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Analysis of low-frequency drone-borne GPR for soil surface electrical conductivity mapping

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In the VHF frequencies, the sensitivity of the reflection coefficient at the air-soil interface with respect to the soil electromagnetic properties, i.e., the dielectric permittivity and electrical conductivity, varies with frequency. The lower the frequency is, the lower the sensitivity to permittivity is and the larger the sensitivity to conductivity is. In this study, we investigated low-frequency drone-borne ground-penetrating radar (GPR) and full-wave inversion for soil surface electrical conductivity characterization. In order to have a good sensitivity to electrical conductivity, we operated in the 15-45 MHz frequency range. We conducted both numerical and field experiments, under the assumptions that the soil magnetic permeability is equal to the magnetic permeability of free space, and that the soil permittivity and conductivity are frequency-independent. Through the numerical experiments, we analyzed the sensitivity of the soil permittivity and electrical conductivity by plotting the objective function in the inverse problem. In addition, we analyzed the effects of modelling errors on the retrieval of the permittivity and conductivity. The results show that the soil electrical conductivity is sensitive enough to be characterized by the low-frequency drone-borne GPR. The depth of sensitivity was found to be around 0.5-1 m in the 15-45 MHz frequency range. Yet, the effects of permittivity cannot be neglected totally, especially for relatively wet soils. For validating our approach, we conducted field measurements with the drone-borne GPR and we compared results with electromagnetic induction (EMI) measurements considering two different offsets, i.e., 0.5 and 1 m, respectively. The lightweight GPR system consists of a handheld vector network analyzer (VNA), a 5-meter half-wave dipole antenna, a micro-computer stick, a GPS receiver, and a power bank. The good agreement in terms of absolute values and field structures between the GPR and EMI maps demonstrated the feasibility of the proposed low-frequency drone-borne GPR method, which appears thereby to be promising for precision agriculture applications.