



Enhancing FD-EMI in-phase observations by means of 3D inversion: the case of Orcines, France

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Abstract

FD-EMI in-phase data were collected at a Gallo-roman site in Orcines, France. 3D inversion unveils features, which are not visible in the recorded in-phase maps.

Keywords

archaeological prospection; electromagnetic induction; magnetic susceptibility; 3D inversion

Introduction

Loop-loop frequency domain electromagnetic induction (FD-EMI) sensors are efficient tools to rapidly sense the electrical and magnetic properties of the subsurface. Maps of either conductivity or in-phase data can be used for delineating buried archaeological remains, which typically produce rather small-scale anomalies while large-scale anomalies are often associated to paleo-environmental deposits. Furthermore, due to the integrative/averaging nature of FD-EMI data, the small-scale anomalies often show relatively low amplitudes in comparison to the large-scale background response. This is particularly challenging for the case of FD-EMI in-phase data, which is significantly affected by noise related to various sources. Classical reduction and enhancement workflows can help but remain inconsistent in an exploration context, for which one does not know the characteristics of noise, the geometry of the targets as well as the characteristics of the background medium in advance. 3D inversion can be considered as an enhancing filter to discriminate pure noise from physically consistent signals of similar amplitude, because we test the lateral consistency of the observed data with respect to physically-based assumptions (a model of subsurface properties). Recent progress in instrumentation including the development of multi-configuration systems, high-resolution kinematic acquisition strategies, and fast 3D spectral

inversion procedures, allows the reconstruction of 3D subsurface electrical and magnetic property distributions with unprecedented details (Guillemoteau and Tronicke 2016; Thiesson et al. 2017; Guillemoteau et al. 2017; Klose et al. 2018; Guillemoteau et al. 2019). In this study, we analyze a synthetic and a field data example in which the target archaeological structures generate an FD-EMI in-phase signal that is in amplitude comparable to the noise level and below the signal amplitude of the geological background medium. This signal is thus hardly detectable with a direct analysis of non-inverted data maps. Using these two examples, we investigate and evaluate how such targets can be detected and characterized by a 3D inversion procedure based on the multi-channel deconvolution (MCD) approach described in Guillemoteau et al. (2019).

Materials and methods

We consider a dense grid (interline spacing of 0.5 m and inline sampling of 0.1 m) of FD-EMI in-phase multi-configuration soundings as collected by a mono-frequency (9 kHz) four-configuration DUALEM21s system, which is placed at a constant height of 0.25 m above ground. The four configurations are two horizontal co-planar geome-

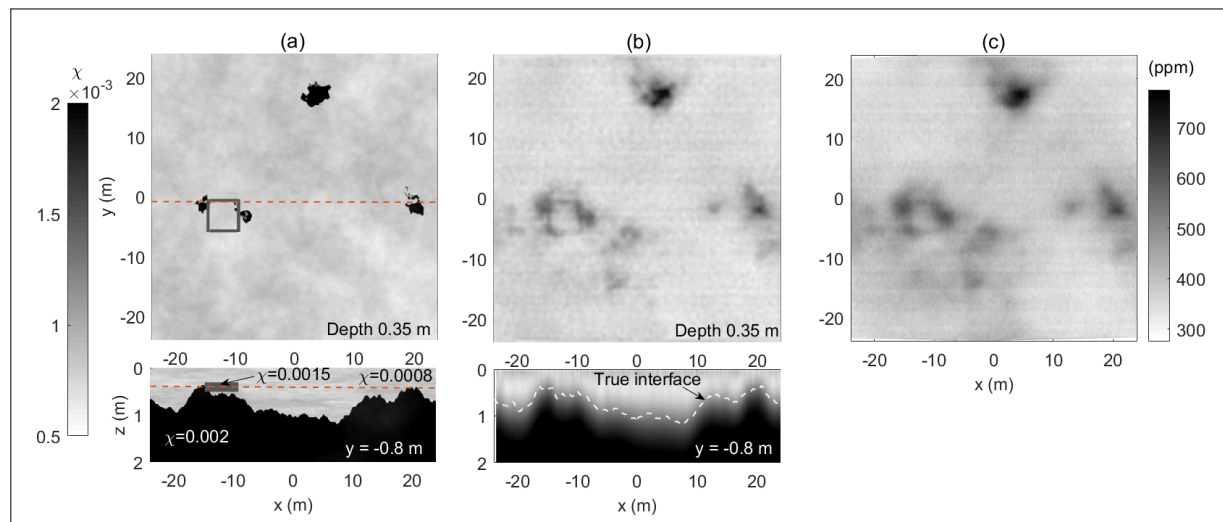


Fig. 1: Synthetic experiment. a) Input model for computing the FD-EMI in-phase data set, b) 3D model of magnetic susceptibility after 3D MCD inversion, and c) best in-phase data channel (PERP1.1) for delineating the archaeological target selected from the four channels available for a DUALEM21s instrument.

tries of coil spacings of 1 m and 2 m (HCP1 and HCP2), and two perpendicular configurations with spacings of 1.1 m and 2.1 m (PERP1.1 and PERP2.1).

