A General Radar Scattering Model for Earth Surfaces

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Abstract: A radar scattering model is developed based on an empirical rough surface scattering model, the radiative transfer model (RTM), a numerical simulation algorithm of radar scattering from particles, and experimental data obtained by ground-based scatterometers and SAR systems. At first, the scattering matrices of scattering particles such as a leaf, a branch, and a trunk, have been modeled using the physical optics (PO) model and the numerical full-wave analysis. Then, radar scattering from a group of mixed particles has been modeled using the RTM, which leads to a general scattering model for earth surfaces. Finally, the scattering model has been verified with the experimental data obtained by scatterometers and SAR systems.

Keywords: Radar scattering model, Earth surfaces, Radiative transfer model

1. Introduction

The radar scattering from earth surfaces involves complicated electromagnetic wave interactions, because the scattering elements have complex geometries and are randomly oriented and distributed in space. When we develop a mathematical model for polarimetric radar scattering from a vegetation layer over earth surfaces, it is impossible to deal with all kind of possible earth elements configurations and conditions. Hence, our attention is always focused on the development of approximate scattering models [1-3].

The approximate radar scattering models have been developed for natural earth surfaces such as bare fields, agricultural areas, mountain areas, and water surfaces for many years. The bare fields include roads, playgrounds, and bare agricultural areas. The dielectric constants and the roughness parameters are key input parameters for the bare fields. The agricultural areas include rice fields and other crop fields such as corn, barley, potato, sweet potato, and grass areas. The agricultural areas have been considered as vegetation canopies over rough surfaces. The vegetation canopy includes various types of scattering particles. The mountain areas include coniferous-tree forest, deciduous-tree forest, and mixed-up forest. The mountain areas have been considered as two-layered vegetation canopies over inclined rough surfaces; *i.e.* a crown layer and a trunk layer.

There are several models for the surface scattering models in the previous literatures such as the geometrical optics (GO), the physical optics (PO), and the small perturbation method (SPM) models. But such traditional theoretical models have strict validity regions. That's why we use the polarimetric empirical model (PEM) [4] to enlarge the validity regions and to improve the accuracy of the surface backscattering coefficients.

The volumetric scattering model is usually based on the radiative transfer model (RTM). It deals with the transport of energy through a medium containing particles, such as leaves, branches and trunks. We assume the vegetation canopy has two layers: a surface layer and a vegetation layer. The vegetation layer involves leaves, branches and trunks mixed together. We used the RTM to calculate the backscattering coefficients of any kinds of vegetation canopies.

2. Modeling Procedure

There is an existing model, Michigan microwave canopy scattering model (MIMICS), which is too complicate to use because of too many input parameters, and is not accurate enough because of using the inaccurate theoretical surface scattering models, such as the PO, the GO, and the SPM models.

We developed a new scattering model, which has only ten input parameters for simple use. Moreover, the model uses the PEM for soil surface scattering, which has broader validity range. The vegetation layer in the model doesn't have the trunk layer as shown in Fig. 1. Instead, the trunks are located inside of the crown layer, that consists of all constituents of particles; leaves, branches and trunks

1) Ground surface scattering model for bare surfaces

For the ground backscattering calculation, the PEM is used. The expression of the PEM is

$$\sigma_{vh}^0 = 0.11 m_v^{0.7} (\cos\theta)^{2.2} \left[1 - \exp(-0.32 (ks)^{1.8})\right], \quad (1)$$

$$\sigma_{vv}^0 = \frac{\sigma_{vh}^0}{q}, \quad (2)$$

$$\text{where } q = 0.1\left(\frac{s}{l} + \sin(1.3\theta)\right)^{1.2} \left\{1 - \exp\left[-0.9(ks)^{0.8}\right]\right\},$$

$$\sigma_{hh}^0 = p\,\sigma_{vv}^0 = \frac{p}{q}\sigma_{vh}^0, \quad (3)$$

$$\text{where } p = 1 - \left(\frac{\theta}{90^\circ}\right)^{0.35 m_v^{-0.65}} \cdot \exp(-0.4(ks)^{1.4}).$$

2) Volumetric scattering model for vegetation layers

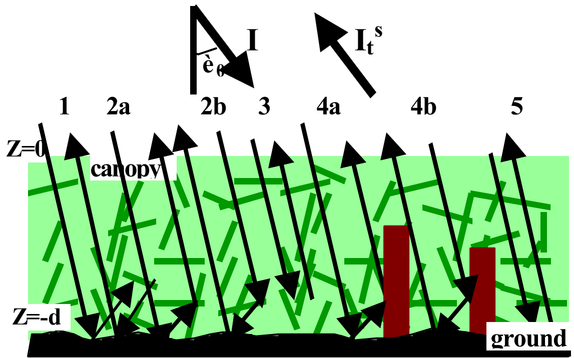


Fig. 1. The configuration and scattering mechanism of volumetric vegetation layer

As shown in Fig. 1, the canopy is considered to consist of a single horizontal vegetation layer of height d over a dielectric ground surface. The total backscattered intensity $I_t^s(m_0,f_0)$ is related to the intensity I_0 incident upon the canopy through the transformation matrix $T_t(m_0, f_0)$ by the equation,

$$I_t^s(m_0,f_0)=T_t(m_0,f_0)I_0(-m_0,f_0)\,. \tag{5}$$

$T_t(m_0,f_0)$ is called the 4×4 total canopy backscattering transformation matrix.

