Backscattering Border Effects for Forests at C-band

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Abstract — A coherent model for simulating interaction of electromagnetic waves with forests has been developed. It allows the retrieval of interferometric and fully polarimetric data. Forests considered, including finite size ones, are generated from a description following ground truth. This model is used here to simulate the impact of border effects in the monostatic case with high resolution.

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1. INTRODUCTION
Radar remote sensing of forests turns out to be of great importance for environmental issues and military ones. To predict and analyze the performances, direct discrete models has been proposed (see [1–5] for example) to account for the wave interaction addressing SAR configurations. Most of these models assume that overflown areas are horizontally statistically homogeneous and of infinite extent. However, borders are often present in SAR images. Logically, their role is enhanced when the imaged landscape is composed of parcels of relatively small extent, and also when the SAR resolution is important. In these cases, simulation of SAR data require correct account of the presence of these boundaries.

In the first part of the paper it is described how the electromagnetic model takes into account these effects. Section 3 illustrates and analyses the results obtained in C-band, stating from previous simulations matched to ERS data [7].

2. MODEL PRESENTATION
2.1. Scene Description
The zone we intend imaging is rectangular, of size $L_x \times L_y$, with a resolution of $dx \times dy$ (see Fig. 1). This zone may include one rectangular parcel of forest, of size $l \times h$, tilted with respect to $Ox$ by an angle $\alpha$. The forest area is generated using a classical multi layer description, which might fit incoherent, monostatic models like for example [1] or [4] or coherent models like [2, 3, 5]. Each pixel in each layer is randomly filled with the more appropriate elements, following statistics representative of in-situ measurements data in terms of sizes, composition, orientations and concentrations of typical discrete constituents. These constituents are represented by canonical elements: flat homogeneous ellipsoids for leaves and finite homogeneous cylinders for branches or trunks. Forest soil is characterized by its root mean square height and a two dimensional exponential correlation function. Outside the forest parcel, we assume here a bare soil following the same characterization but with distinct parameters.

Figure 1: Scene geometry.
2.2. Electromagnetic Computation

Originality of the model lies in its ability of encompassing finite size forests whatever the radar resolution which imply boundary and 3D migration effects. To perform the media electromagnetic response we use Born extended approximation, like in [2, 3] and [5] for example. Contributions of all the scatters present in the scene are coherently summed for all polarizations combinations: this approach is fully polarimetric and phase preserving so it allows full polarimetric, interferometric and POLINSAR simulations. For each scatter we can then distinguish several mechanisms:

*Volume contribution:* Each element is envisioned as a discrete scatter which scattering matrix is analytically known: see [8] for ellipsoids, [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 [7]. 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 [4] factor between emitter and scatter and between scatter and receiver are computed taking into account all eventual path lengths in each layer.

*Soil contribution:* We use Integral Equation Method [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 (see Fig. 2) and subsequent transmissivity matrices derived. For each mechanism, soil specular reflection is accounted for through modified Fresnel coefficients [16, volume 1].

We then can generate two kind of outputs. Traditional ones consists in the complex summation of all the contributions for all the scatterers belonging to a given cell \((idx, jdy)\). In this case border effects emphasize image contrasts [14], reinforcement ahead and shadowing effects at the back, as we can see in Fig. 3. Nevertheless, in high resolution case with low incidence and finite areas, we can’t neglect migration effects so that we need range gated data (equivalent to raw data with a perfect azimuth compression). Each mechanism related to a given scattering element is further located in its corresponding range gate, keeping the azimuth location of the scattering element, before the complex summation of scattering events included in a cell (range, azimuth).

Validation of previous versions of this code have been performed first with comparing with experimental data obtained with ERS on the Fontainebleau forest at C band [5] for the radiometry and with checking expected symmetries in the amplitudes and phases of polarimetric interferometric observables on a canonical random volume over ground case. The present code, with forests of infinite horizontal extent (border effects inhibited), reproduces the previous monostatic results. When matched to parcels, we will see in Section 3 that it retrieves these ERS data.

3. C-BAND RESULTS

We present here radar simulation results to investigate the response of a forest of arbitrarily reduced size based on the ground truth [7] extracted from Fontainebleau area. We choose a surface of 50*45 meters square which is sufficient to fully represent the border effect for the height of 14.5 m at 23 degrees incidence angle (Fig. 8) without introducing unnecessary computations. The parcel is located (see Fig. 3) at coordinates (25, 45, 0) and the radar at (50, 330.103, 785.103). We also
consider two different periods during the year: March and September. For each period we show the 
VV range gated image and the evolution of the VV backscattered coefficient along the site axis, 
after taking the average over the azimuth one.

The main differences between the seasons concern the humidity which affects dielectric constants 
and also the leaves presence or not. We also consider in the two cases a similar soil outside the 
forest. Humidity rate decrease from 53% in March to 47% in September for vegetation and from 
36% to 17% for the soil which fit to the respective dielectric values: $(13.48, -6.979)$, $(10.92, -5.967)$ 
and $(18.12, -2.84)$, $(8.23, -1.04)$.

In Figs. 4 and 5 we can see the energy level for each radar echo and for each electromagnetic 
mechanism, which evolution can be easily explained by means of geometrical considerations as 
shown in Fig. 6. First we have the soil only (before zone one), then gradually the high layer 
contributions to the bottom one. We haven’t got a linear increment because of the fact that 
scatterers are more and more extinguished by the depth penetration. At 45 m, we can clearly 
recognize the beginning of the forest with the double bounce contribution, which imply an significant 
peak to the total contribution as the trunks ahead of the plot aren’t extinguish as those in the core, 
that’s a typical border effect. The soil contribution also present a peak because the soil inside is 
rougher and wetter than outside. Its linear decrement gives directly a idea of the media extinction. 
The third zone (between 51 meters to 56) is also interesting because it will give the same result as
in the infinite forest case. Indeed we retrieve an energy level around $-8.5$ dbm$^2$/m$^2$ given by ERS campaigns. In zone 4, the backscattering decrease gradually as radar cells contains less volume content. In zone 5 (90–96 m) we have only the soil part but lower than the bare soil due to the shadowing effect.

In the second simulation, we can observe the same trends except the fact that the leaves presence is of great importance in the total level. In Fig. 8, $M_1$ means the volume contribution and $M_2$ the double bounce. It is interesting to see that extinction is about 5 db higher and that the leave volume is the major contribution.

4. CONCLUSION

The coherent, polarimetric scattering code for forests of finite extent presented here has shown its ability to reproduce the complex border effects arising with high resolution imaging SAR due the vertical stratification of the forests. The results (total field) presented here have shown to be coincident with reported experimental ones in the part of the parcel where border effects are absent, thereby validating the simulations, but possibly significantly higher or lower in the border zone. The border influence on the partial contributions is much more significant, in their extent and in the variation of their amplitude. Future prospects include the analysis of these effects as a function of the radar parameters, including the bistatic case.

REFERENCES

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