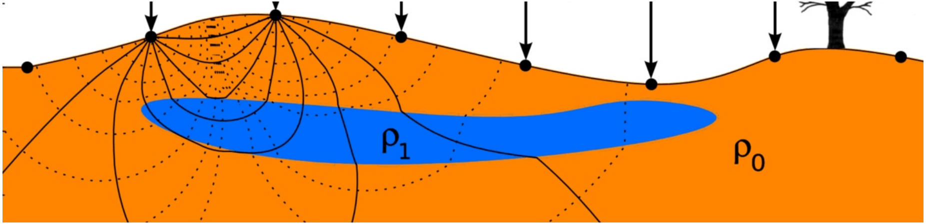
Workshop on pyGIMLi/pyBERT

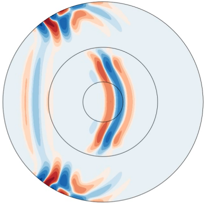
Thomas Günther (LIAG Hannover)

Lund, June 7, 2023

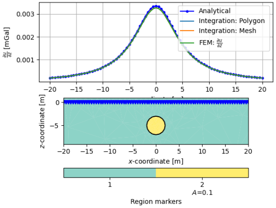


Aim of the workshop

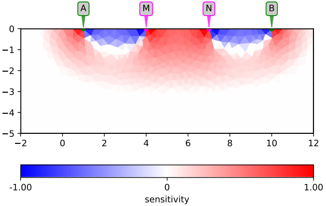
- get you acquainted with the software
- demonstrate what's possible and how easy it is
- enable you to process your data and have trust in the results
- solve some specific problems together
- feeling for how to look at data and models



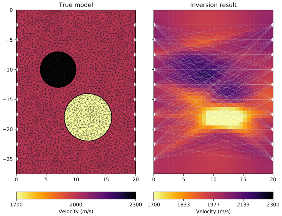
physical fields



geophysical anomalies



sensitivities



imaging

Who am I?

Thomas Günther

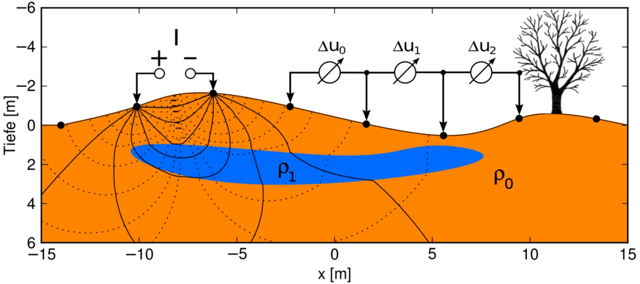
- studied geophysics, TU Bergakademie Freiberg
- PhD 2004
- mathematics in industry & technology, TU Chemnitz
- 2005: GGA Hannover (later LIAG),
- main topical field: Hydrogeophysics
- numerical modelling & inversion, ERT/IP, EM, NMS, SRT, GPR

LIAG Hannover

- Leibniz Institute for Applied Geophysics
- funded by government
- Geocenter Hannover (with BGR+LBEG)
- 80 employees (WM+TM)
- methodological & thematic research
- 5 sections: seismics/potential methods, electromagnetic methods, geochronology, geothermics, petrophysics & borehole geophysics

Dissertation (2004)

Inversion Methods and Resolution Analysis for the 2D/3D Reconstruction of Resistivity Structures from DC Measurements (s. Linksammlung)



- Theory for inversion and regularization, resolution properties etc.
- 2D/3D Inversion of ERT data on FD regular grids
- resolution studies, experimental design

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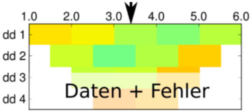
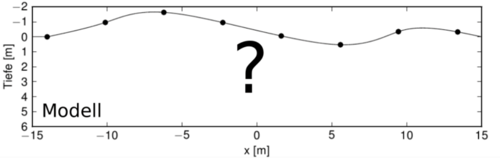


Inversion



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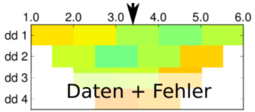
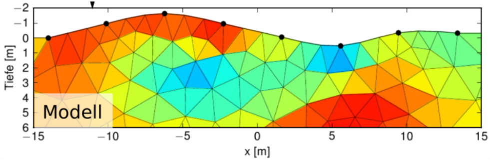


