An Electromagnetic Scattering Model for Tree Trunks Over a Tilted Rough Ground Plane


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Abstract Remote sensing of forest canopies is dominated by the interaction between tree trunks and ground at lower microwave frequencies and/or when the crown layer is tenuous. An efficient and complete electromagnetic scattering model for tree trunks above a tilted rough ground plane has been performed and enhanced. The individual trunks are modelled as finite-length stratified cylinders, with an external corrugated bark layer. The ground plane is modelled as a rough dielectric half space underlying the cylinders. Realistic natural conditions can be simulated by properly setting the parameters of this model. Results have been computed for the mean square error of the bistatic scattering pattern, by means of a Monte-Carlo simulation.

I Introduction

Focusing on the remote electromagnetic characterization of the earth’s vegetation cover, it has been shown from Vector Radiative Transfer Theory [1] that the backscattering from a typical forest canopy at lower microwave frequency and/or when the crown layer is tenuous is dominated by the ground-trunk interaction. Therefore in such cases an accurate model is composed by tree trunks above a ground plane.

It is demonstrated that the multiple scattering from cylinders overlying a dielectric half space is highly dominated by the first order solution (coherent sum of scattered fields by each cylinder as a response of the incident field), and that the interaction among cylinders is only of significance when trees are very close together [2, 3].

Then, for the realistic case of uniformly distributed tree trunks with a fractional surface on the illuminated area of the order of 0.1% occupied by trees, interaction among trees needs not to be considered. The characterization of an individual trunk-ground set has been solved using the model presented in [4], discussed and improved as in [5].

Once the individual trunk-ground sets are characterized, the multiple scattering is obtained by coherently summing the individual scattered fields by each trunk-ground set, each weighted by a phase factor obtained from its position. Results have been computed for the mean square error of the bistatic scattering pattern, using Monte-Carlo simulations. The influence of many variable parameters can be shown by the numerical simulations, allowing a complete study of vegetation covers.

The individual characterization of a trunk-ground set and the multiple scattering algorithm are outlined in the first part. Later, some numerical results and their discussion are explained.

II Formulation

II.1 Single Trunk-Ground Characterization

The characterization of an individual trunk-ground set is made by means of a scattering matrix $S$ that relates the incident and scattered fields [4] in the far field region,

$$\begin{bmatrix} E^i_v \\ E^i_h \end{bmatrix} = \begin{bmatrix} S_{ev} & S_{vh} \\ S_{he} & S_{hh} \end{bmatrix} \begin{bmatrix} E^s_v \\ E^s_h \end{bmatrix}$$

where fields are decomposed into a vertical and a horizontal polarization, using the FSA convention [6].

The computation of the $S$ matrix for a trunk-ground set is made in the same way as [4], but including a rough ground plane which has been characterized using a reflection coefficient matrix $\Gamma$ according to the roughness of the ground. The local to the plane coefficients $\Gamma_{h'}$ and $\Gamma_{v'}$ are the coherent field reflection coefficients from a surface with a Gaussian height distribution [7]. Their expression is,

$$\Gamma_p = \Gamma_{p0} \exp(-2k^2s^2 \cos^2 \theta_i)$$

where the polarization subscripts $p,q$ are either $h'$ or $v'$, the angle $\theta_i$ is both the angle of incidence and reflection, and $s$ is the rms height of the surface. Coefficients $\Gamma_{p0}$ are the Fresnel reflection coefficients [8] of a smooth surface with the same dielectric properties.
II.2 Multiple Scattering

The multiple scattering problem is illustrated in Fig. 1. Multiple tree trunks are positioned over a tilted rough dielectric ground plane. Trunks lengths \( L \) follow a Gaussian distribution with \( L \) mean and \( \sigma_L \) deviation, and positions of trunks \( (r_j^t) \) are uniformly distributed over the elliptic illuminated area of the ground surface.

The orientation of each tree \( j \) is defined by the unit vector \( \hat{z}_j^t \), expressed as,

\[
\hat{z}_j^t = \sin \theta_j^t \cos \phi_j^t \hat{x} + \sin \phi_j^t \hat{y} + \cos \theta_j^t \hat{z}
\]

where \( \theta_j^t \) and \( \phi_j^t \) are elevation and azimuth inclination angles. In the Monte-Carlo simulation \( \theta_j \) follows a Gaussian distribution with zero mean and \( \sigma_{\theta_j} \) deviation, and \( \phi_j \) is uniformly distributed in \([0, \pi]\).

