Assesment of a multi-frequency Slingram EMI for archeological prospection

Francois-Xavier SIMON (GeoSat ReSeArch), Julien THIESSON (UMR Metis), Alain TABBAGH (UMR Metis), Apostolos SARRIS (GeoSat ReSeArch)

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Outlines

- Multi-frequency EMI measurement
- GEM2

- Properties sensitivity
- Depth of investigation (1D and 3D)

- Experimental data:
  - Hungary (Magor Vezto)
  - Greece - Thessaly (Almiriotiki)

Interest of multi-frequency EM

- Electro-magnetic sounding for electrical conductivity

In archaeology :
- Two commercial instruments
EMProfiler (GSSI Ltd.)
GEM2 (Geophex Ltd.)

@ GSSI

- Multi-frequency measurement of the magnetic susceptibility

$$\frac{2}{\pi} K_q = -\frac{\partial K_{ph}(\omega)}{\partial(\ln\omega)}$$

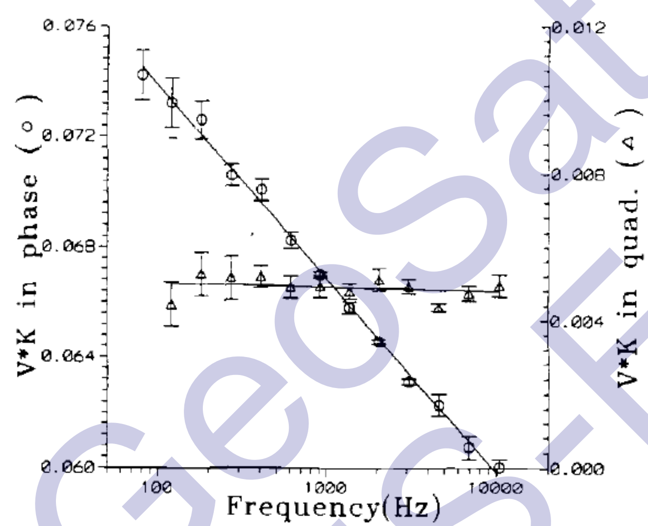


Figure 3. Frequency variations of the in-phase susceptibility (circle) and the quadrature susceptibility (triangles) for sample DC33.

Dabas and Skinner 1993

Sample measurement (FDEM, TDEM), Field Measurement (TDEM)

GEM2 (Geophex Ltd.)

Frequency: 300 – 90 kHz

Coil spacing: 1.66 m

Orientation: Coplanar

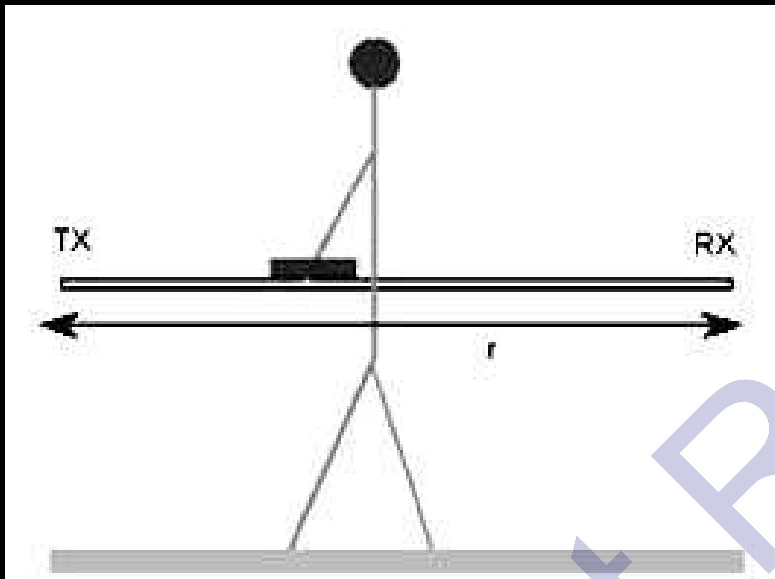
Specificity :
« Bucking coil »
Two reception coils – 1.66 m and 1.035 m
For the compensation of the primary field

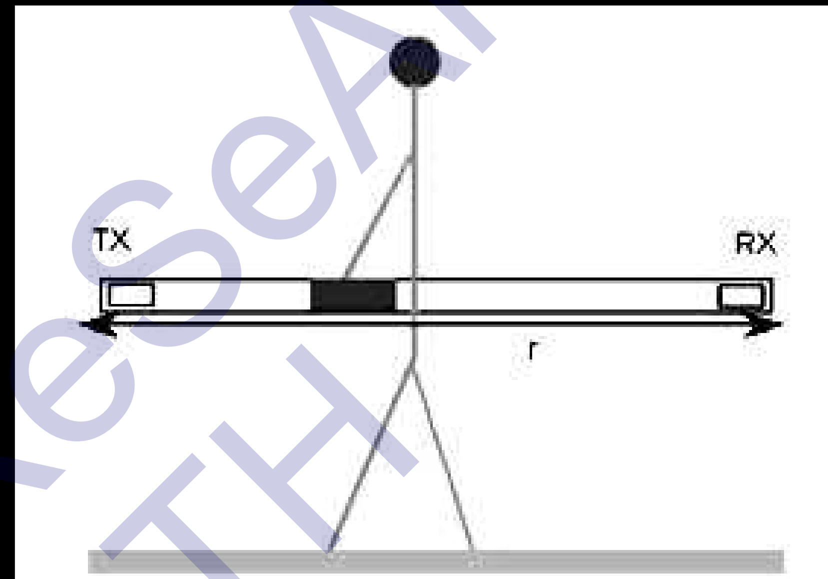
- Increase the stability
- Minimize the instrumental drift

@ Geophex

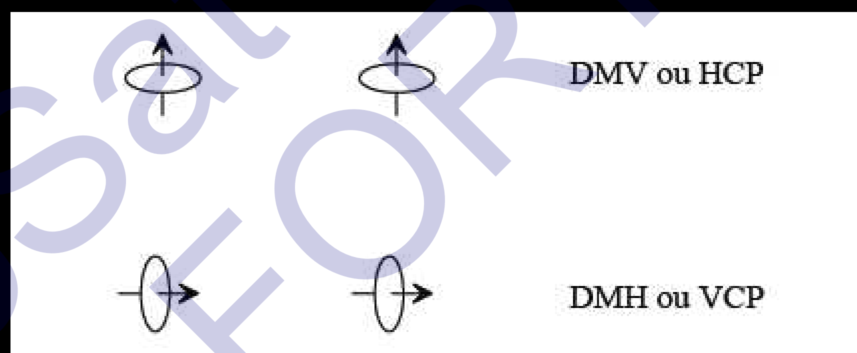
→ Does this specificity affect the response of the instrument ?

Geometries





@ Geophex



Complex signal : in phase (Ph) and quadrature out of phase (Qu)

Low Induction Number

- Meter coils spacing, small coils
- 100 Hz to 100 kHz

Complex signal

↓

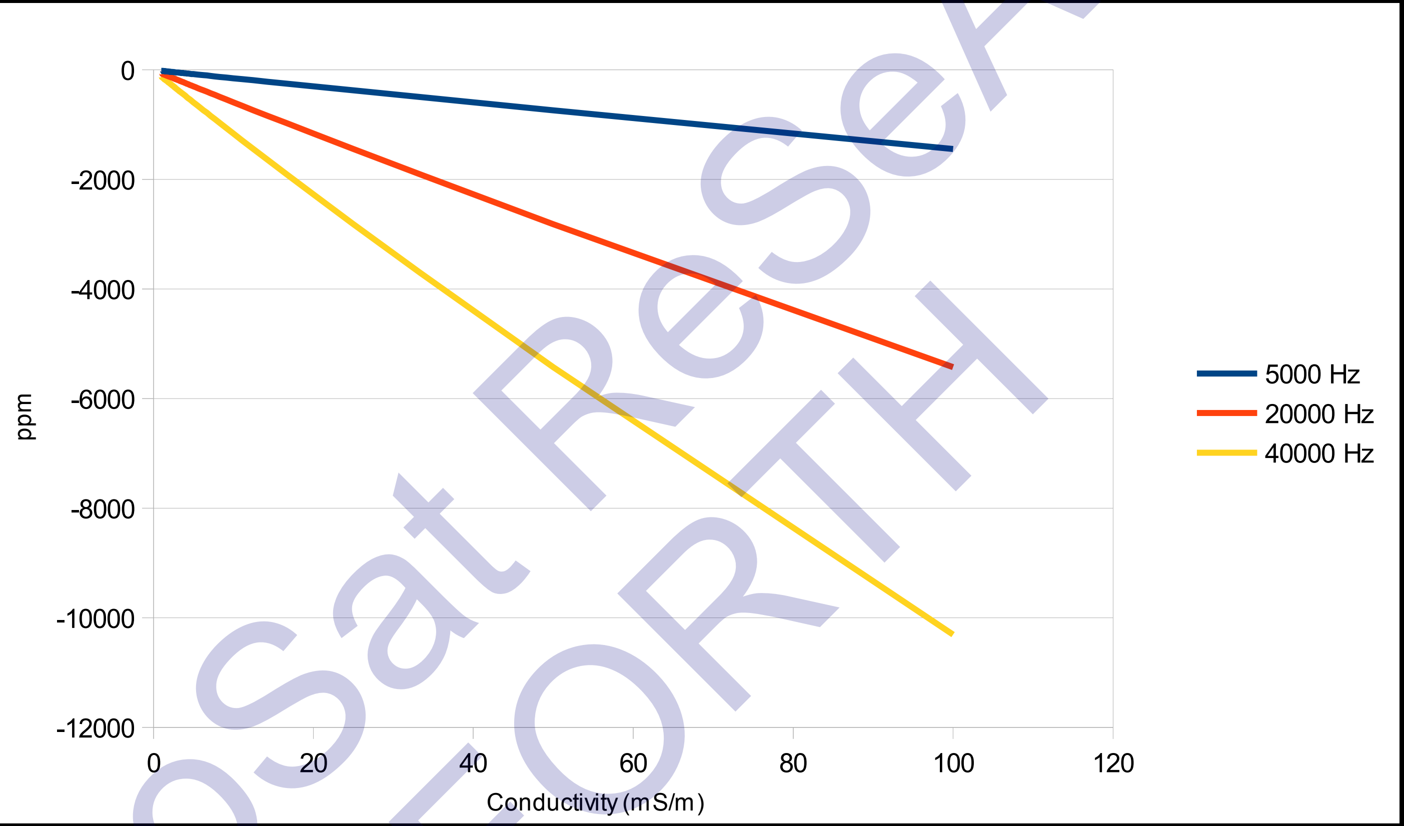
- Depth of investigation depending on the geometries (and not on the frequencies)

- In phase (Ph) link to the magnetic susceptibilty
- Qu link to the electrical conductivity

Reminder : Magnetic susceptibility has a complex form
How this one affect both parts of the complex signal ?

