INTEGRATED APPROACH FOR EFFECTIVE PERMITTIVITY ESTIMATION OF MULTI-LAYERED SOILS AT L-BAND

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Abstract :

Microwave remote sensing instruments are an adequate way to provide soil moisture information at large scale.
Microwave remote sensing data are linked to the electromagnetic properties of soil.
In that context, the objective of this study is to develop an integrated approach to estimate effective electromagnetic properties of soils layers at different scale using ground-penetrating radar (GPR), L-band radiometer, dielectric laboratory measurements, modelling approaches and in situ measurements of essential state variables.

1. INTRODUCTION

Energy and matter fluxes between the atmosphere and the land surface are affected by hydrological states of the terrestrial land surface . We must increase our knowledge of these transfer processes to improve research on climate change. To reach these objectives, we must obtained global information on the hydrological states and properties of the land-surface. The microwave remote sensing instruments are an adequate way to provide soil moisture information at large scale.
Microwave remote sensing data are linked to electromagnetic properties of soil, themselves linked to the soil moisture but also to the roughness, texture and the physicochemical properties of the soil.
In that context, the objective of this study is to develop an integrated approach to estimate effective electromagnetic properties of soils layers using ground-penetrating radar (GPR), L-band radiometer, dielectric laboratory measurements, modelling approaches and in situ measurements of essential state variables.

2. METHOD

Soils were extracted from natural sites. Then the soil structure has been reconstructed at the in situ measurement site in order to characterize the electromagnetic signatures of the different soil layers, the litter, and the vegetation over a wide range of conditions. To control various influencing factors, a sophisticated ground-based remote sensing setup developed by Jonard et al. [1] is used. GPR and L-band radiometer measurements were performed above the soils during several months in order to get a large range of moisture conditions.
In this process, effective soil permittivities will be estimated at different spatial scales. First, permittivity was measured at the IMS laboratory over small soil samples. Measurement were performed on collected sample using a resonant cavity (small perturbation method) and the NRW (Nicholson, Ross and Weir) wave-guide method [2][3] at IMS Laboratory (figure 1).

Additionally, field measurements including GPR and radiometric tower based measurements were performed on the same soil under highly controlled conditions (moisture, temperature,…). The brightness temperatures and the backscatter coefficients measured in the field will be used in inversion schemes to estimate effective soil dielectric constants at the scale of several square-meters. A physical radiative transfer model (e.g. the two-stream approach used in the Microwave Emission Model of Layered Snowpacks (MEMLS) [4][5]) will be used to derive effective soil permittivities from the passive (radiometer) measurements. GPR data will be modeled using full-wave layered medium Green's functions [6]. The effective radiative transfer properties (such as effective permittivities and effective scattering coefficients) obtained from the radiometer and the GPR will then be compared with laboratory measurements.

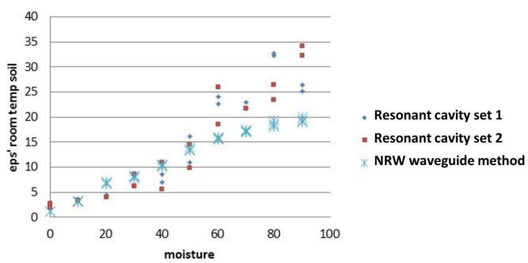

Figure 1 : Example of permittivity measurement obtained over organic soil samples at IMS Laboratory

Then these permitivities will be introduced into a 3D numerical model developed at IMS laboratory. This new approach, firstly dedicated for the calculation of rough surface scattering and emission at L-band has been validated for the case of scattering from rough surfaces of Gaussian autocorrelation function [7]. This approach relies on the use of ANSYS's numerical computation software HFSS, which in turn solves Maxwell's equations using the Finite Element Method [8]. The interest of this approach is that it can be extended to calculate the emission and scattering of complicated multilayer media in term of multi layer effects, heterogeneous media or thermal and moisture gradients.

The numerical approach has been used to simulate the experiment set up in both radiometric and GPR cases. For the radiometric study; multi layer structure has been included into the numerical model, taking into account the various permittivities measured at IMS lab for each horizons (i.e. each layer) and the emissivity of the entire structure is computed. For the GPR study, in addition of the multi layer structure; a horn antenna is introduced to simulate as closed as possible the experiment. In both cases (numerical approach and experiment) the horn antenna is placed above the soil and the S11 coefficient is measured or computed at the input of the horn antenna.

