Validity range of some approximations involved in vegetation modelling through numerical approaches

Pierre Borderies[1], Ludovic Villard[1]

[1] ONERA-DEMR,
2-Avue E. Belin 31055-Toulouse-Cédex, Pierre.borderies@onecert.fr

1. Introduction

Electromagnetic models of interaction with natural land media are extensively used to analyze and foresee the Synthetic Aperture Radar observables, and may be used to study the robustness of retrieval algorithms. However, usually, these models rely on approximations of various origins which may jeopardize the relevancy of some simulations, all the more so as retrieval algorithms rely more and more on complex sets of observables including polarimetry and interferometry, which makes the requirements toward these models still more demanding than for the mere radiometric outputs. In particular, the need for deriving phase properties has led to the development of coherent codes (e.g. [8][9][10]), which deliver greater range of outputs but may incorporate more approximations.

Concerning these approximations, comparisons with experimental data are of course necessary but may be not sufficient. Indeed, since the land cover scenes are generally very complex, when a disagreement occur between simulated and experimental data it may be very difficult to attribute the discrepancy to a particular cause. Then the use of numerical techniques for studying a particular point inside a complex continental land scene may be relevant. The goal of the present paper is to illustrate that Finite Differences in Time Domain (FDTD) is well matched to treat such problems in their specificity and that it permits answering to lot of questions relative to these approximations. Section 1 deals with the numerical approach and section 2 illustrate its application to vegetation scattering.

2. Numerical approach

Vegetation interaction modelling for SAR applications presents some specificity. First, the materials to be considered are dielectrics of high permittivity due to the strong influence of moisture content, and then sampling in all cases has to be fine with respect to wavelength. Then, one encounter pieces of vegetation of various shapes and sizes, with curved surfaces, among which are very thin (leaves) or elongated (branches) objects. Series of tests involving several numerical techniques, namely method of moments [4], DDA [7] and Galerkin Discontinuous [5] were performed. It was found that FDTD [1][2]was the most convenient since its well known parasitic staircase effect are annihilated by the fine sampling which is necessary and since it is very efficient in computation power. To illustrate the current precision which is currently obtained, Figure 1 presents the L1 error between the FDTD computation and the MIE series [6] reference scattering diagram in E plane for typical values of radii and dielectric constant encountered in vegetation modelling. It can be checked that the corresponding errors are very small

$$L_1 = \frac{\sum_1^N \left| RCS^{ref} - RCS^{comp} \right|}{\sum_1^N RCS^{ref}}$$

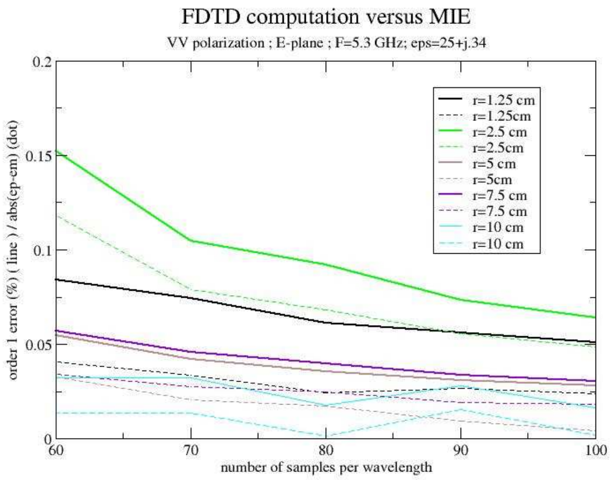

Figure 1: L1 error for large spheres as a function of number of samples per wavelength: E plane; in dots: corresponding differential error (modulus of difference between positive and negative errors)

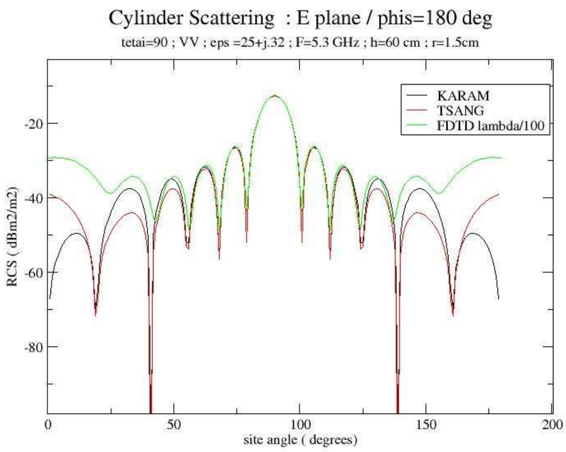

Figure 2: Scattering diagram in VV of an homogeneous cylinder of permittivitty (25.,-1.) , radius 5 mm and length 15 cm. Incident plane wave is at C band and normal incidence. The 3 represented curves correspond to the FDTD and both Karam and Tsang analytical approximations. The diagrams are represented in the incidence plane in the upper hemisphere (which incorporates the backscattering direction). The cylinder is vertical.

The range of precision obtained for the sphere was found to be in the order of the one obtained for the homogeneous finite length cylinder (Figure 2), in which case the reference solution is the very finely sampled scattering object. In the case of very thin scattering objects, like for leaves or needles in trees, homogenization techniques are used. For collection of objects, a multiple domain approach [3] has been used.

