Resolution analysis of different transmitters in Controlled-Source Radio-Magnetotellurics (CSRMT)

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Introduction

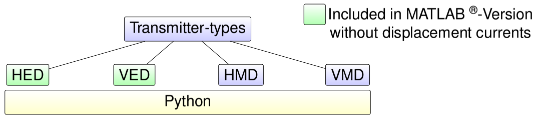
Radio-magnetotellurics (RMT) denotes a commonly used passive EM-method in geophysics. The method uses remote radio antennas broadcasting in a range of 10-1000 kHz as transmitters. Caused by the limitations of RMT in its depth of investigation and its dependency on transmitters with sufficient signal strength, new controlled sources (CSRMT) in the range of 1 kHz - 1 MHz have and shall be developed.

Like for lower frequency CSEM, magnetic and electric dipole transmitters are possible. It can be expected that magnetic and electric dipole sources have different resolutions due to different coupling with anomalies, caused by their different current modes. Therefore, by choosing an appropriate transmitter type for an a-priori known anomaly, an improved subsurface model can be derived.

Currently no 3D study, comparing different sources in high frequencies (1-1000 kHz) exists. To fill this gap the University of Cologne (UoC) collaborates with St. Petersburg State University (SPbSU) in a DFG-funded project. SPbSU develops newly high frequency magnetic sources (1-1000 kHz), whereas UoC provides necessary modelling and inversion software. UoC thereby, improves MR3DMod [1], a ModEM based, existing object-oriented code, to include different high frequency transmitters.

Project goals UoC

- Translate existing MR3DMod (MATLAB ®) to Python (speed optimisation)
- Implementing necessary transmitter types


🟩 Included in MATLAB ®-Version without displacement currents

Transmitter-types

HED
VED
HMD
VMD

Python

- Include displacement currents
- Comparing results for newly implemented transmitters with existing codes (e.g. 3DINV by Grayver & Streich)
- Resolution studies on synthetic data (with & without displacement currents) in order to determine the most suitable parameters of the survey set-up
- Perform validation field measurement in Russia

References

[1] Cherevatova, M.; Egbert, G.D.; Smirnov, M.Yu. A multi-resolution approach to electromagnetic modelling. Geophysical Journal International, (214):656-671, 2018.

[2] Ren, Z.; Kalscheuer, T. Uncertainty and Resolution Analysis of 2D and 3D Inversion Models Computed from Geophysical Electromagnetic Data. Surveys in Geophysics, (41):47-112, 2020.

Background Resolution Calculation

The resolving power can be analysed in a linearised model framework:

- Comparison between true model and inversion results
- Model resolution matrix R_m

R_m is given by [2]:

$$R_\mathrm{m} = J_\mathrm{w}^{-g} J_\mathrm{d} \tag{1}$$

with the weighted sensitivity matrix $J_\mathrm{d} = W_\mathrm{d} J$ and the general inverse J_w^{-g}. J_w^{-g} is dependent on the model regularisation matrix W_m and is given by:

$$J_\mathrm{w}^{-g} = (J^\mathsf{T} W_\mathrm{d}^\mathsf{T} W_\mathrm{d} J + \alpha W_\mathrm{m}^\mathsf{T} W_\mathrm{m})^{-1} J^\mathsf{T} W_\mathrm{d}^\mathsf{T} \tag{2}$$

→ Entries with little spread around the main diagonal of R_m can be used for geological interpretation ([2]).
→ Inversion result fits the true model perfectly if $R_\mathrm{m} = \mathbb{1}$.

Resolution study - 1D

A 1D resolution study with synthetic data for already implemented transmitter types can be carried out for different receiver positions. We use:

- Two transmitter types: **electric point dipole** and **extended cable source** with a current strength of 1 A.
- Two subsurface models with resistivities low enough to neglect displacement currents (Figure 1).
- Receiver positions in transition zone and far field (Figure 2).
- 5% gaussian noise on the synthetic data.

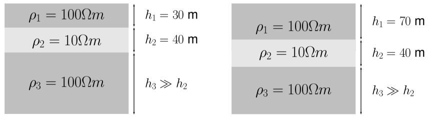


Figure 1: 1D models for resolution study. Left: conductive layer in 30 m depth; right: conductive layer in 70 m depth

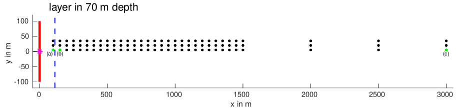


Figure 2: Receiver & transmitter positions in the 1D study. Shown are point dipole-position, wire-position, receivers, receivers for comparison between model result and true model and the transition between near field and far field for 1kHz ($r = \delta/\sqrt{2} \approx 112$ m)

Conductive layer at a depth of 30 m

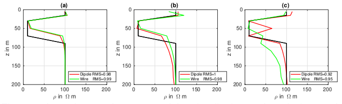


Figure 3: Inversion results: true model, point dipole-result and wire-result

- Figure 3
  - (a) and (b) transition zone: Both transmitter types generate comparable results
  - (c) far field: Bottom line of the conductive structure is better reconstructed using the point dipole
- Figure 4
  - Top of the conductive layer well resolved (values > 0.7).
  - The resolution for both transmitter types is generally decreasing for larger depths within the conductive layer.

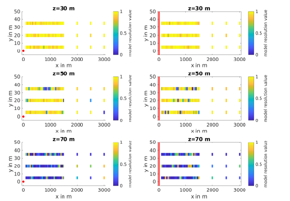


Figure 4: Main diagonal entry of R_m for all used receiver stations for different model parameters at depth z for point dipole (left) and wire (right); perfect resolution of model parameter in case of value 1.

Conductive layer at a depth of 70 m

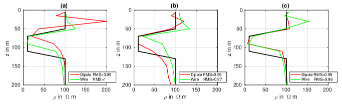


Figure 5: Inversion results: true model, point dipole-result and wire-result

- Figure 5
  - For all cases, the resistive layer in shallow depth is not represented well
  - In comparison to the conductive layer in a depth of 30 m, (c) is improved while (a) and (b) are deteriorated.
- Figure 5
  - As for figure 4, the resolution decreases with depth.
  - In general the far field models are better resolved using the wire instead of the point dipole.

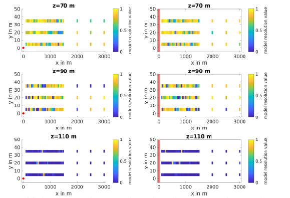


Figure 6: Main diagonal entry of R_m for all used receiver stations for different model parameters at depth z for point dipole (left) and wire (right); perfect resolution of model parameter in case of value 1.

Conclusion

We studied the effect of a conductive layer buried at different depths on the resolution for an electric point dipole and a wire source in 1D. For both transmitter types, the upper boundary of a shallowly buried conductor can be well resolved. However, its resolution power decreases with increased depth supported by the model resolution matrix entries. From the presented studies, we recognise that even in the 1D-case different transmitter types have an impact on the resolution of layer parameters. In particular, for the deeper located conductive layer, the wire source resolves the structure better than the point dipole in the far field. Thus, we also expect effects on the sensitivity for such source geometries in future 3D studies.