Inversion



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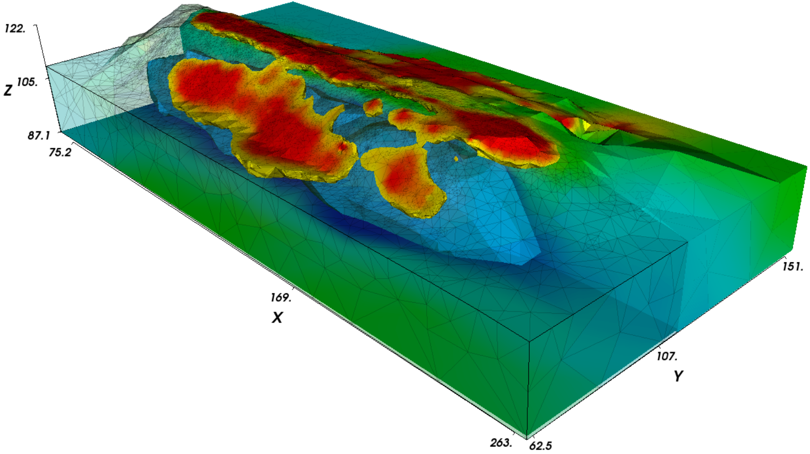
3D modelling with FEM and inversion on irregular meshes

Rücker et al. (2006), Günther et al. (2006), Udphuay et al. (2011)

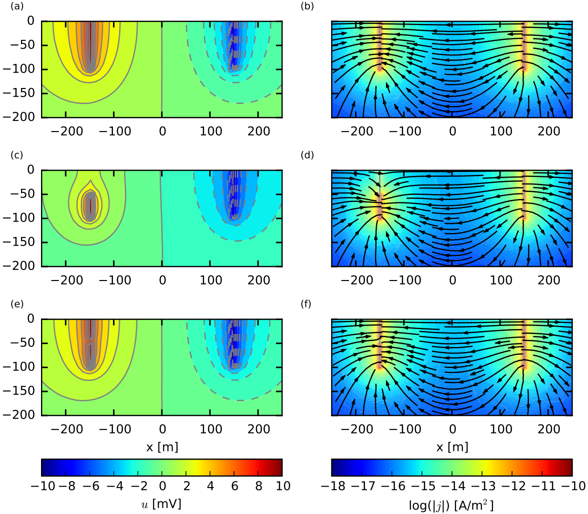
Basis for BERT (Boundless Electrical Resistivity Tomography) Code



Modelling extended electrodes

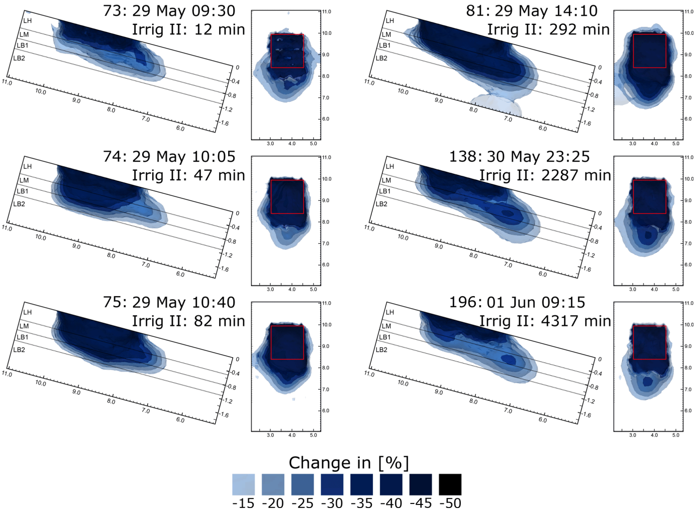
Rücker & Günther (2011), Ronczka et al. (2015)

Complete Electrode Model (CEM) and Shunt Electrode Model (SEM)



Geoelectrical monitoring

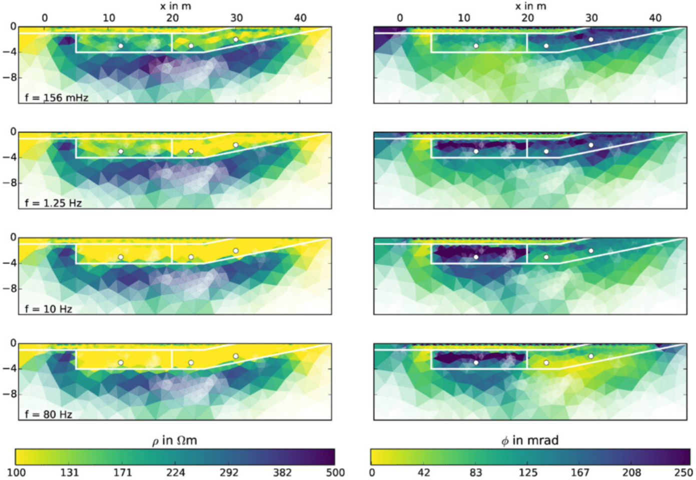
Clement et al. (2009, 2010), Garre et al. (2010, 2012), Bechtold et al. (2012), Beff et al. (2013), Audebert et al. (2014a/b), Persson et al. (2015), SaMoLEG (Ronczka et al. 2015, 2020), Hübner et al. (2015, 2017)



