

3DMCD/1DLCI inversion of an FD-EMI dataset: the case study of the paleolandscape of Bourbourg/Loon-Plage (France)

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Abstract

An electromagnetic survey supports the archaeological field evaluation. Data calibration with electric sounding is necessary before inversion. The 1D LCI inversion is accurate enough if the horizontal variation is smooth. The 3D MCD inversion considerably reduces lateral effects. To date, the 3D/pseudo-3D is not required in the field evaluation phase.

Keywords

conductivity; development-led archaeology; electromagnetic low-frequency; inversion; paleolandscape

Introduction

Since 2015, when the first geophysical survey was carried out on the Port of Dunkirk extension land planning project, more than 600 ha have been surveyed. The aim of this work was to support the conventional methods of investigation used in France: trial trenching with mechanical shovels. Here, loop-loop frequency domain electromagnetic induction (FD-EMI) surveying is used as a complementary tool to map sedimentary deposit variations at the scale of the construction scheme (Deschodt et al. 2021).

Initially, these FD-EMI prospections were carried out using a single-receiver instrument (Geonics EM31), in vertical co-planar (VCP) mode. This first campaign showed that the contrast of electrical conductivity between the fairly sandy surrounding soil and the filling of the paleochannels and old drainage ditches, can be well detected by the FD-EMI method. From 2019 onwards and in order to specify the nature of these variations, we decided to use a three-receiver instrument (GF Instruments CMD Explorer) that allows measurements at three different depths. In order

to increase the depth of investigation, the configuration was switched to a horizontal co-planar (HCP) mode. The results were just as convincing but small-scale anomalies inversions related to the complexity of the response of the HCP configuration were observed on channels 2 and 3. Preliminary inversion tests showed very convincing results. This is why we decided in 2021 to continue this research and to carry out measurements with a six-receivers instrument (GF Instruments CMD6L) in preparation for both 1D and 3D inversion experiments. Beyond the inherent technical difficulties of EMI instruments (e.g., their calibration), a discussion has been initiated on the interest of a 3D characterization of the geomorphological shape of the soils and their impact on the land analysis by the archaeological teams.



Fig. 1: View of the acquisition system (GF Instruments CMD6L).

