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Closing the gap between galvanic and inductive methods: EEMverter, a new inversion tool for Electric and Electromagnetic data with focus on Induced Polarization

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SUMMARY

EEMverter is a modelling software specifically developed to model electric and electromagnetic data taking into account the IP phenomenon. Four distinctive features have been implemented in EEMverter: i) selectable IP parameterisations are allowed, ranging from Constant Phase Angle to Debye-Warburg decomposition, also making use of petrophysical relation for defining IP parameters in terms of hydraulic properties; ii) 1D, 2D and 3D forward modelling can be mixed sequentially or simultaneously in the iterative process within multiple inversion cycles, for diminishing the computational burden; iii) the joint inversion of Airborne IP (AIP), ground EM-IP and ground galvanic IP data is fully supported with a common IP parameterization; iv) time-lapse inversions of AIP, EM and galvanic IP data is possible with both sequential and simultaneous approaches.
EEMverter is distributed freeware in its LITE version, which allows to run modelling of galvanic data with induced polarization and of ground-based inductive data, together with EEMstudio, a QGIS plugin for data visualization processing in GIS environment. We believe that EEMverter, with its common inversion environment for the IP inversion of inductive and galvanic data will help in closing the gap between galvanic and inductive IP.

Key words: Induced Polarization, modelling, galvanic, inductive.

INTRODUCTION

The phenomenon of Induced Polarization (IP) is commonly studied with galvanic methods, both in the field and in the laboratory. IP effects on inductive electromagnetic (EM) data have been reported since the early '80s, but the attention of the EM community in IP focuses mainly on exploration purposes, because strong chargeable anomalies trigger negative EM responses. However, Fiandaca et al. (2022) showed that the IP effect strongly affects EM data also in sand/clay environments, with a variety of acquisition systems, ranging from airborne EM to systems for continuous ground acquisitions. In this study we present a novel inversion software, EEMverter, specifically developed to model electric and electromagnetic data taking into account the IP phenomenon. Four distinctive features have been implemented in EEMverter: i) selectable IP parameterisations are allowed, ranging from Constant Phase Angle to Debye-Warburg decomposition, also making use of petrophysical relation for defining IP parameters in terms of hydraulic properties; ii) 1D, 2D and 3D forward modelling can be mixed sequentially or simultaneously in the iterative process within multiple inversion cycles, for diminishing the computational burden; iii) the joint inversion of Airborne IP (AIP), ground EM-IP and ground galvanic IP data is fully supported with a common IP parameterization; iv) time-lapse inversions of AIP, EM and galvanic IP data is possible with both sequential and simultaneous approaches.

METHOD AND EXAMPLE

In EEMverter the inversion parameters are defined on model meshes which do not coincide with the forward meshes used for data modelling: the link between model and forward meshes is obtained interpolating the model mesh parameters into the forward mesh discretization, as done for 1D AEM in Christensen et al. (2017), in 3D galvanic IP in Madsen et al. (2020) and in 3D EM in Zhang et al. (2021) and Xiao et al. (2022a,- 2022b). This spatial decoupling allows for defining the model parameters, e.g. the Cole-Cole ones, on several model meshes, for instance one for each inversion parameter. In this way, it is possible to define the spectral parameters, like the time constant and the frequency exponent in the Cole-Cole model, on meshes coarser than the resistivity and chargeability ones, vertically and/or horizontally, with a significant improvement in parameter resolution.

Figure 1 presents the model and forward meshes for a joint inversion, in which 1D AEM and 1D ground EM computations are combined with 2D galvanic computations.

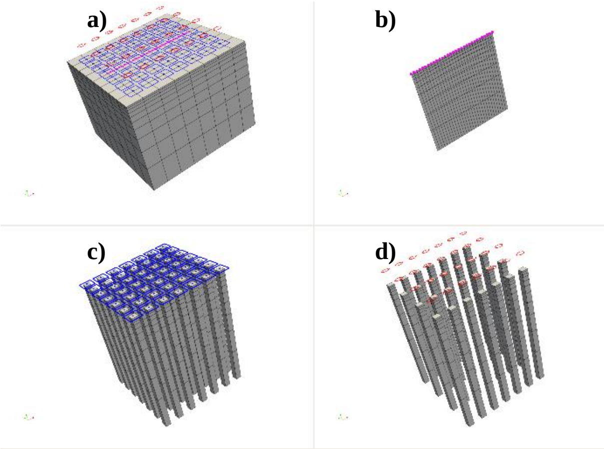

Figure 1. EEMverter multi-mesh inversion scheme for Joint inversion of inductive and galvanic data. a) Model mesh and data positions: red polygons for AEM frames; blue squares for ground TEM frames; magenta line for galvanic 2D profile. b) Galvanic 2D forward mesh. c) Ground TEM frames (blue squares) and corresponding 1D soundings (grey bars). d) AEM frames (red polygons) and corresponding 1D soundings (grey bars).

