Complex magnetic susceptibility measurement using a multi-frequency Slingram EMI instrument

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GEM2
(Geophex, Ltd.)

Introduction

The use of EMI devices for soil mapping is well-known, especially for the measurement of electrical conductivity in environmental or archaeological studies. To neglect displacement currents, the used frequencies are lower than 100 kHz. According to the low induction number (LIN) approximation, conductivity is in quadrature out of phase from the transmitter moment which allows the measurement of the magnetic susceptibility on the in-phase part of the signal. Under this approximation also the depth of investigation only depends on instrument geometry, meaning the choice of coils spacing and orientations. We try here to expend the multi-frequency measurement of the magnetic susceptibility with a handel EM mulit-frequency device.

Complex magnetic susceptibility

Studies on soil samples and TDEM measurements in the field have shown that the magnetic susceptibility is a complex quantity (Mullins and Tite 1973, Dabas and Skinner 1993). According to the dispersed single-domain grain theory, the imaginary part κqu called the magnetic viscosity and the real part κph of the magnetic susceptibility are linked by the following relation. It means that the in-phase magnetic susceptibility is a frequency dependent quantity and the out-of-phase magnetic susceptibility a non-dependant one. In common soils the quadrature part of the magnetic susceptibility is approximately 6% of the in-phase part. The knowledge of the magnetic susceptibility components is particularly interesting for determination of the size of the magnetic grains and is related to the nitrogen and carbon contents (Thiesson et al. 2012).

$$\kappa = \kappa_{ph} - i\kappa_{qu}$$

$$\frac{2}{\pi}\kappa_{qu} = \frac{\partial \kappa_{ph}(\omega)}{\partial Ln(\omega)}$$

EMI Multi-frequency

To manage these multi-frequency measurements we used the **GEM2 (Geophex, ltd)**. It is a broad-band instrument with a coil spacing of 1.66 m (Won et al. 1996). The two coils are **Co-Planar** allowing me asurement in both HCP and VCP modes. One can choose 5 **different frequencies between 300 Hz and 90 kHz**, with an algebraic or a logarithmic progression. The instrument is not a simple dipole-dipole one because it includes a bucking receiver coil at 1.035 m from the transmitter coil and the measured quantity is the difference between responses at the two receiver coils. Any interpretation must also use this difference and not the signal at the 1.66m coil.

