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Multi-Frequency Loop Electromagnetic System Measurement on Shallow Offshore Archaeological Site of Oulos

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Highlights:

- *Multi-frequency loop electromagnetic system measurements can be done on shallow offshore sites.*
- *Multi-frequency sounding is relevant in this environment.*

Keywords: shallow offshore, multi-frequency, electromagnetic, modelling, case study.

INTRODUCTION

Electromagnetic induction (EMI) equipment with a multi-frequency harmonic source of the Slingram type and small coil spacing, was initially intended for multi-depth electrical conductivity mapping. This type of "vertical" multi-frequency EMI sounding implies that the operating frequencies significantly change the depth of investigation, which, in the case of the small loop loop Slingram systems, requires measurements at large induction numbers. In the frequency range used by these systems (300 Hz-90 kHz), this condition is rarely encountered because near-surface conductivity values are very often less than 0.5 S/m. For this environment, the depth of investigation is then essentially determined by the coil spacing and geometry rather than by the frequency of the transmitter. With this constraint, these devices have nevertheless proved to be interesting for multi-parameter approaches where in some contexts, dielectric permittivity and magnetic viscosity can be estimated (Simon *et al.*, 2015, 2019). In a marine setting, the high conductivity of the water layer allows us to move out of the low induction number domain (Hunkeler *et al.*, 2016). In this context, it is expected that the salt-water layer amplifies the frequency dependence of the vertical sensitivities, thus making the information from a "multi-frequency" sounding usable for the characterization of the underlying environment. In order to determine the feasibility of such an approach in the context of archaeological prospecting, we performed a two-stage study. Initially, we carried out 1D and 3D simulations based on a realistic model. We then performed a field survey using both the electromagnetic and electrical methods (3D ERT) in an area where the bathymetry was accurately determined.

METHODS

We used the GEM2, which provides measurements over a frequency range between 300 Hz and 90 kHz. With this device, it is possible to collect phase and quadrature data on

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five different frequencies simultaneously. It also has a fairly good mechanical stability. The presence of a 'bucking coil' located at a distance of 1.035 m from the transmitter also lets the instrumental drift be regulated. The spacing between the transmitting and receiving coils is 1.66 m, which allows structures to be resolved on a meter scale. The GEM2 is a relatively lightweight and fairly easy to handle device, and can be connected directly to a GNSS system. It was placed on a platform of floating buoys (Fig. 1), Data acquisition was carried out in a favourable meteorological context in order to avoid any pitch and roll effects that could considerably affect the signal quality. All these instrumental parameters were taken into account when modelling the response of the device, considering 1D and 3D distributions of electrical conductivity. The 1D solution is based on the method of integrals that allowed the effect of the different frequencies and the seawater layer to be visualized. The 3D modelling procedure is based on the method of moments (Tabbagh, 1985).

Figure 1. Acquisition of multi-frequency electromagnetic data at the archaeological site of Olous (Greece).

