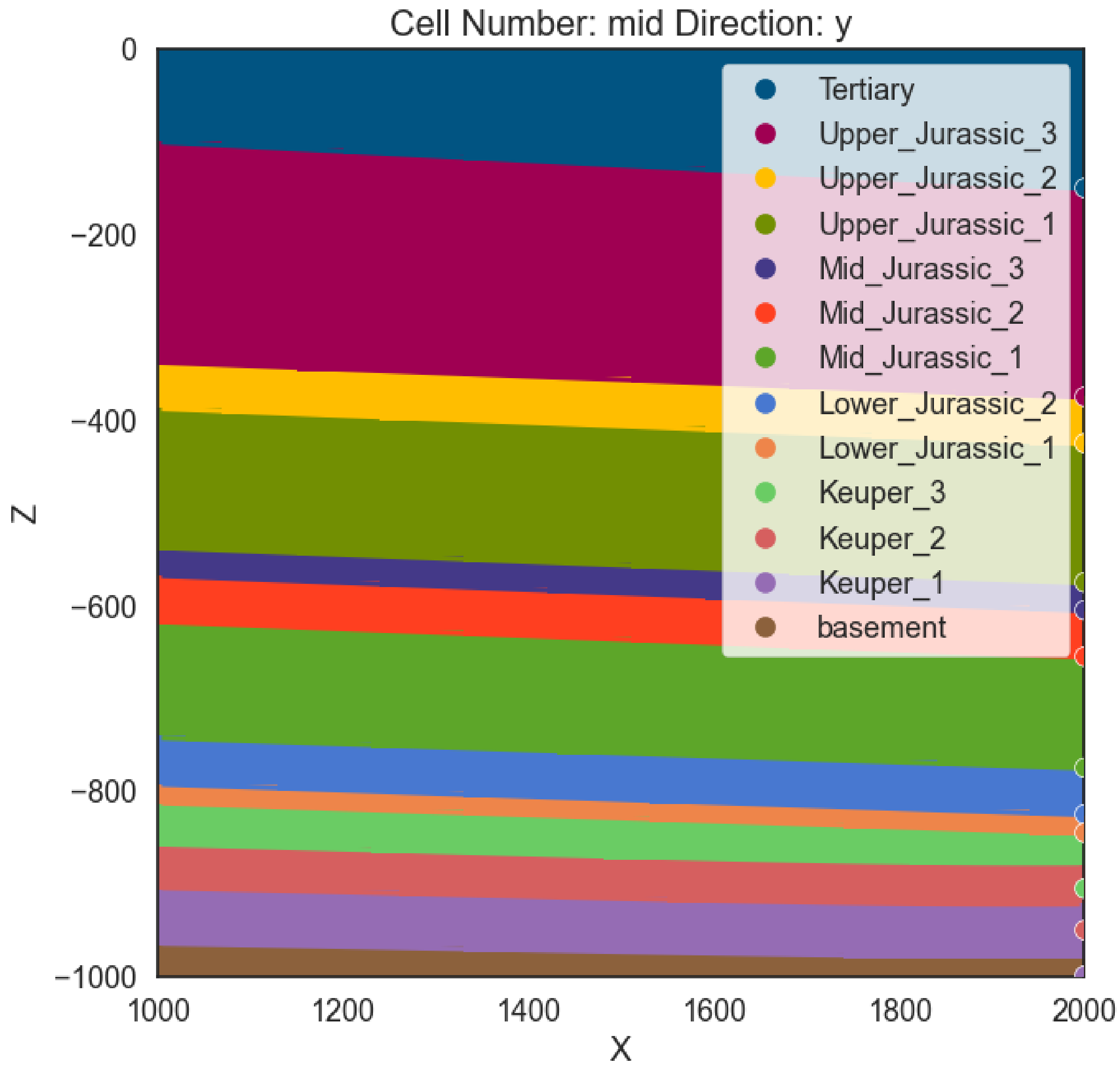
Reference model claystone (Northern Germany)