Induced polarisation

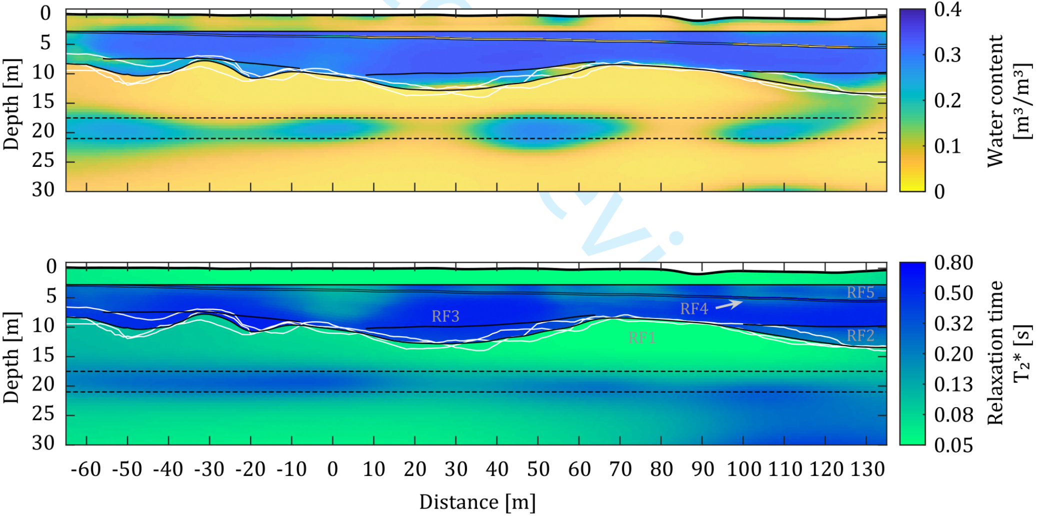
Martin & Günther (2013), Günther & Martin (2016), Bazin et al. (2018), Rossi et al. (2018), Martin et al. (2020, 2021)

Spectrally constrained inversion of FDIP data, TDIP inversion



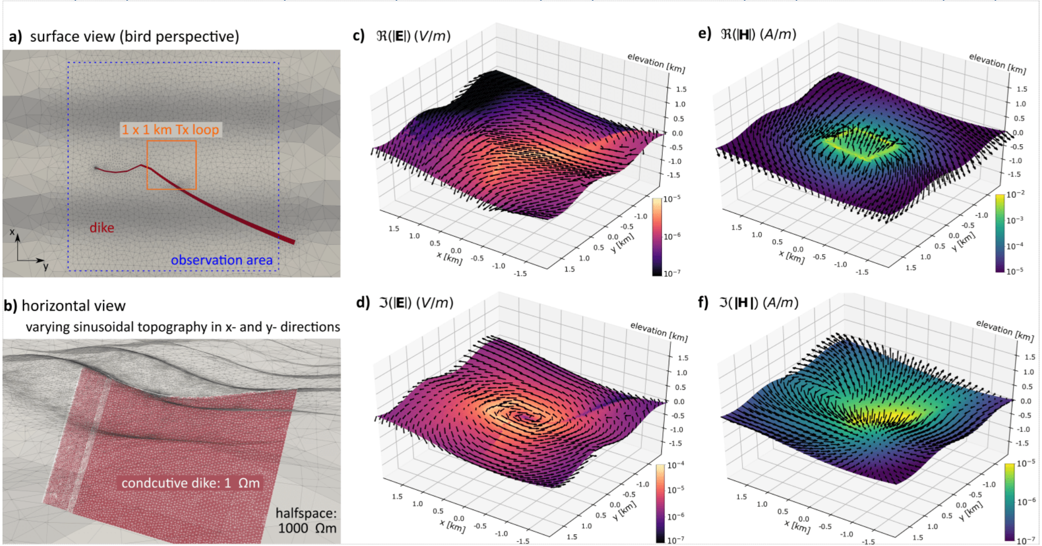
Magnetic resonance tomography with ground-penetrating radar

