New Results in Microwave Remote Sensing of Vegetation

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Abstract

For active and passive remote sensing of vegetation biomass and underlying soil moisture, it is important to have an accurate physical model and an inverse method that relies on as few parameters as possible. In this paper two new modeling results and one new inverse method will be described. The active/passive response of a quasi periodic canopy such as corn will be treated. It will take into account radiation resulting from space harmonics that is generated by the quasi period character of the vegetation. Next, the effect of incoherent double bounce backscatter in forests with an underlying rough surface will be discussed. Finally, a new inversion technique to determine forest attenuation from backscattered radar signatures will be addressed.

1. Remote Sensing from Quasi Periodic Canopy

Modeling of organized canopies such as corn has presented problems for the usual procedures such as the Distorted Born Approximation. These methods don't account for the azimuthal anisotropy of the canopy, i.e. the dependence of the sensor response on the azimuthal direction.

In an attempt to understand the effect of row structure in corn canopies on active and passive remote sensing, a simulated canopy consisting of only stalks over a flat perfectly conducting plane is examined [1]. The canopy is constructed on a rectangular lattice or grid (rows are along the vertical direction) as shown in Figure 1. To account for the quasi periodic nature of the canopy, stalks are placed at the lattice intersections and then given a random placement in a small area surrounding each intersection. An average backscattering coefficient and an average brightness temperature are computed by a Monte-Carlo procedure.

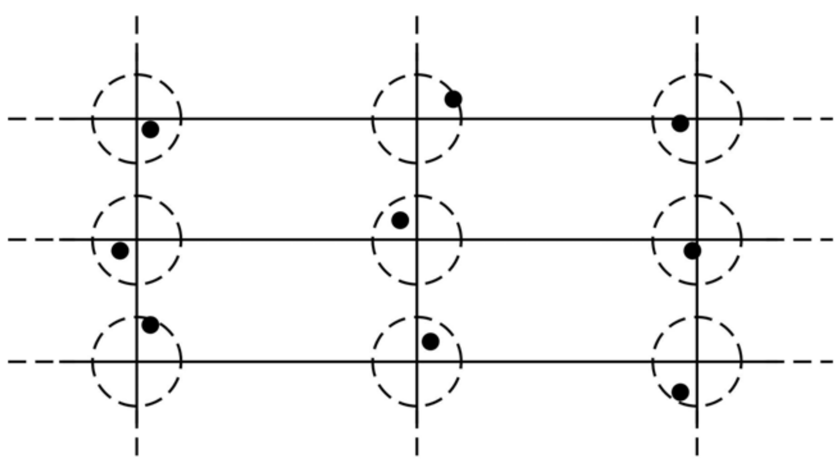

Figure 1 Quasi periodic placement of stalks

The computational aspect of the simulations for emission by the stalks involves the use of the generalized Kirchhoff's law. This law states that the emission by a body in a specific direction is equal to the absorption by that body when it is illuminated by a plane wave incident in that specific direction. A plane wave is therefore assumed to be incident on the canopy; the fields inside the stalks are expressed in a Fourier-Bessel series. During each iteration of the Monte-Carlo averaging procedure, a system of equations for the coefficients of Fourier-Bessel expansion for each stalk is solved based on a multiple scattering formulation. The internal field coefficients are, in turn, used to compute the absorption by each stalk. The sum of the absorption from all stalks yields the emission by the canopy for that realization. Similarly, the backscattering coefficient for each realization is obtained by computing and coherently adding the fields scattered by each stalk. The average canopy backscattering and the average emission are obtained by averaging the backscattering coefficient and absorption over all Monte-Carlo realizations.

Simulation results show that both the backscattering coefficient and the brightness temperature can be strongly dependent on the azimuth orientation of the radiometer with respect to the rows of the canopy. This effect is not observed when a uniform distribution of stalks is assumed; this effect is related to the existence of space harmonics. The harmonics diminish as the stalks become more random, however, quasi periodic effects are observed when considering corn.

