Session 1A3b
Interaction of Microwaves with Vegetation

Scattering by a Vertical Tree Trunk over a Flat Ground: A Comparison between Analytical and Numerical Approach

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Most microwave models of forests neglect the near field interaction of the trunk and the surface of the ground. In this paper we investigate this interaction and compare the result with the standard analytical approach. Plane wave scattering by a vertical trunk over a flat lossy ground is considered.

The problem is first treated numerically. Using a surface integral equation formulation, the method of moments is used to determine the equivalent surface currents on the finite cylinder. The procedure exploits the rotational symmetry of the cylinder, and employs a dyadic Green's function for the half space. From the equivalent surface currents the bistatic scattering coefficient is evaluated. In the analytical approach, the contribution from the ground is taken into account in the computation of the scattering coefficient in the form of a double bounce effect between the cylinder and the flat ground.

The numerical results are compared to the approximate analytical approach for frequencies from 200 MHz to 2 GHz. It is seen that the approximate approach losses accuracy as the frequency decreases. However, it is noted that the approximate analytical method is computationally much faster.

Experimental and Model Investigation about Forest Emission at L Band

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In the near future important projects, aimed at monitoring soil moisture and land properties by L band spaceborne radiometers, are foreseen. In particular, technological efforts are being done for the development and launch of SMOS and HYDROS. Since these systems will collect microwave signatures at large scale, the contribution of surfaces covered by forests must be investigated. In fact, forests cover a large fraction of land, so that several pixels will be affected, partially or even totally, by their presence.

Up to now, most of theoretical and experimental studies about microwave interaction with forests have been based on active systems. Therefore, presently available results about emissivity are rather limited and sparse. New efforts are required to estimate the emission due to forest components and attenuation introduced over soil emission, which are important to fully exploit the potential of future L band radiometers.

In this work, results of model simulations and recent experiments are described and compared against each other. The model is based on routines, developed at Tor Vergata University in recent years, representing electromagnetic effects of trunks, branches, leaves, and soil. Single effects are then combined in order to simulate the emission of the whole medium. This basic electromagnetic software has recently been joined with a set of basic allometric relationships, available in the literature for several forest categories. This allows us to estimate forest emission without need of very detailed ground truth.

Experimental data were collected during the autumn 2004 in the Research Centre Jülich (Germany). The L-Band 1.4 GHz radiometer ELBARA, as well the X-Band 11.4 GHz radiometer MORA, were installed looking in the upward direction in a mixed hardwood forest. The average height of trees was about 20 meters, and the leaf fall process was monitored. Measurements with ELBARA allow distinguishing the horizontal and the vertical polarisation, and the antenna beamwidth is 12 degrees. In November 2004, the ELBARA radiometer was located above the same forest, looking downward from a 100 m tower. The experiment was repeated after covering the soil with a metallic foil.

The theoretical model has been adapted to the structural and geometrical properties of the forest. It was run in order to simulate the cases of upward looking radiometer and downward looking radiometer in absence and presence of the metallic foil. Comparisons between simulated and measured data are shown. The model represents several basic properties of experimental data. Some critical points, requiring further work, are identified.

Angular Normalization of ENVISAT ASAR Data over Sahelian-grassland Using a Coherent Scattering Model

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Abstract—ENVISAT-ASAR acquires data at different incidence angles. For temporal soil and vegetation parameters retrieval it is necessary to normalize the radar data for the angular behavior of the radar backscatter. A simple method for characterizing the angular behavior is by plotting the measurements of the backscattering coefficient during the dry season (stationary target) as a function of the incidence angle and considering that this angular dependence is conserved throughout the rainy season as well. However, this method is not sufficiently precise for data gathered in the rainy season since the scattering mechanisms of the vegetation and soil are different. Instead, we propose the use of a coherent scattering model for vegetation in order to carry out a more precise angular normalization. With this method, a higher precision is obtained for the normalization of the backscattering coefficient at VV polarization during the rainy season, in which the main contribution to the backscatter is attributed to vegetation.