Hertrich et al. (2007), Dlugosch et al. (2011, 2014), Günther & Müller-Petke (2012), Costabel & Günther (2014), Costabel et al. (2016, 2017), Skibbe et al. (2018, 2020, 2021), Jiang et al. (2020)



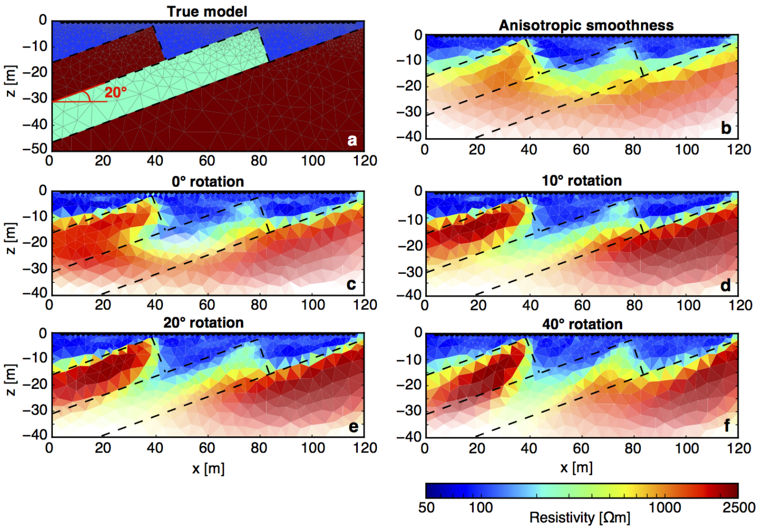
Inductive electromagnetics

Siemon et al. (2015), Rochlitz et al. (2018, 2019), Steuer et al. (2020), Becken et al. (2020), Wadas et al. (2022)



Problem-dependent regularisation methods

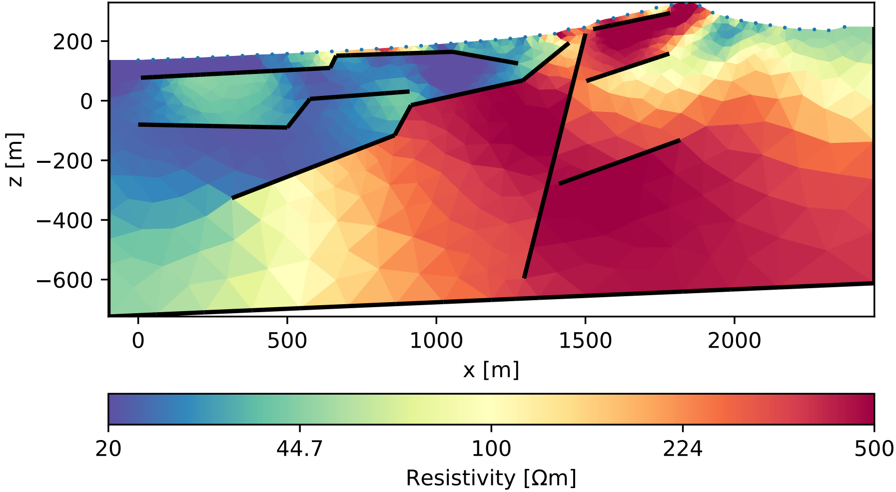
Doetsch et al. (2010), Coscia et al. (2012), Jordi et al. (2018)



Structurally Constrained Inversion

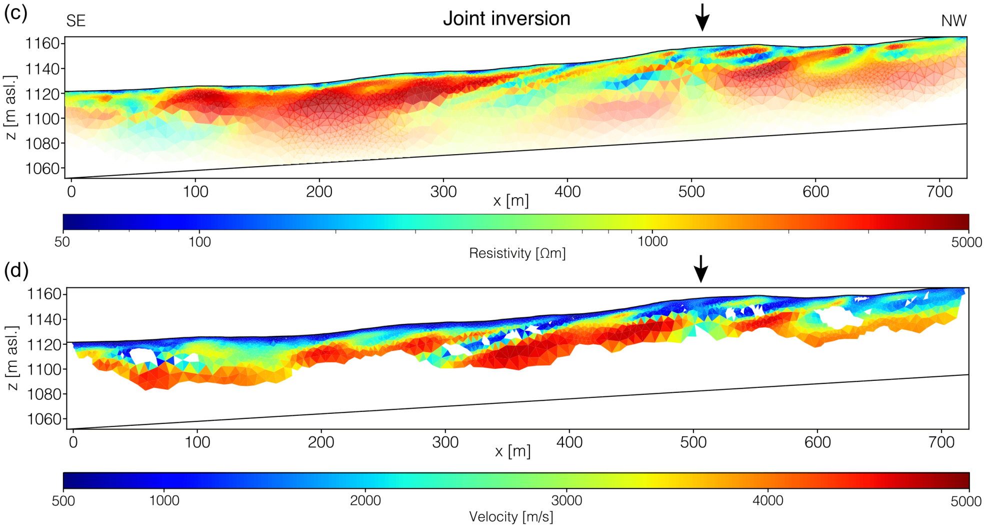
Günther, et al. (2009), Tanner et al. (2019), Doetsch et al. (2012), Jiang et al. (2020)