The synthetic data have been generated for the input model shown in Figure 1a by considering a DUALEM21s instrument heading toward positive x . The modelled data consist of four maps of in-phase response in ppm corresponding to the four configurations of the instrument. To simulate realistic conditions, we modelled the data on irregular recording locations, taken from a real data set, and adding different kinds of noise.

The field data have been collected with the same acquisition setup as used in our synthetic study, except for the system heading which is toward positive y . The survey has been performed near Orcines (France) on the flank of the Puy de Dômes volcano, where the remains of buried Gallo-roman foundations were expected from several pedestrian archaeological surveys and the analysis of mole mounds. The collected material are ceramics of I-II century AD and basaltic rocks used for the constructions.

Results

For the synthetic case, a horizontal slice of the 3D susceptibility model obtained by 3D MCD inversion is shown in Figure 1b. We see that the rectangular target is more clearly delineated than in the selected data map (Fig. 1c). Performing a 3D inversion also allows the vertical separation

of this rather shallow body from the underlying magnetic bedrock; i.e., the inversion result provides the relative position/depth of the different units of interest.

For the real data case, the model obtained from 3D inversion (Fig. 2b) provides an image with better resolved signatures. Moreover, it highlights signatures where the background geology (basaltic bedrock) shows high responses (noted A in Fig. 2b) and even unveils some part of the buried foundations (B in Fig. 2b).

Conclusion

By a synthetic study, we demonstrate how a full 3D inversion of noisy in-phase data can unveil subsurface magnetic signatures, which might be hardly detected by a qualitative analysis of the data without inversion. We further confirm these observations using a field data set acquired at a Gallo-Roman archaeological site in Orcines, France. Here, the 3D inversion of FD-EMI in-phase data unveils the presence of archaeological remains that are not visible in the original in-phase data maps. In addition, the overall appearance of the image is improved with sharply imaged signatures. This study confirms the limitations of a qualitative analysis of in-phase data maps and thereby demonstrates the potential of 3D acquisition and interpretation procedures, which are able to optimally exploit the information provided by FD-EMI in-phase data. ■

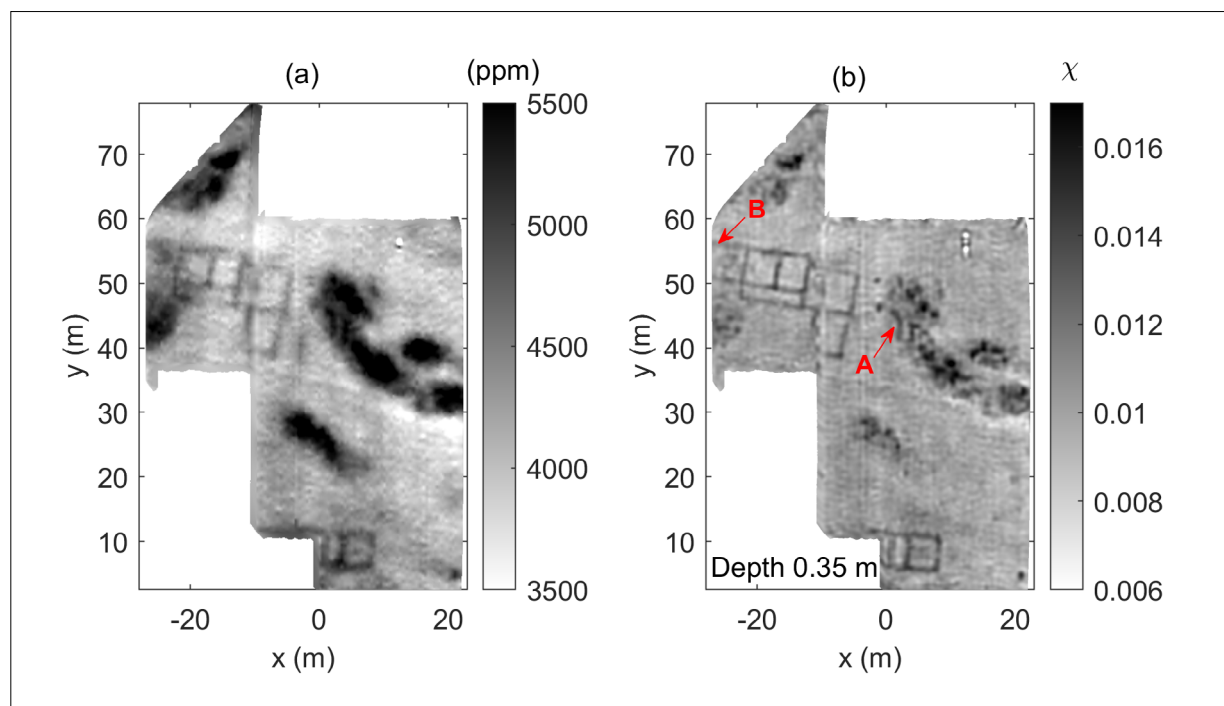


Fig. 2: Field data example from Orcines, France. a) Best in-phase data channel (PERP1.1) for delineating the archaeological target selected from the four channels available for a DUALEM21s instrument. b) Horizontal slice (depth 0.35m) of the 3D susceptibility model provided by the 3D MCD inversion.

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