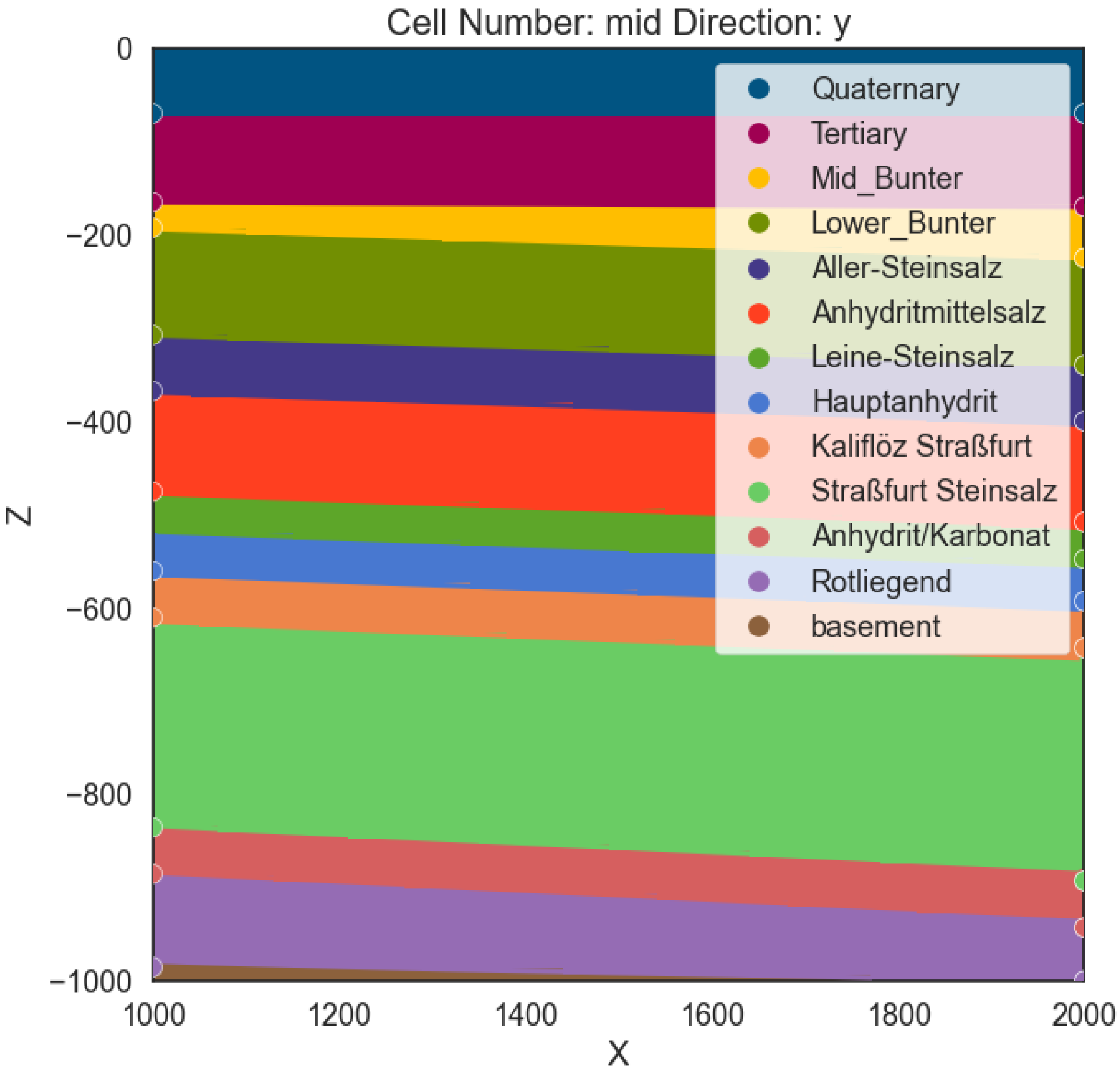
- Claystones of **Barremian and Hauterivian** age (cretaceous)
- Depth of host rocks: **500 to 850 m** below ground level
- **Underlying**: Formations of **Jurassic and Triassic**
- **Overlying**: Upper Cretaceous and **Cenozoic** units
- Model represents geologic conditions of **Northern Germany** (according to Reinhold et al., 2013)

Reference model claystone (Southern Germany)



