Sensitivity study of random volume over ground electromagnetic scattering versus volume fraction

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1. Introduction

A forest may be described as a collection of discrete scattering elements. Actually, most existing scattering models rest on evaluating the global scattering with as a starting point such a discrete description, and also usually the consideration of layering is introduced. The considered scattering elements are usually modelled as finite length dielectric cylinders for trunks and branches and ellipsoids for leaves. Al low frequencies such as P band, most scattered power is originated by trunks and branches, and also the underlying soil in its direct contribution but also in its interaction with the volume. Branches have typical values of a few cm radii and a few m length (for example 1.5 cm radius and 3 m length). Then at P band their scattering regimes are between the Rayleigh region and the resonance region, so that that the electromagnetic field scattered grows as long as their dimensions grow for each individual element, but for a set of scatterers this trend is balanced by the growing extinction inside the medium.

The goal of this paper is to analyze the behaviour of the electromagnetic scattering of a volume composed of a set of randomly oriented typical dielectric cylinders over a typical soil as a function of the descriptive parameters: radius, moisture content, volume fraction and concentration. It is organized as follows. Section 2 presents the simulation tools which are going to be used. Section 3 describes the results for single element. Section 4 is dedicated to a collection of scatterers.

2. Description of the model

The model is able to encompass infinite size forests as well as finite ones whatever the radar resolution. To compute the electromagnetic response of the medium we use Born extended approximation, like in [2]- [5] for example. Contributions of all the scatters present in the scene are coherently summed for the various combinations of all polarizations: this approach is fully polarimetric and phase preserving so it allows full polarimetric, interferometric and POLINSAR[14] simulations. As previously mentioned, both emitter and receiver may have any location which permits to simulate also any bistatic configuration with these observables.

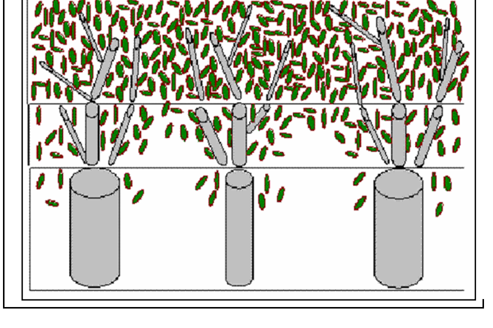

Figure 1: Layers description

For each scatter we can then consider several mechanisms:

Volume contribution : Each element is envisioned as a discrete scatter which scattering matrix is analytically known: see [8] for ellipsoïds, [9],[10] for finite size cylinders. Influence of the surrounding scatters are accounted for with Foldy-Lax approximation through the use of an effective propagation constant (attenuation) derived from the forward scattering theorem [6]. Geometrical computations are performed to compute all intersection points if any between emitter-scatter ray and all vertical and horizontal boundaries of the layers. This process is repeated for the scatter-receiver ray. Then complex transmittivity matrices [3] factor between emitter and scatter and between scatter and receiver are computed taking into account all eventual path lengths in each layer. Moisture content influence on complex permittivity follows [11].

Soil contribution : We use Integral Equation Method [12, 13]. To account for speckle effects and fit with observed data, we spread the backscattering coefficient on the pixel surface with sub-sampling it and attributing to it a random phase, which traduces large scale roughness.

Interaction volume/soil : For each path considered, similar geometrical computations are implemented and subsequent transmissivity matrices derived. For each mechanism, soil specular reflection is accounted for through modified Fresnel coefficients[1],[3].

3. Individual scatterers

Figure 2 presents the variation of the backscattering coefficient σ_0 of a dielectric cylinder representing a typical branch: its length is typical (3m) and the radius varies from .5 cm for small, high order branches to a few cm for primary branches and grows up to trunks dimensions. This plot is reproduced for various moisture contents from 30% which correspond to dry conditions to 80% for wet conditions inside the matter. Actually, these quantities are certainly interrelated since large radius branches are certainly dryer than the extremities which are thin. However, it is interesting to look at the influence of these parameters independently.

For this range of values, in VV, whatever the moisture content, only one resonance peak and subsequent dip appear. The dip is weaker and weaker as moisture content increases: indeed, in this case, complex permittivity increases both in real and imaginary part, which induces a smaller penetration into the cylinder and also a stronger attenuation inside it. In the resonance zone, RCS is not related to volume scatterer and then to biomass : increasing biomass may correspond to lower RCS. In the Rayleigh zone, before the first resonance peak, there is a very strong increase of RCS with radius. This monotonous growing behaviour exists for all cylinders whose radii are less than 4 cm. Above resonance, there is still a growth of RCS with radius and then biomass : the range of radii involved here makes it more interesting for specular direction. This slow growth can be interpreted as the consequence of growing of effective section of the cylinder in the high frequency regime. Note the very strong differences in VV and HH behaviour, in the Rayleigh and resonance regions, which makes that a vertical scatterer roughly saturates at 2-3cm whereas an horizontal one saturates at 8-10 cm.

On the plot, HV is not represented since it is unsignificant.

Moisture content have a strong influence on the resonance frequency, and this frequency shift strongly affects the branches RCS. A zoom of the representation is shown in Figure 3 for branches between .5 cm radius and 3 cm radius. Whereas HH is poorly dependant on moisture content, one can check that VV is strongly dependant on both radius and moisture. Branches with 80% mc saturate at 1.5 cm, whereas 30%mc ones saturate beyond 3 cm.