1. Introduction

The ENVISAT satellite was launched by ESA (European Space Agency) in March 2002 on a sun-synchronous orbit at a mean altitude of 800 km and an inclination angle of 98.5°. In this study, we analyzed the data gathered by the multimode ASAR (Advanced Synthetic Aperture Radar) sensor [1], which operates at C-band at VV, HH, HV and VH polarizations. Its incidence-angle range is from 15° to 45°.

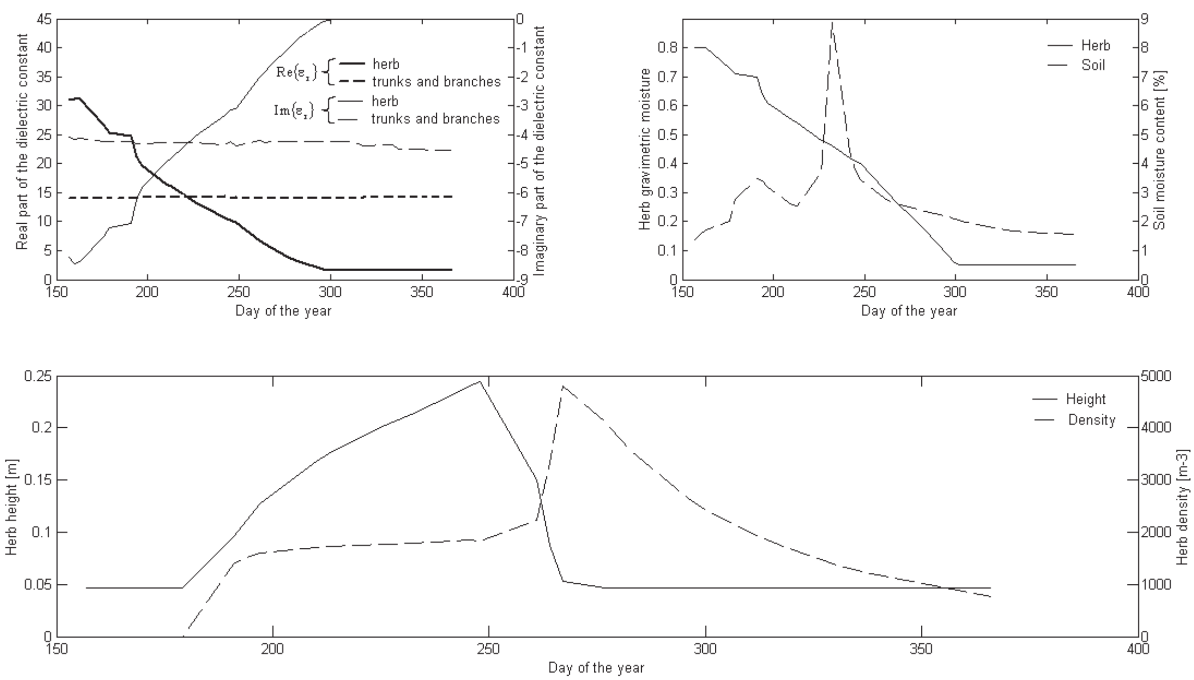


Figure 1: Vegetation parameters and soil moisture content (data taken in 2004).

Due to the fact that data acquisition for a given spot is provided at different polarizations and incidence angles, it is necessary to perform an angular normalization before exploit the data. When only measured data are available, a simple procedure to normalize them is by considering that the angular dependence is conserved during dry and humid seasons. For the gathered 2004 ENVISAT data, it is possible to employ the HH-polarization response in the dry season to obtain the adjusted angular-dependence curve.

2. Background

The study site is located in northern Mali, in the Gourma region. Its geographical coordinates are 15.35° N and 1.48° W.