incorporating structural information from seismics into ERT



Structurally Coupled Inversion

Günther & Rücker (2006), Hellmann et al. (2017), Roncka et al. (2017), Skibbe et al. (2018, 2021), Jordi et al. (2020)



Current projects

- DESMEX II & DESMEX real: ore exploration with semi-airborne electromagnetics (SAEM)
- DynaDeep: studying the dynamics of high-energy beaches with multi-scale ERT
- GeoMetEr: exploring potential nuclear waste disposal sites with combined seismics and EM
- Oger: exploring groundwater deposits with seismic and electromagnetic methods
- TONIA: precision farming using continuous geoelectrics
- BlueTransition: making my region climate resilient (GPR, DC/IP, SAEM)

Development of open-source software

- DC2dInvRes/3d/Tree: ERT with user interfaces
- BERT (Boundless Electrical Resistivity Tomography): ERT code (Günther et al. 2006)
- pyGIMLi (Python Geophysical Modelling & Inversion Library): framework (Rücker et al. 2017)
- custEM (customized Electromagnetic Modelling): Rochlitz et al. (2019)
- COMET (Coupled Magnetic Resonance & Electrical Resistivity Tomography
  Skibbe et al. (2020)

Our credo: reproducible science

make all data and codes available, so that results can be reproduced

Lecture

provide students a feeling for applied geophysics with modern, hands-on teaching methods

pyGIMLi: An open-source library for modelling and inversion in geophysics

pyGIMLi

Geophysical Inversion & Modelling Library

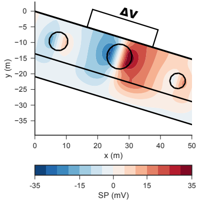
- management of **regular and irregular meshes** in 2D & 3D
- efficient **finite-element and finite-volume solvers**
- **various geophysical forward operators**
- frameworks for **constrained, joint and coupled inversions** with **region-specific regularization**
- **open-source, cross-platform**, documented & tested
- well suited for **teaching & reproducible research**

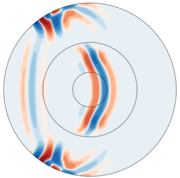
Website & Documentation: `www.pygimli.org`

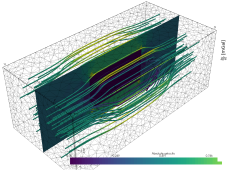
Rücker, C., Günther, T., Wagner, F.M., 2017. pyGIMLi: An open-source library for modelling and inversion in geophysics, *Computers and Geosciences*, 109, 106-123. doi: 10.1016/j.cageo.2017.07.011.

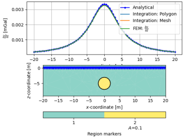
Acknowledges to colleagues

- Carsten Rücker (TU Berlin, BASE)
- Florian Wagner (RWTH Aachen)