An analytic approach has been proposed for the mean field analysis of non-overlapping organized distributions such as the quasi-periodic distribution for the two dimensional scalar problem [2] and later for the complete vector problem [1].

2. Incoherent Double Bounce Backscatter from Forests

The radar backscatter from the trunk-rough surface interaction will be computed and its importance assessed. Traditionally, radar backscatter from forests has been decomposed into three types of scattering effects: volume scatter, trunk-ground interaction and surface scatter. The volume scatter comes mostly from branches and needles (leaves). The trunk-ground interaction contribution is due to an incident wave that is *specularly* reflected from the trunk and then *specularly* reflected from the average ground surface. Finally, the surface scatter results when incident energy is directly backscattered from the rough ground surface. In mature forests with long trunks, the trunk-ground interaction term can be large since the long cylinders have a high gain. As the surface roughness increases, however, the average reflection coefficient of the surface rapidly becomes smaller. This decreases the size of the interaction contribution. In this work the importance of *non-specular* backscatter from the trunk and rough surface interaction will be examined [3].

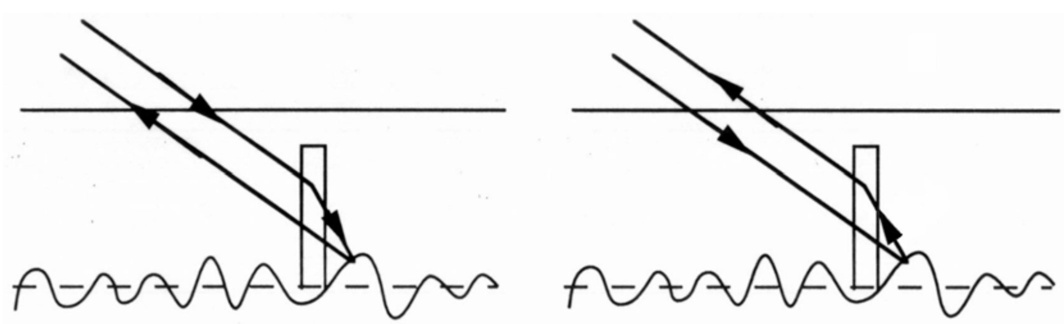

Figure 2 Incoherent Double Bounce Scattering from a Trunk and the Underlying Rough Surface

Incoherent or nonspecular scatter is the result of two scattering processes. As is shown in the diagram on the left hand side of Figure 2, the incident wave is scattered by the trunk. The scattering pattern of the trunk illuminates the rough surface. The rough surface scatters back to the radar. Since the scatter from the trunk illuminates the rough surface over a given area, each portion of the illuminated surface scatters back to the radar. As a result, all the scattering from the surface must be summed. The scattering process occurs, as well, in the reverse direction as is shown on the right hand side of Figure 2.

Normally, this nonspecular scatter is assumed to be small and, therefore can be neglected. A careful calculation shows, however, that as the specular double bounce contribution decreases due to increasing roughness, the lost power shifts to the incoherent double bounce contribution. Initially, the incoherent wave maintains its approximate specular direction but its contributing signals are out of phase due to the surface roughness. As the roughness increases, the incoherent double bounce contribution diminishes, since scattering increasingly occurs over a wider circle of directions.

The model results including the noncohernet double bounce scattering were verified by comparison with P and L band SAR data taken over an experimental research site in Howland, Maine in 1989-90. The plot consisted of mature hemlock trees (over 75%) with a rough underlying surface. Careful ground truth data was taken. Tree density and dbh (diameter at breast height) statistics were measured. Several trees were destructively sampled. Profiles of the rough surface were taken and a surface correlation function computed. Using a distorted Born model with the noncohernet double bounce term added, results showed that at P band the incoherent double bounce scatter made a substantial contribution while at L band the contribution was smaller but not negligible [3].

3. Remote Estimation of L band Canopy Attenuation

Estimation of soil moisture under a forest canopy has many inherent problems. The preferred method for making this measurement is by a radiometer because of its insensitivity to details of the forest geometry and surface roughness, however, the canopy attenuates the emission from the ground. To correct for this reduced emission, one must measure the canopy attenuation. Here a method is proposed for measuring canopy attenuation at L-band frequencies provided that the forest height is sufficient to separate components of the transient response.