The site Agoufou is steered by a semi-arid tropical climate defined by the water resources, the day duration and the temperature amplitude. The rainy season, during the African monsoon, generally starts at the end of June and finishes in September. The vegetation dynamic is mainly determined by rainfall during the monsoon [2]. Vegetation development starts after the first rain (not prior to June) and unless the annual plants wilted before maturity due to lack of rain, the senescence follows the fructification that matches with the end of the rainy season. This vegetation is composed by shrubs (1% cover), trees (3% cover) and annual herbaceous layer (5–40% cover). Soil cover range is between 60% and 95% depending on the season. Trees can be classified into four species: Acacia senegal, Acacia raddiana, Balanites aegyptica and Leptadenia pyrotechnica which is the main species. During the dry season (from October to June), there is no green vegetation apart from exception of shrubs and trees. The soil is essentially composed of sand (91.2%) and of clay (4.5%) [2]. Figure 1 shows physical characteristics of soil and vegetation. The vegetation input data were derived from terrain measurements performed during the 2004 rainy season. The characteristics of both trees and soil roughness are assumed to be constant throughout all the year.

The herb description is 10 cm length, 0.3 cm width, 0.03 cm thickness and with an erectophile orientation ($0 < \alpha < 360°$, $0° < \beta < 35°$, $40° < \gamma < 50°$). We assume that branch and trunk moistures are constant throughout the year and are set at 50% and 60%, respectively and its geometrical characteristics are shown in Tab. 1.

Table 1: Tree description.

Layer	Layer height [m]	Vegetal scatterer	Height [m]	Diameter [cm]	Density [$\#/m3$]	orientation	
						$\beta[°]$	$\gamma[°]$
1 (bottom)	0.15	Trunk	0.15	5	0.04	0–30	0–30
2	0.65	Branch	0.65	4	0.036	0–30	0–30
3	0.60	Branch	0.60	2.5	0.098	0–35	0–50
4 (top)	0.60	Branch	0.60	1.76	0.05	0-35	0-50

3. Angular Normalization Algorithm

Currently, angular normalization is based on the hypothesis of the angular dependence preservation throughout all the year. For ENVISAT 2004 data this process is applied because most of them were gathered at HH polarization; at this polarization, the main contribution can be assigned to scattering from the soil.

The use of only HH-polarization data does not give enough information about the Sahelian grassland, hence it is also necessary the VV polarization to understand the savanna response. This establishes the requirement of a general normalization procedure considering as well the grass contribution when it exits.

To normalize angularly the ENVISAT data, we propose a hybrid algorithm using both measurements and a coherent scattering model. This algorithm is composed of three main steps:

1. Determination of the soil contribution from the backscattering coefficient data at HH polarization during the dry season. For this extraction, we consider that soil properties do not suffer any change during this season.
2. Simulation of the backscattering coefficient as a function of both time (during the growing season) and incidence angle $\boldsymbol{\sigma}(\mathbf{t}, \boldsymbol{\theta}_i)$ employing the roughness parameters obtained from Step 1 and ancillary data (vegetation type, density, etc). This allows for a first-order correction to gentle angular variations of backscattering coefficient.
3. Determination of the angular normalization factor plot of normalized backscattering coefficient $\boldsymbol{\sigma}_{\theta_0}$ (normalized to mean incidence angle) as a function of time to monitor long term temporal variations.

