# Electromagnetic Scattering from Agricultural Vegetation in Clusters Using Monte Carlo Simulation

Shu-Qing Li and Wen-Bing Wang

***Abstract*—An electromagnetic scattering model for agricultural vegetation where leaves occur in clusters is developed in this letter. By applying the Monte Carlo simulation technique, the backscattering properties of vegetation are studied for two different cases where the position distribution of clusters is regular or random. The results show that the position distribution of clusters plays an important role in determining the observed coherent effects. The incoherent scattering parts in the two different cases are almost equal and the regular position distribution of clusters can lead to a strong coherent part despite the random orientation of leaves. The work of this letter indicates that it is necessary for theoretical scattering models to take the position distribution of clusters into account.**

***Index Terms*— Microwave remote sensing, vegetation scattering.**

## I. Introduction

MICROWAVE remote sensing has been widely applied in the remote measurement of agriculture field properties because of its independence on weather conditions. Theoretical investigation of the scattering from agricultural vegetation can interpret the remotely collected data to obtain the valuable information about the vegetation. In the recent years, the theoretical scattering model, which treats the vegetation as a discrete random medium associated with the radiative transfer technique, has been widely used for the study of electromagnetic scattering from vegetation [1], [2]. The discrete medium approach models the vegetation as a random collection of discrete scatterers, such as trunks, branches, and leaves with different size and position. This scattering model does not take into account the relative phase shift due to the relative positions of scatterers and the clustering effects of leaves. For actual agricultural canopy, such as crops, etc., the scatterers often occur in clusters and the clusters may be planted in a regular row arrangement. This regular position distribution of clusters which is like an antenna array shows great effects on the scattering pattern. In this letter, we propose a cluster scattering model for agricultural vegetation which considers the positions of scatterers and clusters, and analyze the effects of different clusters position distributions on scattering properties.

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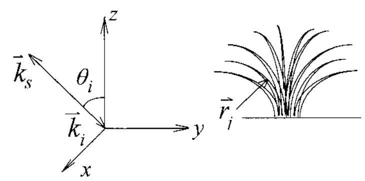


Fig. 1. The structure of a cluster of leaves.

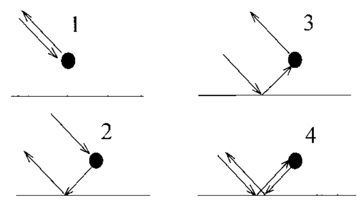


Fig. 2. Assumed four scattering mechanisms.

## II. Scattering Modeling

Assume the agricultural canopy consists of leaves only. This happens at the early growing stage of vegetation, when the clustering effects are evident. Fig. 1 illustrates a typical cluster structure. The constituent leaves are modeled by elliptical discs with random orientations. To simplify the computation, all the leaf elements are assumed to scatter independently. The electromagnetic interactions between leaves are ignored and only the phase shift caused by different locations is considered. Scattering from such a cluster can be approximated by a sum of single scattering of leaves

$$\vec{E} = \sum_{n=1}^{N} \vec{E}_n \exp[j(\vec{k}_i - \vec{k}_s) \cdot \vec{r}_n] \tag{1}$$

where $N$ is the number of leaves in the cluster, $\vec{r}_n, \vec{E}_n$ represent the location and scattered field of leaf $n$, respectively, and $\vec{k}_i, \vec{k}_s$ are the incident and the scattering wave vectors, respectively. Due to the presence of the ground surface, the incident wave may be reflected from a leaf via four main mechanisms which are shown in Fig. 2. Hence the scattering field $\vec{E}_n$ consists of four main terms

$$\vec{E}_n = \sum_{k=1}^{4} \vec{E}_{nk} \tag{2}$$

where $\vec{E}_n$ is determined by the scattering properties of leaf and ground. In the present paper, the field scattered from a