3. RESULTS

Currently, very few information on the effect of Organic Horizon (i.e. OL, OF, OH) surface layers on active and passive microwave signals are available in the literature. So we present this integrated approach applied, as an application example, on an experiment conducted on organic surface soil layers in the framework of ESA's SMOSHiLat project. In that case organic-rich soils were extracted from a heathland coniferous forest in Gludsted, Denmark (HOBE (Hydrological Observatory) test site in the Skjern River Catchment). Then the soil structure has been reconstructed [4] at the TERENO site Sellhausen (Germany) where in situ measurement setup is available. It includes an L-band radiometer installed at 4 m height with a fixed incidence angle of 36 degrees to measure time series of brightness temperatures at horizontal (H) and vertical (V) polarizations. Furthermore, an ultrawideband off-ground GPR is fixed above the soil surface to measure backscatter at normal incidence. Both instruments are pointing to a 2 × 2 m box filled with the soil structure to study.

Permittivity measured at IMS laboratory obtained on organic soil sample collected on the same site than soil study on TERENO site has been introduced into the FEM computation model.

The numerical and experimental results are compared.

First results on sand layer in GPR case show good agreement between the results of S11 parameter computed/measured (Figure 2).

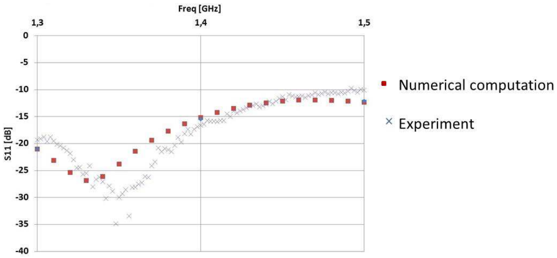

Figure 2 : Comparison between experimental measurement and numerical computation. GPR measurements over a sand layer.

Figures 3 and 4 present results obtained on the Ah layer of organic soil structure (i.e. mineral layer (sand: 85%, silt 14%, clay 1%)) in the case of emissivity measurement/computation.

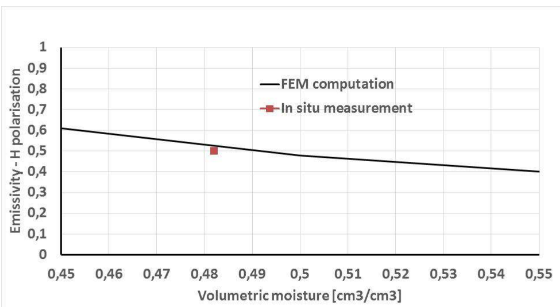

Figure 3 : Comparison between experimental measurement and numerical computation of emissivity over Ah layer of organic soil structure. H polarization

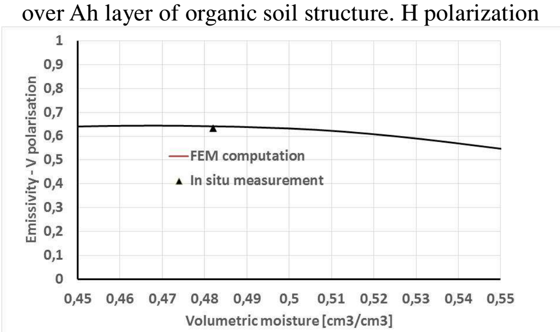

Figure 4 : Comparison between experimental measurement and numerical computation of emissivity over Ah layer of organic soil structure. V polarization

In both case (radiometric and GPR study) we obtained good agreement between computed and measured data.

These results confirm that the permittivities measured on sample at laboratory deal exactly to the electromagnetic behavior of the soil studied.

This approach will then be very useful in the case of more heterogeneous media such as organic layer. It will confirm that permitivities measured at laboratory correspond to electromagnetic behavior of the soil considered in active or passive remote sensing case.

4. CONCLUSION

This study will provide valuable insights into the electromagnetic characterization of the soil layers considered and will be useful to improve the quality of remote sensing data products obtained e.g. by the ESA's Earth Explorer Soil Moisture and Ocean Salinity (SMOS) mission which [9] carries passive L-band microwave (1.4 GHz) radiometer [10][11]. Furthermore, the planned studies contribute to improve our understanding of the complementary information contained in active and passive microwave signatures. Accordingly, these studies are also useful in the framework of the upcoming NASA's Soil Moisture Active and Passive (SMAP) mission.

The integral approach presented will be a powerful process to estimate the effective permittivity of all type of soil at small and medium scale. Involving analytical and numerical modeling, this approach will also permit the creation of databases linking for example emissivity and moisture or backscattering coefficient and moisture.

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