4. Coherent Model

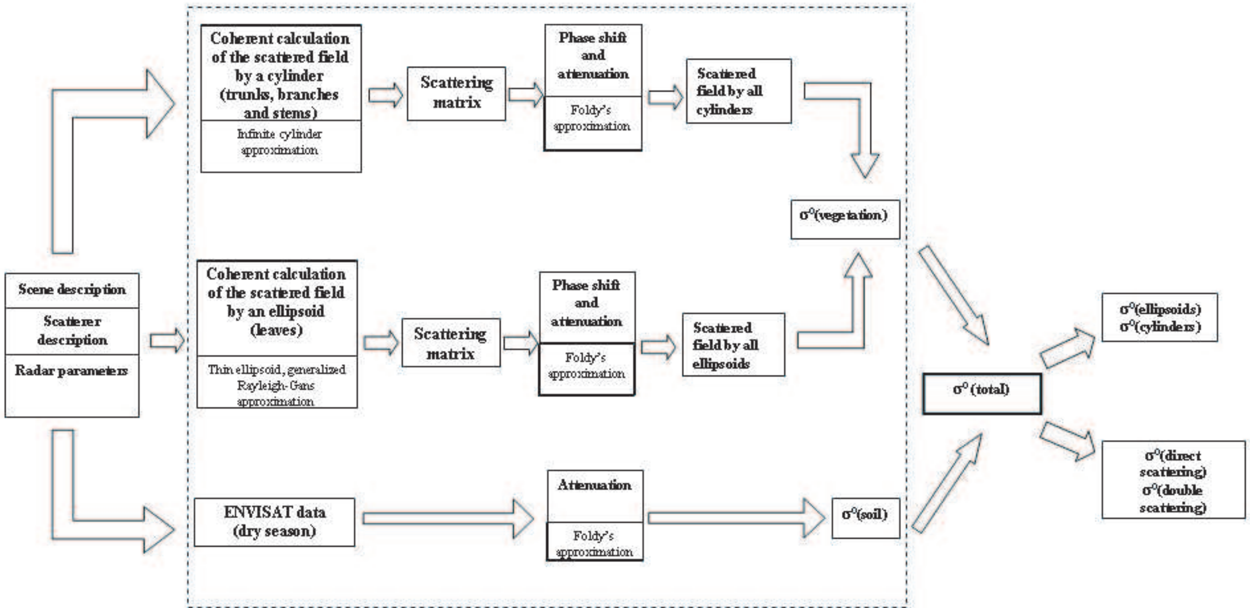


Figure 2: Coherent model description.

This paper is based on a coherent model for forest scattering [3], which has been adjusted to the grassland case. In this model, the vegetation is described as a discrete medium placed on a dielectric soil and composed of superposed horizontal layers. Each layer is defined by its height and the characteristics of the individual scatterers. Each scatterer type is described by its dimensions, its spatial density, its moisture content and its spatial description (orientation and position). The vegetation is represented as a cluster of scatterers composed of smooth dielectric circular cylinders and thin dielectric ellipsoids [4, 5]. The vegetation generation is based on the description of each layer. The scatterers are positioned, taking into consideration the no-superposition condition between elements enforcing a minimal distance between them and using a probabilistic function to have a realistic distribution.

