Numerical modeling approach for calculating the rough surface scattering and emission of a soil layer

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Continental Surfaces

Laboratory contribution

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Approche numérique de calcul de l'émissivité et du coefficient bi-statique de structures pédologiques rugueuses

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Abstract

We developed a new 3D numerical modeling approach for calculating the rough surface scattering and emission of a soil layer. The approach relies on the use of the Finite Element Method to solve Maxwell's equations. We compared results of rough surface scattering and emission with results of the Method of Moments and a good agreement (~3 K) was obtained. The new approach appears to be a good complementary method with the advantage that studies can more easily be extended to 3D heterogeneous media.

Résumé

Nous avons développé une nouvelle approche de modélisation numérique 3D de calcul du coefficient bi-statique et de l'émissivité de structures pédologiques rugueuses. Cette approche est basée sur l'utilisation de la méthode des éléments finis pour résoudre les équations de Maxwell. Nous avons comparé les résultats obtenus avec la méthode des Moments. Les résultats montrent un bon accord (~3 K). Cette nouvelle approche a l'avantage de pouvoir étudier des milieux hétérogènes 3D.

There is currently great interest in studies of rough surface scattering and emission with applications to both passive and active microwave remote sensing of the Earth, including satellite missions such as the current Soil Moisture and Ocean Salinity (SMOS) mission [1].
It is also of interest to extend such studies to include the scattering and emission of heterogeneous media such as forests, ice packs, etc. Scattering and emission from these media involve rough surface effects as well as volume effects from multi-layers, or permittivity gradients, and/or inclusions such as buried rocks. Numerical studies would provide a good approach for studying the scattering or emission of these media, allowing us to control the many parameters involved.

Currently, the most widely used numerical method for studying rough surface scattering and emission is the Method of Moments (MoM), due to its high accuracy coupled with implementation of a fast solution method. This method is particularly well suited to the surface roughness case. However it is not well suited to studies of heterogeneous media. Numerical methods that utilize volume meshing, such as the Finite Element Method (FEM), are well suited to studies of heterogeneous materials but are not considered as accurate as the Method of Moments for the rough surface case.

In this study, we developed a numerical modeling approach for calculating the scattering and emission of a soil layer using ANSYS' numerical computation software HFSS, which in turn is based on the Finite Element Method (FEM). In the Finite Element Method the computation region is divided into a mesh of many small regions, called cells, and then Maxwell's equations are solved in each cell. Once a solution has been found the mesh is refined many times and a new solution obtained. With each refinement (iteration) the change in the calculated energy value, ΔE, of each solution is obtained. A final solution is obtained by imposing a convergence criterion on ΔE. Other parameters such as the maximum number of iterations can also be set.

The numerical approach developed comprised 3 main stages:

- Firstly, a 3-dimensional layer with a rough surface was introduced into HFSS's calculation area by the following procedure. A randomly rough surface was generated in the form of {x,y,z} points using the 'R' statistical software©. It is also possible to introduce roughness profiles measured experimentally. This rough surface had a given value of standard deviation of surface heights, σ, and auto correlation length, L_c, as well as a defined autocorrelation function which was either of Gaussian or exponential form. Once the surface was created it was then transformed into a 3-dimensional layer using C4W's '3D Shop Model Design'© software before being introduced into HFSS. In HFSS a dielectric permittivity constant was applied in all the cells of the soil layer.
- Then we calculated the electric field scattered off this structure. This was repeated for a number of different structures, each different but with the same values of σ and L_c.
- Finally we computed values of the bistatic scattering coefficient, backscattering coefficient and emissivity from the scattered electric field, averaging the values obtained over the ensemble of rough surfaces that had the same values of σ and L_c.

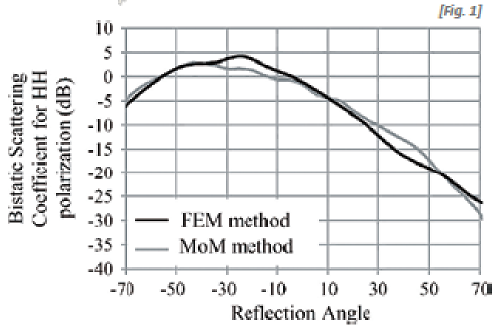
The advantage of HFSS as a numerical computation tool is that it allows us to vary many parameters, including incident angle and the dielectric permittivity constants, in one calculation. We evaluated whether improved simulations can be obtained for FEM using this tool, by comparing results with MoM presented in [2][3].

Results for the scattering case (bistatic scattering) are presented in Fig. 1. As an example, the bistatic scattering coefficient is shown at H polarization but very similar results were achieved at V polarization. Examples of results for the passive case are presented in Table I. Results show a good general agreement between the new method and the Method of Moments, for both the active and passive case. The differences for the scattering case (active) are approximately 1 – 3 dB for angles up to and including 40°, and 2 – 4 dB for angles from 50° to 70°. Agreement for the passive case is to within 3.2 K in brightness temperatures for low roughness conditions and 3.6 K for high roughness conditions, assuming a soil temperature of 290 K.

We conclude that the new approach provides results of adequate accuracy for scattering and good accuracy for emission, making it a good complimentary method for rough surface scattering and emission.

The advantage of the new approach over MoM is that is better suited to model the scattering and emission of 3D heterogeneous media. For example the L-Band emission of heterogeneous structures with rough surfaces such as forest layers, and permafrost could be modeled, which would be useful in the context of passive microwave missions such as the current SMOS mission. Future work will evaluate this.

[Fig. 1]



[Fig. 2]

polarization	angle	MoM emissivity	FEM emissivity	T_B(FEM-MoM)
H	30	0.5891	0.5920	0.8
H	40	0.5465	0.5535	2.0
H	50	0.4930	0.4987	1.6
V	30	0.6951	0.7020	2.0
V	40	0.7397	0.7467	2.0
V	50	0.7997	0.8107	3.2

[Fig. 1]
Bistatic scattering coefficient for the MoM and the FEM models calculated at 1.4 GHz for ε_r = 4+1i and [σ, Lc] = [3.41 cm, 20.5 cm] with an incident angle of 30°.

[Fig. 2]
Emissivity for the MoM and FEM models, calculated at 1.4 GHz H and V polarizations for a surface of σ = 0.4 cm and Lc = 8.4 cm, exponential autocorrelation function, and permittivity of ε_r = 15.57 + 3.71i.

References

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