→ Simulation of the behaviours for different frequencies

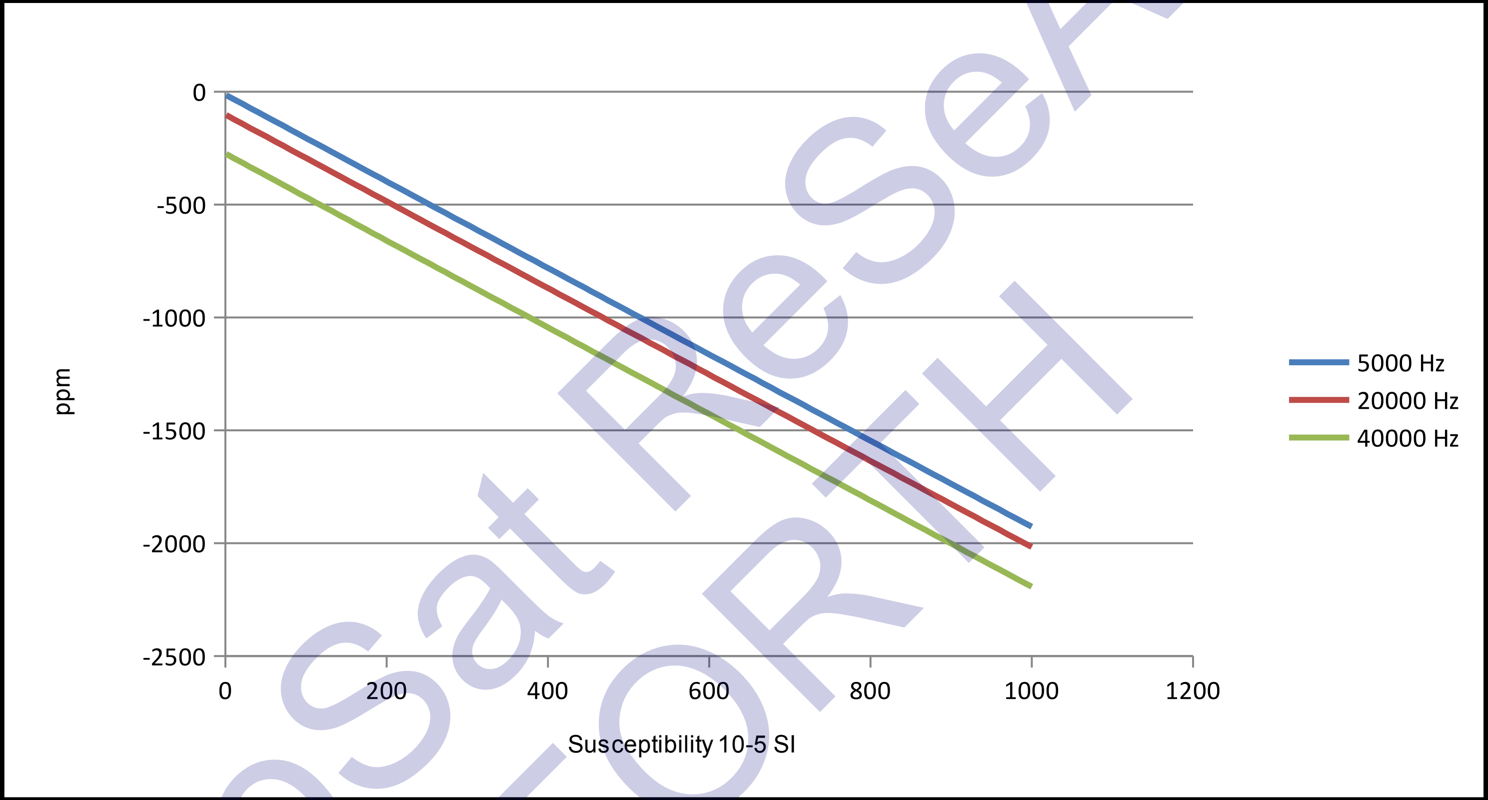
Theoretical response (Qu) to conductivity for different frequencies



Dynamic range of values induce by the frequency

Greatest dynamic range for the highest frequency

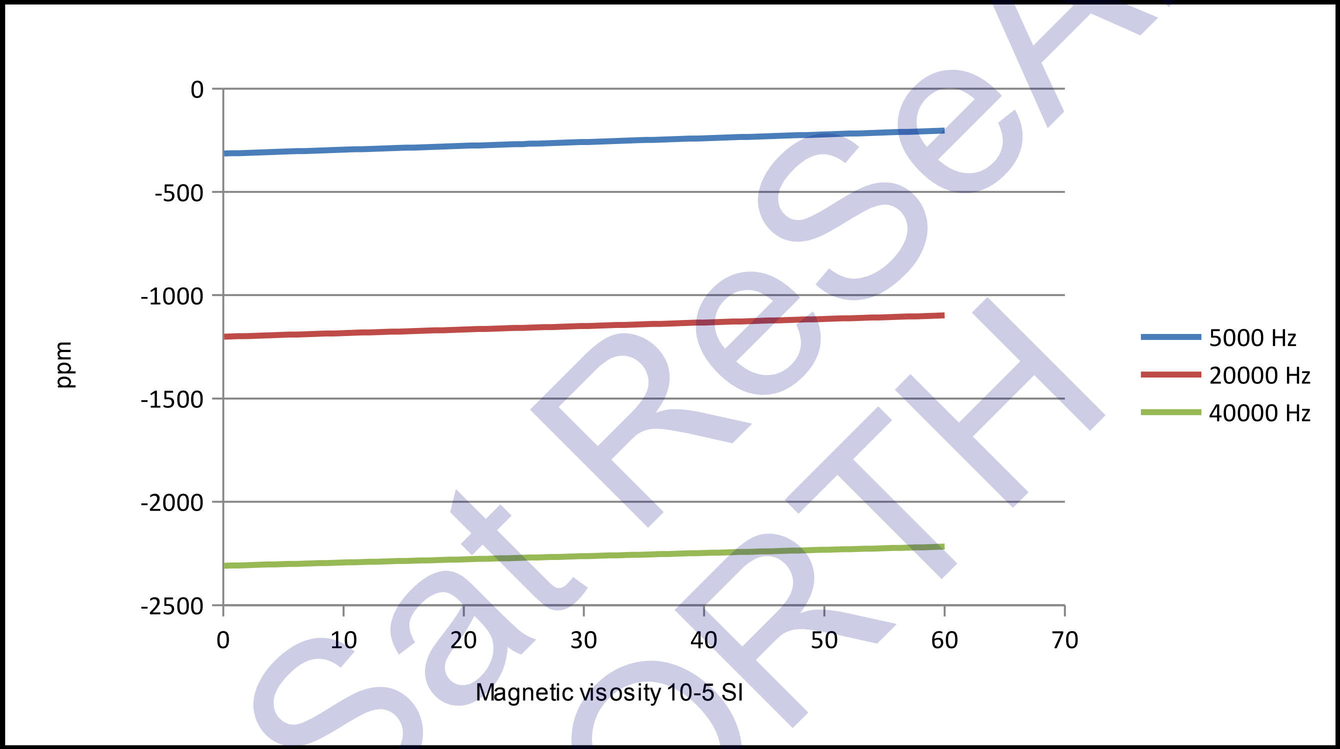
Theoritical responses (Ph) to susceptiblity for different frequencies



Offset link with electrical conductivity

Similar slopes for the different frequencies

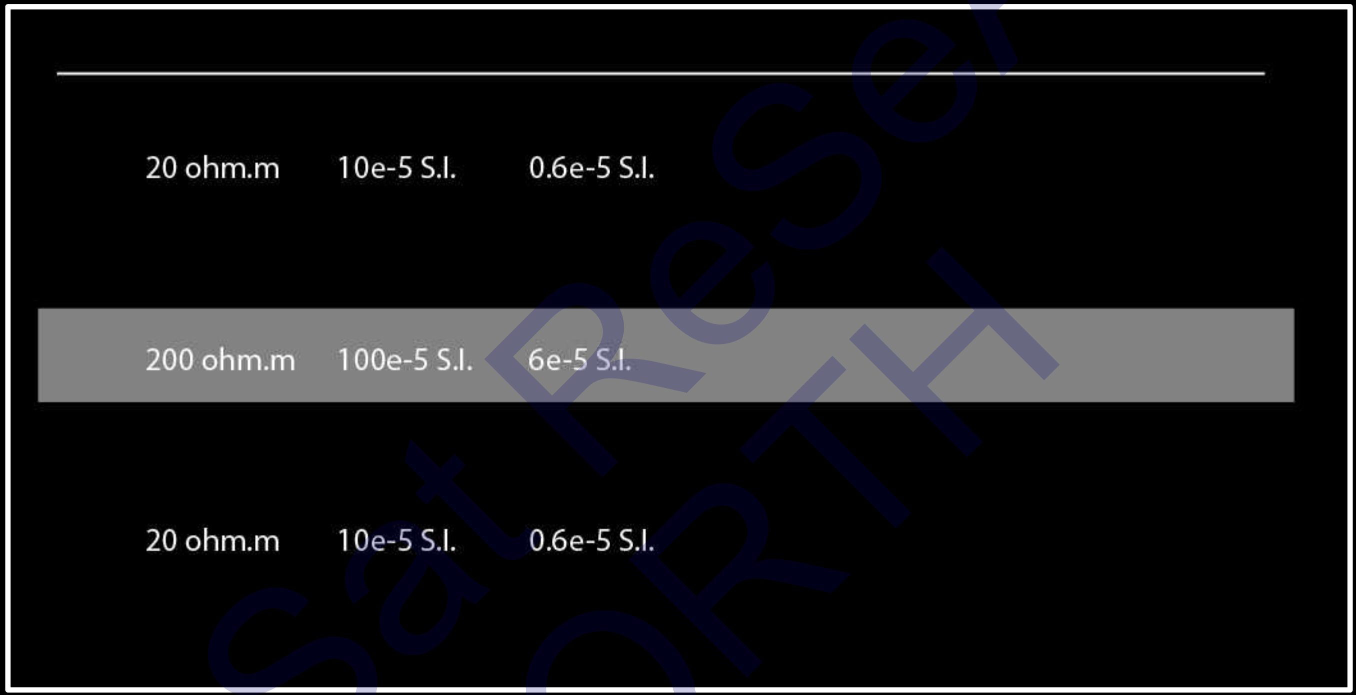
Theoritical response (Qu) to magnetic viscosity for different frequencies



Slope independant with the frequency (offset induced by the conductivity)

Different behaviours with the frequency allows the separation of the different properties

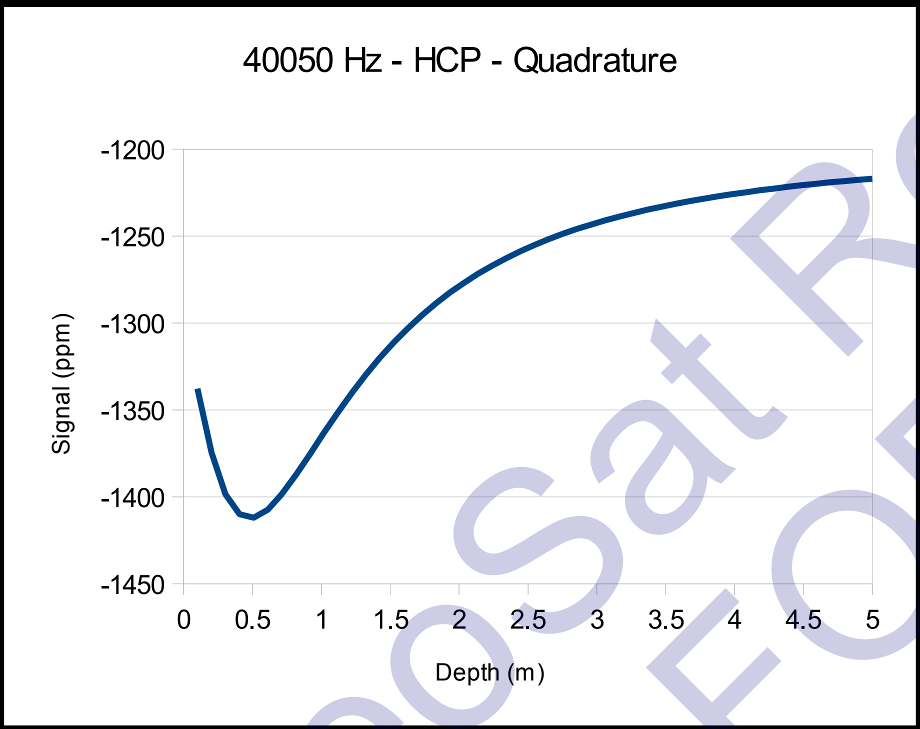
1D geometry for assesing depth of investigation