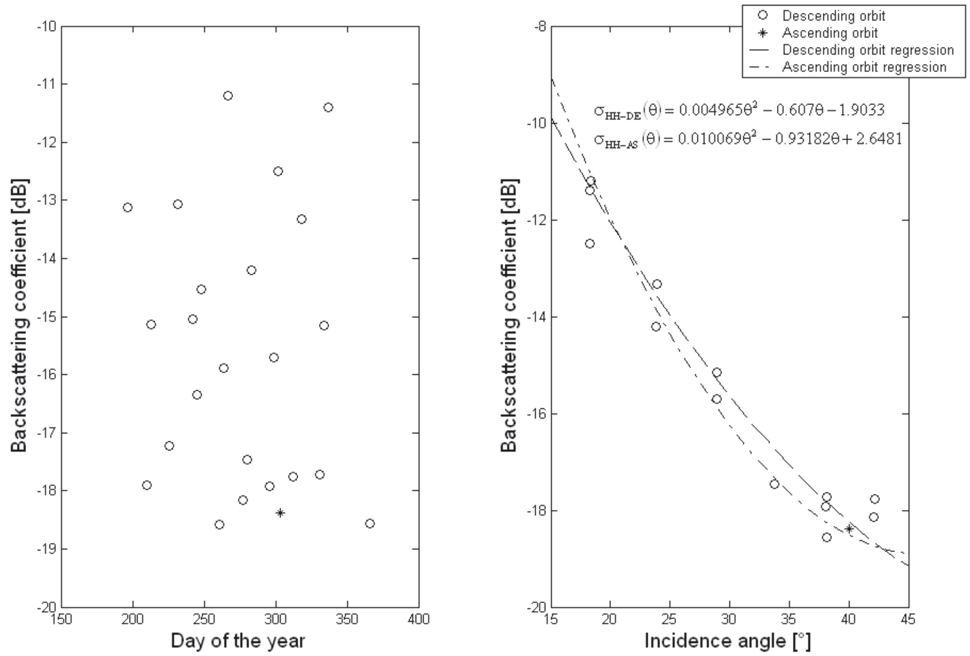
The coherent model inputs are the scatterer description, the number and the height of layers, the rough-surface description and radar parameters. The coherent model outputs are the backscattering coefficient (calculated by adding coherently the scattered fields of the observed region), the different scatterer contributions and the scattering-mechanism contributions. A schematic representation of the model is shown in Figure 2. The scattering matrix describing each element of the vegetation is built considering four main scattering mechanisms: direct scattering from vegetation scatterers, soil-vegetation interaction, vegetation-soil interaction and soil-vegetation-soil interaction. In this analysis, multiple scattering between scatterers is neglected. In order to take into account superior layer influence, all of these contributions are attenuated and shifted in phase using Foldy's approximation [6]. By adding coherently these two results, the vegetation backscattering coefficient is obtained.

Soil contribution is then reduced taking into account the attenuation due to vegetation layers. Finally, the total backscattering coefficient is the addition of the vegetation contribution and the soil contribution. An average backscattering-coefficient value is obtained by performing the backscattering coefficient over several realizations to warrant the convergence of the response (100 realizations for the grassland case).

For the case of the Sahelian grassland, trees and herbs were separately generated due to our model generator. Herbs were modeled enclosed in only one layer and trees were divided in 4 layers. Herbs are modeled as thin ellipsoids (stems contribution is neglected) and trees as smooth dielectric cylinders (trunks and branches). Total backscattering coefficient is then built by the incoherent addition of herb and tree contributions.

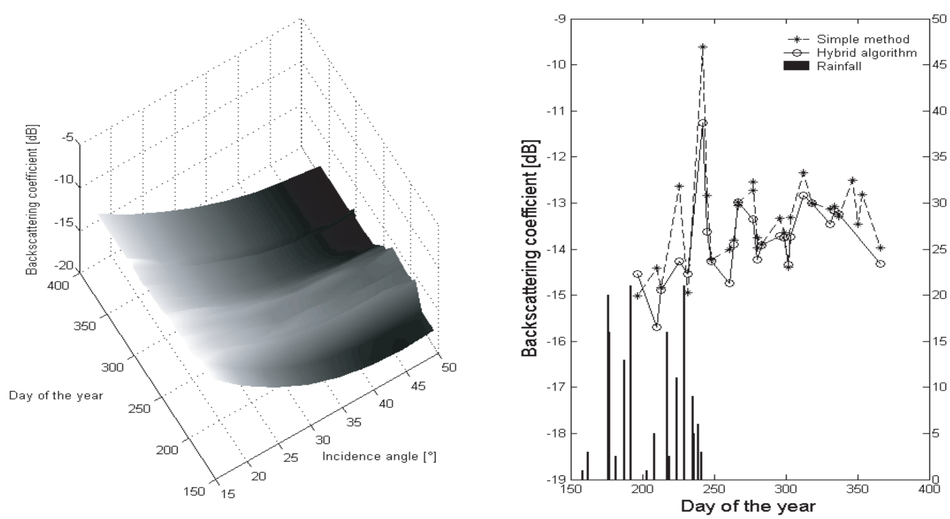
5. Simulation Results

Figure 3 shows the ENVISAT measured data for the site 17 (Agoufou) at Global Monitoring Mode without any normalization, and the angular dependence curve for measured soil contribution. The start of the dry season is supposed to be on October 3^{rd} (day 277).



