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DISCRETE RANDOM MEDIA TECHNIQUES FOR MICROWAVE MODELING OF VEGETATED TERRAIN

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1. Introduction

Microwave remote sensing of vegetated terrain has been studied. Vegetation is modeled so that backscattered radar signals can be used to infer parameters which characterize the vegetation and underlying ground. The vegetation is modeled by discrete lossy dielectric scatterers with prescribed characteristics. The goal of the modeling effort is to remotely sense vegetation type (classification), growth stage, and plant/ground moisture. This information can then be used as input into agricultural, forestry and global circulation models. The microwave frequency spectrum, particularly L and C bands, are especially appropriate for this purpose since the wavelength is comparable to plant leaf and stem size. The resulting resonant interaction leads to backscattered data highly depend on plant shape and orientation. In addition, the transparent nature of the atmosphere in this frequency regime allows for algorithm development which requires no atmospheric correction.

2. Technical Approach

The modeling approach characterizes the vegetated terrain as a layer of plant growth over a possibly rough surface. The plants are viewed as composites of leaves and stems which are modeled by dielectric discs (not necessarily circular) and rods. The discs and rods are placed at random locations throughout the layer; their size and orientation statistics are chosen to correspond to the vegetation being modeled.

Once the discrete stochastic model has been specified, the average backscattering coefficients are computed for both like and cross polarizations. The calculation is made amenable to analysis by the presence of a small parameter - the fractional volume of vegetation. It is then possible to employ the distorted Born approximation or transport theory (depending on albedo size) to calculate the backscattering coefficients. This constitutes the formulation of the discrete problem, i.e., given the distribution of scatterer sizes and orientations, the backscattered power can be computed. The final step in the procedure to obtain a remote sensing algorithm is to invert this direct problem. The performance of the inversion assumes that the backscattering coefficient is given as a function of angle of incidence and/or frequency. From this data, the statistical characteristics of the scatterers are computed. This calculation is often numerically ill-conditioned and needs special treatment.

3. Research Results

Over the three year period, results have been obtained in all areas needed for algorithm development. Electromagnetic modeling of plant elements has been addressed, backscattering coefficients have been calculated and inversion algorithms have been developed.

Simple plant canopies such as soybeans can be modeled by replacing the plant's leaves and stems by dielectric discs and rods respectively as is shown in Fig. 1. The relative dielectric constant used for the discs and rods is the equivalent dielectric constant of the plant material. The use of this equivalent dielectric neglects scattering effects caused by internal variations within the plant. This is small however, because of the long wavelength involved.

Scattering amplitudes have been computed for both the disc and stem elements. The resulting formulas for the scattering amplitudes are particularly simple because they take advantage of the small ratio of thickness to radius in the case of the discs and radius to length in the case of the rods. The simple formulation is particularly important since the results must be averaged over both inclination and size distributions.

Backscattering from the modeled plant canopy has been treated by two techniques: the distorted Born approximation and the transport theory. The two methods are equivalent when the albedo of the scatterers is small and no coherent (planar) boundaries are present. It has been shown for the case of a flat ground that the transport theory neglects certain coherent interference terms which are taken into account by the distorted Born approximation. It should be noted that this effect is a low frequency (L-band) phenomenon because at higher frequencies the surface appears rougher, and as a result, coherence effects disappear. Since the distorted Born method is applicable in the L band frequency regime, since it contains the interference terms and since it is relatively simple in formulation as compared to vector transport theory, it has been used almost exclusively, to calculate the backscattering coefficients.

Application of the distorted Born theory to the modeling of crops such as soybeans has yielded interesting results. Fig. 2 shows some of these results for a frequency of 1.5 GHz. The figure is a plot of σ^0_{vv} versus angle of incidence. An examination of the figure shows that for vertical-like polarized returns the leaves are dominant at low angles and the stems are most important at large angles of incidence. This is not surprizing since the electric field is aligned with most stems at large angles of incidence.

The model whose results are shown in Fig. 2 consists of leaves having radii of 2.5, 3.5 and 5.0 cm. Each of these leaf types has a density of 333/m . The stems are all taken to be 20 cm long and with a density of 1000/m . The leaf and stem size characteristics were obtained by the principal investigator who made on-site measurements at Beltsville.

Although Fig. 2 just shows the vertical-vertical backscattering coefficient, simple expressions were obtained for the horizontal-horizontal case as well as the cross polarized returns. These appear to be valid for frequencies below 4 GHz as long as the correct dielectric constants for the discs and rods are used. The de-Loor formula has been used for the calculation of disc and stem dielectric constants however, at lower frequency (≃ 1-2 GHz) a conductive contribution should be included.