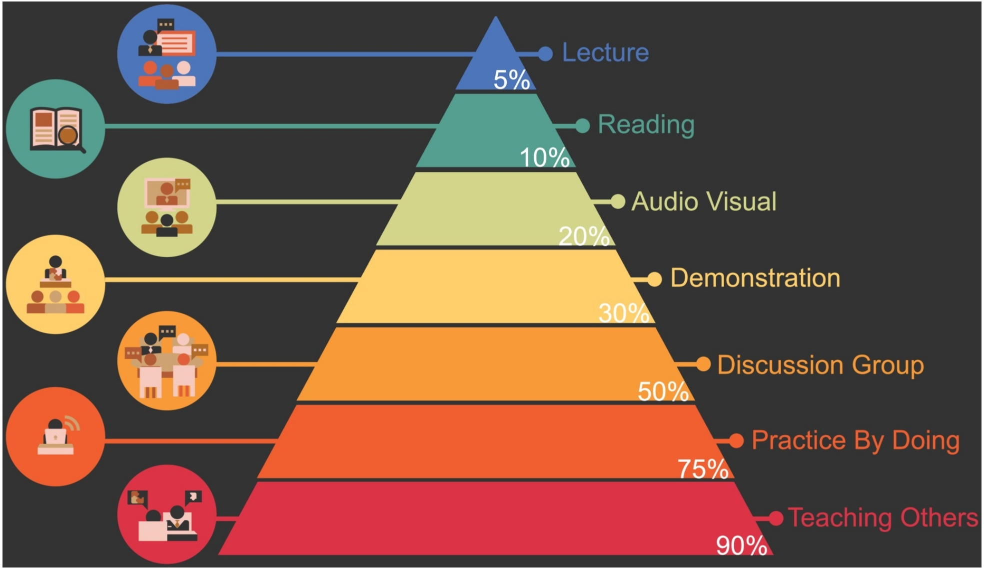








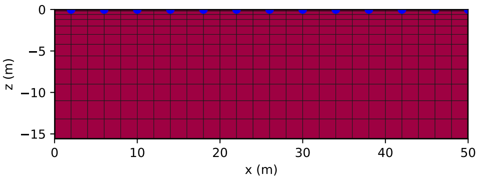
Learning pyramid

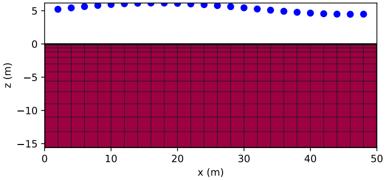


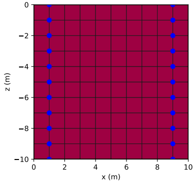
Geophysical methods

Geophysical measurement

measure physical fields (at the surface, in the air, inside the subsurface)







Geophysical imaging

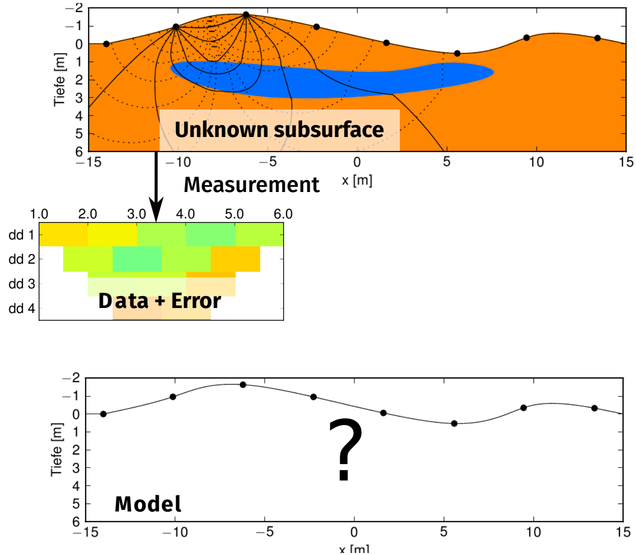
reconstruct a parameter distribution in the subsurface

Overall aim

Deduct a geological/environmental etc. interpretation (knowledge needed)

Geophysical imaging: A typical workflow

1. Data acquisition
2. Preprocessing (quality check and filtering)
3. Parameterization (i.e., mesh generation)
4. Inversion
5. Evaluate fit between measured & simulated data
6. Postprocessing & visualization of final model(s)
7. Interpretation



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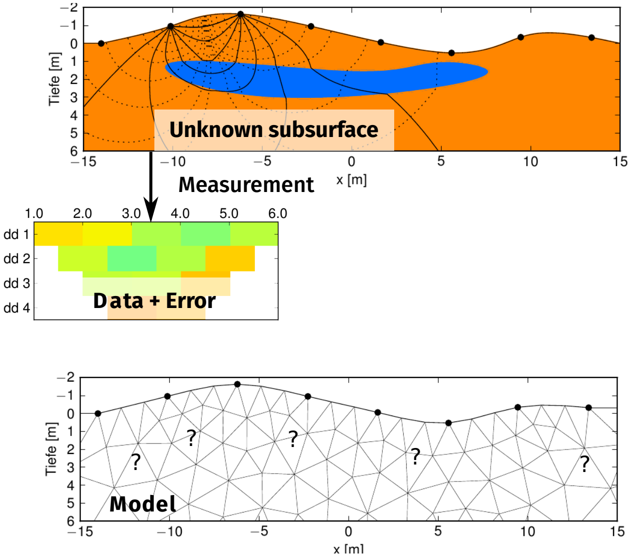