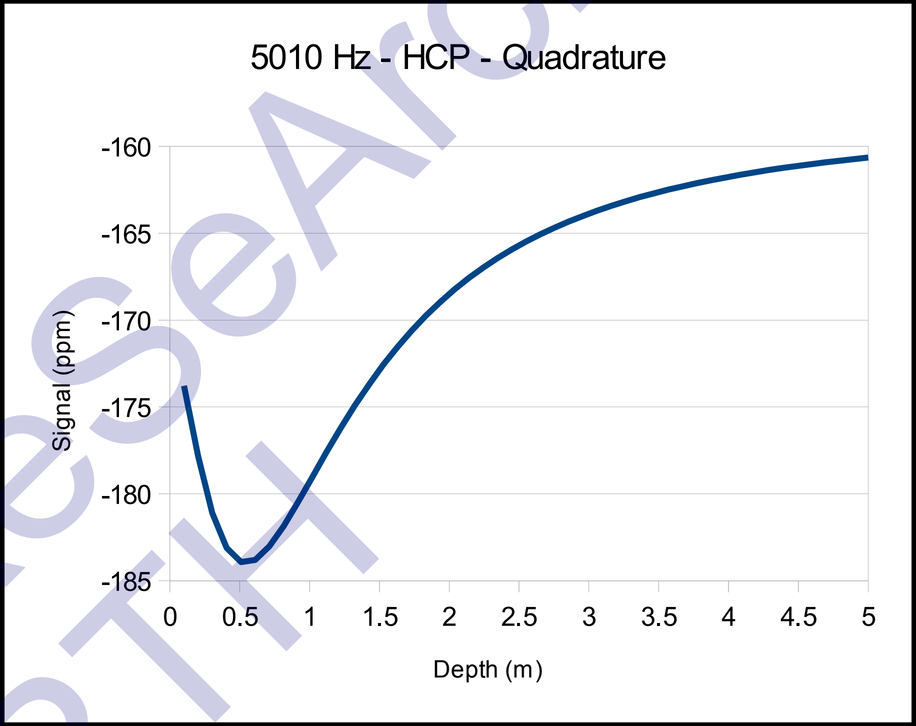


- Shifting of a thin resistive and magnetic layers (from topsoil until 5 m depth)
- Use of two frequencies (5010 Hz and 40 050 Hz)
- HCP / VCP

Depth of investigation

HCP – Qu

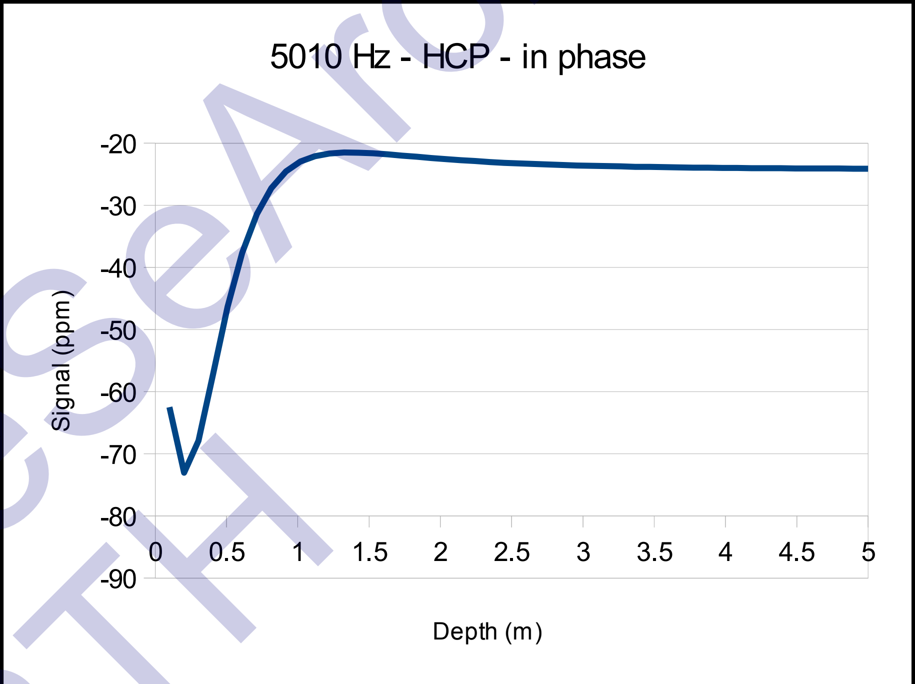


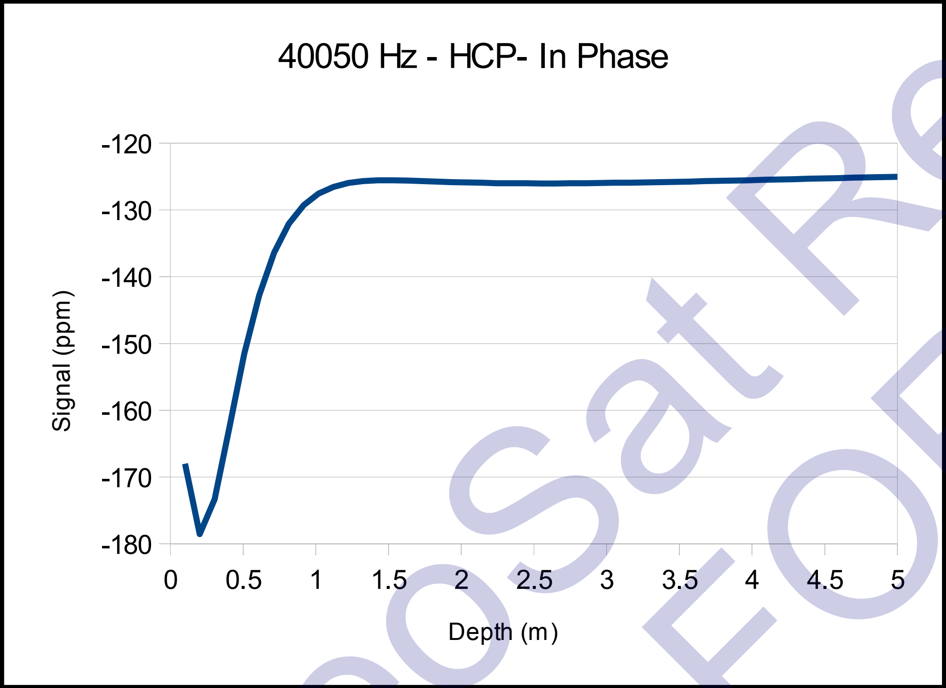


- Same sensitivity
- Different range of values (dependence on frequency)

Depth of investigation

HCP – Ph

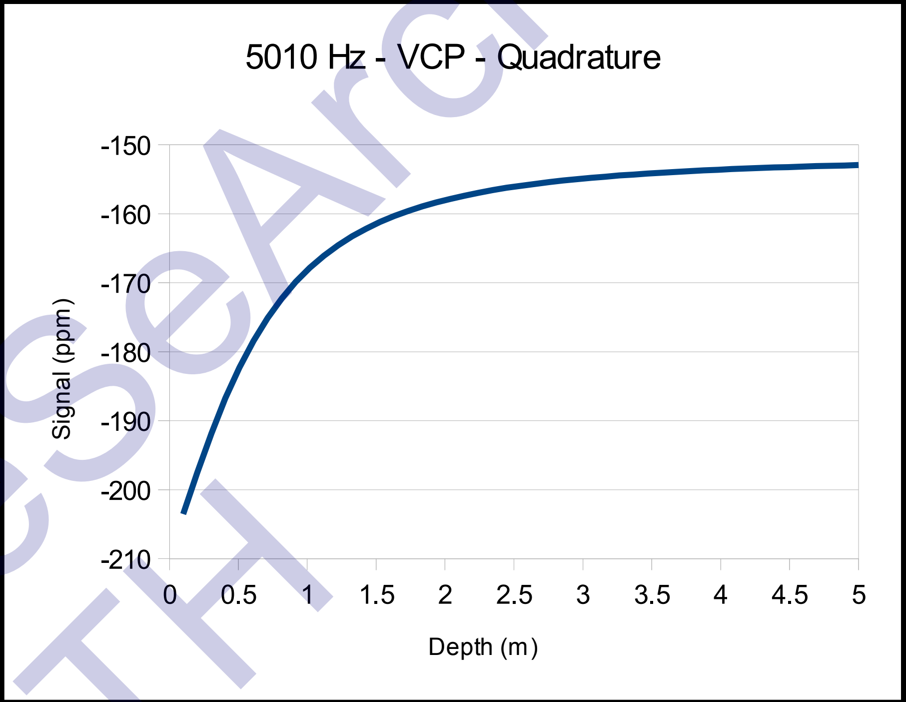


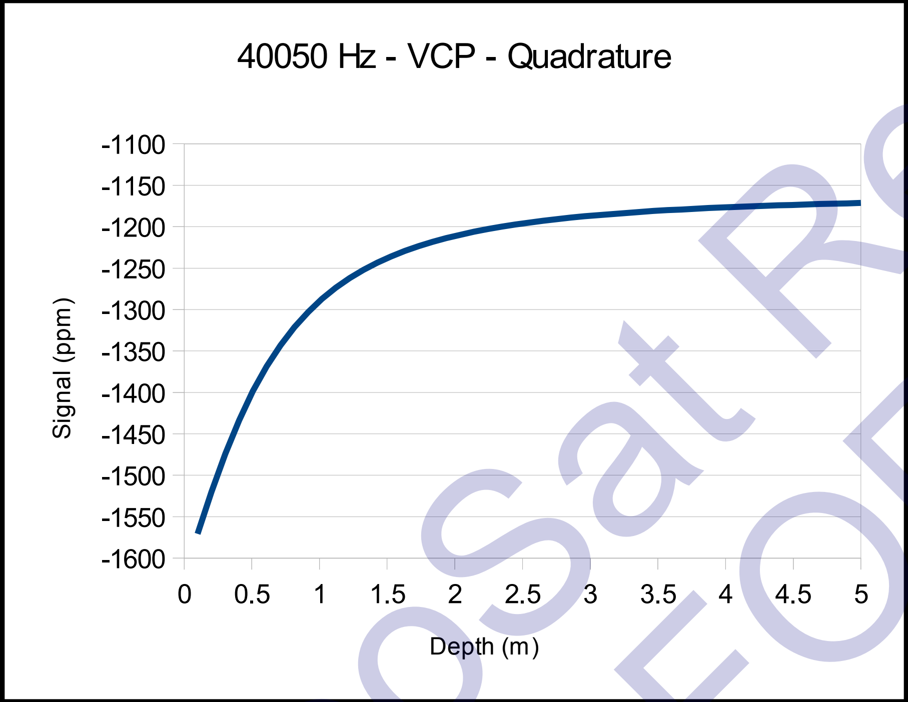


- Same sensitivity – Negative anomalies for a magnetic anomalies
- Different offset of values (dependence of the frequencies)