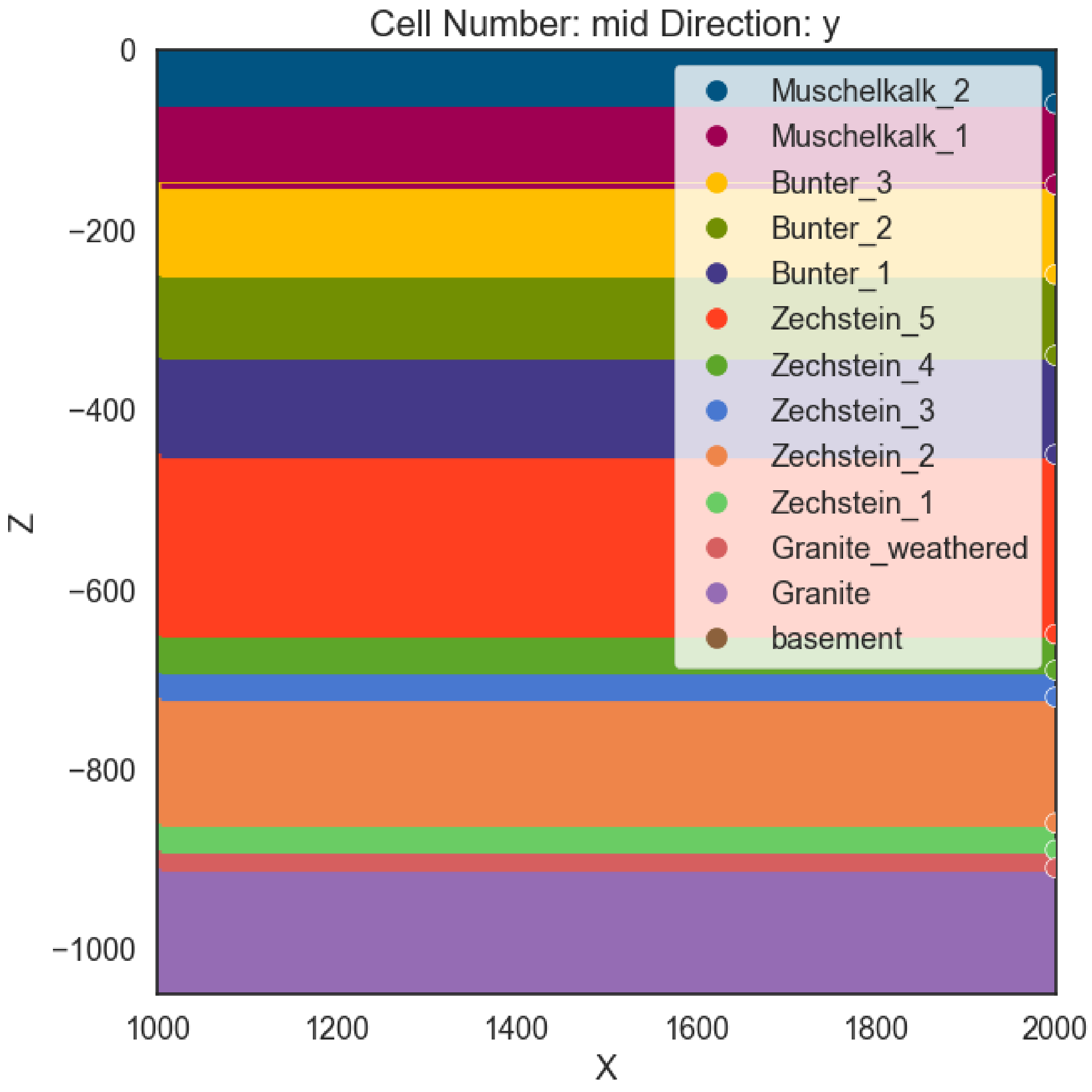
- Second model represents **Opalinus clay** formation in Southern Germany (**Mid_Jurassic_1**)
- Depth of host rock formation: **600-800** m bsl
- **Underlying**: Jurassic and Keuper
- **Overlying**: Upper Jurassic, Tertiary
- **Karstification** of limestone layers
- Model represents geologic conditions of **Swabian Alb** and comparable regions (Reinhold et al., 2016)

Reference model rock salt (stratiform salts)



- Model focuses on rock salt of the **Zechstein** (in particular: **Straßfurt** formation)
- Depth of the host rock: **600-850** m below surface
- **Underlying**: Zechstein anhydrite and Keuper
- **Overlying**: younger Zechstein succession, Bunter, Cenozioc sedimentary rocks
- Model information are taken from the **KOSINA project** (BGR, 2017)

Reference model crystalline rock



- Crystalline Model in **Granite**
- Depth of the host rock**: < 900 m** below surface
- **Underlying**: -
- **Overlying**: Triassic sediments
- Model represents **geology of the *mitteldeutsche Kristallinschwelle*** according to project **CHRISTA-II** (BGR, 2021)

Reference models – Physical model parameters

- Stored as YAML-files, containing most relevant **physical properties** of formations in reference models:
  - Density
  - (Effective) porosity
  - Permeability
  - Heat capacity
  - Heat conductivity
  - Seismic velocities
  - Specific electrical resistivity
  - Diffusivity

Reference models – Summary

Synthetic models are based on **Europe-wide studies**:

- **Claystone**: Mont Terri URL (Switzerland), ANDRA URL (France), ANSICHT (Germany)
- **Rock salt**: German salt structures (Gorleben, Asse)
- **Crystalline**: Äspo URL (Sweden), TURVA (Finland)