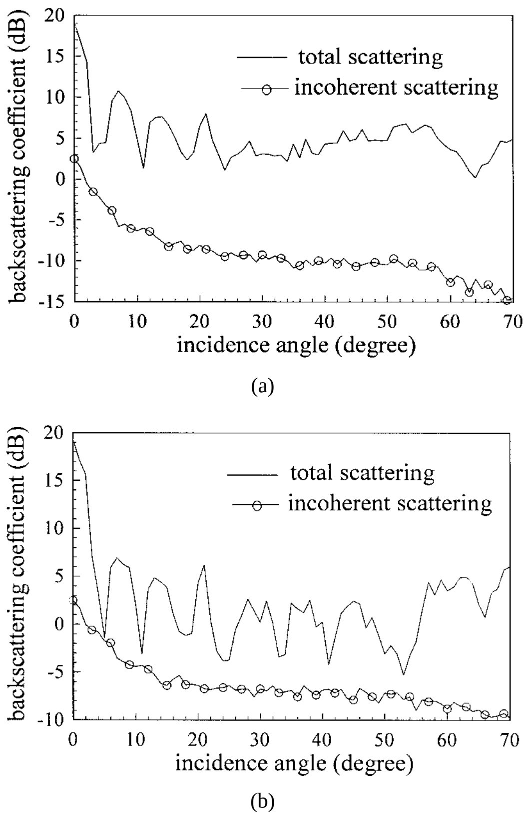


Fig. 3. Backscattering coefficient versus incidence angle. Regular distribution of clusters. (a) VV polarization. (b) HH polarization.

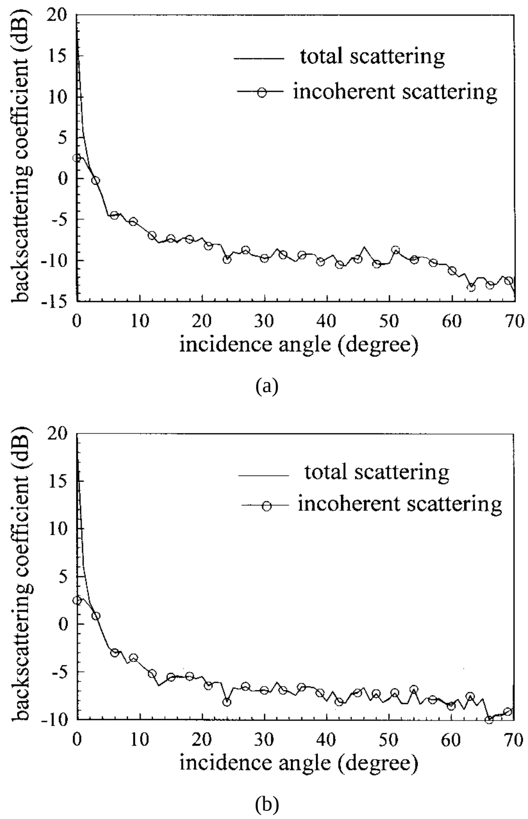


Fig. 4. Backscattering coefficient versus incidence angle. Random distribution of clusters. (a) VV polarization. (b) HH polarization.

single leaf under plane wave incidence is obtained by using the generalized Rayleigh–Gans approximation [3]. The ground is modeled as a randomly rough surface, whose scattered field can be obtained under physical optics approximation [4].

The actual agricultural vegetation can be described by a collection of many clusters. If $N_s$ clusters are assumed within a pixel, the total backscattered field can be written in terms of the field $\overrightarrow{E}_m$ scattered by an individual cluster

$$\overrightarrow{E} = \sum_{m=1}^{N_s} \overrightarrow{E}_m \exp(2j \overrightarrow{k}_\rho \cdot \overrightarrow{\rho}_m) \tag{3}$$

where $\overrightarrow{E}_m$ represents the field scattered from cluster $m$, and can be obtained according to (1). $\overrightarrow{\rho}_m$ is its position, and $\overrightarrow{\rho}_m = x_m\hat{x} + y_m\hat{y}$, $\overrightarrow{k}_\rho = k_{xi}\hat{x} + k_{yi}\hat{y}$.

The varying position distribution of clusters has a considerable influence on the backscattering properties of the agricultural canopy. The situation is analogous to that of an antenna array whose structure has significant effects on the radiation field pattern. Two cases are studied here. In one case the position distribution is random and in another is regular. The direct backscattering from the ground is ignored in the computations.