Depth of investigation

VCP – Qu

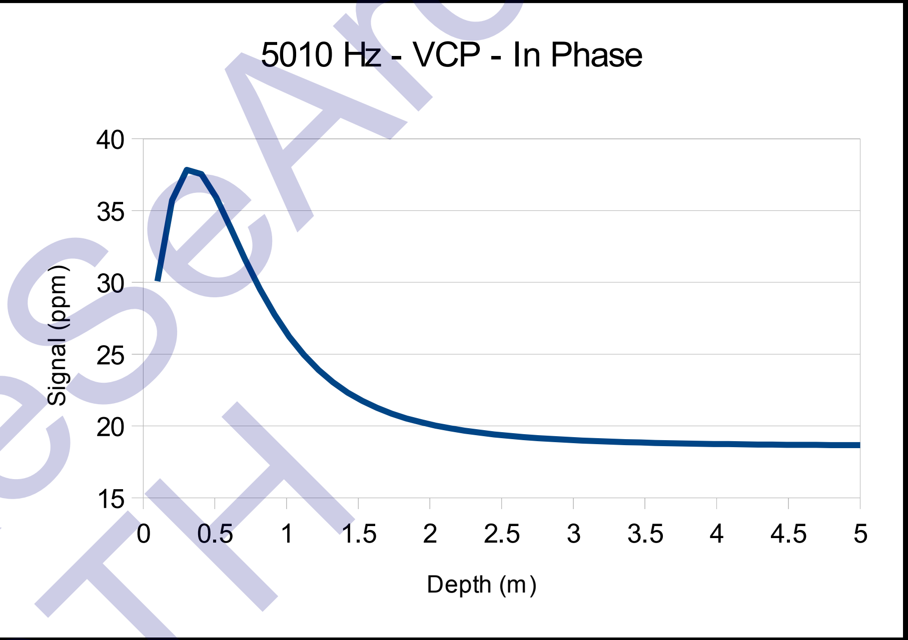


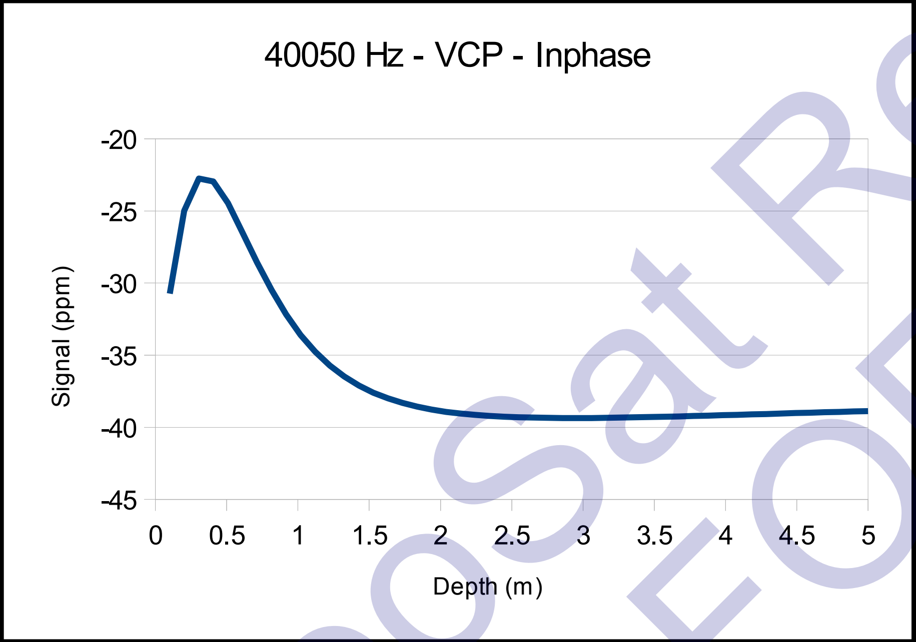


- Same sensitivity
- Different range of values (dependence of the frequencies)

Depth of investigation

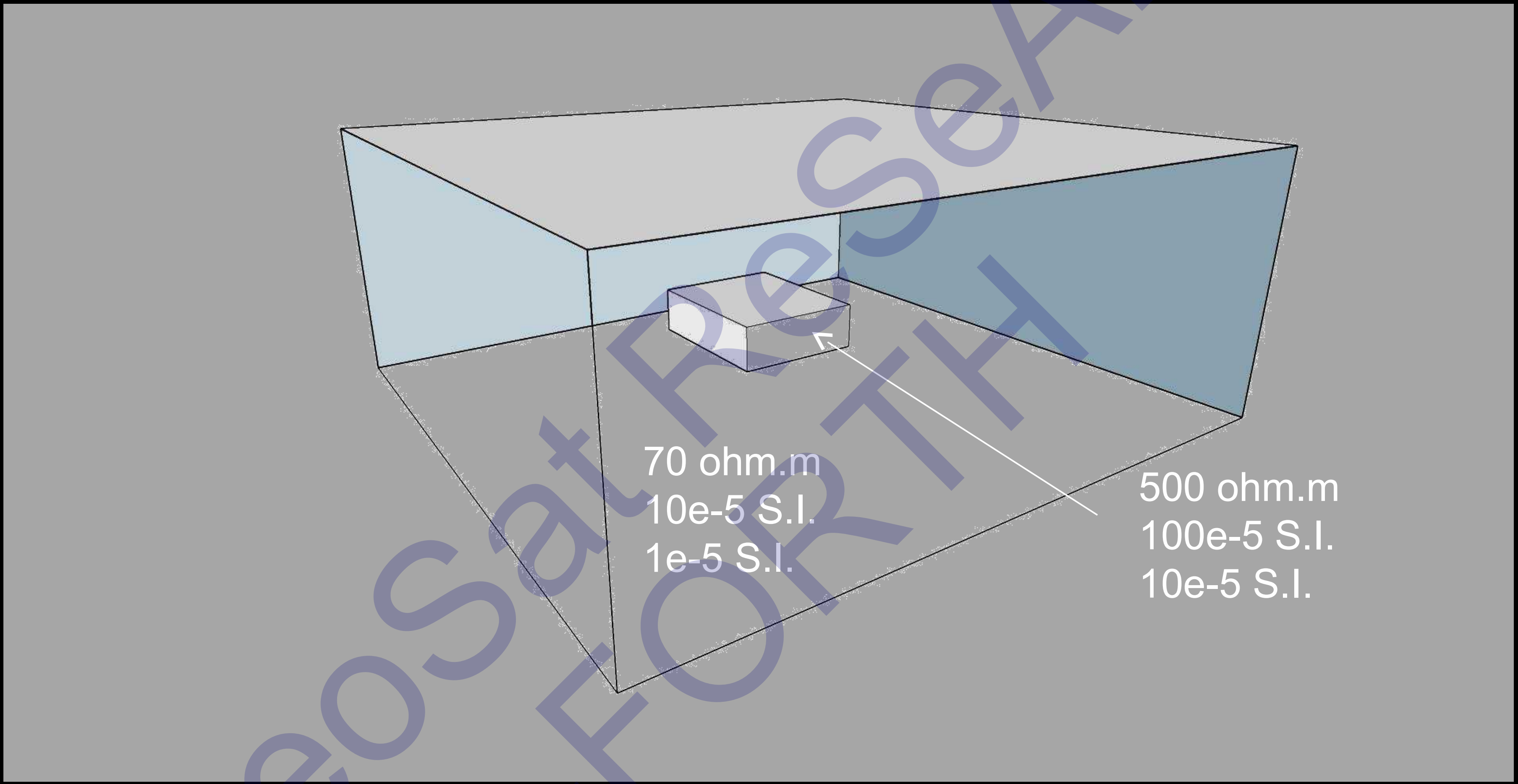
VCP - Ph





- Same sensitivity – Positive anomalies for a magnetic anomalies
- Different offset of values (dependence of the frequencies)

3D geometry for assesing depth of investigation

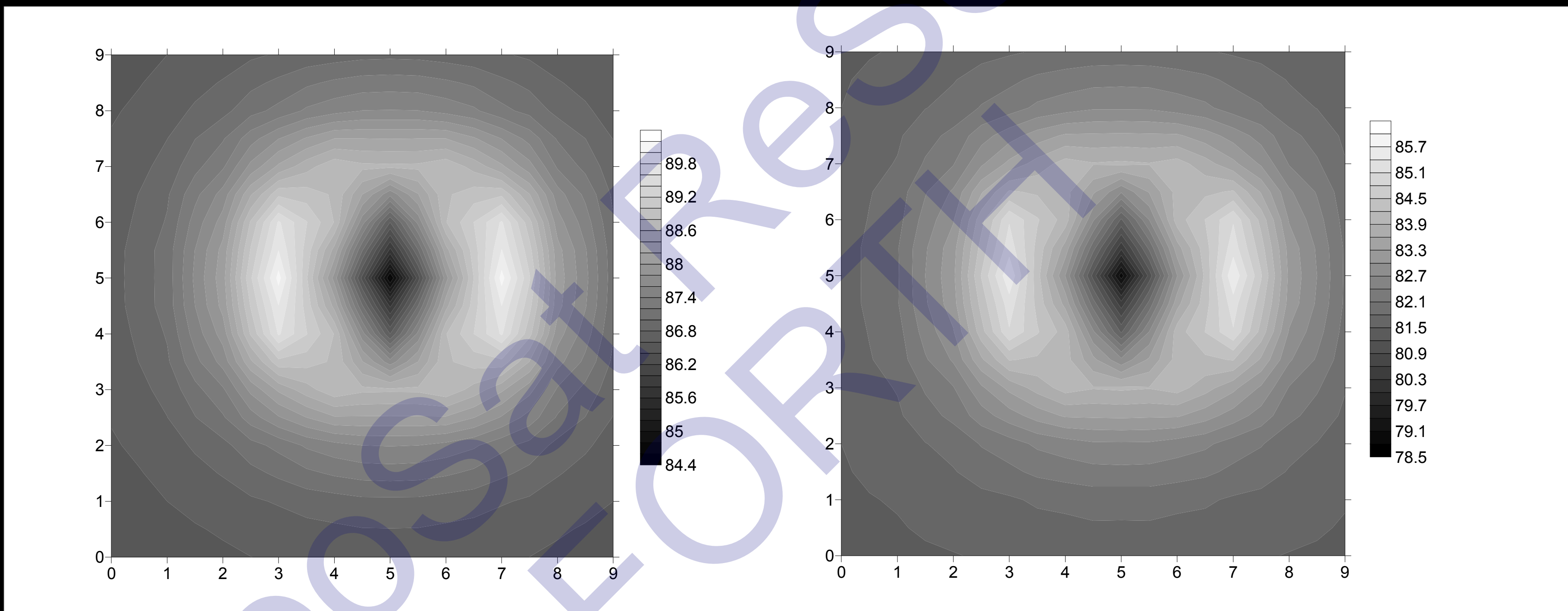


- 2*2*1 m block in an homgeneous media (two depths : 1 and 2 m)

- Results in conductivity (Qu)
and magnetic susceptibility (Ph)