(a) (b)

Figure 3: HH polarization ENVISAT-ASAR measured data without any normalization. b) Angular dependence curve for the HH polarization acquired during the dry season.



(a) (b)

Figure 4: a) HH polarization factor plot surface for the angular normalization. b) Comparison between simple method and hybrid method for 23° incidence angle (vertical bars represent temporal rainfall).

The surface representing the backscattering coefficient at HH polarization as a function of time and incidence angle is presented in Figure 4 (a). It is shown that as the incidence angle increases, the grass contribution is more significant to the total backscattering coefficient in the growing period, changing in this way, the incidence angular dependence depicted during the dry season.

Figure 4 (b) presents the comparison between the simple procedure and the hybrid method for the HH polarization for 23° incidence angle. The simple method depicts a higher dynamic (5.4 dB), in contrast the hybrid method presents a lower dynamic (4.4 dB).

Both two methods describe a similar behavior but with different maximum levels (about 1.6 dB of difference) on 29 August (day 242), for which soil moisture content is maximal. The main differences occur during the period of maximal grass biomass (from 28 July up to 17 September). This confirms the contribution of grass to the total backscattering coefficient shape and the importance of taking into account grass influence in the normalization process.

6. Conclusion

This paper proposes a hybrid algorithm to normalize angularly the ENVISAT-ASAR data for the Sahelian grassland and a comparison with a simple normalization. This algorithm allows a correction to get a more accurate angular normalization than that obtained by the simple method.

The most important contribution of the hybrid algorithm is the grass-effect calculus on the backscattering-coefficient shape causing a difference of about 1.5 dB; however it has two important limits: the need of the ground data and the computing time to carry the simulations out.

This study shows differences when grass contribution is considered within the normalization procedure. In this case, only HH polarization was analyzed. Following this algorithm, differences with the simple method could be amplified at VV polarization for which the vegetation contribution is more significant.

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Model Approaches for Scattering and Extinction of Thin Stems

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In the recent years, important advances in microwave remote sensing of crops were achieved. The availability of spaceborne SAR systems, as well as airborne campaigns, made several radar signatures available over agricultural fields. In some cases, also detailed ground truth are available. Moreover, several new theoretical efforts led to refine scattering models of vegetated fields. In spite of these important advances, discussion is still open about important topics. Several works are aimed at refining the techniques to combine the contributions of different scattering sources within vegetated media. However, also single element representation requires further work.

Detailed ground truth collected during experimental campaigns indicated that the stem diameter measured by a meter was appreciably higher than the diameter obtained by using weight measurements and information about wet and dry matter density. This discrepancy may be explained by stem hollowness, which is evident in the mature phase of the cycle for some crops, like wheat.

In this work different approaches, adopted to represent scattering and extinction of wheat stems, are presented and compared against each other. Adopted models for stems are: i) full cylinder with diameter equal to the one measured by a meter; ii) full cylinder with "equivalent" diameter, obtained by weight measurements; iii) hollow cylinder, with external and internal diameters obtained by using both meter and weight measurements. A specific electromagnetic routine, derived for the third case, is described.

Backscattering coefficients of wheat fields, simulated using the three techniques, are compared to each other at different frequencies, angles and stages of growth. Also extinction coefficients are compared. It is shown that "equivalent" and "hollow" cylinder techniques lead to similar results, while "full" cylinder technique leads to appreciably different results. For the C band case, some comparisons with experimental data, collected by ERS-2 SAR and ENVISAT ASAR, are presented. Better agreements are achieved by using the "equivalent" and "hollow" cylinder approaches.