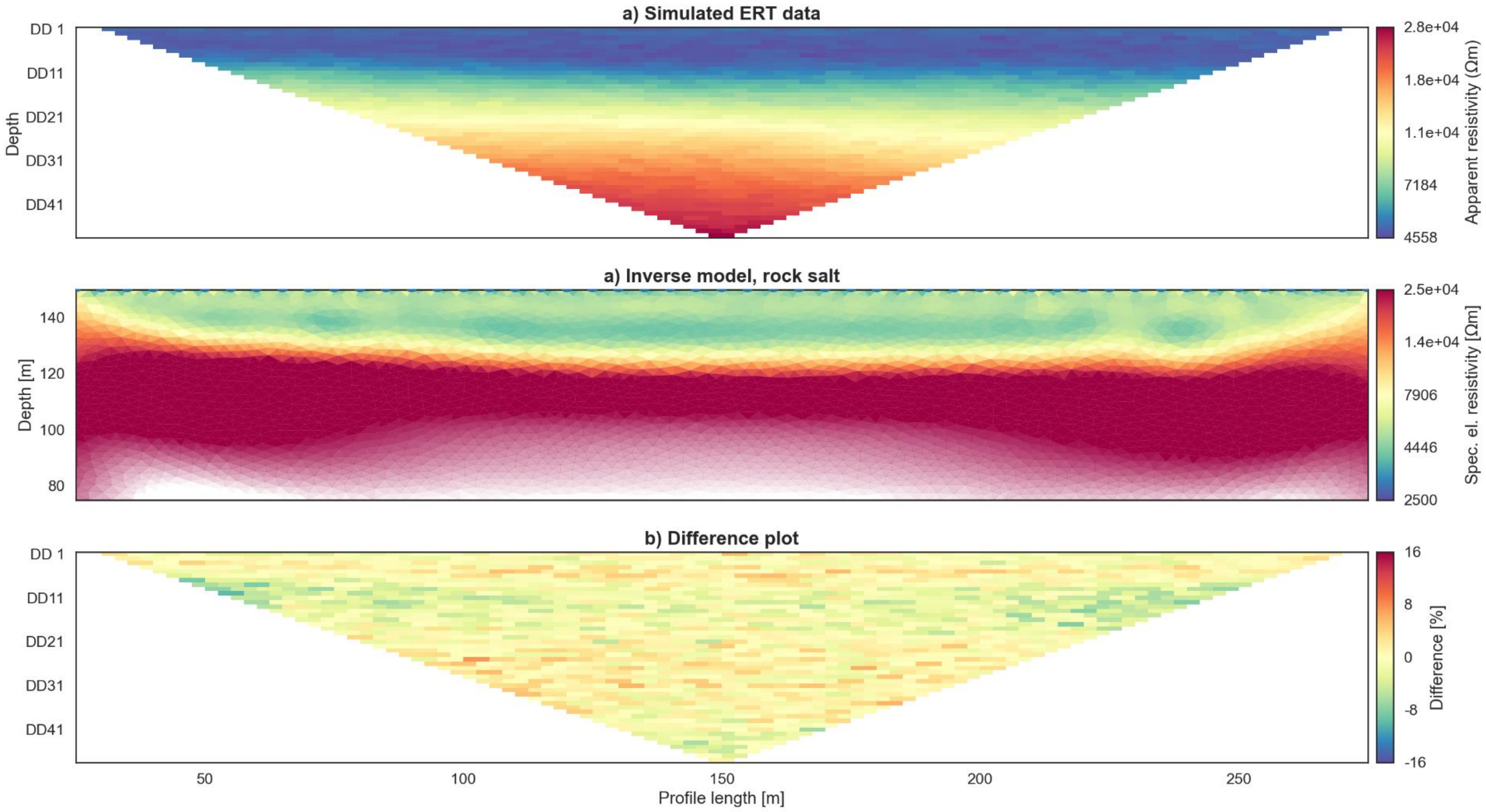
However, do the synthetic models represent scenarios that are close enough to **real geological conditions**?

- Detailed research by BGE in two areas (*Gebiete zur Methodenentwicklung*)
- Possibilty to access geological models and adapt for our needs

Geophysical modelling – Forward models

Geophysical forward modelling in pyGIMLi:

- Performed on geological models (*GemPy-pyGIMLi* **link**)
- Only **geoelectric** measurements up to this point
- **Borehole-** or **surface-based** surveys



