Advanced Electromagnetic Tools for Environmental, Geological and Archaeological Exploration

(Proponent: Prof. Giorgio Cassiani)

Electro-magnetic methods are based on Faraday's induction law, and are among the most established geophysical techniques, dating back at least one century. Electro-magnetic induction (EMI) can be conducted with no contact with ground, thus allowing for fast subsurface investigation over large areas.The technique is articulated in a variety of specific instrument designs and investigation strategies ranging in investigation depth from very shallow (the first meter or so) to tens of kilometers. For shallow applications, EMI has had widespread use in hydrological and hydrogeological characterizations, hazardous waste characterization studies, precision-agriculture application locations, archaeological surveys, geotechnical investigations and unexploded ordnance (UXO) detection. EMI measurements at small scale are typically conducted in the frequency domain (frequency domain electromagnetics or FDEM), and the results are classically expressed as apparent electrical conductivities (ECa) using the so-called low-induction number approximation. In addition to ECa mapping, the development of multifrequency and multicoil instruments has recently enabled the possibility of inversion of EMI measurements to provide quantitative models of depth-dependent electrical conductivity (EC), as the different acquisition configurations either in terms of coil geometry or frequency allow for multiple independent data to be acquired in sufficient number to warrant inversion. The majority of inversion algorithms use a 1D forward model based on either the linear cumulative sensitivity (CS) forward model or nonlinear full solution (FS) forward models based on Maxwell's equations. As with EMI mapping, applications using inverted EMI data have also been diverse. Applications typically focus on using an inversion based on either the CS or an FS forward model to produce regularized, smoothly varying models of EC with fixed depths or sharply varying models of EC where layer depths are also a parameter. In the most advanced cases, a full 3D model of electrical conductivity can be reconstructed over a relatively large area, similar to what can be obtained at a larger scale by using, e.g., time-domain airborne EMI systems. The use of small FDEM measurement systems, with rapid response and easy integration into mobile platforms, is the key factor in the success of EMI techniques for near-surface investigations in these fields, as they allow dense surveying and real-time conductivity mapping over large areas in a cost-effective manner. However, sufficient control on the acquisition geometry is often needed, as the instrument response has a strong dependence also on the elevation above ground and the relative height of the primary and secondary coils.

This PhD project will be based on a methodological assessment of different EMI acquisition and inversion strategies particularly for small scale FDEM multi-coil or multi-frequency instruments, with applications ranging from sedimentological studies to environmental and hydrological applications and to engineering and archaeological investigations. Collaboration within international projects and with international partners are warranted.

Collaborations: Lancaster University (UK); Hebrew University (Israele); University of Bonn (Germany), DICEA and DBc (UNIPD).

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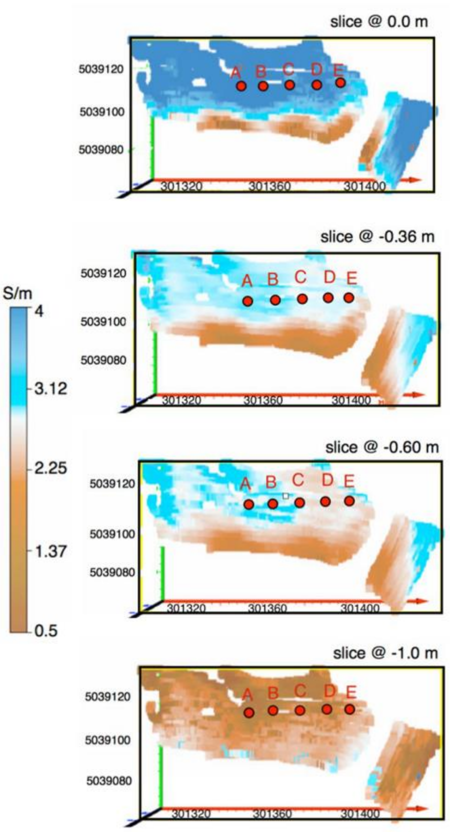
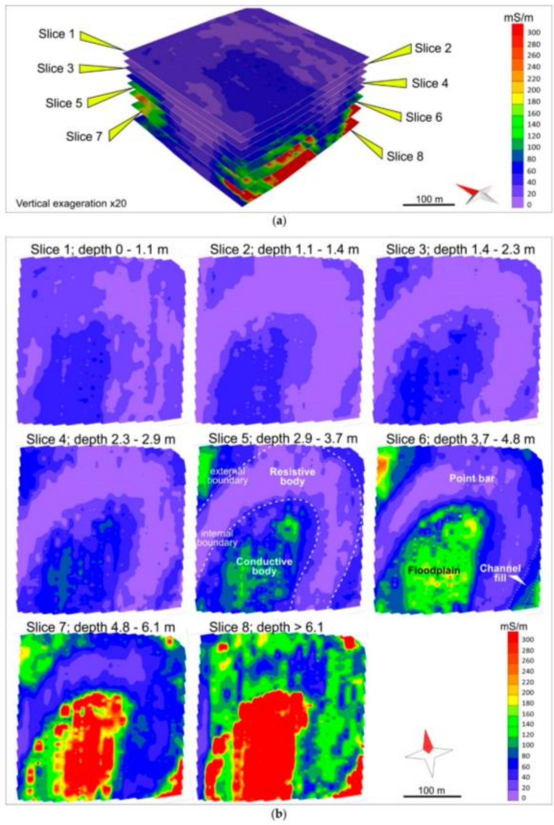


Electrical conductivity maps, at different depths, derived from multi-frequency electro-magnetic data inversion of data from the Venice Marshlands (Boaga et al., 2018, *Scientific Reports*)



Electrical conductivity maps, at different depths, derived from multi-coil electro-magnetic data inversion of data from the lower Veneto plain (Cassiani et al., 2020, *Remote Sensing*).