To solve for the total canopy backscattering transformation matrix, the problem is divided into two parts. The one is for vegetation canopy and the other is for ground surface. Then the total canopy backscattering transformation matrix becomes

$$T_t(m_0,f_0)=T_c(m_0,f_0)+T_g(m_0,f_0) \tag{7}$$

where $T_c(m_0,f_0)$ and $T_g(m_0,f_0)$ are the canopy and ground backscattering transformation matrices, respectively.

The expression for T_g is given by

$$\overline{T}_g(m_0,f_0)=\exp(-\overline{k}_e^+d/m_0)\overline{G}(m_0)\cdot\exp(-\overline{k}_e^-d/m_0)\,, \tag{8}$$

where $\overline{k}_e^+$ and $\overline{k}_e^-$ are the 4×4 extinction matrices of the vegetation layer for upward and downward propagation, respectively. $\overline{G}(m_0)$ is the ground backscattering matrix given by

$$\overline{G}(m_0)=\frac{1}{\cos q_0}\overline{M}_m\,, \tag{9}$$

where $\overline{M}_m$ is the modified Stokes scattering operator, which describes ground backscatter[3].

The expression for T_c is given by

$$\begin{aligned}T_c=&\frac{1}{m_0}\exp(-K_c^+d/m_0)R'(m_0,f_0+p)e_c(-m_0,f_0+p)\\&\cdot A_1e_c^{-1}(m_0,f_0)R'(m_0,f_0)\exp(-K_c^-d/m_0)\\&+\frac{1}{m_0}\exp(-K_e^+d/m_0)R'(m_0,f_0+p)e_c(-m_0,f_0+p)\\&\cdot A_2e_c^{-1}(m_0,f_0)\\&+\frac{1}{m_0}e_c(m_0,f_0+p)A_3e_c^{-1}(m_0,f_0)R'(m_0,f_0)\\&\cdot\exp(-K_c^-d/m_0)\\&+\frac{1}{m_0}e_c(m_0,f_0+p)A_4e_c^{-1}(-m_0,f_0)\\&+\frac{1}{m_0}\exp(-K_c^+d/m_0)\exp(-K_t^+H_t/m_0)R(m_0)\\&\cdot e_t(-m_0,f_0+p)A_5e_t^{-1}(m_0,f_0)\exp(-K_c^-d/m_0)\\&+\frac{1}{m_0}\exp(-K_c^+d/m_0)e_t(m_0,f_0+p)A_6e_t^{-1}(m_0,f_0)\\&\cdot R(m_0)\exp(-K_t^-H_t/m_0)\exp(-K_c^-d/m_0)\end{aligned} \tag{10}$$

Finally, we can get the backscattering coefficients as the following expressions [3].

$$\begin{aligned}s_{vv}^0&=4p\cos q_0[T_t(m_0,f_0)]_{11}\\s_{hh}^0&=4p\cos q_0[T_t(m_0,f_0)]_{22}\\s_{hv}^0&=4p\cos q_0[T_t(m_0,f_0)]_{21}\\s_{vh}^0&=4p\cos q_0[T_t(m_0,f_0)]_{12}\end{aligned} \tag{11}$$

