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Full-waveform modelling of electromagnetic induction data for improved estimation of soil electrical properties

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Electromagnetic induction (EMI) is intensively used since the 70's to retrieve soil physico-chemical properties through the measurement of soil apparent electrical conductivity. Soil electrical conductivity is determined by several factors, mainly soil water content, clay content and temperature, and to a lower extent, mineralogy, porosity, structure, cation exchange capacity, organic matter and bulk density. Given this integrative dimension of soil apparent electrical conductivity, EMI has been shown to be useful for a wide range of environmental applications. Furthermore, non-invasiveness and fast data acquisition make EMI an efficient technique for characterising large areas with fine spatial and/or temporal resolutions. However, existing EMI sensors suffer from several limitations, related more particularly to (i) the lack of robustness of their empirical calibration procedure which limits the reliability of the data for quantitative analysis as well as to (ii) the strong simplifying assumptions that are generally considered in modelling the antenna-subsurface system.

In order to overcome these limitations, we have developed a new full-waveform EMI model in which the antenna effects are accounted for using a linear system of complex transfer functions and the air-subsurface is represented by a 3-D multilayered medium for which Maxwell's equations are exactly solved. The method has been validated in laboratory conditions with an EMI prototype antenna especially designed to operate in zero-offset mode. The antenna was connected to a vector network analyzer (VNA) used as a stepped frequency continuous wave generator. This setup allows for accurate and reproducible calibration, which is physically well-defined as an international standard. Besides, the same modelling approach has been successfully applied for processing EMI field measurements acquired with commercial sensors (i.e. EM-38 and EMP-400 Profiler), using transfer functions determined in the laboratory and validating the results with electrical resistivity tomography (ERT) data. Finally, using this approach, EMI measurements may be advantageously combined with ground penetrating radar measurements (GPR) in an integrated inverse modelling scheme, allowing to better regularize the inverse estimation problem and providing more accurate estimates of soil electrical properties given the complementary in the information contained in the EMI and GPR signals.