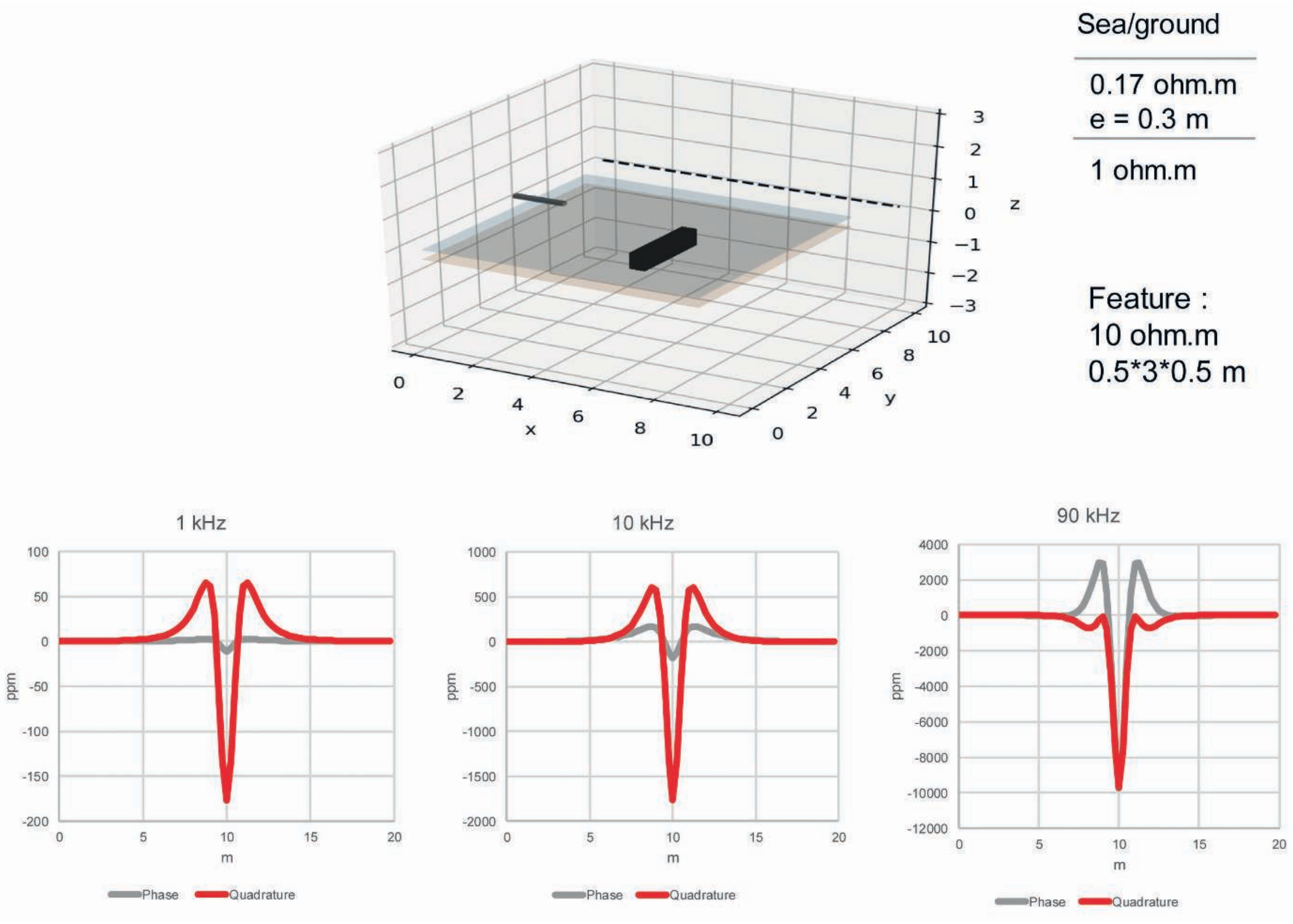

Figure 2. 3D-modelling of a wall under the sea surface at a water-depth of 0.3 m.