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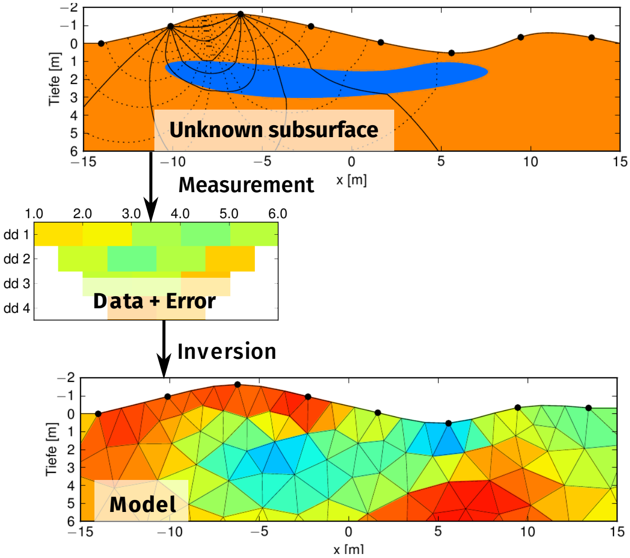

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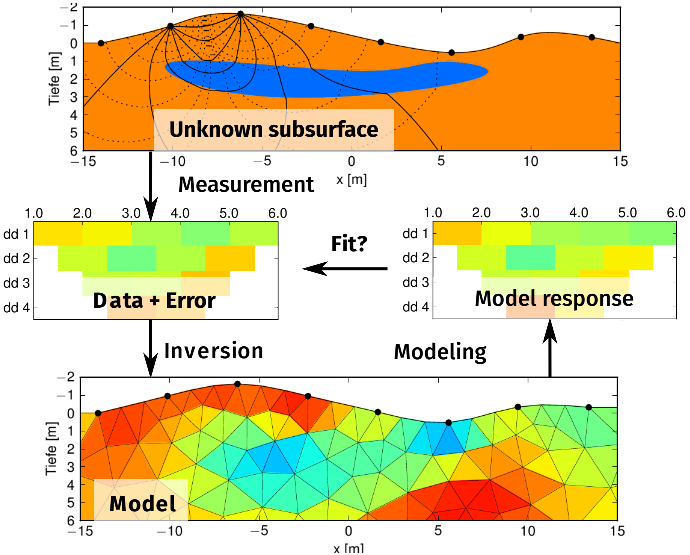

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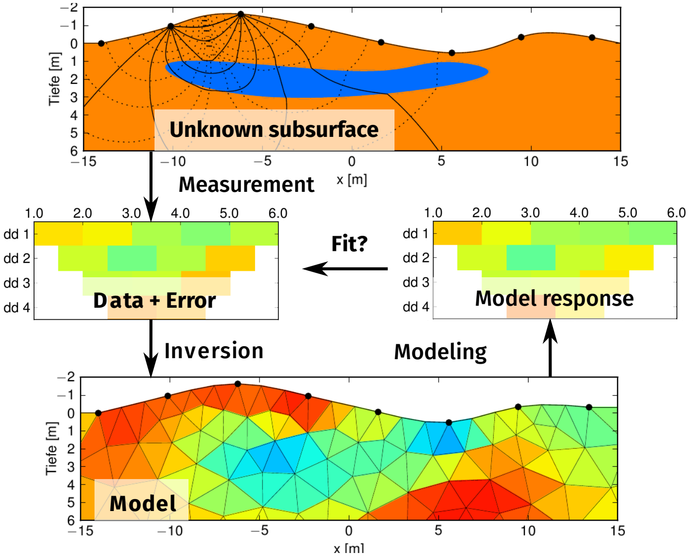

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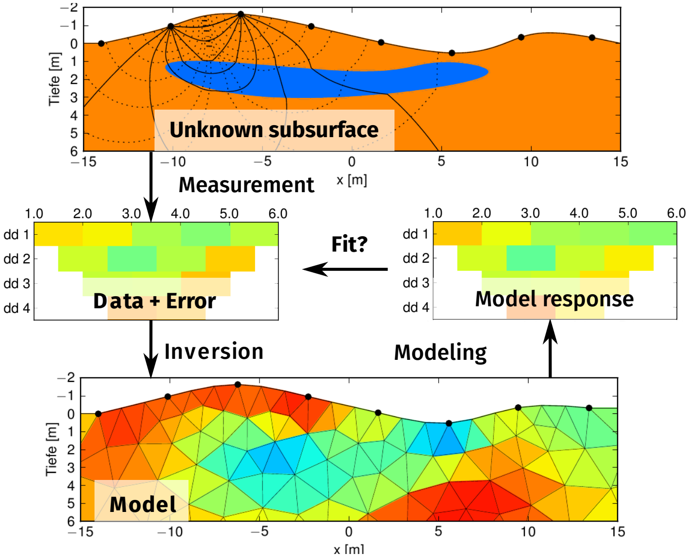