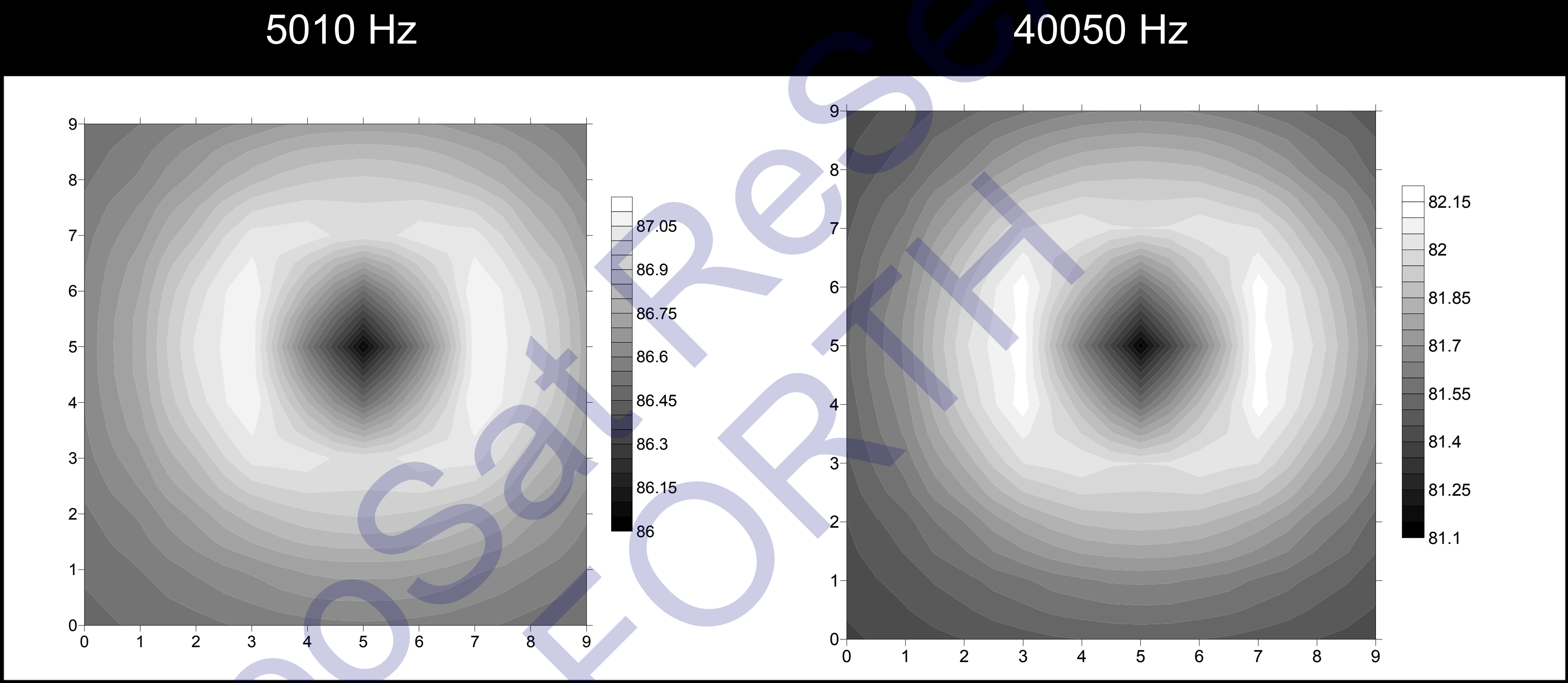
Apparent resistivy (Qu) for a depth of 1 m

5010 Hz 40050 Hz



- Complex signature of a simple block
- Offset between the two frequencies (effect of the magnetic viscosity)
- Same dynamic range of values (induce by the same depth of investigation)

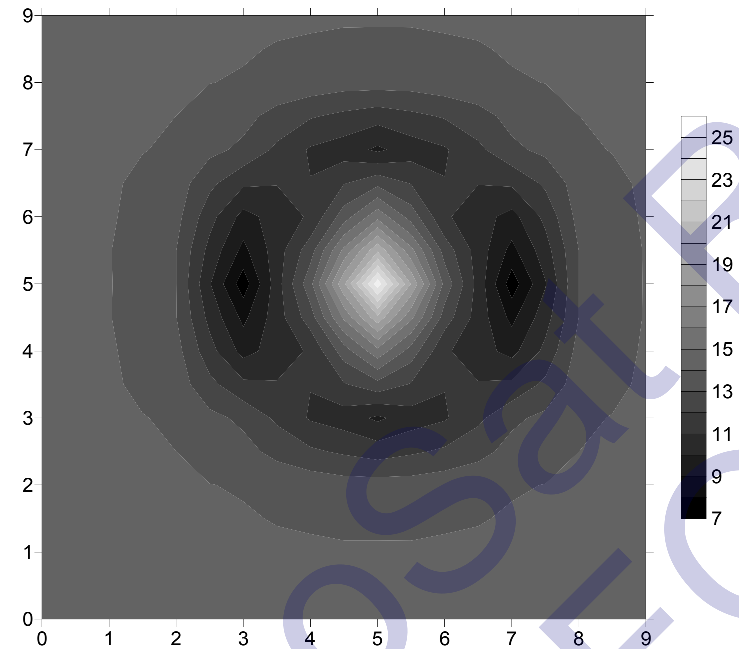
Apparent resistivy (Qu) for a depth of 2 m



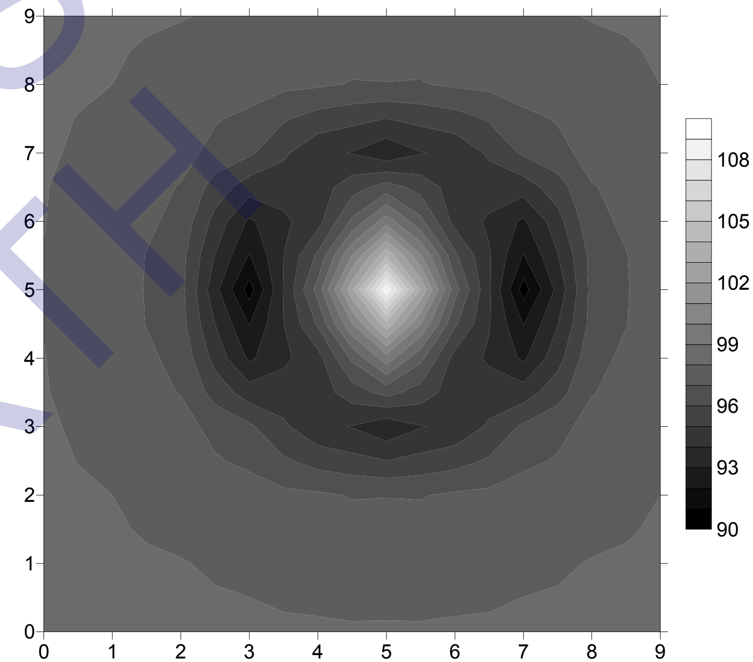
- Complex signature of a simple block
- Offset between the two frequencies (effect of the magnetic viscosity)
- Same dynamic range of values (induce by the same depth of investigation)

Magnetic susceptibility (Ph) for a depth of 1 m

5010 Hz



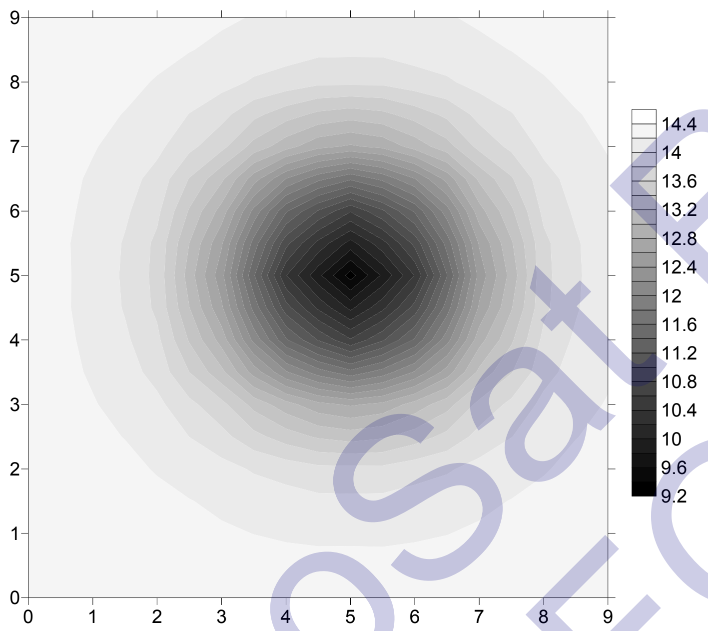
40050 Hz



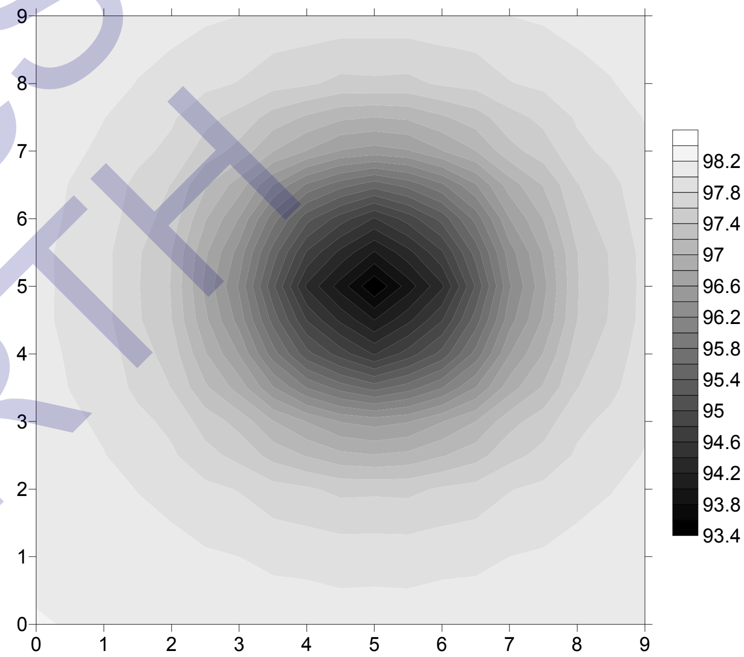
- Similar shape
- Complex shape of the anomaly
- Great offset induce by the frequency dependency of the susceptibility

Magnetic susceptibility (Ph) for a depth of 2 m

5010 Hz

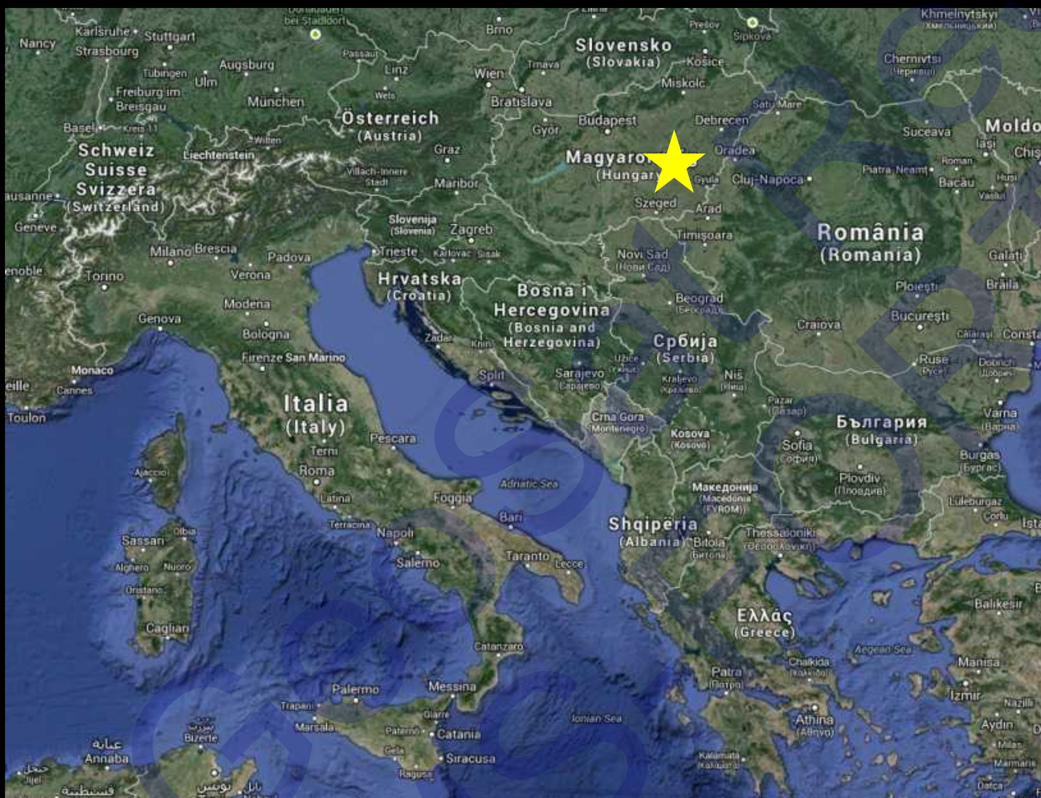


40050 Hz



- Same shape
- Simple shape of the anomaly
- Great offset induce by the dependecy of the susceptibility