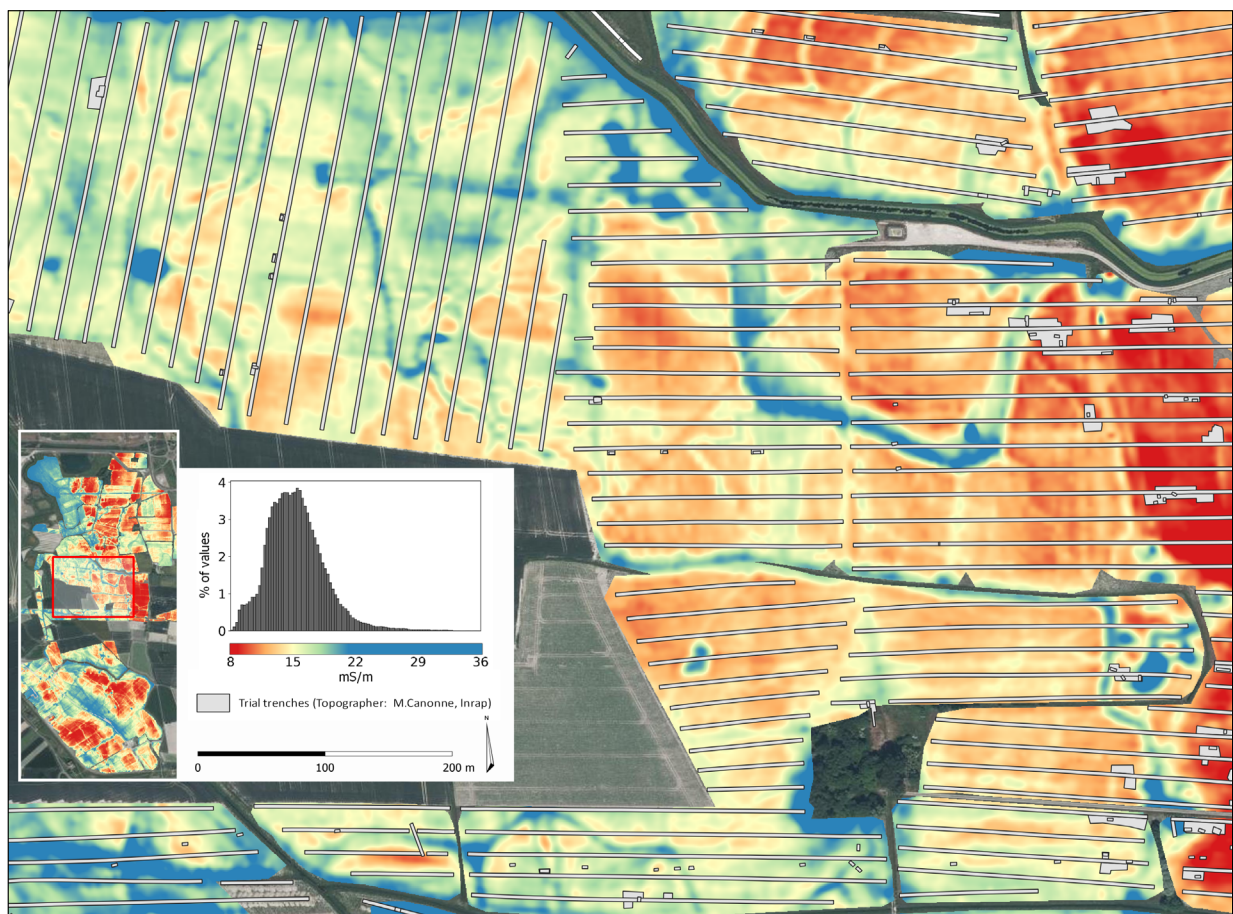


Fig. 2: Map of the apparent electrical conductivity (CMD6L, coil spacing = 1.05 m, HCP configuration) (background: ortho-photography IGN©).