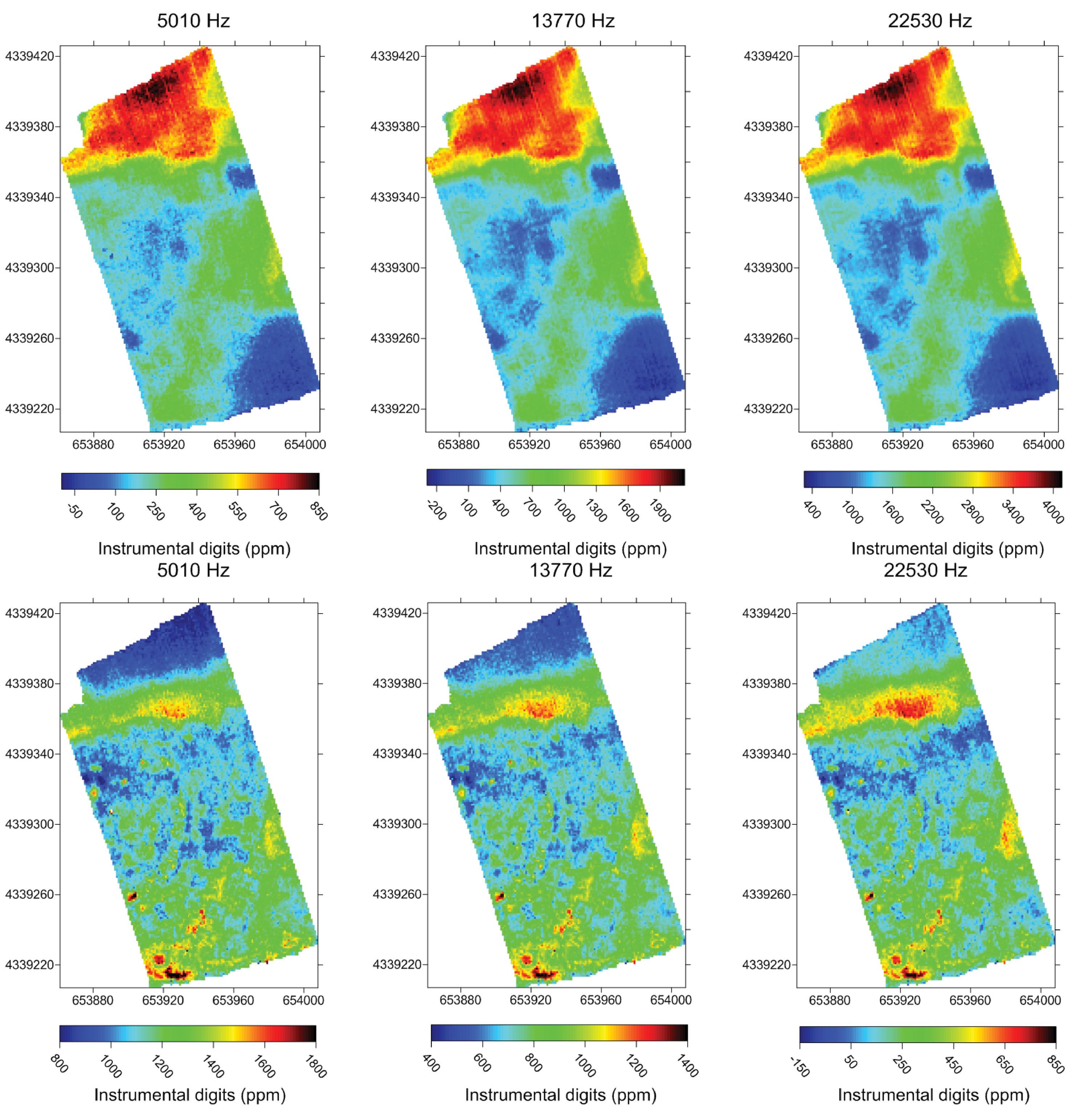
The response generated by the imaginary part of the complex susceptibility adds algebraically to the one generated by the conductivity in the quadrature out-of-phase component of the signal.

The response of the quadrature part of the signal due to the conductivity increases with frequency, unlike the magnetic susceptibility.

The use of different frequencies therefore allows separating the conductivity and the magnetic viscosity responses.

