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Constitutive models for the joint estimation of electrical conductivity and permittivity of variably-saturated soils

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In the context of sustainable development, there is a growing interest in mapping soil characteristics and land use, in particular to evaluate threats to soil quality. Fast non-invasive geophysical surveys have been used to estimate the areal distribution of soil properties, such as moisture content, texture and salinity. All geophysical methodologies rely on constitutive relationships to convert the measured variables in the corresponding properties of interest. Among the most used methodologies are those that measure soil electrical properties, in particular DC electrical conductivity and permittivity in the static limit. Traditionally, these two variables have been treated separately, that is, different constitutive models have been used to parameterize and link the measured response of the soil to its hydrological state and its texture. A number of works however have shown that these two quantities depend to a large extent on the same soil characteristics, and can therefore be jointly studied. The aim of this study was to identify and compare possible petrophysical constitutive models to be used to parameterize electrical conductivity and permittivity with the same conceptual approach, and to evaluate whether soil parameters estimated with one model can be used with a different equation based on the same parameterization. In addition, one such constitutive law was developed. The new petrophysical equation is derived combining the Hashin and Shtrickman upper and lower bounds with Archie's law. A large suite of laboratory measurements was used to test the model in different conditions (soil types, mineralogy, texture, etc), and good comparison was found in most cases. Five existing models that use a parameterization of the soil response compatible with that of the new equation were compared. In particular, in all models the soil texture and the geometrical and topological properties of the pore-space were expressed through Archie's cementation factor and saturation exponent. It was found that only three models were fully interchangeable, while the remainders predicted a different response for the same soil texture. Following this analysis, a methodology to estimate soil salinity based on simultaneous measurements of bulk electrical conductivity and permittivity was developed and validated with laboratory experiments. The successful estimation of pore-water salinity without any knowledge of other soil properties and without tuning of the model confirmed that the combined use of simultaneous measurements of DC conductivity and permittivity is an extremely powerful tool to map soil properties over large areas, because it reduces the calibration needs.