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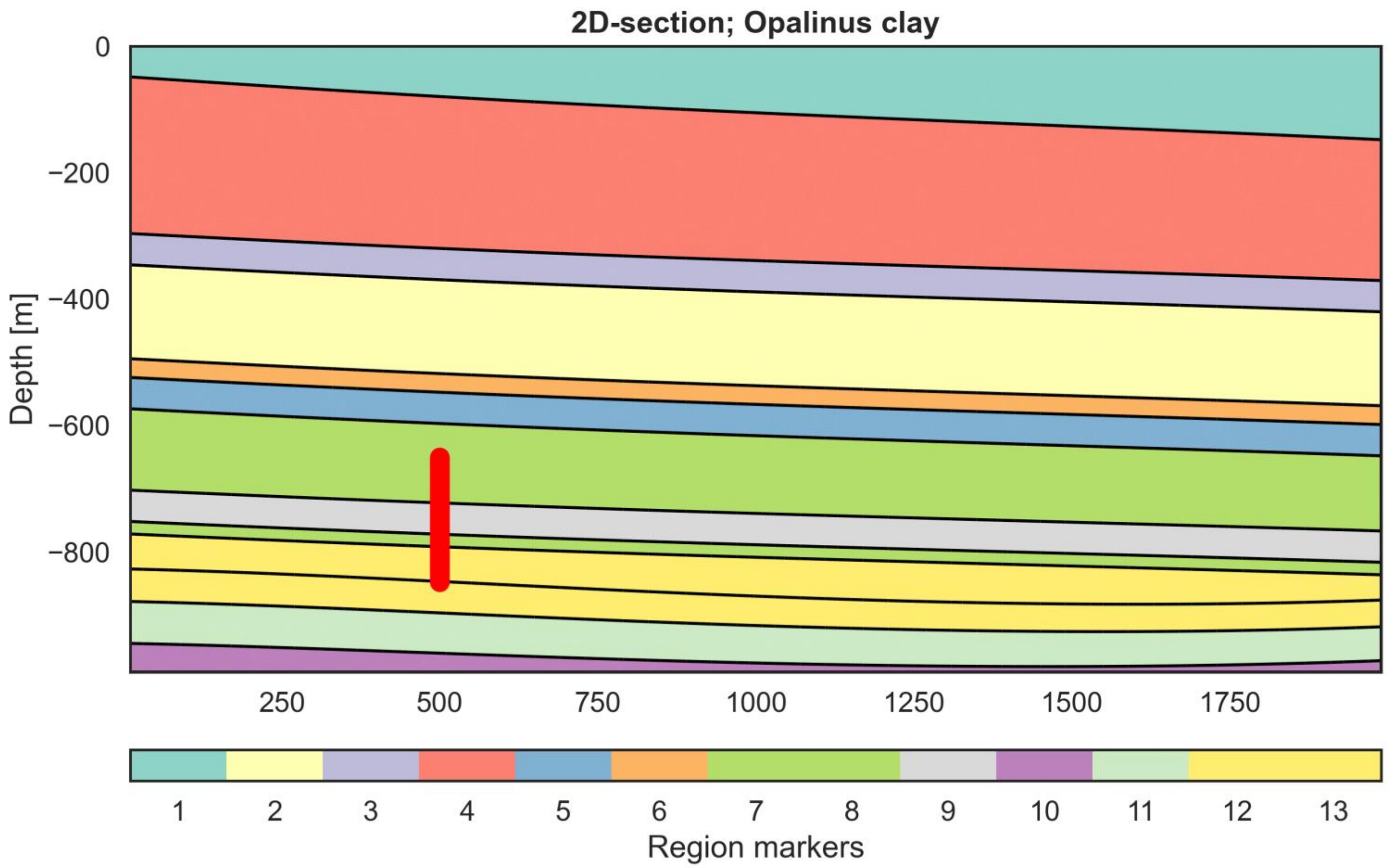