The final step in any remote sensing problem is the inversion process. Results in this area have been obtained this year. Attention has been focused on the relationship between the backscattering coefficient σ^0_{hh} and the joint probability density of disc radii and inclination angles. The expression derived by the distorted Born approximation has been used. An examination shows that it is nonlinear in nature. The relationship has been linearized in the 1-2 GHz region where the skin depth is large. The linearized expression (a Born approximation) is a Fredholm integral equation of the first kind. Inversion problems of this type are usually ill-conditioned and must be regularized.

To simplify the inversion procedure further, it has been assumed that the radii and inclination angle densities are independent. If it is assumed that the density of one variable is known, then the other can be found through the integral equation with the knowledge of the backscattering coefficient for various angles of incidence. Such an inversion is shown in Fig.3. Here the leaves have fixed radius of 4 cm. The inclination angles density is shown by the solid line in Fig. 3. The combined joint density is then used to generate σ^0_{hh} for various angles of incidence. The calculated values of the backscattering coefficient are corrupted by noise and a Phillips-Twomey inversion algorithm is used to compute the inclination angle density at certain discrete points. The results, which are good, are shown by small circles, squares and stars in Fig. 3.

The Phillips-Twomey method has also been applied to the inversion of the complete two-dimensional density of radii and inclination angles. Here it has been assumed tht backscattering data is known at different angles of incidence and for different frequencies.

4. Significance of Results

The results just presented provide a direct relationship between the backscattering coefficient and the detailed parameters that characterize the scatterers. This means that by remote L band radar measurements at different angles of incidence and for different frequencies, such quantities as leaf inclination angle distribution and leaf area distribution can be determined. These distributions can then be directly used to estimate growth stage by knowledge of the area density of leaves and to estimate stress, due to lack of water, by knowledge of the inclination angle density.

5. Future Work

The model developed thus far has been directed toward leafy agricultural crops such as soybeans. By incorporating other scattering types of a more complex nature, other crops and forests can be modeled and inversion algorithms developed. Future scatterer development should include the modeling of non-planar leaves, branches and stalks with periodic nodes (corn).

An experiment should be planned so that the theoretical developments can be tested. The experimental approach is particularly important in the inversion algorithm development since equipment limitations can force consideration of different inversion techniques