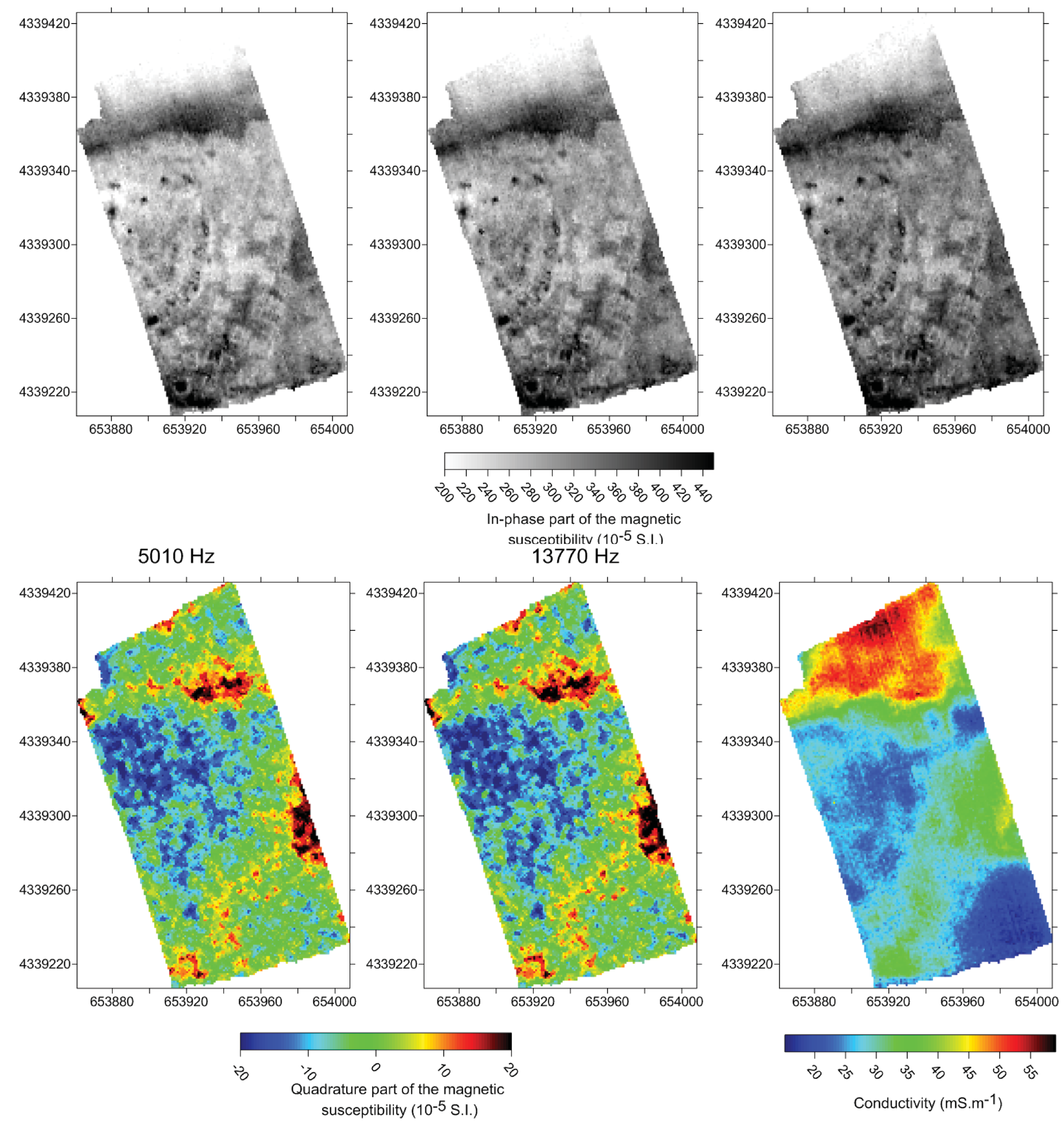
Depth of investgation is not frequency dependent

Raw data



For the in-phase component of the raw signal, some differences, especially to the north part of the map are related with the conductivity effects. Offsets for each frequency and each component suggest the requirement of a calibration.

Process data : Physical properties



The conductivity is relatively high which explains its contribution in the in-phase components of the raw signal for the highest frequencies. For the in-phase magnetic susceptibility the three different frequencies show different zero adjustments partialy induce by a poor calibration and by the complex variation of sign of the anomaly with depth in HCP. Nevertheless, with some a priori on the context, it could be also informative about the depth of detected features. One observes that the relationship between quadrature and in-phase values is not far from the 6% value and that quadrature values don't change with the frequency according with the theory.

