# Modeling of the L-Band emission and scattering of soil layers with consideration of Moisture and Temperature gradients.

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## I. INTRODUCTION

In the context of the European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS) mission, we present a study of the emission and the bistatic scattering coefficient of rough surfaces at 1.4 GHz and the effects of moisture and temperature gradients. Surface roughness is a key influencing parameter on ground emission. A new approach for the calculation of rough surface scattering and emission at L-band has recently been validated for the case of a single layer rough surface of Gaussian autocorrelation function [3]. This approach relies on the use of ANSYS's numerical computation software HFSS (High Frequency Structure Simulator), which in turn solves Maxwell's equations using the Finite Element Method (FEM). The interest of this approach is that it can be extended to calculate the emission and scattering of complicated multilayer media, including features such as volume effects, gradients effects and inclusions, as well as rough surfaces. This is therefore especially useful for the problem of the emission from soil-litter systems in forests.

We have validated this numerical approach and demonstrated its capability of calculating the L-band emission of the soil-litter forest system.

At L band, volume effects in the upper layer of soil should be taken into account. In particular, moisture or thermal phenomena lead to the presence of gradients. In this paper we present the work we have done to use FEM (Finite Element Method) method to compute thermal effects and water infiltration effects in ground. Coupling electromagnetic and thermal computation we are able to study scattering of media such as permafrost or effects of rapid changes in temperature condition. We can also study the effect of moisture gradients or the impact of rainfall events on bistatic scattering coefficient or emissivity of soil. It can also be very useful for global observations with a frequent repeat coverage (future NASA Soil Moisture Active/Passive mission SMAP). In the present study we present the effects of water infiltration in ground (as moisture gradients) on the emissivity and bi-static scattering coefficient of soil.

## II. METHOD

The study of soil needs to take into account numerous parameters. Moisture and temperature can vary strongly depending on the type of soil, climate or country considered. These parameters affect the soil permittivity and so, the electromagnetic behavior of the structures. Gradients of these properties can exist and probably affect, in some cases, the remote sensing measurements.

In the context of active and passive remote sensing analysis of soil, the moisture and temperature gradients must be taken into account in some cases. In order to complete our numerical approach we have worked to take into account these gradients in our multi layer model of soil. Our electromagnetic approach allows the resolution of Maxwell's equations using the finite element method (FEM). We also use this method to solve other equations. It enables the creation of moisture or thermal profiles in the soil structures.

The process can be divided into three steps. Initially, applying boundary conditions to our structures, we solve the equations related to thermal phenomena or diffusion of water in the layers. This resolution achieves the creation of a 3D numerical meshing of the multilayer structure profiles (temperature or moisture).

The second step deals with the replacement of the moisture and temperature variables, in each mesh of the structure simulated, by the permittivity of the material according to the temperature or moisture value. This is possible using relations linking permittivities to temperature or/and moisture (Figure 1). These relations are obtained thanks to measurements in the IMS laboratory using the wave guide experimental set-up presented in [2] or computations using soil permittivity estimation model (Mironov's model) [6] [7].

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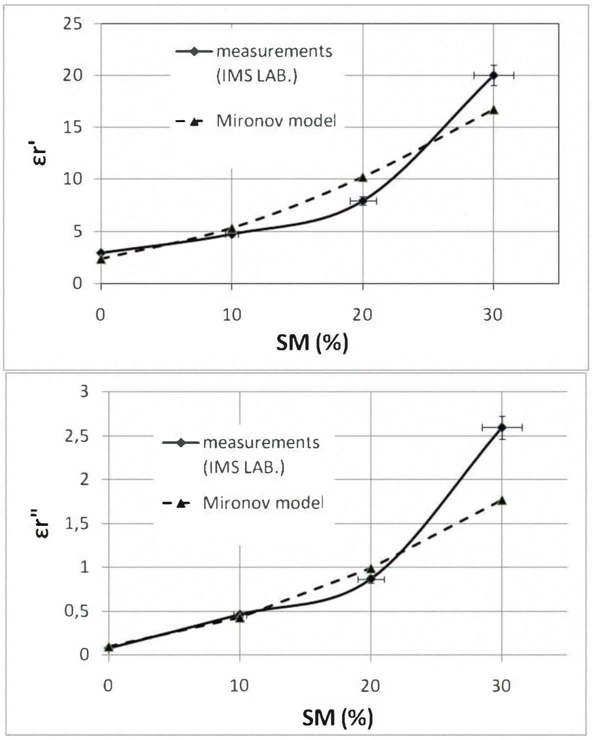

Figure 1 : Real and Imaginary part of the permittivity vs SM(%). Measurement and Mironov model computation

The last step deals with the integration of these permittivity profiles in the numerical computation approach to solve Maxwell's equations. This allows us to calculate the emissivity or the bi-static scattering coefficient of the structures.

## III. RESULTS

To present the first results of this approach we focus in this paper with the study of the moisture gradients (Figures 2 and 3).These were created by applying moisture gradients between the soil surface and in depth of the layer (15cm). Note that these gradients are not realistic but will allow us to highlight the inclusion of profiles in our model.