The transmitting antenna is supposed to produce an elliptic beam (spot-like coverage). The lengths of the axes of the incident beam in the plane defined by \( k_i \) are \( \Delta_v \) (ground-range) and \( \Delta_h \) (cross-range), respectively. This ellipse has been projected over the ground surface by means of a geometrical method.

The multiple scattering problem consists of \( N \) tree trunks. For each trunk \( j \), its position, height and orientation together with the ground tilt and roughness is used to construct the scattering matrix \( S_j \) that characterizes its interaction with the ground plane. Once all matrices \( S_j \), are computed, summation of all \( E_j^t \) gives the total scattered field by the layer of tree trunks after the first interaction, providing the so called first order solution for the multiple scattering problem,

\[
\begin{bmatrix}
S_{ev}^M & S_{eh}^M \\
S_{he}^M & S_{hh}^M
\end{bmatrix} = \sum_{j=1}^{N} \begin{bmatrix}
S_{ev}^j & S_{eh}^j \\
S_{he}^j & S_{hh}^j
\end{bmatrix} e^{i k_0 (k_i - k_j) \cdot r_j^t}
\]

III Results and Discussion

Numerical results have been computed using Monte-Carlo simulations with 50 realizations in order to guarantee their random features. The displayed value is the mean square error of the Bistatic Scattering Coefficient \([2]\), defined by,

\[
\gamma_{\beta_0} = \lim_{r \to \infty} \frac{4 \pi^2}{|E_0|^2} \left| \frac{E_{\beta_0} - \left< E_{\beta_0} \right>}{A_i \cos \theta_i} \right|^2
\]

where angular brackets denote average over realizations, \( A_i \) is the illuminated area and \( \alpha, \beta \) represent, respectively, the input and output polarizations.

The \( \gamma_{HH} \) and \( \gamma_{VV} \) coefficients as a function of the elevation observation angle are shown in Fig. 2 for a uniform distribution of vertical homogeneous dielectric cylinders \( (\epsilon_r) \) of radius \( a \), overlying a straight smooth dielectric half space \( (\epsilon_0) \). The spot coverage ground and cross range are equal, and cylinders occupy 0.1% of fractional surface. Fig. 2 is the simplest case, and most values for the involved parameters have been taken from \([2]\) for comparison. All results appeared there for the first order solution agree with the ones obtained using this method.

In the simplest case, the Bistatic Scattering Coefficient when all trunks are equal and collinear is the bistatic response of an individual trunk-ground set weighted by the array factor of \( N \) elements positioned at \( r_j^t \) each one. Thus the mean square error of the Bistatic Scattering Coefficient is the mean square error of the array factor. Two maxima appear in the back and forward regions, a dip just in the specular direction, and there is a relation between the angular width of both maxima and the ratio.
wavelength over cylinders’ average length, as shown in [2].

Many simulations have been performed to analyze the sensitivity of the bistatic scattering pattern to every involved parameter. For example, the influence of the ground tilt is presented in Fig. 3. The slope of the ground plane is characterized by a directional vector \( \mathbf{n}_g \), which depends on \( \theta_g \) and \( \phi_g \) (elevation and azimuth inclination angles, respectively). Fig. 3 shows the response for a typical small elevation angle \( \theta_g = 10^\circ \). As expected, the backscattering maximum disappears because cylinders are not perpendicular to the ground. Moreover, if the azimuth inclination ground angle \( \phi_g \) becomes non-zero, a high cross-polarized signal appears (see VH) as it occurs for an individual trunk-ground set [4]. Another important effect is the missing dip for \( \theta_s = 45^\circ \), since the true specular direction when \( \phi_g \neq 0 \) does not occur for \( \phi_s = 0 \).

Fig. 4 shows the effect of the non-colinearity of trunks. The former situation (vertical trunks) is compared with that of trunks randomly oriented, with \( 7^\circ \) of standard deviation around the vertical position. The peak in the specular direction is unchanged due to the array factor not being modified, but the backscattering peak disappears and there is a high level of cross-polarized signal due to trunks not being normal to the ground.

Other observed effects have been the dependence to the height of the ground roughness, the sensitivity to the dielectric characteristics of the trunk layers, the effect of the incidence angle, the frequency and the trunks dimensions.

IV Conclusion

An efficient, complete and realistic model for multiple tree trunks above a tilted rough ground plane has been presented. This model is an improved combination of the model described in [4] for a single tree trunk above a tilted ground plane and the model for multiple vertical cylinders overlying a dielectric half space presented in [2]. An algorithm for obtaining a matrix providing the scattering in the far field zone and the first order solution was developed.

This scattering model allows a complete study of forest canopies, since many parameters can be customized and many realistic features have been added.

REFERENCES