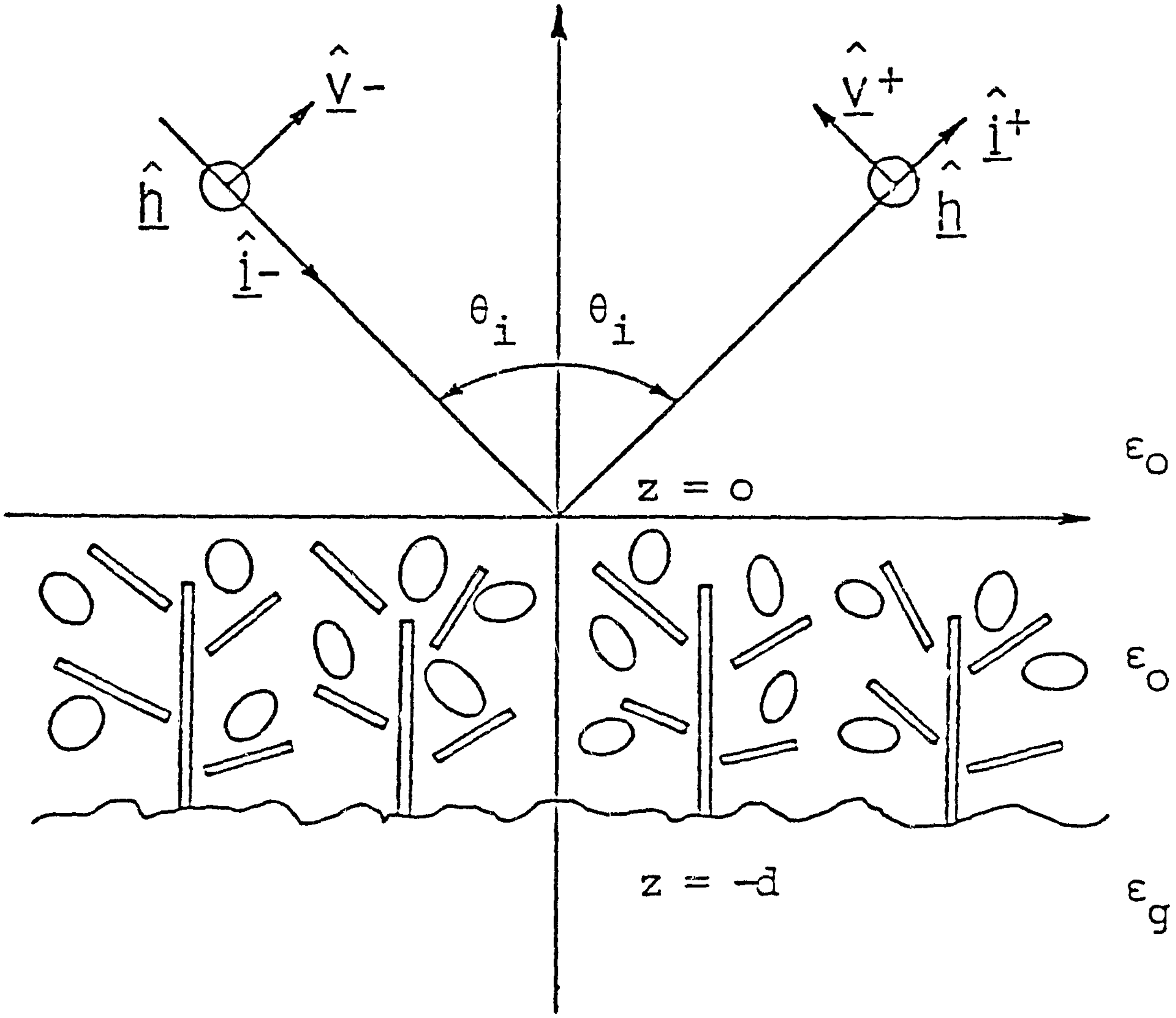

Fig. 1. Vegetation Layer Modeled by Leaves and Stems

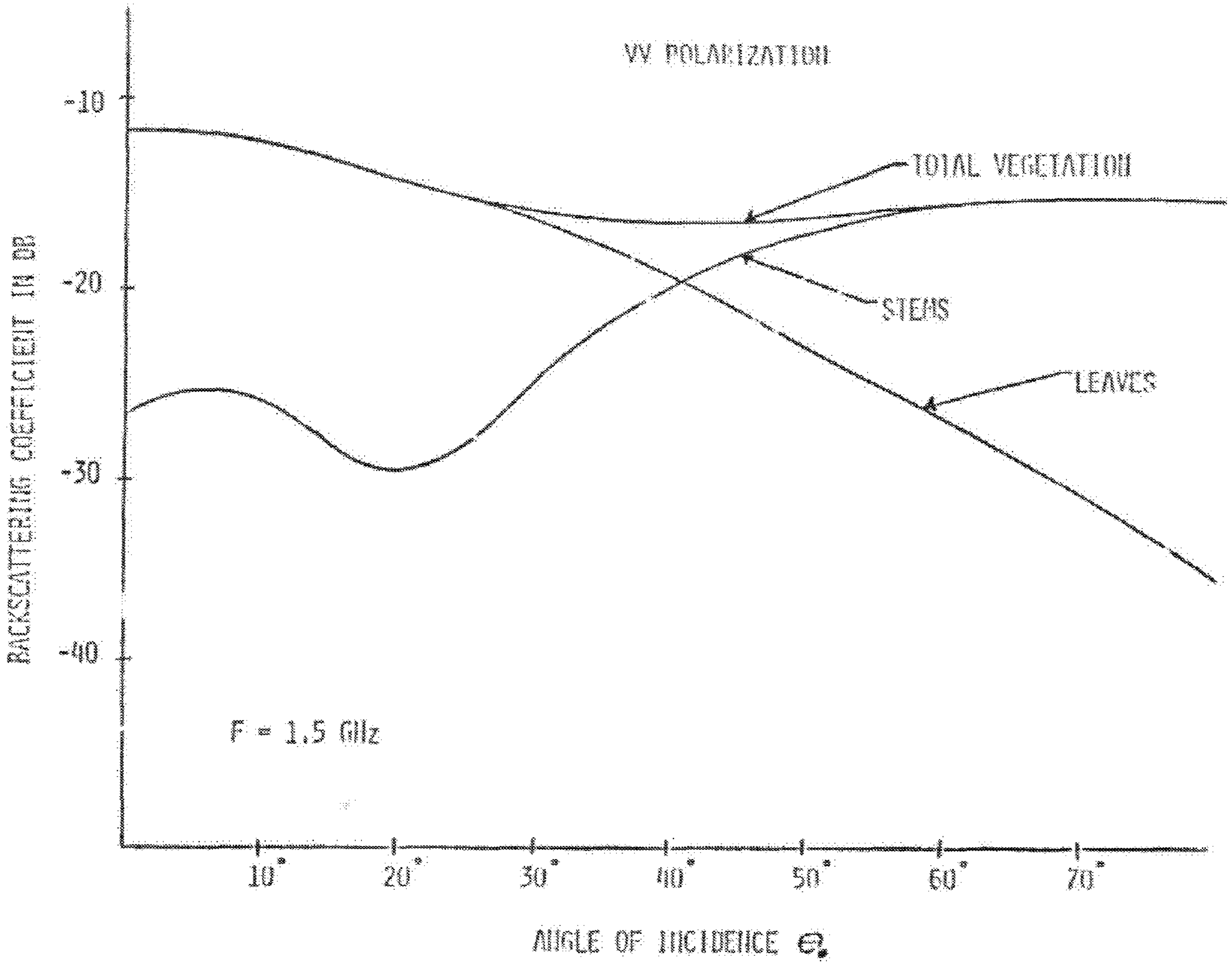

Fig. 2. Backscattering Coefficient