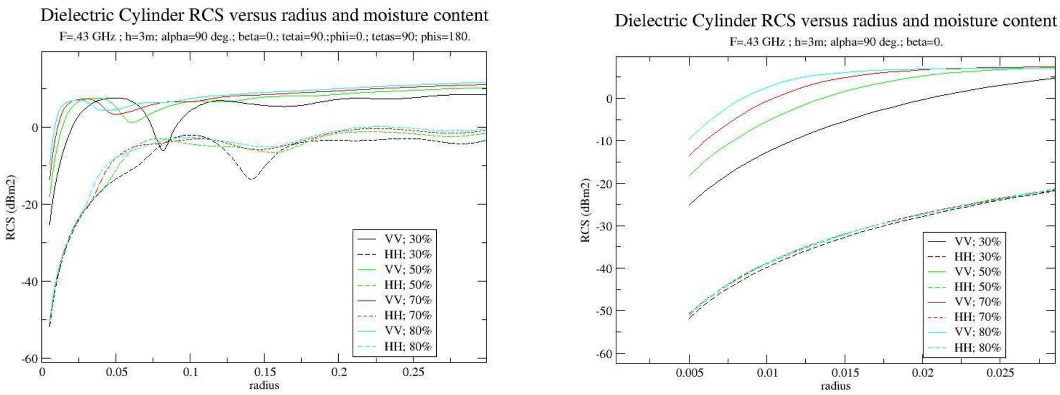

Figure 2: Backscattering of a single homogeneous dielectric cylinder RCS 3m high as a function of radius with normal incidence illumination; left : zoom for branches sizes

4. Random Volume

In this part a layer of thickness 5 m filled with randomly oriented dielectric cylinders is considered. The scene is figured with 3m*3m pixels on a horizontal surface incorporating 40 by 40 pixels. These cylinders are 1.5 m long and backscattering coefficient is studied as a function of volume fraction, which is proportional to biomass, and with varying parameters both radii and moisture content as in previous section (Figure 3). Actually, one would expect that the random volume follows the trend of the single cylinder at normal incidence since HV is mainly originated by the co-polarization echoes and the geometrical effect, also since the specular reflection somehow drives the backscattering diagram and at last because in a random volume major contributors are those which are illuminated at normal incidence. As a matter of fact, if this trend is identical for the lowest volume fractions, it becomes opposite for the highest ones. Indeed, for each couple of parameters (radius, moisture content), there is first a growth of σ_0 , then a plateau and at last a decrease : this variation may be due to the balance between forward and backward scattering, but apparently there is a strong effect of coherent scattering which reduces the backscattering when it is effectively limited by the mean free path to a thinner and thinner effective layer smaller than the quarter of wavelength, which can be viewed also as moving from volume scattering regime to surface scattering predominancy. Actually, the collective effects induce a saturation of the echo which depends on both parameters. One may see on the plots that the moisture content plays a very important role according to the radius range. Nevertheless, for forests, one should usually locate at volume fractions in the range of 10^{-4} for which the single element characteristics obviously predominate.

5. Conclusion and future prospects

During the presentation the various effects presented here will be discussed and influence of remaining parameters (layer height, cylinder length, …) will be presented. Influence of these results in the interpretation of experimental data for real forest will be discussed too.

Acknowledgments

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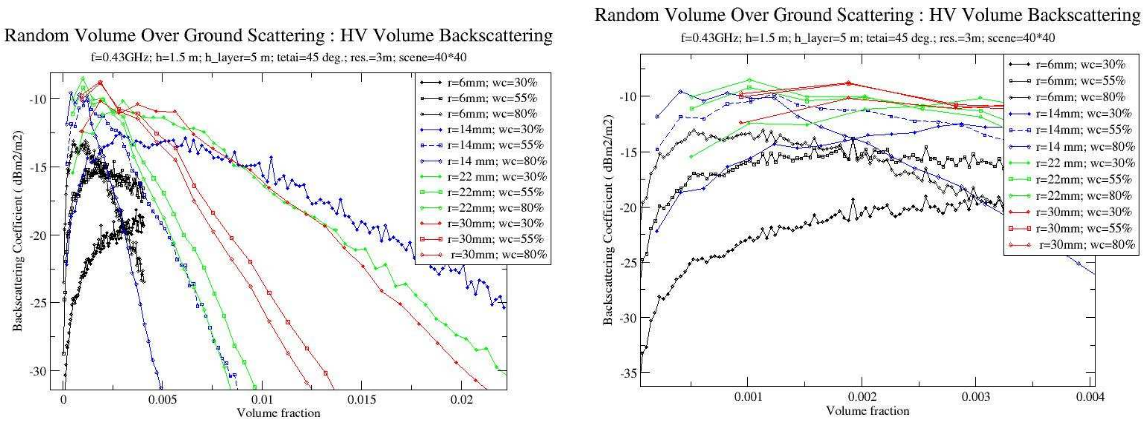

Figure 3 : Backscattering coefficient of an horizontal layer filled with randomly oriented cylinders as a function of volume fraction; HV polarization, 45 degrees incidence; left : zoom for realistic volume fractions

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