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Measurement of the dielectric permittivity through multi-frequency EMI for archaeological prospection

François-Xavier Simon[a, c], Alain Tabbagh[b] and Apostolos Sarris[c]

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INTRODUCTION

Recent developments in EM instruments have opened new opportunities for archaeological surveying. New devices with multi-coil spacing had already allowed investigation of multi-depths for

[a] Plateforme Intelespace, Maison des Sciences de l'Homme, Clermont-Ferrand, France
[b] Laboratory METIS, Pierre and Marie Curie University, Paris, France
[c] Laboratory of Geophysical – Satellite Remote Sensing and Archaeoenvironment, Institute for Mediterranean Studies, Foundation for Research and Technology – Hellas, Rethymno, Crete, Greece

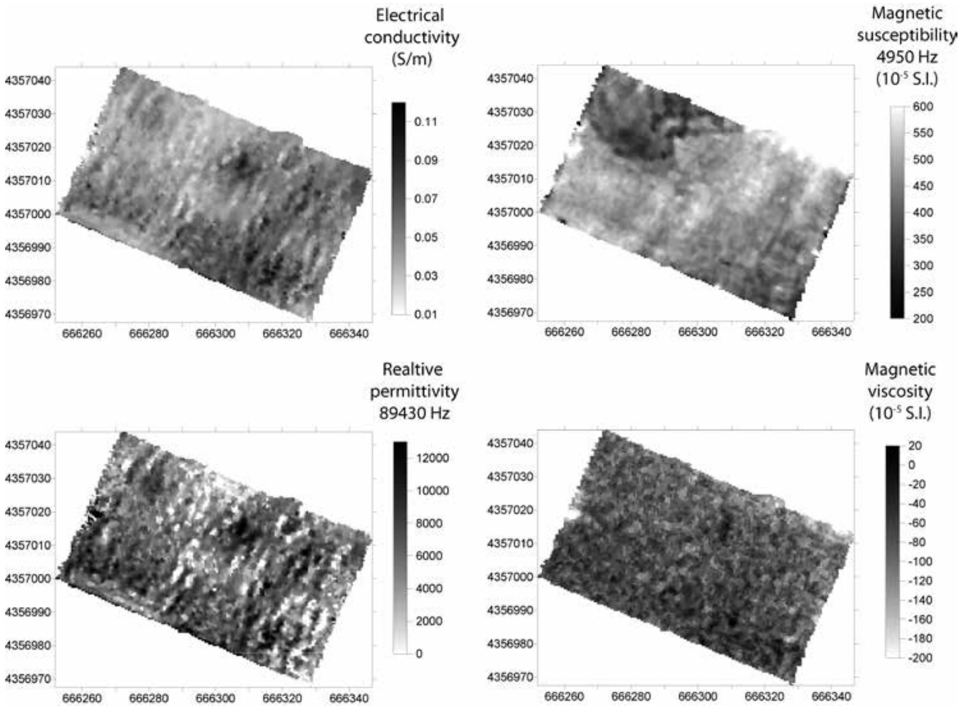

Fig. 1. Result of EM multi-frequency investigation at Demetrias with electrical conductivity (supposed to be independent of frequency) (upper left), magnetic susceptibility at 4950 Hz (upper right), relative permittivity at 89430 Hz (lower left) and magnetic viscosity (lower right). Magnetic viscosity and relative permittivity show an offset that could not be removed despite the application of calibration procedures

characterizing the depth of the remains (Bonsall *et al.* 2013), but also for a better understanding of soil and embankment depth (De Smedt *et al.* 2014). Moreover, EM instruments have also been developed recently for *in situ* measurement of complex magnetic susceptibility (Thiesson *et al.* 2007). Applications of multi-frequency EMI for characterizing magnetic viscosity (together with electrical conductivity and magnetic susceptibility) have demonstrated in turn some effects at the highest frequencies, leading to the present research focused on EMI measurement of dielectric permittivity impact.

STATE OF THE ART

The use of EM theory for geophysical prospection is based on approximations of Maxwell's equation in order to minimize the complexity of the signal and to make a link between the response of the instrument and the physical properties primarily affecting the response. As electrical conductivity mainly affects the response at low frequency, it was an obvious choice to use EM instruments to map it (Mc Neill 1980). It was also proved that for a low induction number, the complex EM signal could be used to map simultaneously both electrical conductivity and magnetic susceptibility (Parchas and Tabbagh 1978).

Since magnetic susceptibility has complex form and since this complex form delivers useful information on magnetic viscosity (Mullins and Tite 1973), the GEM-2 instrument from Geophex Ltd was used to map magnetic viscosity *in situ* (Simon *et al.* 2014). It allows measurement at five different frequencies. Unexpectedly, the results for the highest frequencies were distorted by new effects. As the assumption of the low induction number was not fully justified (we were using a high frequency close to the limits of the assumption <100 kHz), we had expected some effects related to the depth of investigation. For these frequencies, the induction number could be dependent not only on coil geometries, but also on frequency.

But earlier studies and recent experiments seem to follow another track. For twenty years it has been demonstrated that EMI instruments are sensitive to dielectric permittivity, if the frequency is sufficiently high. Authors were firstly interested in the simultaneous mapping of magnetic susceptibility, electrical conductivity and dielectric permittivity (Tabbagh 1994) and for this purpose they explored the middle frequency range of the instruments. It was shown that the EM response is affected by electrical conductivity and dielectric permittivity, but magnetic susceptibility has a negligible effect in this frequency range. This was verified using a new instrument allowing direct measurement of both electrical conductivity and dielectric permittivity at 1.5 MHz frequency (Kessouri 2012). More recently, the effect of dielectric permittivity was used to explain measurements performed at 30 kHz on saline soils (Benech *et al.* 2014), following an approach which is usually applied in mining EM prospection with greater inter-coil spacing instruments (Huang and Fraser 2001).

METHODOLOGY

Our focus was firstly on the electrical conductivity and on the effect of the magnetic viscosity on the quadrature part of the signal. To extract the electrical conductivity we did the subtraction of the measurement at two different frequencies that were as low as possible. As the effect of magnetic viscosity is independent of the frequency, the use of these two frequencies allows for the effect of this parameter to be removed. Then the effect of electrical conductivity on both components of the signal was removed in order to establish the value of magnetic susceptibility using the in-phase part of the signal and magnetic viscosity using the quadrature part. We used these three values (σ, κ_q and κ_p) to do a simulation of the EM response for the highest frequencies, in order to remove this contribution on the raw EM signal and to keep only the effect of dielectric permittivity. The last step aimed at transforming the resulting values into dielectric permittivity.

RESULTS

The above procedure was applied using a GEM-2 instrument from Geophex at two sites in Greece. The first one was the Hellenistic site of Demetrias, close to Volos, and the second one was a Neolithic tell (*magoula*) in Thessaly. Other methods were also used on both sites (magnetic survey, resistivity and GPR) as comparative data for the assessment of the efficiency of our methodology. The results for Demetrias are presented in Fig. 1. It remains difficult to define the zero in-phase values (mechanical drift of the instrument) and thus to affect the observed offset at either magnetic susceptibility or dielectric permittivity. However, the high permittivity values are in agreement with the problems encountered in the GPR survey (but at higher frequencies).

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