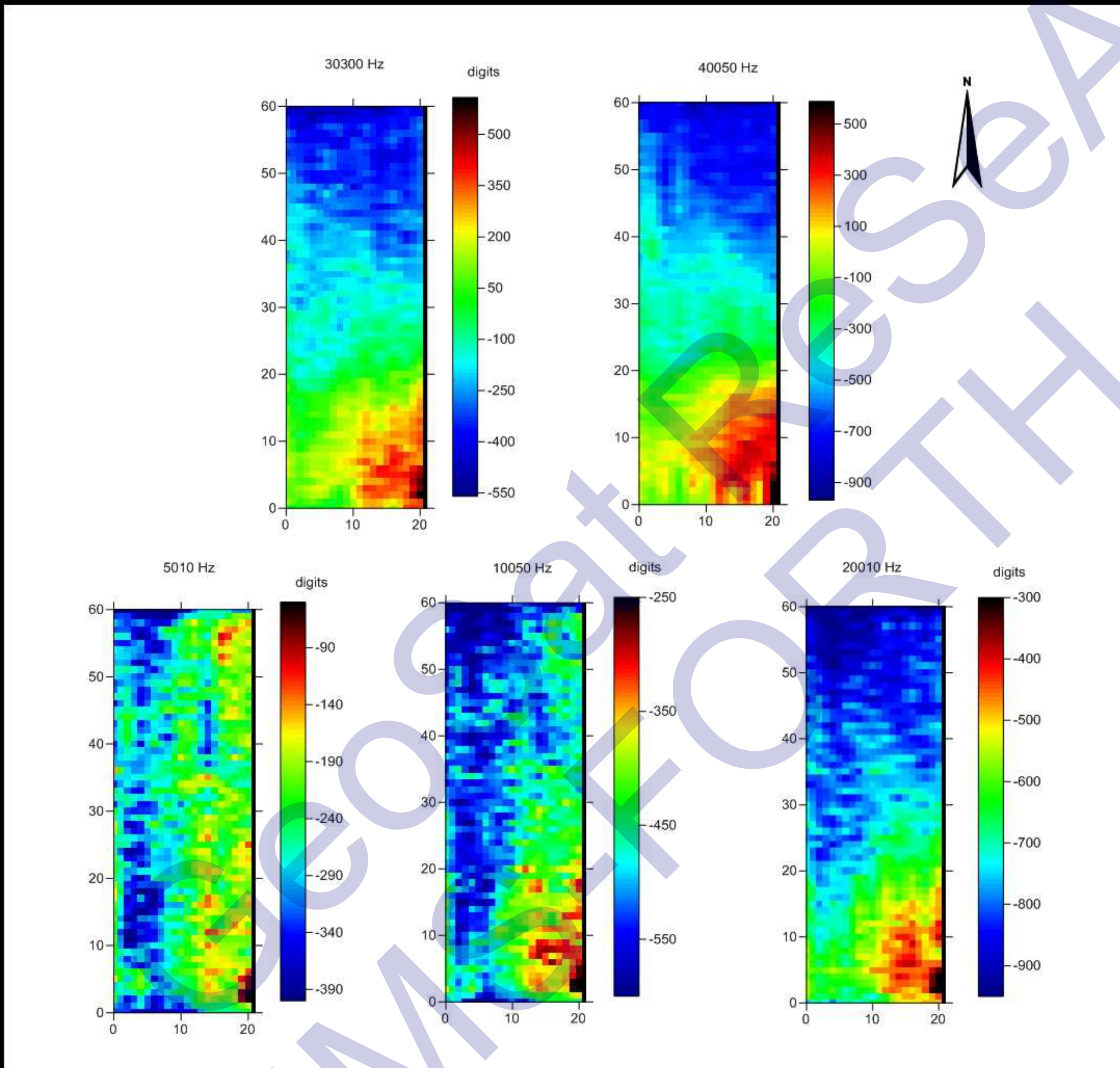
First case study : Hungary – Magor Veszto

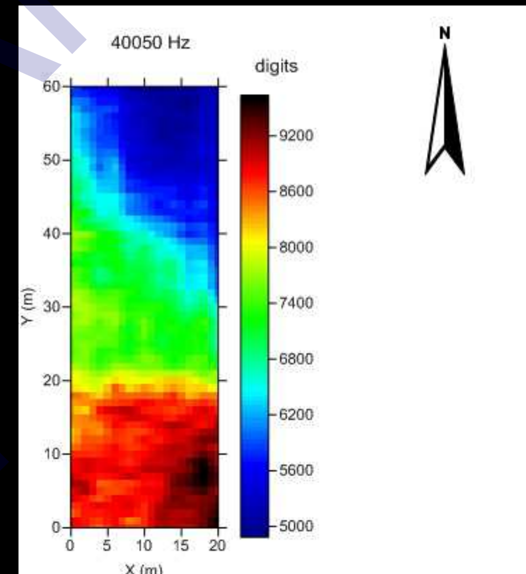


Dataset with a classical procedure :

- 5 frequencies
- raised to a heigth of 1 meter
- 2 meter between each profile

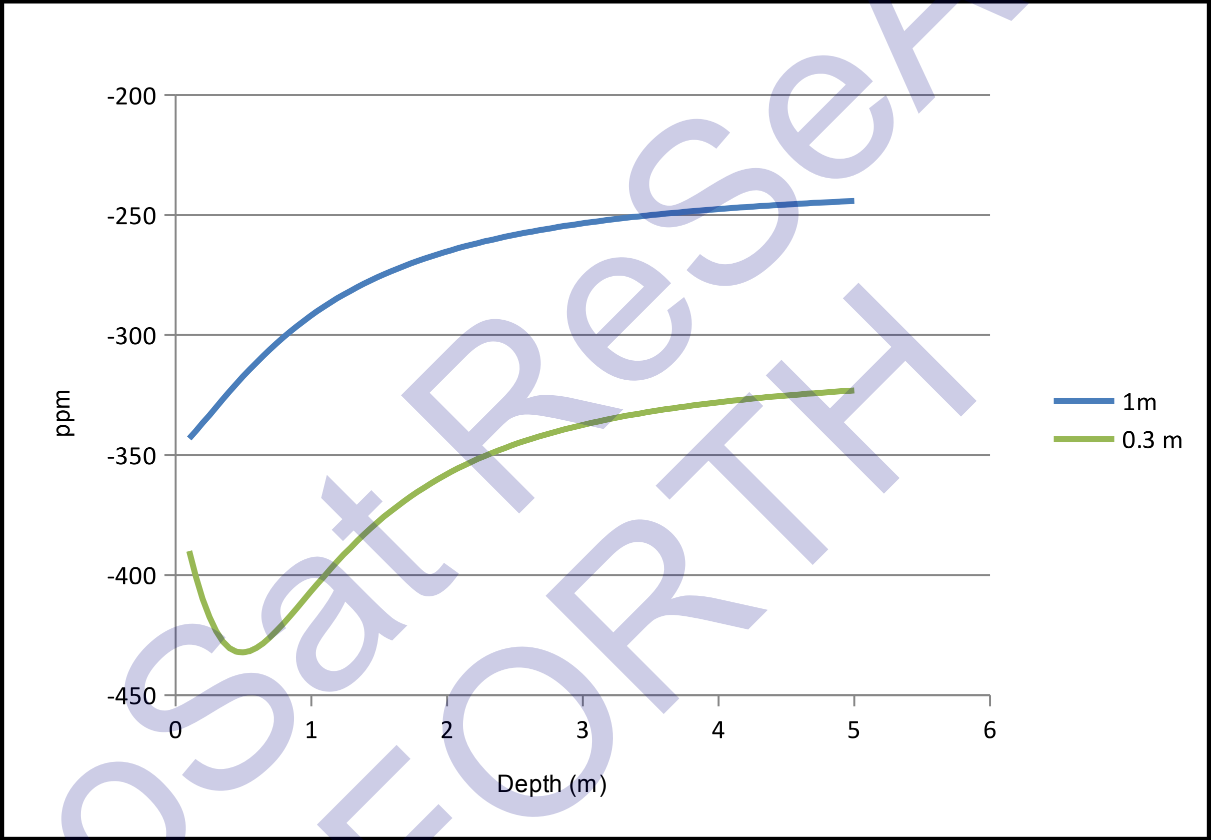
Ph measurements for the different frequencies





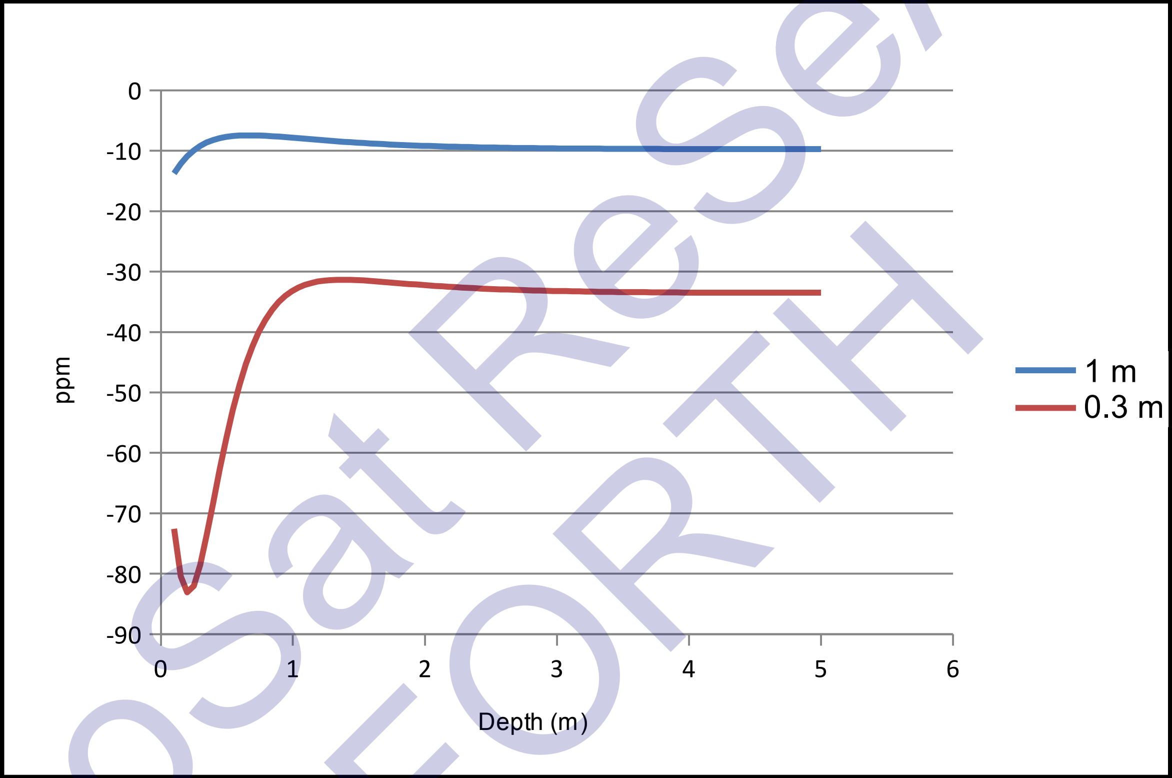
- Great effect of the conductivity
- High noise for lowest frequencies
- Poor resolution