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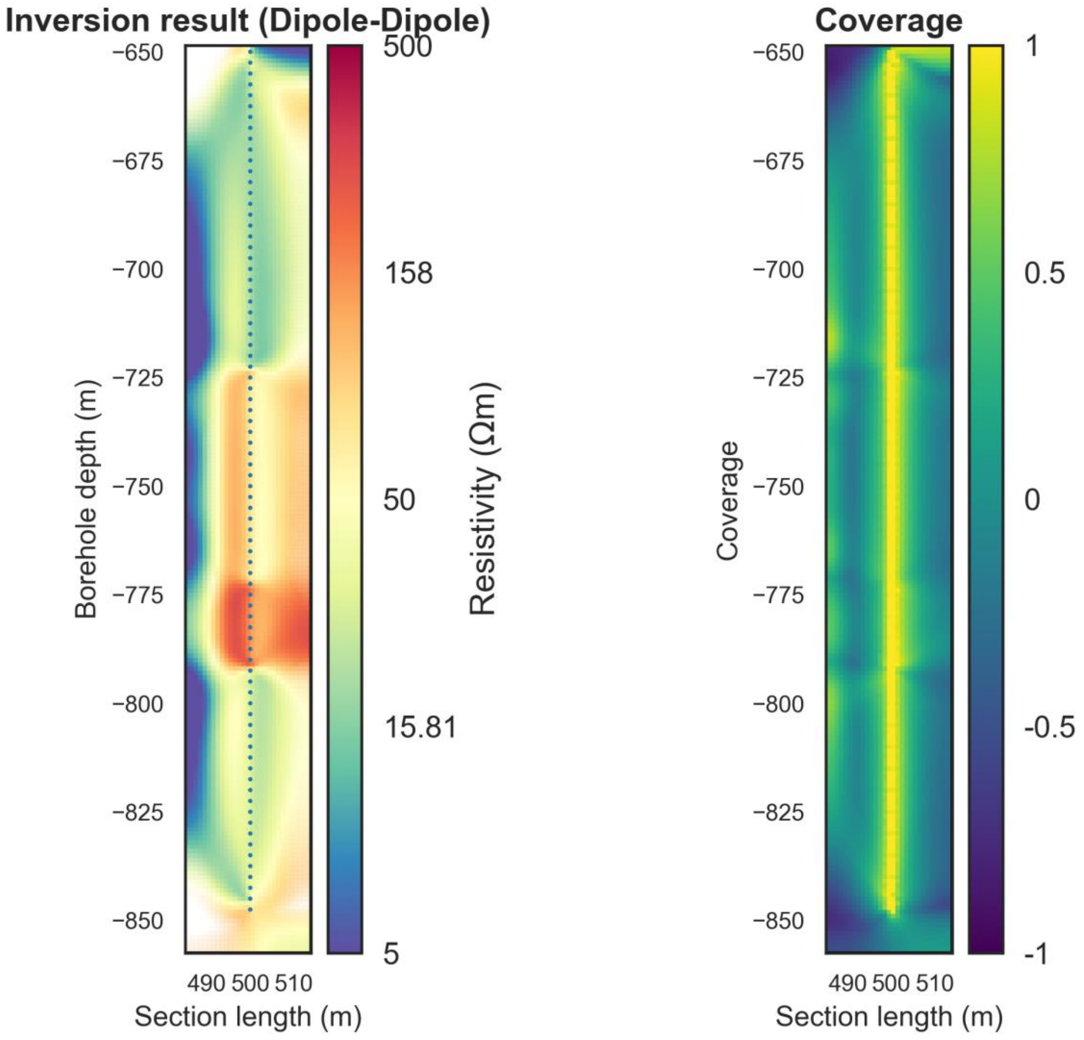