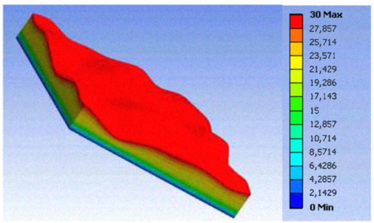

Figure 2 : Soil moisture profile 1 introduced. Surface SM = 0.30 $m^3/m^3$-Deep SM[15cm] = $0m^3/m^3$

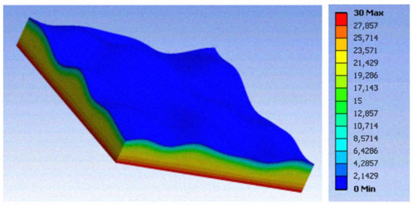

Figure 3 : Soil moisture profile 2 introduced. Surface SM = $0m^3/m^3$-Deep SM[15cm] = 0.30 $m^3/m^3$

Soil moisture was initially regarded as homogeneous. We calculated the bi-static scattering coefficient (coherent and/or non coherent contributions) and emissivity of soil (soil texture = [17% Clay 36% Sand] Roughness [kσ = 1, kLc = 6]). The results are shown in figures 4 and 5. In these figure we observe the effects of moisture gradients.

For profile 1 (0.30 $m^3/m^3$ for the surface moisture and 0 $m^3/m^3$ at 15 cm depth) the value of the bi-static scattering coefficient computed fluctuates between the coefficients calculated for 0.30 $m^3/m^3$ and 0.20 $m^3/m^3$ moisture. The effect on the bi-static scattering coefficient is more pronounced for the profile 2 (0 $m^3/m^3$ for surface moisture and 0.30 $m^3/m^3$ at 15 cm depth).

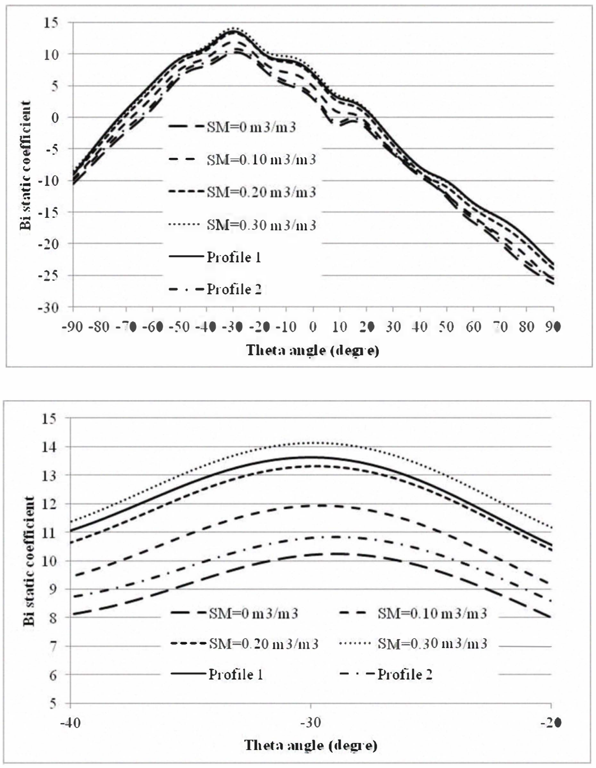

Figure 4 : Bi-static scattering coefficient (coherent and non coherent contribution) of soil layer with rough surface Frequency=1.4GHz, Incident angle phi=0° Theta=30°, Observation angle phi=0°, HH polarization, soil texture = [17% Clay, 36% Sand], Roughness [kσ=1,klc=6], Homogeneous soil temperature=25°C, Inhomogeneous [profile 1 & 2] and homogeneous soil moisture profile [0 $m^3/m^3$,0.10 $m^3/m^3$,0.20 $m^3/m^3$,0.30 $m^3/m^3$].

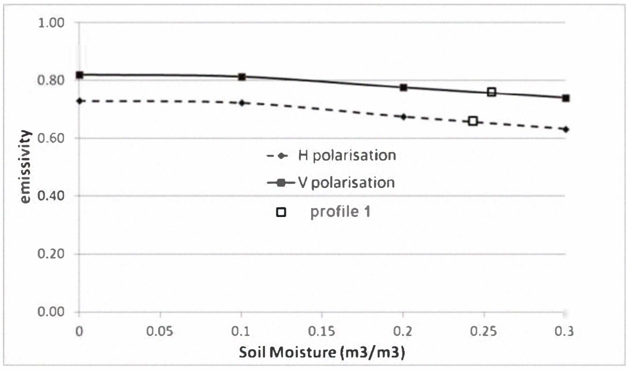

Figure 5 : Emissivity of soil layer with rough surface Frequency=1.4GHz, Observation angle phi=0°, Theta=30°, H and V polarization, soil texture = [17% Clay, 36% Sand], Roughness [kσ=1,klc=6], Homogeneous soil temperature=25°C, Inhomogeneous [profile 1] and homogeneous soil moisture profile.

If we compute the emissivity of the soil considered (Figure 5), we observe an important effect on the computation of the emissivity for the profile 1. In this case, if we compute the emissivity of the soil we obtain an emissivity similar to the emissivity of soil with homogeneous moisture of 0.25 $m^3/m^3$. So, if we compare this value to the 10 cm depth moisture (0.19 $m^3/m^3$) we observe that the emissivity computed is linked to an higher moisture (0.25 $m^3/m^3$) than the moisture in depth. We can link this observation and the increase of the emissivity of soil obtained with radiometric measurement just after a rainfall event.

## IV. CONCLUSION

These studies were designed to ensure correct inclusion of profiles into our model. These promising results will be followed by a validation stage. To do that, we have experimental data sets. We have moisture measurements (with the presence of gradients) and emissivities from the site of SMOSREX (nearly no temperature gradients). On the other hand, we have measurements of high temperature gradients, moisture, emissivity and bi static scattering coefficients from a measurement site in Siberia [8].

The profiles of humidity and temperature will be integrated into our model and results will be compared with experimental data to validate the introduction of moisture and temperature gradients into our model.

This new capabilities of our numerical approach to compute bi-static scattering coefficient and emissivity of soil will permit to improve the knowledge of the electromagnetic behavior of such structures and so the accuracy of the inversion algorithm used in remote sensing missions.

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