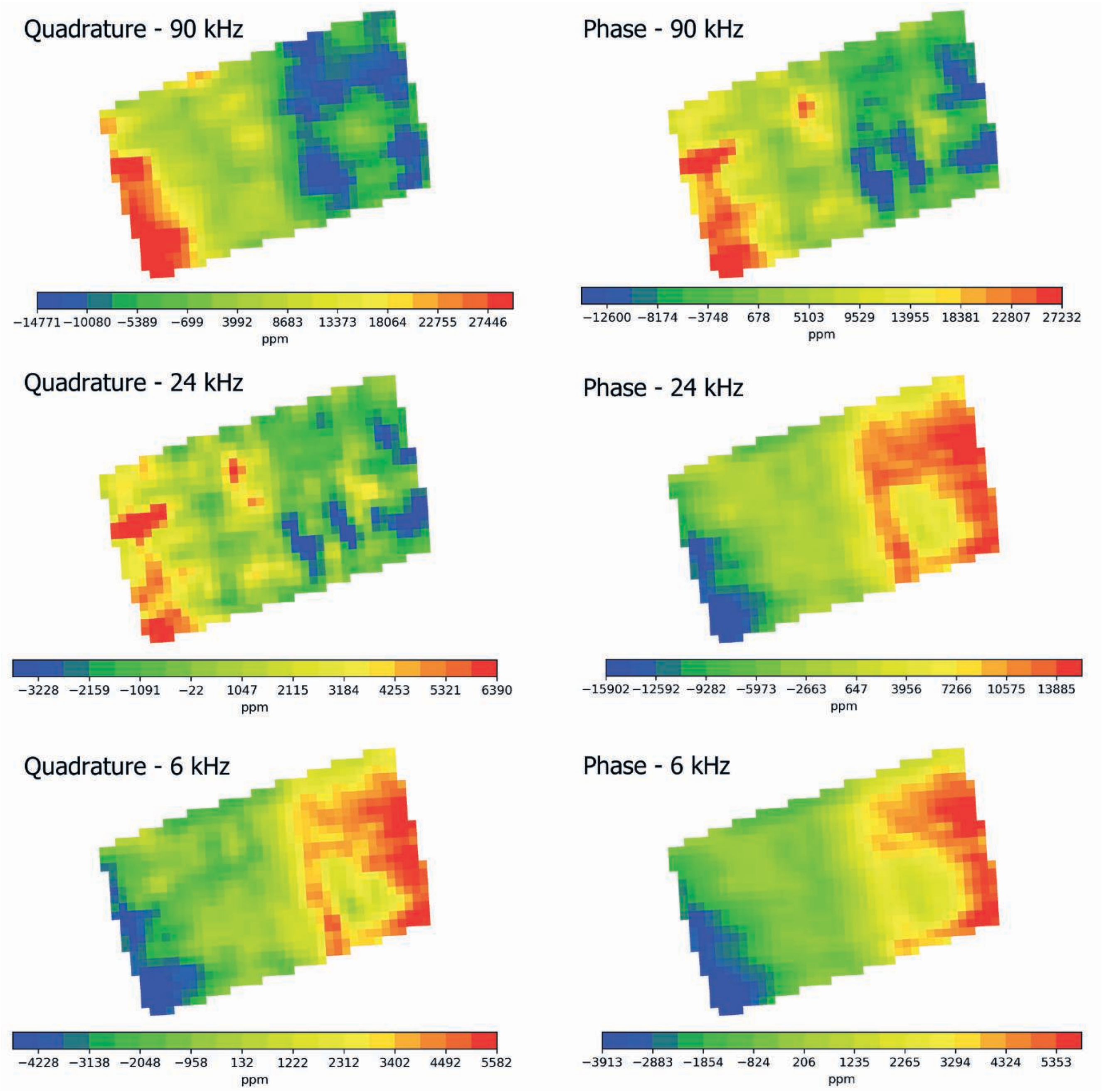

Figure 3. In-phase and out-of-phase mapping of electromagnetic data at 90 kHz, 24 kHz, and 6 kHz.

The first modelling results show that below a layer of saline water it is possible to study the substratum conductivity at variable depths with multi-frequency EMI data. The dynamics of the measured signal is relatively strong for relatively thin water slices but when the water thickness increases, this dynamic is strongly reduced. It is therefore essential to know the thickness and the conductivity of the water layer in order to better characterize the variations of conductivity below the seabed.

The results of the 3D modelling also show that the sensitivity to conductivity variations is different for the in-phase signal and for the quadrature signal, but that the observed difference is barely dependent on the frequency used (Fig. 2).

RESULTS

A test was carried out in August 2020 on the archaeological site of Elounda in Greece. A section of the site had already been investigated with 3D electric prospecting and a precise bathymetric model also exists. The average water depth of this site is 0.3 m. The electromagnetic device was positioned on a floating platform at 0.3 m above the water level in horizontal mode and connected to a GNSS antenna (Fig. 1). The observed results (Fig. 3) show significant variations in phase and quadrature component, indicating a high induction number domain. Measurements made at different frequencies allow maps to be drawn with different electrical conductivity distributions over the different frequencies. These maps also show dissimilar lateral variations which could be associated to the multi-depth response of the substratum. However, one must remain vigilant regarding expected complex interactions (i.e., specific to each frequency) with the thickness of the seawater layer.

CONCLUSION

Experimental results confirm the potential of the electromagnetic method in a shallow marine environment. However, further modelling is necessary to separate the substratum response from the (preponderant) sea layer response. According to preliminary sensitivity tests, a small loop-loop multi-frequency Slingram EMI system may allow multi-depth investigations. The continuation of this work will focus on the 1D inversion of the collected GEM2 data including the bathymetry. Additional surveys are also planned with a denser 3D spatial sampling allowing the interpretation of the 3D anomalies, and limiting the lateral aliasing typically observed if the distance between points/profiles is too large.

If it proves capable of detecting a heterogeneous distribution of conductivity in a marine environment, the EMI method would allow data acquisition that is much less constraining to implement than in the case of the electrical method. Inversion of EMI data is therefore essential, if one wishes to obtain understandable results.

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