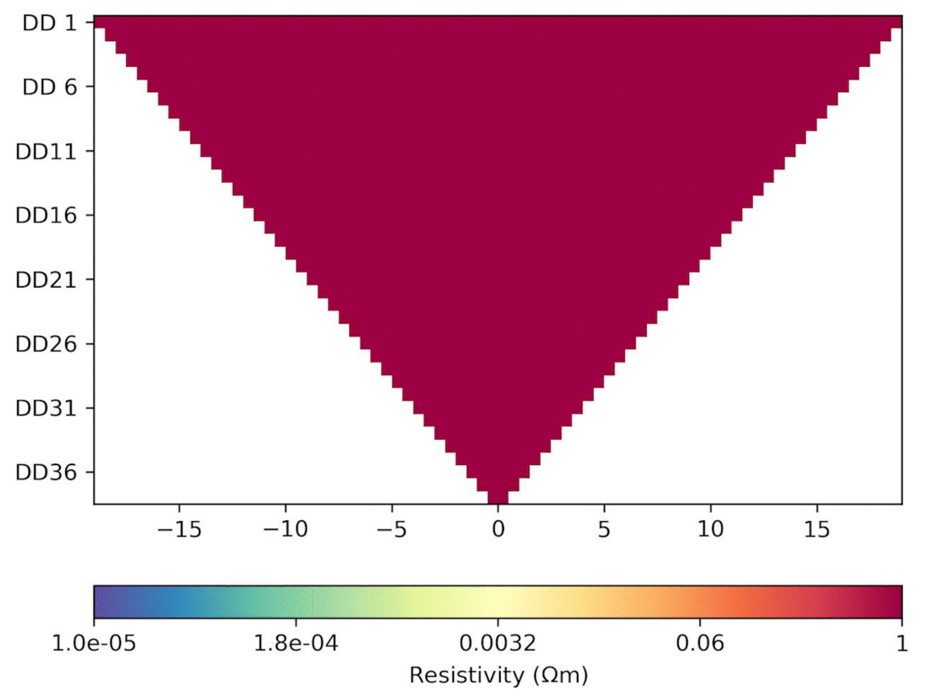
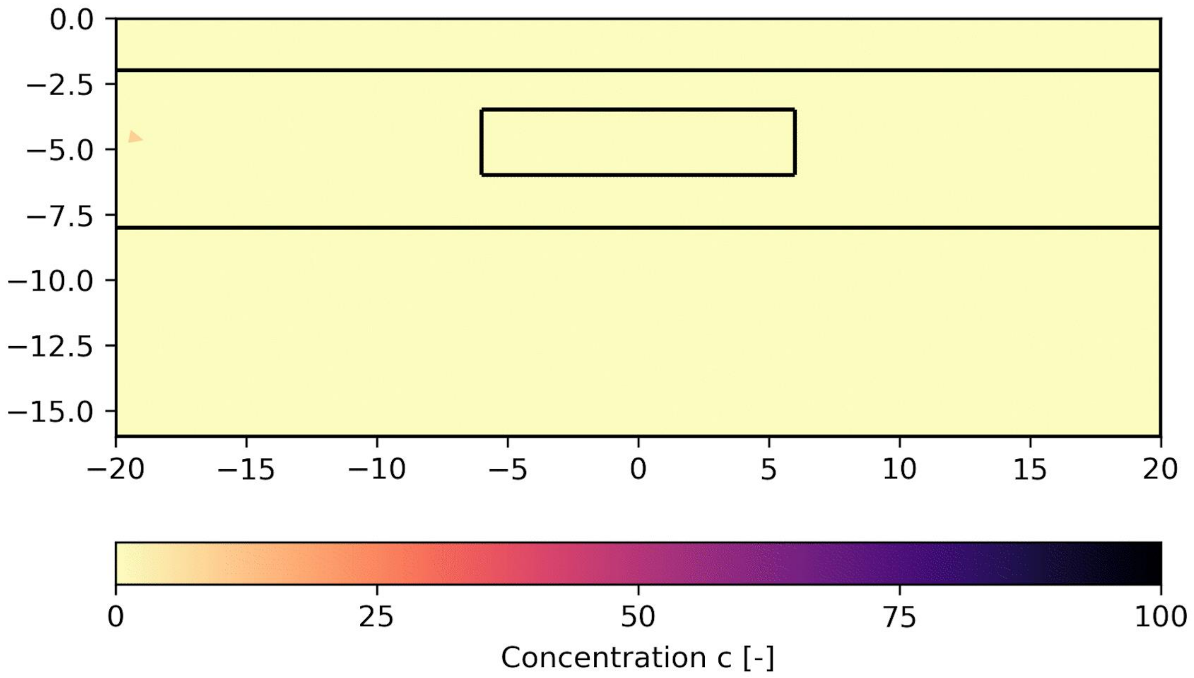