## III. Monte Carlo Simulation and Numerical Results

A Monte Carlo simulation is applied to obtain the statistical scattering properties of the canopy. According to the measurements on an actual agricultural context, the orientation distributions of Eular angles $\alpha$, $\beta$, $\gamma$ of leaves are assumed to be independent, and uniform in the ranges of $0° \sim 360°$, $30° \sim 90°$, $0° \sim 30°$, respectively. The leaf number in each cluster randomly varies from 30 to 60. The average dimensions of leaves are $a = 40$ cm, $b = 0.8$ cm, $c = 0.02$ cm, and the relative dielectric constant determined by leaf moisture is assumed to be $\varepsilon_r = 28 - j1.5$. The row and column distances between clusters are both 0.25 m. Assume the simulation area is $A = 4 \times 4$ m$^2$. The incident plane wave frequency is 3 GHz. The Monte Carlo simulation steps are as follows.

1) The orientations of $\alpha$, $\beta$, $\gamma$ leaves are divided into $N_\alpha, N_\beta, N_\gamma$ equal intervals, respectively, which leads to $N_\alpha \times N_\beta \times N_\gamma$ possible orientations. The leaf backscattered field associated with each possible orientation is calculated according to (2) and stored.
2) The field backscattered from a cluster is calculated by summing up the fields scattered by constituent leaves according to (1). The leaf number of each cluster is generated randomly from 30 to 60. For each leaf in the cluster, an orientation is randomly selected among $N_\alpha \times N_\beta \times N_\gamma$ orientations and the corresponding backscattered field is singled out. $N_c$ clusters backscattering fields are calculated and stored, where $N_c$ is an large number should define the statistics.
3) For each case of position distribution of clusters random or regular, a corresponding ensemble is generated. In one case, the cluster positions are uniformly randomly distributed within the area $A$, and in the other, the clusters are regularly arranged in rows and columns. The

number of clusters in the ensemble is dependent on the row and column distances and the simulation area.

4) Each cluster scattering field is randomly selected among the $N_c$ clusters scattering fields previously computed. Summing up all the fields scattered by clusters within the area $A$ leads to the computation of a sample of scattered field, according to (3).
5) Steps 3) and 4) are repeated until a number of samples sufficient to define the statistics are obtained. In this letter, the sample number is 100.
6) The values of the backscattering coefficients are obtained by averaging all the samples derived in step 5).

The backscattering coefficient is defined by

$$\sigma_{pq} = \lim_{r \to \infty} \frac{4\pi r^2 \langle |E_p^s|^2 \rangle}{A|E_q^i|^2} \tag{4}$$

where $p, q$ represent the polarization of incident and scattering waves, respectively. The backscattering coefficient may be divided into two parts: one is the coherent coefficient corresponding to the mean scattered field and another is the incoherent coefficient corresponding to the fluctuating scattered field. The incoherent coefficient is defined as

$$\sigma_{pq}^i = \lim_{r \to \infty} \frac{4\pi r^2 \langle |E_p^s - \langle E_p^s \rangle|^2 \rangle}{A|E_q^i|^2} \tag{5}$$

where $\langle\rangle$ denotes the average over all the realizations.

Figs. 3 and 4 illustrate the numerical results obtained for backscattering coefficients versus the incidence angles for the two cases, respectively. It is shown that the coefficients mainly consist of incoherent scattering in case of random position distribution, while the regular position distribution greatly increases the coherent scattering part. The incoherent coefficients are almost equal in both cases, which means that the coherent part is mainly dependent on the regular position distribution of clusters and the incoherent part is determined by the random orientation distribution of leaves. The fluctuating behavior of the backscattering coefficient as function of incidence angle in Fig. 3 is caused by the regular distribution of clusters positions.

## IV. Conclusion

In this letter, an electromagnetic scattering model is developed for a clustered agricultural canopy. The effects of cluster position distribution on the backscattering properties are studied by using a Monte Carlo simulation. The results show that different position distributions of clusters have a considerable influence on the backscattering coefficients. A regular position distribution may lead to a relatively strong coherent part in the total backscattering from the vegetation.

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