limited sensitivity and resolution, inherent (petrophysical) ambiguities

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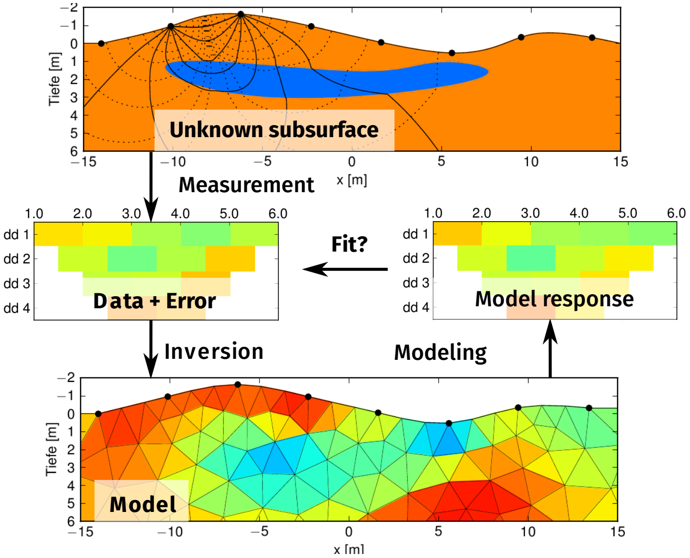

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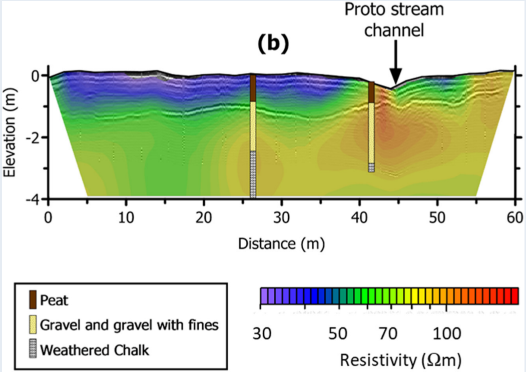
Methods and challenges

A typical geophysical result



(Johnes et al. 2020, Water)

Hydrogeophysical methods

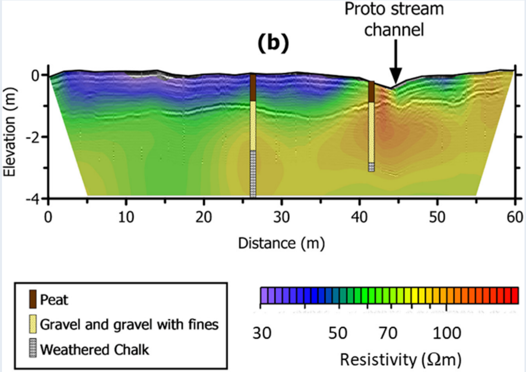
- Electrical Resistivity Tomography (ERT)
- Spectral Induced Polarization (SIP)
- Ground-Penetrating Radar (GPR), seismics
- Magnetic Resonance Tomography (MRT)
- Controlled-Source Electromagnetics (CSEM)

Cross-dimensionality of methods

- boreholes provide just 1D data
- some restricted to 2D (ERT/IP, MRT)
  $\Rightarrow$ subsurface is inherently 3D
  $\Rightarrow$ many tasks are on a regional scale

Geophysics as being seen by non-geophysicists

A typical geophysical result



(Johnes et al. 2020, Water)

Identified issues

- **smooth** subsurface image ("resolution eye")
  $\Rightarrow$ **incorporate expectations** into inversion
- result ambiguous (interpretation, equivalent)
  $\Rightarrow$ decrease by **additional data**
- different methods merely compared
  $\Rightarrow$ **data fusion** to provide unique image
- boreholes are just used for "validation"
  $\Rightarrow$ **use valuable information** actively
- missing link to target parameters
  $\Rightarrow$ **incorporate petrophysics** into inversion
- data analysis tools typically **black box**
  $\Rightarrow$ open & flexible **numerical toolbox**