versus Angle of Incidence for Mature Soybean Model

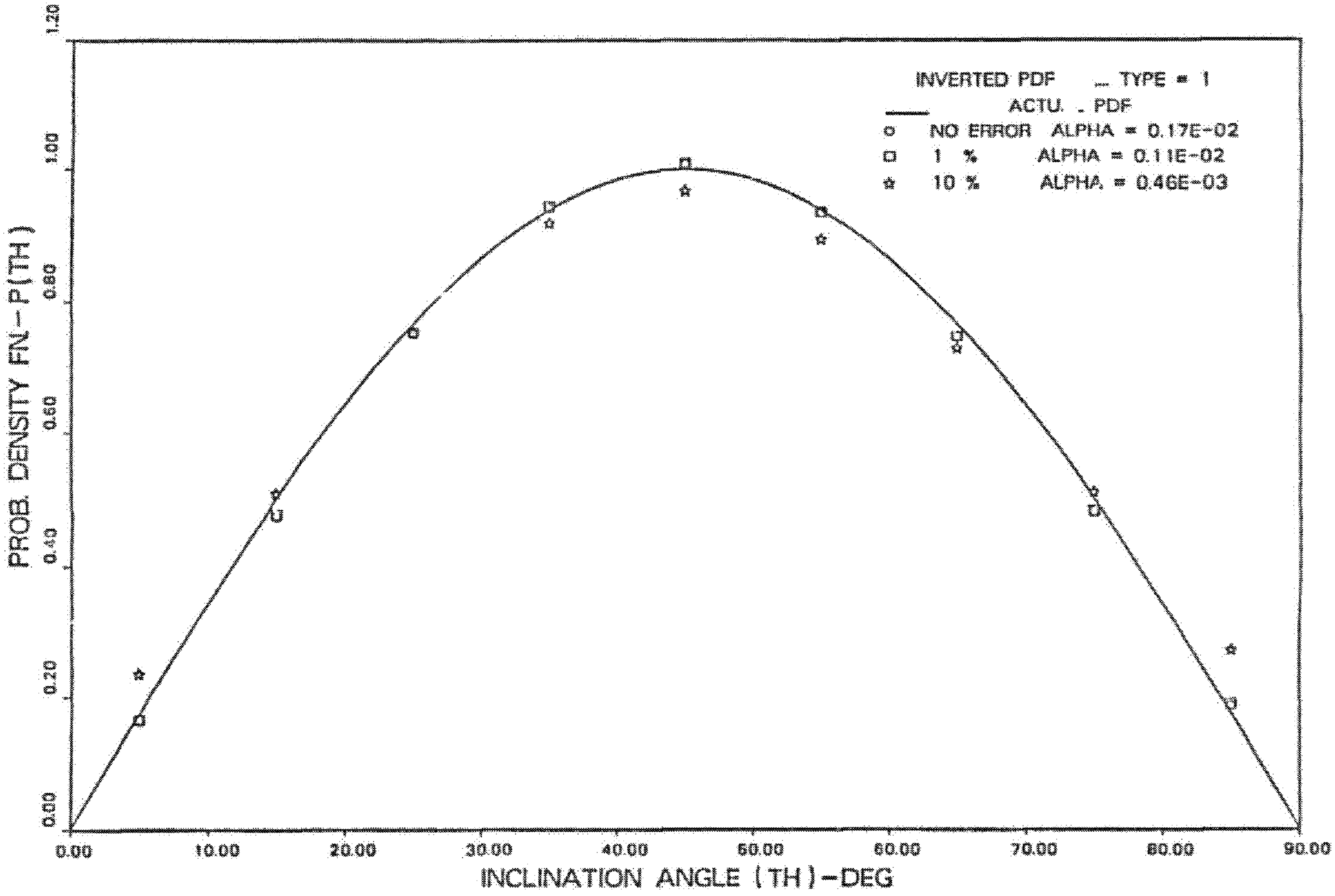

Fig. 3. Probability Density Inversion versus Leaf Inclination Angle.