3. Applications

Actually, several vegetation modelling issues have been tested with FDTD. To illustrate it, the following problem is proposed. In the forest, when a branch is joined to a trunk, usual models consider both of them as separate, uncoupled scattering objects. To test this effect, P band was

chosen since it is the frequency band for space applications for which this kind of phenomenon may play a significant role due to the penetration beneath foliage and the possible impact of these junctions. The geometry under study consists in a portion of a perfectly vertical trunk 2 meters high and with a radius of 8 cm, and a typical branch (1.2 meters long, 2 cm radius) starts from the trunk with an angle β with respect to the vertical. Incident plane wave, in polarization V or H, is at site 45 degrees and azimuth varies over 360 degrees, which accounts for random orientation of the junction with respect to this kind of junction.
Figure 3 gives the backscattering diagram of this set for β=90 degrees and azimuth angle ϕ 180 degrees, which correspond to the attitude in which the junction is seen as an acute dihedral, for which coupling should be maximum if the dielectric branches were substituted by metallic plates. In the figure, 45 degrees correspond to the backscattering and 135 degrees to the specular scattering and observation directions lie in the incidence plane. On the figure are represented the results in co-polarization and cross polarization, when the two cylinders slightly overlap (junction case) or are slightly separated of 2 cm (no junction case). Actually, a zone of relatively high RCS may be observed around the backscattering direction in co-pol which means that the dihedral effect is well present and the specular peak dominates, presumably due the specular reflection on the trunk. Then one can observe on the figure that the junction has a significant influence on the co-pol curve and a bigger one on the cross-pol one: in this case of strong coupling between trunk and branch, permitting a continuous flow of electromagnetic energy between elements yield significant changes in scattering diagram. However, after averaging over a lot of azimuth angles of incidence, it was seen that such an effect is second order one whatever the value of β considered.

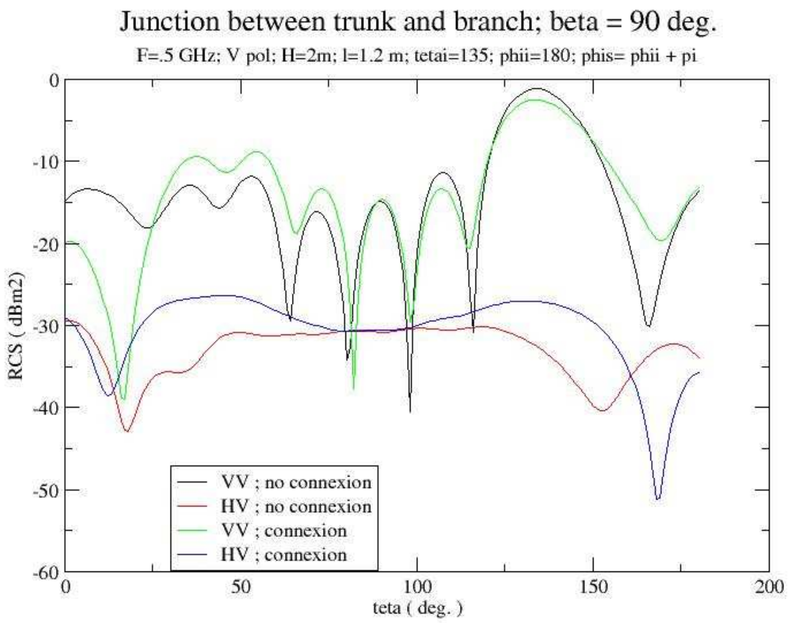

Figure 3 : junction between a vertical branch (radius 8 cm , length 2 m) and an oblique one (radius 2 cm, length 1.2 m) making an angle β with the vertical; illuminating plane wave is θ=45 deg. incidence angle; frequency is .5 GHz; backscattering diagram in the plane of the cylinders, V polarization.

4. Conclusion and future prospects

Several modelling issues following the above methodology including electromagnetic approximations in analytical models, shape effects and collective effects have been studied and will be presented in the oral presentation.

Acknowledgments

This work is extracted from ESA funded work.

References

[1] K. S. Yee. Numerical solution of initial boundary value problems involving Maxwell's equation in isotropic media. IEEE transactions on Antennas Propagation, 14: 302-307, 1969.

[2] G. Mur. Absorbing boundary conditions for the finite difference approximation of the time domain electromagnetic field equation. IEEE Trans. Electromagn. Compat., 23 : 377-382, 1981.

[3] V. Mouysset, P. Mazet and P. Borderies 'A multidomain decomposition to solve electromagnetic problems in time domain', Radio Science, Vol 42, 2007.

[4] Umashankar, K.; Taflove, A.; Rao, S. "Electromagnetic scattering by arbitrary shaped three-dimensional homogeneous lossy dielectric objects", IEEE Trans. On Antennas and Propagation,Volume 34, Issue 6, Jun 1986 Page(s):758 - 766

[5] S. Pernet, G. Cohen, X. Ferrières "An HP - Discontinuous Galerkin Method to solve Maxwell's equations in time domain" Eccomas 2004 Congress, Jyvaskyla July 24-28, 2004

[6] Bohren F. , Huffman D.R. "Absorption and Scattering of Light Particles", Wiley Science Paperback Series, 1983.

[7] L. Tsang, J.A. Kong "Scattering of Electromagnetic waves: Advanced Topics", Wiley Interscience, 2001.

[8] K. Sarabandi,"Δk-radar equivalent of interferometric SAR's : A theoretical study for determination of vegetation height", IEEE Trans. Geosc. Remote. Sensing, vol 35, pp 1267-1276, Sept 1997

[9] F. Marliani, S. Paloscia, P. Pampaloni and J.A. Kong " Simulating Coherent Backscattering From Crops During the Growing Cycle ", IEEE Transactions on Geoscience and Remote Sensing, vol. 40, no. 1, January 2002.

[10] C. Ruiz, P. Borderies, "Sensitivity analysis for forest interferometric, polarimetric observables estimation", proceeding of Polinsar2005, January 2005, Frascatti, It.