Measurement at 1m height of the signal (Qu) in HCP



- Small changes of the depth of investigation
- Different sensitivity with depth (less affected by surface disturbances)

Measurement at 1m height of the signal (Ph) in HCP

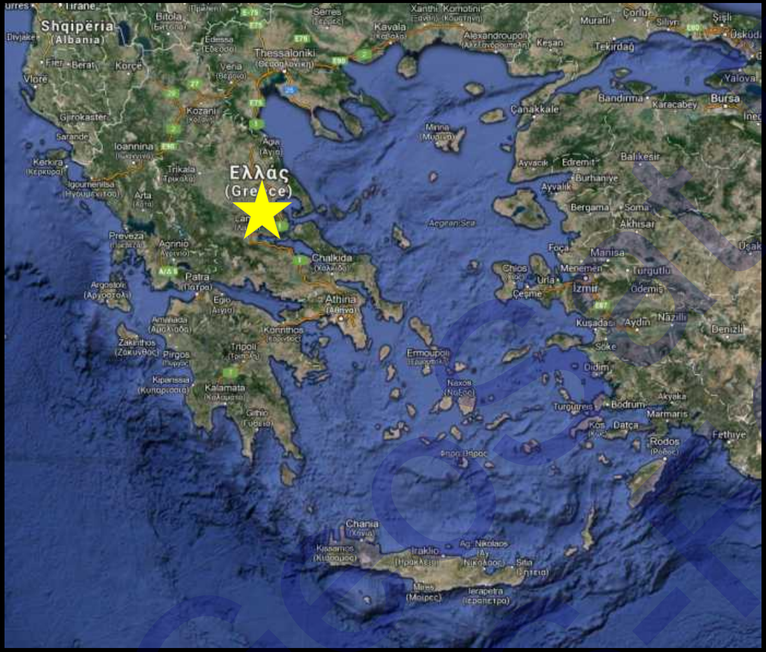


- Huge changes of the depth of investigation
- Different sensitivity with depth (less affected by surface disturbances)

Changes of the procedure

Second case study :

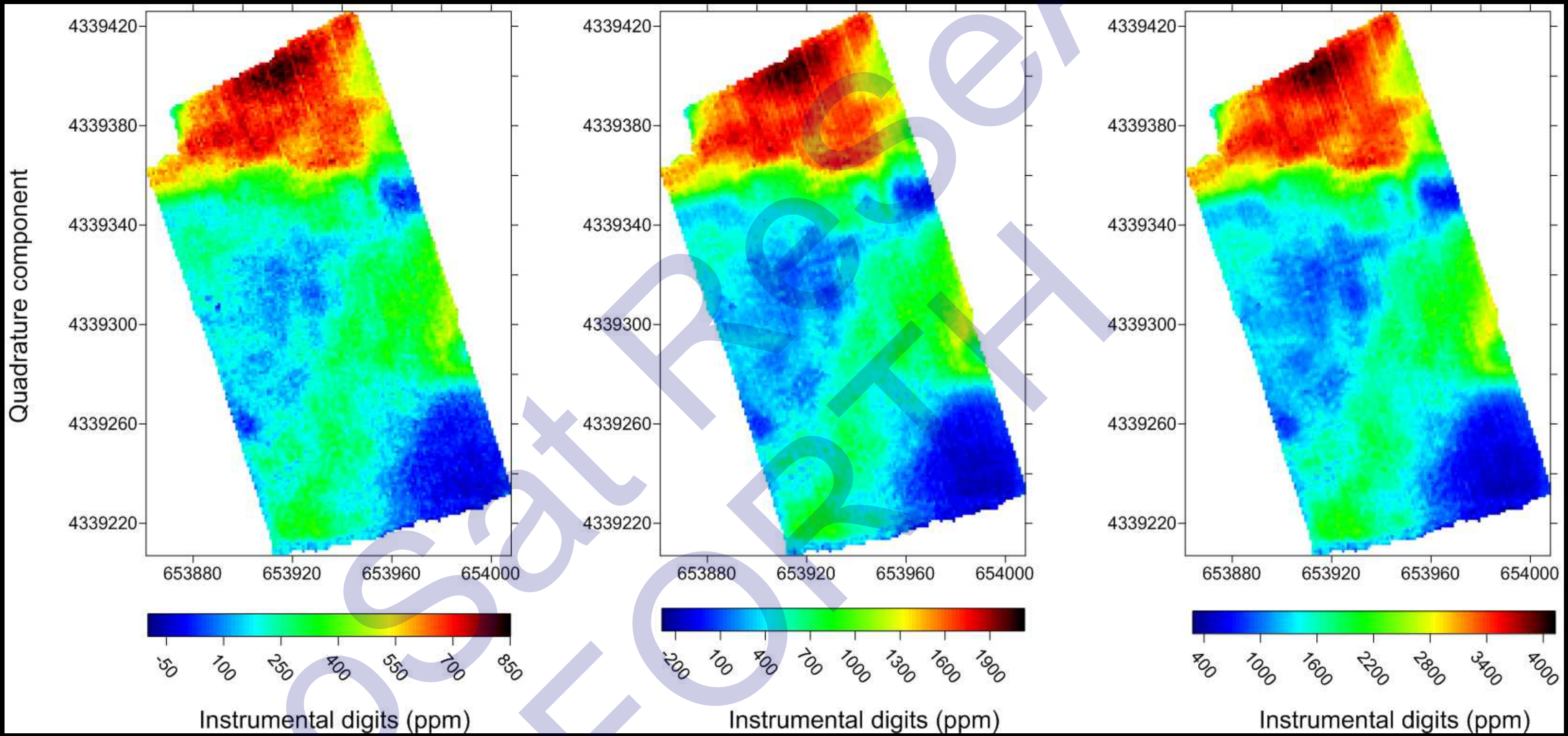
A Magoules in Thessaly Plain
Almiriotiki (Neolithic Tell)



Dataset with a
new procedure :

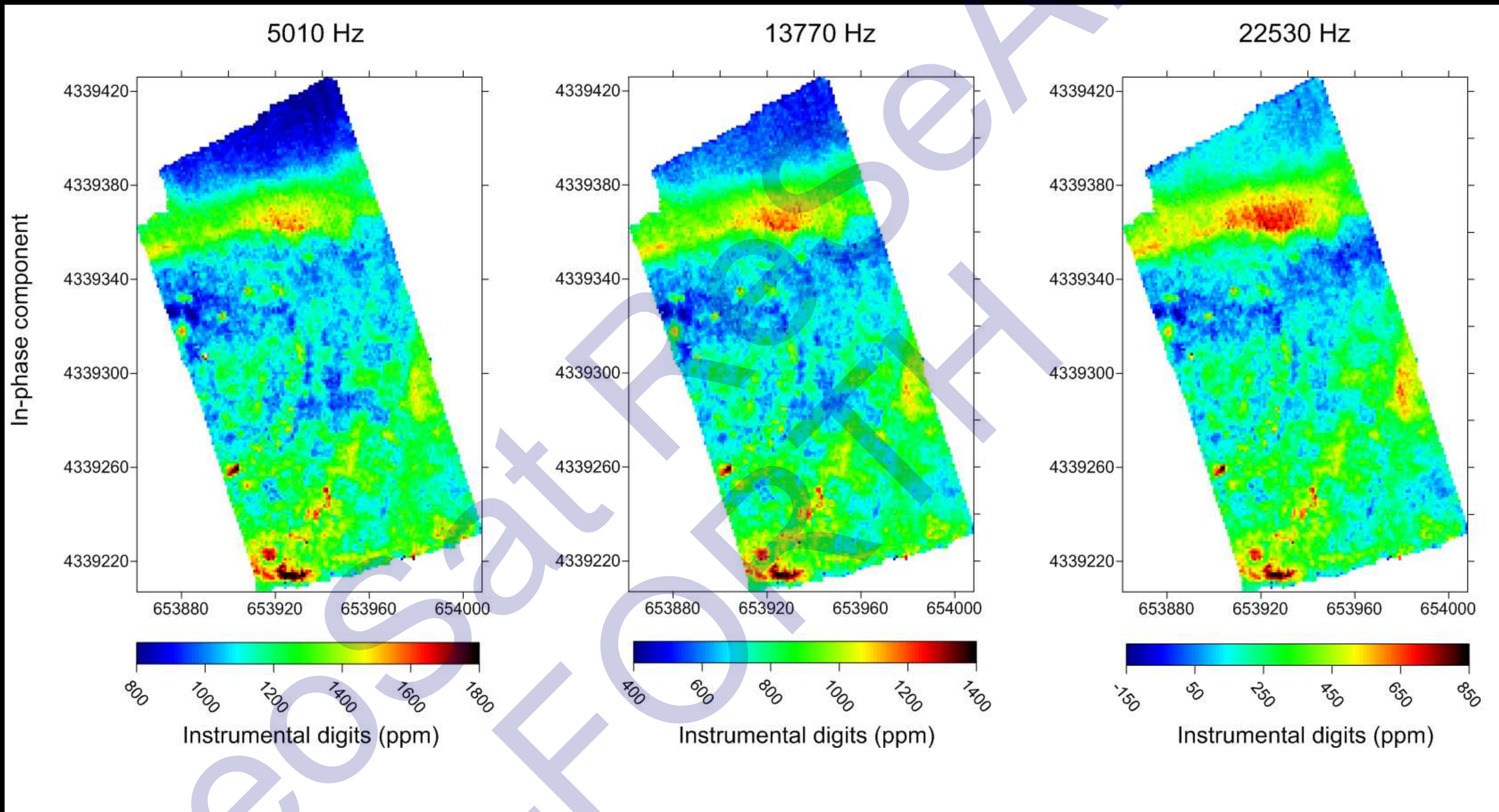
- 5 frequencies
- raised to a heigth of 0.3 meter
- 1 meter between each profile

Quadrature part of the signal : Raw data



- Small changes with the frequency for the quadrature part of the signal

In-phase part of the signal : Raw data



- Highest frequency start to be affect by the conductivity

Correction procedure

Raw data

Offset correction / coefficient (digits/ppm) correction

Difference of two frequencies (only related with the conductivity)

Extraction of the **conductivity** and
expression in physical properties (ppm to mS/m)