Optimal Experimental Design – Theoretical background



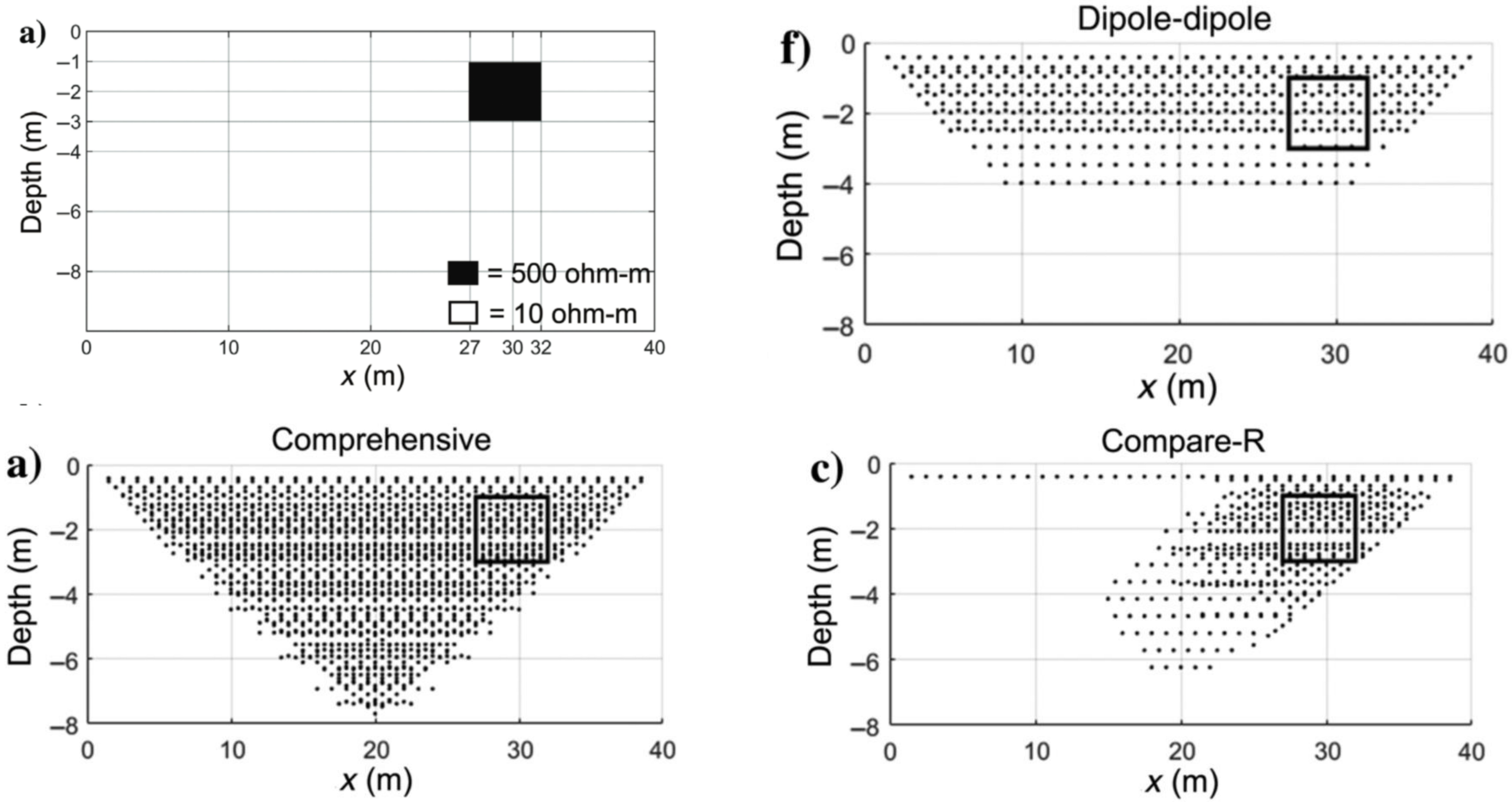


"Conventional" data acquisition:

- **All electrodes** along a survey line are used for measurement (in the case above**: 40 electrodes -> 741 data points** per time step)
- Includes measurements that contain **no new / relevant information** for measurement

Optimal Experimental Design – Theoretical background

“Compare-R” method:



Qiang et al., 2022

Optimal Experimental Design – Theoretical background

“Compare-R” method (Uhlemann, 2018)**:**

- Uses **resolution matrix** of linearized Gauss-Newton solution for ERT problem; defined as:

$$R = (G^T G + C)^{-1} \, G^T G$$

- Iterative optimization starts from a set of **base measurements** -> calculation of **change in resolution matrix** for each possible new measurement:

$$\Delta R_b = \frac{z}{1+(g*z)}(g^T - y^T) \qquad \text{where} \quad z = \left(G_b^T g_b + C\right)^{-1} g, \qquad y = \left(G_b^T G_b\right) z$$

- All additional measurements are **ranked according to improvement** of resolution matrix:

$$F_{CR} = \frac{1}{m} \sum_{j=1}^{m} \frac{w_{t,j} \, \Delta R_{b,j}}{R_{c,j}}$$

- Depending on chosen step size, **n measurements** with greatest benefit **are added to base set**

Optimal Experimental Design – Theoretical background

“Compare-R” method:

- Provides possibility to **optimize** geoelectrical measurements in **2D and 3D**
- Application to (petrophysical) joint inversions?

SmartMonitoring – Next steps

Geophysical modelling and OED:

- Implement CR method and apply to first small-scale experiments
- Implement seismic forward simulations and inversions on reference models
- Work on OED for joint inversion approaches
- Look into other approaches of OED (using Bayesian experimental design)

Thanks for your attention!

QIANG, S., SHI, X., KANG, X., & REVIL, A. (2022). Optimized arrays for electrical resistivity tomography survey using Bayesian experimental design. *GEOPHYSICS*, *87*(4), E189–E203. https://doi.org/10.1190/geo2021-0408.1

REINHOLD, K., STARK, L., KÜHLENZ, T., & PTOCK, L. (2016). *Endlagerstandmodell Süd (AnSichT)—Teil 1: Beschreibung des geologischen Endlagerstandmodells* (Ergebnisbericht Nr. 9Y3207000000; F+E Endlagerung, S. 72). Bundesanstalt für Geowissenschaften und Rohstoffe.

UHLEMANN, S., WILKINSON, P. B., MAURER, H., WAGNER, F. M., JOHNSON, T. C., & CHAMBERS, J. E. (2018). Optimized survey design for electrical resistivity tomography: Combined optimization of measurement configuration and electrode placement. *Geophysical Journal International*, *214*(1), 108–121. https://doi.org/10.1093/gji/ggy128