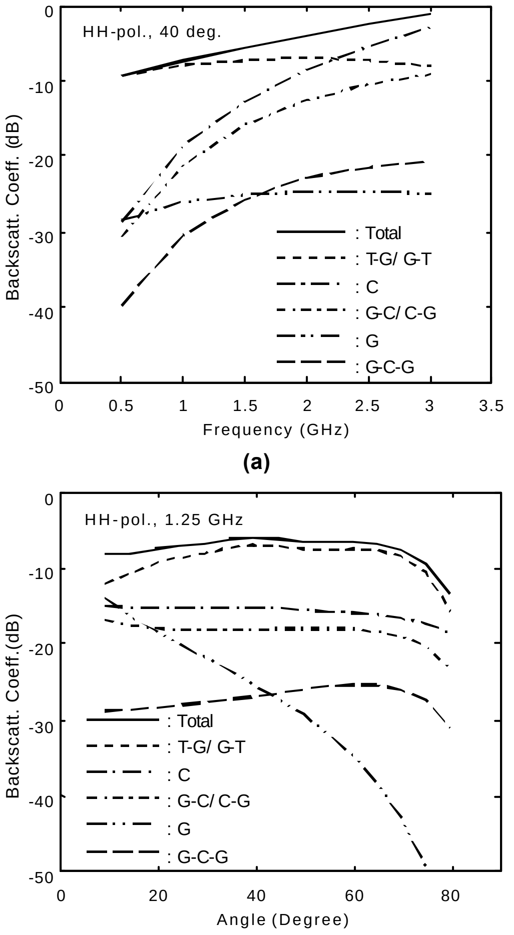
3) Model computation

The developed new scattering model needs only ten input parameters. The ten input parameters listed in Table 1 are core parameters for the scattering model. Among other minor parameters, some varies with the input parameters and some are fixed to certain values. For example, the correlation length l for ground surface is fixed to 10 cm and the trunk diameter is varying with the trunk length l_t; *i.e.*, l_t/10.

Fig. 2 shows the computation results for the values in Table 1 for a forest area. The letters G, C, and T in Fig. 2 denote ground, crown and trunk, respectively. For example, G-C-G means the scattering mechanism 1 in Fig. 1. The scattering coefficient is dominated by the ground-trunk scattering mechanism at lower frequencies and by the crown-direct scattering mechanism at higher frequencies in this case as shown in Fig. 2 (a). Fig. 2 (b) shows an angular dependency of the backscattering coefficients for HH-pol. at 1.25 GHz.

Table 1. Input parameters for developed model and the common parameter values

Classes		Input parameters	Value
Ground surface		m_v (moisture content)	0.15
		s (rms height) [cm]	0.5
Vegetation Layer	Vegetation layer height [m]		5
	Leaf	Length [cm]	6.0
		Width [cm]	6.3
		Density [m^3]	200
	Branch	Length [m]	0.75
		Density [m^3]	4.1
	Trunk	Length [m]	2.5
		Density [m^3]	0.1



(a)

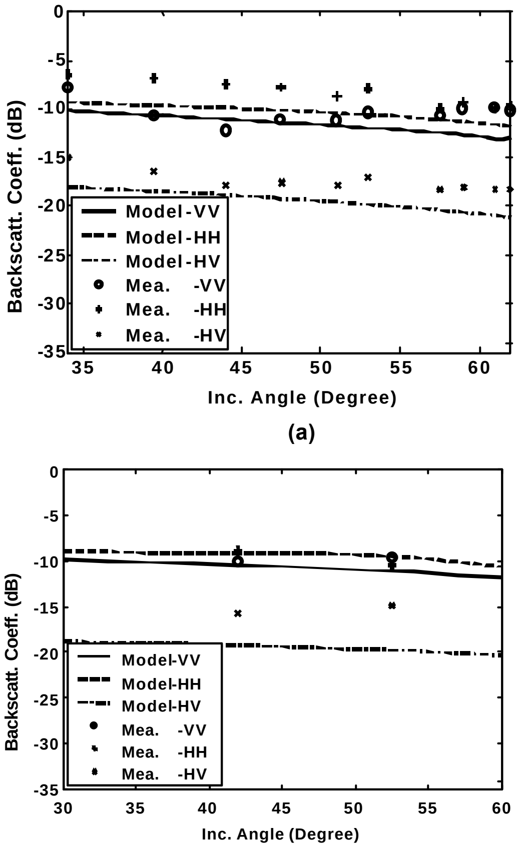
(b)

Fig. 2. Computation results for a typical forest.

4) Verification with measured data

The backscattering coefficients are computed by the new scattering model and compared with the JPL/AirSAR measurements obtained at Non-San area for the PACRIM-2 campaign in Korea in 2000. The computation results are based on the ground truth data measured at that area at the same time.

Fig. 3 (a) shows the comparison between the computations and the measurements of the backscattering coefficients of ten rice fields. A good agreement is shown in the figure. The disagreement about 2 to 3dB may be from the ground truth data deviation and also from the modeling. Fig. 3 (b) shows the comparison between the computations and the measurements for three forest areas. It was shown that the computed cross-polarized backscattering coefficients are lower than the measurements. The deviation may be caused from that the model includes only the first-order multiple scattering and ignores the higher-order multiple scattering terms.



(a)

(b)

Fig. 3. The comparison with SAR measurement data and computation results for (a) rice fields and (b) forests.

3. Conclusions

A radar scattering model is developed for earth surfaces with vegetation canopies, which consist of leaves, branches, and trunks. The model was tested for many kinds of vegetation canopies, and verified with the JPL/AirSAR measurement data sets for rice fields and forest areas. Good agreements are shown between the computed backscattering coefficients for the fields and the measurements. It was also found that the model predicts a lower cross-polarized response because of ignoring the higher-order multiple scattering.

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