Figure 2 presents the resistivity section of a synthetic model that mimics the electrical properties (both conduction and polarization) of sand, clay and consolidated formations, based on the petrophysical relations described in Weller et al. (2015), together with the inversion model of inductive and galvanic data. In particular, four different inversion results are presented: direct current and full-decay induced polarization (DCIP) galvanic data, with 10 m electrode spacing and 2D gradient sequence; AEM + ground EM data, with sounding distance of 40 m; AEM+ground EM + tTEM data (Auken et al., 2019), with tTEM soundings every 10 m; all data together in a joint inversion scheme.

The joint inversion presents much better resolution capability, with the inductive and galvanic data complementing each other in resolving both conductive and resistive layers. Examples of joint inversion of AEM, ground EM and galvanic IP data through EEMverter are presented in Dauti et al. (2024) in applications related to mineral exploration and in Signora et al. (2023) for the characterization of the HydroGeosITe, the Italian reference and calibration site for hydrogeophysical methods under development in Brescia, Italy.

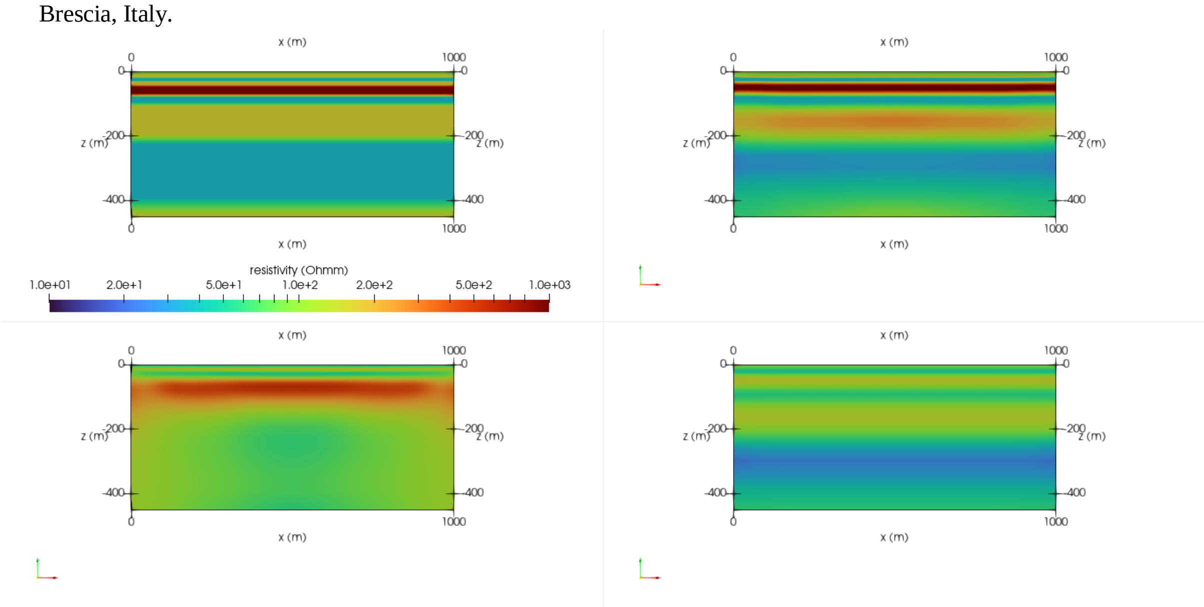

Figure 2. Synthetic model and inversion results. Top left) resistivity section of a MPA IP simulation of electrical properties; Bottom left) inversion model of DCIP data; Bottom right) inversion model of AEM+ground EM data; Top right) joint inversion of all inductive and galvanic data.

GRAPHICAL USER INTERFACE

A graphical user interface for EEMverter has been developed as a QGIS plugin, i.e. EEMstudio (Sullivan et al., 2024). Furthermore, EEMstudio allows to visualize and process inductive and galvanic data in a GIS environment. EEMstudio is distributed freeware and open source, and EEMverter is distributed freeware together with EEMstudio in its LITE version, which allows to run modelling of galvanic data with induced polarization and of ground-based inductive data.

CONCLUSIONS

We presented EEMverter, a novel inversion software for electric and electromagnetic data with focus on induced polarization. EEMverter allows to model IP with selectable parameterisations, mixing 1D, 2D and 3D forward modelling of inductive and galvanic data sequentially or simultaneously in the iterative process, also in time-lapse. We believe that EEMverter, with its common inversion environment for the IP inversion of inductive and galvanic data will help in closing the gap between galvanic and inductive IP.

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