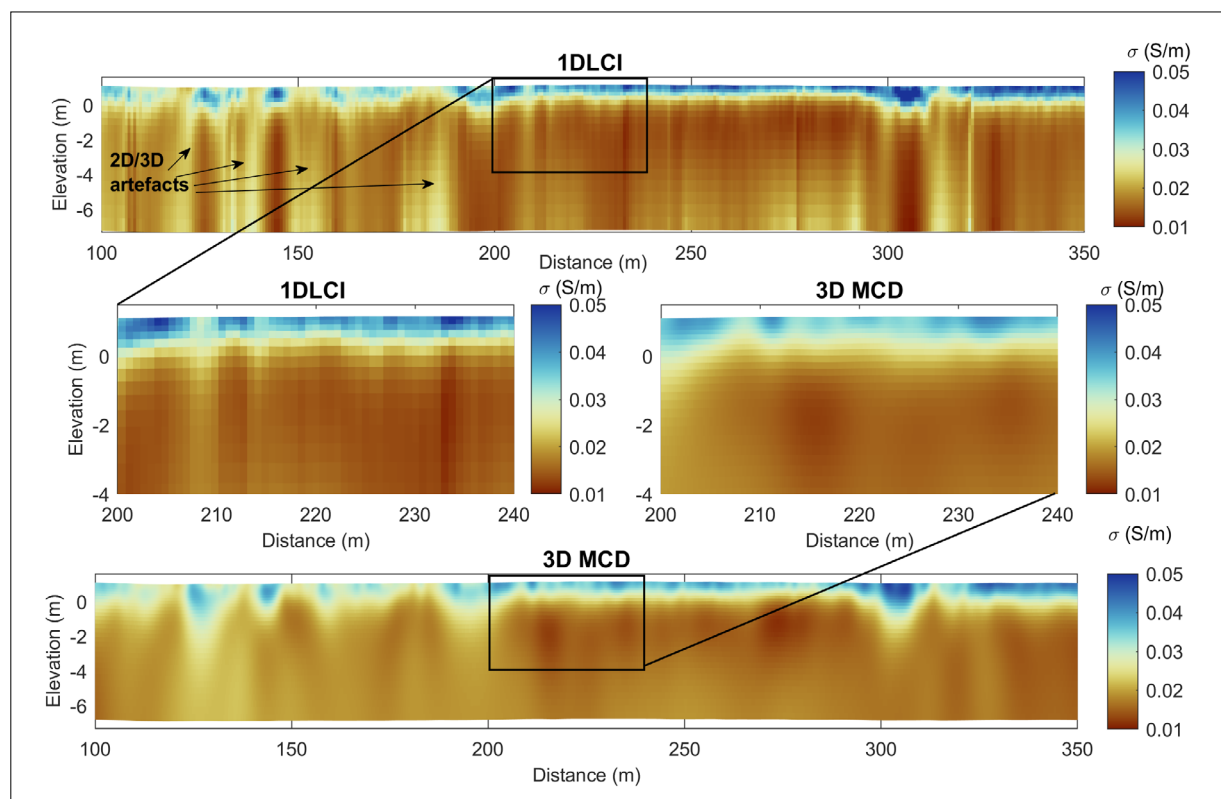


Fig. 3: Results of both inversion algorithms.

Materials and methods

The survey was carried out with the CMD Explorer 6L (GF Instruments). It includes a transmitting coil that emits an electromagnetic field at a frequency of 10 kHz and 6 receiving coils. These coils are separated by 0.6, 1.05, 1.6, 2.45, 3.30 and 4.23 m. The device was mounted on a sledge providing acquisition at a constant height of less than 30 cm above ground. The system was pulled with a 4x4 vehicle located at a distance of 6 m ahead (Fig. 1).

In order to carry out the calibration of the data, several vertical electrical soundings were repeated over the whole area of the project with the Lippmann 4 Point Light. These electrical soundings were inverted with Ipi2Win and the response of the CMD6L was modelled for each sounding point for comparison and calibration.

We then inverted a selected high-resolution dataset using two types of inversion: the non-linear 1D laterally constrained inversion (1D LCI) described in Klose et al. (2022), and the linear 3D inversion based on the multi-channel deconvolution (3D MCD) method (Guillemoteau et al. 2016; Guillemoteau et al. 2017; Guillemoteau et al. 2019).

Results


The results of both 1D LCI and 3D MCD inversion techniques can be used to determine the depth and shape of the detected features. They also allow archaeologists to visualize geophysical properties in vertical slices of soil rather than horizontal maps of apparent electrical conductivities, which, by definition, show less contrasted anomalies. Furthermore, in case of small-scale lateral variations (i.e., at the order of the coil distance), apparent conductivity anomalies have complex shapes due to 2D/3D effects and are difficult to interpret (e.g., three-peaks anomalies typically observed for the HCP configuration) (Fig. 2). By definition, the 1D or 3D inversion are able to correct the first effect or both effects, respectively and reconstruct a more realistic spatial distribution of the electrical conductivity (Fig. 3).

Discussion

This dataset allowed us to assess the contribution of such an approach for the study on Dunkirk port extension proj-

ect. The distortions linked to the shape of the anomalies are largely reduced thus the geomorphologist is able to predict the layout of the paleochannels at different depths. However, the latter information is partly redundant with his work. In order to clearly define and characterize the geomorphological features and sedimentary deposit process, direct inspection is essential. Despite inversion, the uncertainties on the depth estimation based on geophysical data remain significant and cannot be substituted for direct observation. Apparent conductivity maps would be sufficient to identify areas of interest for geomorphological test pits. However, once integrated with archaeological and geomorphological observations, the inversion provides a laterally continuous information, which can link the coarser grid of test-pit points.

Conclusion

After a proper calibration (e.g., based on few VES soundings), the loop-loop FD-EMI data collected by a CMD6L instrument can be inverted to reconstruct the true spatial distribution of subsurface conductivity within the first 5-6 m of the subsurface with a sub-meter lateral resolution. This inversion process reduces interpretation errors among archaeologists and geomorphologists and realistically characterizes conductivity variations of the soil. 

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