Past work on scattering from a layer of vegetation over a flat ground [4] has shown that if the layer thickness (in wavelengths) is large enough, the backscatter from the canopy arrives at the receiver earlier than it arrives from the trunk-ground scattering. This separation will be used to find the canopy attenuation. The separation of canopy and trunk-ground returns has been demonstrated in a simulation of the radar signature for a 13 meter high stand of Paulownia trees located in Maryland. Canopy and ground data have been used in a distorted Born approximation to compute the radar signature for HH and VV polarizations. These simulation results at a frequency of 1.25 GHz are shown in Figure 3. There the returns are shown at several incident angles as a function of round-trip delay. The first response is the canopy return while the second peak is from the trunk-ground return. The figure clearly shows that for this canopy the two contributions are separated.

The algorithm for the estimation of canopy attenuation is based on separating the canopy and the trunk-ground return. To separate these returns, the radar signatures are gated and transformed into the frequency domain. Using these transformed returns, the frequency correlation function is generated for difference frequencies in the bandpass of the radar system [5-6]. The ratio of canopy to trunk-ground return is computed to eliminate system characteristics such as antenna gain. The ratios are calculated for an array of difference frequencies over the system bandpass. They provide a system of equations depending only on the canopy thickness, on the canopy attenuation and on a combined parameter involving the forest scattering coefficients and the ground reflectance. A least squares method is used to solve for the attenuation and the combined parameter assuming the canopy thickness is known a priori. The technique has been used with the ComRad 1.25 GHz radar over the Paulomnia tree site in Maryland to verify that the algorithm results match the simulated data.

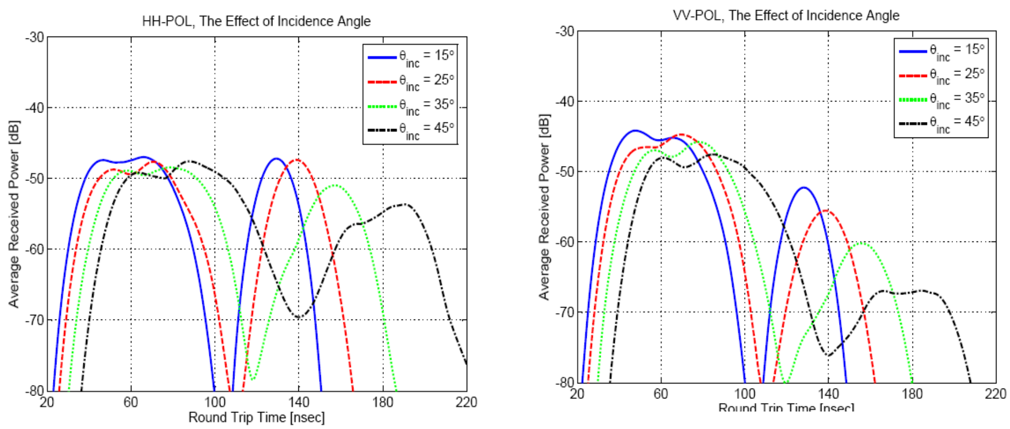

Figure 3 Separation of canopy and trunk-ground returns from a forest canopy

4. Conclusions

Three new techniques for improving the microwave modeling and inversion of radar returns from vegetation have been discussed. First, it has been shown that the quasi periodic arrangement of corn plants leads to anisotropic effects characterized by the presence of space harmonics. Second, the non specular return from the trunk-ground backscatter accounted for increased return from forest surfaces rough enough to have reduced specular trunk-ground return. Finally, an overview of a method to estimate the canopy attenuation from forests is given. Attenuation is estimated with few a priori data requirements and compared with experimental results

5. Acknowledgments

The authors would to thank Peggy O'Neill, Tom Jackson, Mike Cosh and Alicia Joseph for their help in implementing a small tree experiment that has been used to verify the algorithm developed here.

6. References

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