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Joint data inversion of multiple electromagnetic induction systems for high lateral, vertical, and temporal resolution toward the field scale and beyond

Christian von Hebel, Michael Iwanowitsch, Manuela S. Kaufmann, Lutz Weihermüller, Harry Vereecken, and Jan van der Kruk

Forschungszentrum Jülich, Institute of Bio- and Geosciences, Agrospehere (IBG-3), Jülich, Germany

Detailed knowledge of soil layers and subsurface structures such as buried paleo-river channels is highly important for improving our understanding of hydrological properties, physio-chemical processes, biological activities, and/or human-induced interactions in the near-surface. Subsurface layers and structures can be non-invasively imaged through geophysical measurements and data inversion. Often, either a high vertical resolution with limited spatial coverage or a high lateral resolution with limited depth information is provided such that we lack highly resolved 3D models of the near-surface. To resolve subsurface layers and structures laterally and vertically with high resolution, joint data inversion of multiple multi-coil electromagnetic induction (EMI) systems with different coil configurations (separations, orientations), and frequencies can be used. Using three multi-coil EMI systems with in total 24 coil configurations, we measured along transects crossing buried paleo-river channels. These EMI data were calibrated based on direct current methods prior to inversion. The quantitative EMI data were inverted for 2-, 3-, 4-, and 5-layer models for the upper 4 m. Comparing the results with undisturbed 2 m long soil cores clearly shows that the 4- and 5-layer scheme inverted layer interfaces close to the actual measured depths. This demonstrates that our quantitative EMI data inversion scheme non-invasively obtains soil layers and structures with high resolution, which can consequently fill the gap in providing highly resolved 3D subsurface images at the field scale and beyond.

In a subsequent EMI time-lapse study from late to early summer in two consecutive years, soil water dynamics across a paleo-river channel area were investigated. Before translating the inverted electrical conductivity into soil water content (SWC), a novel temperature correction using temperatures from time-lapse depth-dependent modeling corrected the inverted quantitative time-lapse EMI data. Using a modified Archie's law, time-lapse SWC estimates were obtained. Especially, SWC dynamics were observed within the paleo-river channel. Whereas the paleo-river channel structure, consisting of fine textured soil surrounded by gravel, was less visible in the rainy autumn to winter 2017, the electrical conductivity and therefore the SWC of the paleo-river channel increased towards May 2018, which was most likely due to retarded water recharge. The SWC estimates obtained from using Archie's law and literature values for cementation factor, porosity, etc., were in good agreement with gravimetrically obtained SWC. Consequently, quantitative time-lapse EMI inversions can be used to investigate soil water dynamics with high lateral, vertical, and temporal resolution.