Vertical multi-frequency FDEM loop-loop soundings for sub-surface conductivity imaging: comparison of HCP and PERP configurations for different environments

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Frequency domain loop-loop electromagnetic induction (FDEM) soundings using decametric coil-separations and multi-frequency sources have been used for decades to investigate the electrical conductivity of top 100 m of the subsurface. The most common coil configurations include horizontal and vertical co-planar (HCP and VCP) setups, and the data recorded with a rather large station spacing are typically processed assuming 1D layered media. In many geological situations, the subsurface shows significant lateral contrasts in the electrical material properties, especially, in regoliths close to earth's surface. Here, the HCP and VCP 2D/3D sensitivity functions show complex and rather extended lateral sensitivity patterns. Therefore, in presence of high lateral variations in the uppermost layers, assuming 1D layered media for interpreting HCP and VCP profiles is often not valid. Furthermore, using rather large lateral station spacings often hinders the identification (and removal) of 2D/3D effects. In consequence, the overall 1D FDEM profiling procedure is often considered to be less robust than other electrical imaging techniques (e.g., DC tomography) to depict near-surface horizontal variations of the subsurface.

In shallower FDEM applications focusing on the characterization of the uppermost soil layers, portable loop-loop FDEM sensors (e.g. rigid boom systems with coil separations < 6 m) are used to explore the subsurface electrical properties. Here, it is commonly known that the PERP configuration shows better lateral resolution and apparent conductivity maps closer to the actual conductivity distribution. The latter feature is in fact crucial for the validity and applicability of the 1D approximation. The robustness of the PERP configuration regarding the 1D assumption can be explained by its sensitivity pattern showing a preponderant sign and a rather focused pattern, centered approximately below the receiver.

In order to evaluate the benefit of the PERP configuration for systems with decametric coil separation, we present two case studies, where densely sampled profiles of 1D inversions of multi-frequency FDEM HCP and PERP data are compared to 2D ERT inverted models and additional
independent borehole and rigid-boom FDEM sensor data. In the first case study, we explore a coastal environment near Bourbourg, France, where only minor lateral variations in the subsurface are expected. Here, our results demonstrate that a 1D inversion of HCP and PERP data result in similar models. In the second case study, we explore debris flow deposits close to Braunsbach, Germany, which are characterized by significant near-surface lateral variability. In this case, only the 1D inversion of our PERP data results in a pseudo 2D model being in agreement with the inverted 2D ERT data. These two case studies confirm that the 1D inversion of PERP data (only) yields results that are more robust regarding 2D/3D artifacts than the 1D inversion of HCP data, or a joint inversion of HCP/PERP data. In conclusion, we propose that the 1D inversion of spatially densely sampled multi-frequency PERP data should be further evaluated in view of characterizing the lateral variations within the first 20 m of the subsurface because it could represent an efficient alternative to ERT methods in selected applications.