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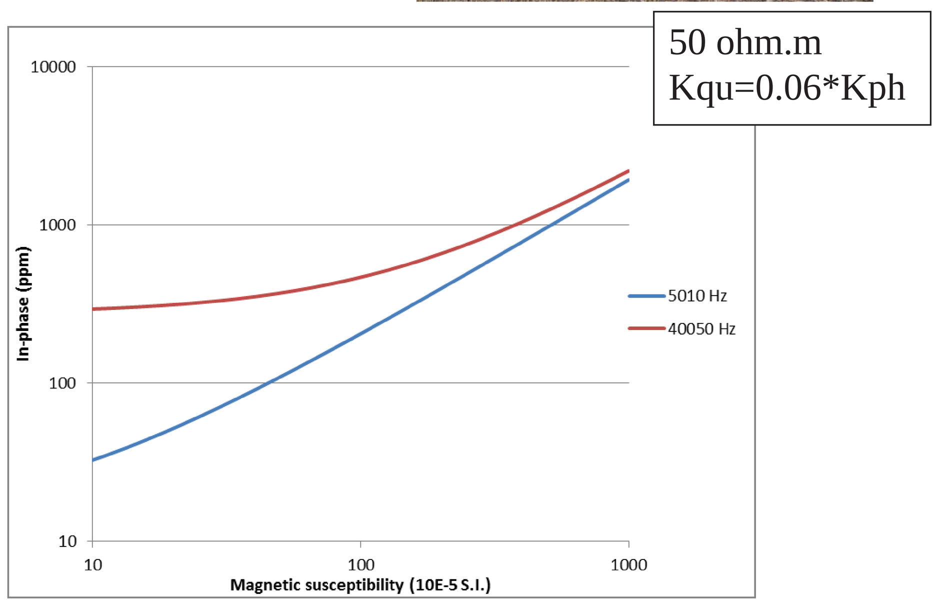
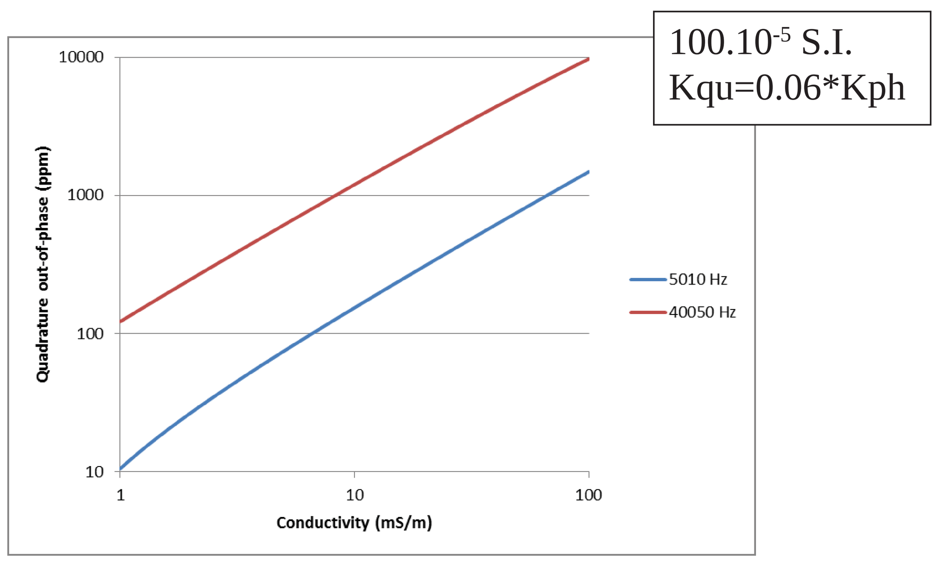


In-phase measurement function of the magnetic susceptibility. We see for the highest frequencies a higher sensitivity to the electrical conductivity.



Offset and difference of dynamics for the quadrature out-of-phase part of the signal at two different frequencies.

Processing and interpretation

Calibration of the response
(offset and instrumental coefficient)

Determination of the electrical conductivity
Use of the 2 lowest frequencies : 5010 and 13370 Hz
(less affected by the dielectric permittivity)

Removing effect of the electrical conductivity in both part of the signal

Determination of the complex magnetic susceptibility for each frequency

The particular methodology was used on the archaeological site of Almiriotiki magoula, in Almyros, Thessaly (Greece) to map the spatial organization of the Neolithic settlement. The survey was carried out along parallel profiles one meter apart with a frequency of acquisition of 1 Hz. We used 5 different measurement frequencies: 5010 Hz, 133700 Hz, 22530 Hz, 31290 Hz and 40050 Hz. The instrument was carried at an altitude of 0.3 m from the ground.

Discussion

Due to the information born by the complex magnetic susceptibility such measurements open new paths in soil properties' mapping that will be very interesting to study. The use of multi-frequency can also be improved, for instance by using frequencies close to 100 kHz, to determine the dielectric permittivity in this part of the low frequency range (Huang and Fraser 2002). Still, effects of polarization are probably not negligible and this property needs to be taken into account for a precise determination of the conductivity.

Aknowledgment

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