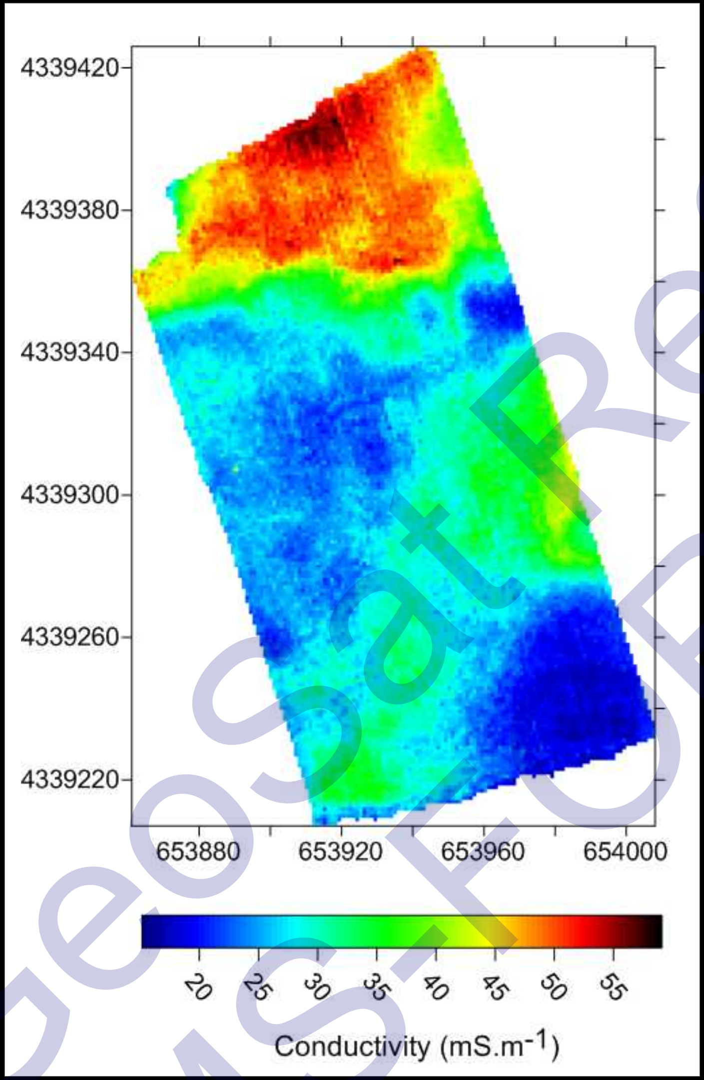
Simulation to the part of the conductivity on the real and imaginary part of EM signal

Substraction of the simulation and the corrected data

Magnetic susceptibility

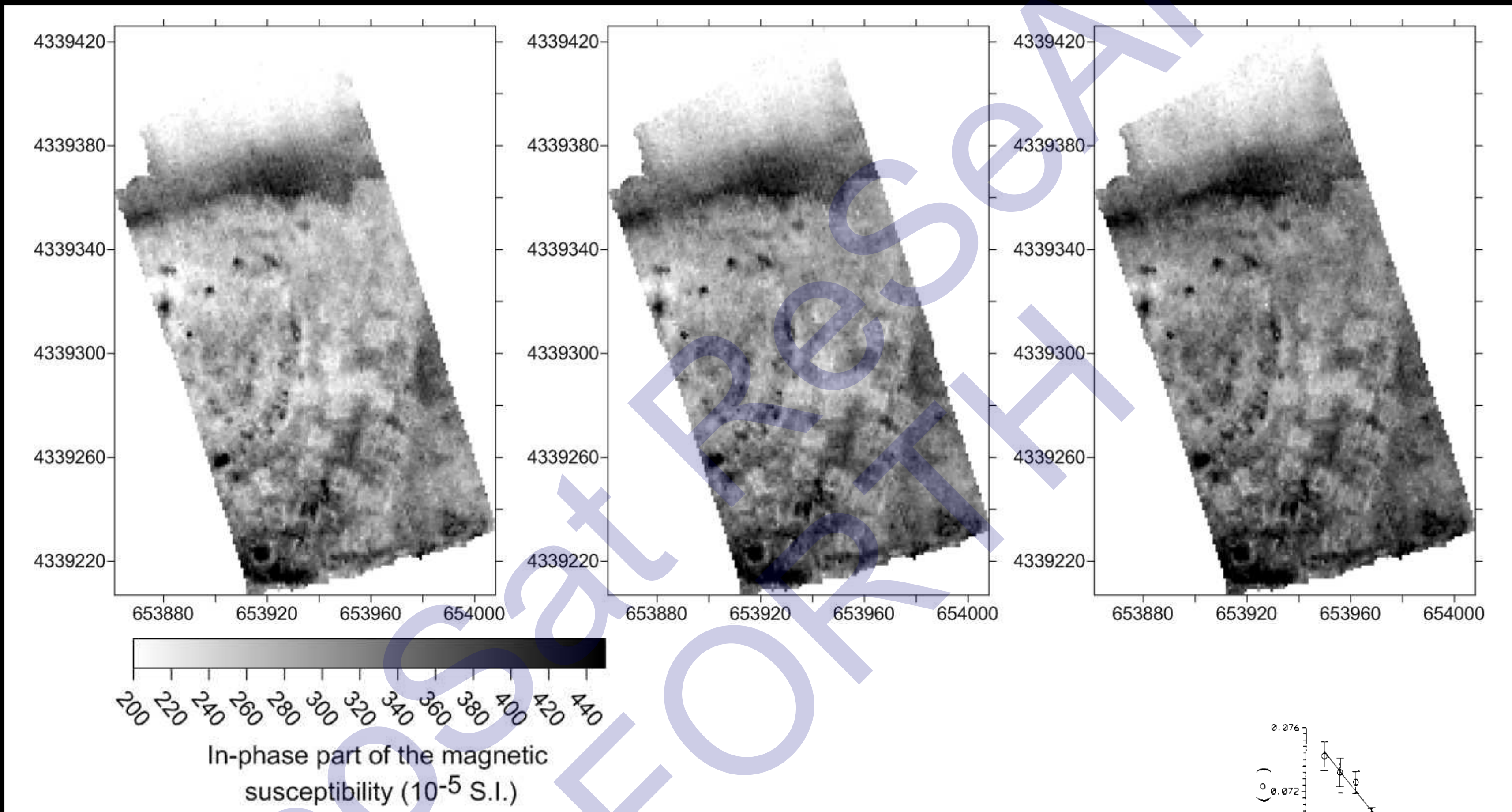
Magnetic viscosity

Conductivity



- Similar contrast between raw data and processed data (du to the high conductivity)
- The true values of the conductivity allows an accurate interpretation

Magnetic Susceptibility



- In-phase magnetic susceptibility increase with the frequency (unexpected by the thoery)

- Very high values of susceptibility (???)

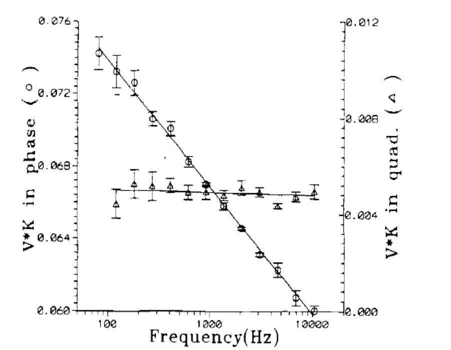
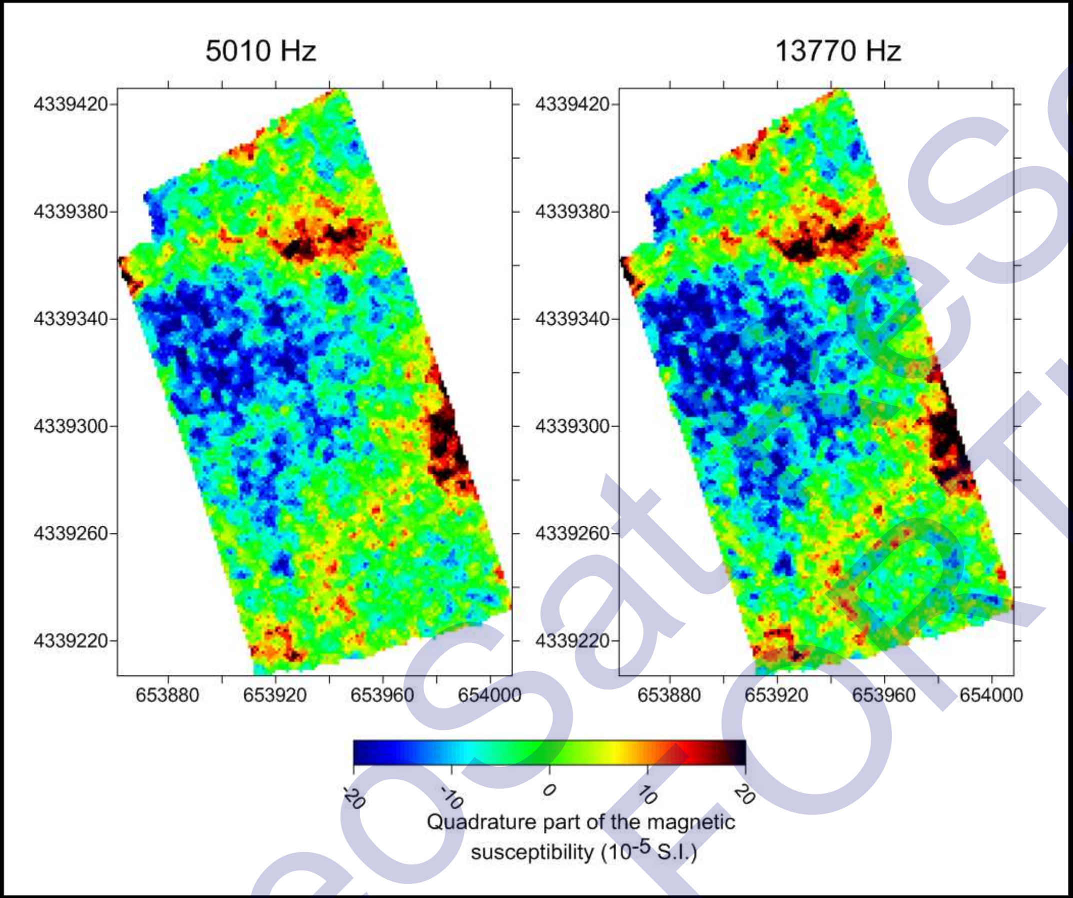


Figure 3. Frequency variations of the in-phase susceptibility (circle) and the quadrature susceptibility (triangles) for sample DC33.

Magnetic viscosity



- Constant values of quadrature magnetic susceptibility, as expected in the theory
- Poor resolution

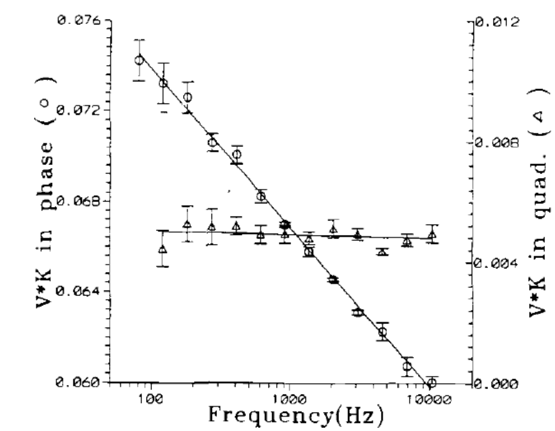


Figure 3. Frequency variations of the in-phase susceptibility (circle) and the quadrature susceptibility (triangles) for sample DC33.

Results :

- Depth of investigation independant of the frequency (LIN assumption)
- Height of instrument : 0.3 m is better than 1 m
- Useful for the correction of the effect of the conductivity on the in-phase part of the signal
- Useful for the correction of the effect of the magnetic susceptibility on the quadrature part of the signal
- Measurement of both magnetic susceptibility and viscosity

Multi-frequential EM instrument is useful for archaeological prospection

Prospects :

- What happen for the highest frequency (especially close to 100 kHz) ?
- What is the behaviour with these geometries (VCP-HCP) ?
- Are the theory about magnetic susceptibility still relevant ?

THANK YOU FOR YOUR ATTENTION !

This work was performed in the framework of the IGEAN (“INNOVATIVE GEOPHYSICAL APPROACHES FOR THE STUDY OF EARLY AGRICULTURAL VILLAGES OF NEOLITHIC THESSALY”) project which is implemented under the "ARISTEIA" Action of the "OPERATIONAL PROGRAMME EDUCATION AND LIFELONG LEARNING" and is co-funded by the European Social Fund (ESF) and National Resources.