Modeling and Analysis of Bistatic Scattering from Forests in Support of Soil Moisture Retrieval

Amir Azemati
Ming Hsieh Department of Electrical Engineering
University of Southern California
Los Angeles, CA, USA
azemati@usc.edu

Mahta Moghaddam
Ming Hsieh Department of Electrical Engineering
University of Southern California
Los Angeles, CA, USA
mahta@usc.edu

***Abstract*—We present a bistatic forward scattering model at L-band and P-band for vegetated land covers including forests. In this model, the three major scattering categories of contribution include direct ground scattering, vegetation volume scattering, and the scattering due to the interactions between the vegetation layer and ground. All mechanisms are considered simultaneously in the bistatic scattering geometry, and treated using wave-based coherent models. The total bistatic radar scattering cross section (RCS) can be determined by superimposing the RCS for each of the stated contributions. This paper includes an overview of the model, cross section simulations from a forest, and a sensitivity analysis with respect to soil moisture for specular and backscatter observation directions.**

I. Introduction

Soil moisture is a key parameter in controlling the partitioning of water between the atmosphere and the land surface, improving our knowledge of the global water and energy cycle. Soil moisture impacts many areas of human interest such as drought, flooding, and weather. Therefore, development of reliable soil moisture retrieval techniques is a subject of great interest. Most of today's airborne and spaceborne soil moisture missions use monostatic radars, which only measure the scattered wave in the backscatter direction. However, a more general approach is to extend the observation scenario to utilize bistatic multi angle measurements. Taking advantage of bistatic or multi-static observations allows the opportunity to take measurements through passive receiver systems, which are simpler and less expensive than conventional fixed incidence angle monostatic radar observations. Moreover, it is possible to measure the scattered field in various directions, which potentially leads to more accurate soil moisture retrievals. As an illustration of multi-static observation techniques, the L-band GNSS/GPS reflected signals can be utilized in order to retrieve soil moisture over different types of land covers [1]. Although several recent papers have addressed bistatic soil moisture retrieval methods over bare or low-vegetated surfaces with acceptable results, it may be possible to estimate soil moisture over forested areas and reach higher soil moisture estimation accuracy by applying proper bistatic scattering models. In this paper, we propose a coherent bistatic scattering model, which is built upon the backscatter-only model [2], [3], and it is applicable for various types of vegetated terrain. As depicted in Fig. 1, this model has the same three major categories of contributions as the monostatic case: (a) direct ground scattering (G) (b) vegetation volume scattering (B) and (c) scattering due to interactions between ground and the over laying vegetation layers (BG & TG). However, each mechanism has to be generalized and adapted to all scattering angles instead of just the backscatter case.

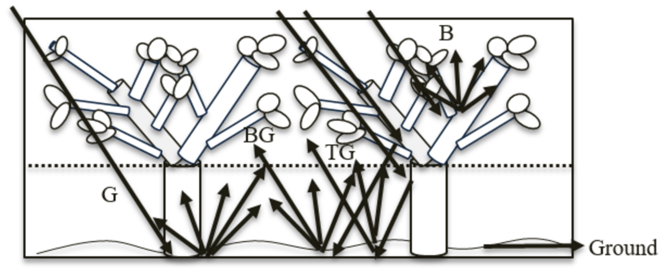

Fig. 1. A single species coherent bistatic scattering geometry with three major scattering mechanisms (G, (BG & TG), and B).

II. Coherent Bistatic Scattering model for vegetated land cover

A. Direct ground bistatic scattering

In the Analysis of bistatic scattering from ground layer, forest floor is modeled as the dielectric random rough surface and the Small Perturbation Method (SPM) is used up to second order for the direct ground contribution [2]. Furthermore, SPM is valid for the slightly rough surface with the condition k.h < 0.3, which for L-band (1.26 GHz) means h < 1.5 cm where k and h are wavenumber and root mean square profile height deviations from the mean surface, respectively.

B. Vegetation Volume bistatic scattering

The crown layer of the forest is treated as vertically (trunks) and randomly oriented (branches , leaves) dielectric cylinders over the rough ground. The scattering matrix of a finite cylinder with length L is utilized to describe the scattering from vertical cylinders (e.g., [3]):

$$S_{pq}(\theta_i, \varphi_i, \theta_s, \varphi_s) = \frac{ikl \sin\theta_s}{\pi \sin\theta_i} \, \frac{\sin\, kl(\cos\theta_i+\cos\theta_s)/2}{kl(\cos\theta_i+\cos\theta_s)/2} \, . A_{pq}(\theta_i, \varphi_s - \varphi_i) \quad (1)$$

where $A_{pq}(\theta_i, \varphi_s - \varphi_i)$,and $S_{pq}(\theta_i, \varphi_i, \theta_s, \varphi_s)$, are scattering matrix for an infinite and finite cylinder, and θ_i , θ_s , φ_i and φ_s

are denoted as the incidence, scattering, and azimuth angles, respectively. Fig. 2 shows the parameters used to define the scattering geometry. Scattering matrix for a randomly oriented

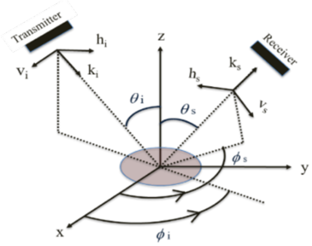

Fig. 2. The forward scatter alignment (FSA) convention is used for the bistatic scattering coordinate system of the proposed model. Thus, for backscattering direction $\theta_s = \theta_i$, $\varphi_s = \varphi_i + \pi$ and for Specular direction $\theta_s = \theta_i$, $\varphi_s = \varphi_i$.

cylinder $S(\theta_i , \varphi_i , \theta_s , \varphi_s , \delta , \Psi)$ is determined by using Eqn. (1) and a transformation matrix, where Ψ is the tilting angle within the incidence plane and δ is the angle of tilting from the direction normal to the incidence plane. Moreover, based on empirical field observations, the probability density function (pdf) of randomly oriented branches often has a $sin^2\alpha$ dependence, where α is the orientation angle from the vertical line [3]. This pdf is used to calculate transmission and scattering stokes matrices of vegetation layer.

C. Vegation ground double bounce bistatic scattering

The trunk-ground and branch-ground bistatic scattering cross section is calculated by using coherent scattering matrices of pertinent cylindrical distributions and the random rough ground surface. The new bistatic scattering matrix is represented as:

$$S = \begin{bmatrix} 2g_{hh}s_{hh} & (r_h' + r_v')s_{hv} \\ (r_h' + r_v')s_{vh} & 2g_{vv}s_{vv} \end{bmatrix} \tag{2}$$

$$r_h' = r_h \exp(-2h^2k^2cos^2\theta_i), r_v' = r_v \exp(-2h^2k^2cos^2\theta_i) \tag{3}$$

Where (r_h' , r_v') and (g_{hh} , g_{vv}) are modified Fresnel reflection coefficients and SPM co-pol bistatic scattering elements, respectively. In the special case of backscatter scattering the co-pol elements are: $g_{hh} = g_{hh} + r_h'$ and $g_{vv} = g_{vv} + r_v'$, which results from specular scattering in the second bounce (second scattering path) of TG or BG contribution.

III. Forward model Simulation Results

We present numerical results for the coherent bistatic scattering model from a forest with input parameters shown in Table I. The co-pol bistatic scattering cross section results at L and P band are depicted in Fig. 3. Moreover, Fig. 4 illustrates the total RCS sensitivity analysis with respect to soil moisture content in the backscattering and specular directions. Similar to monostatic models, for each contribution the attenuation within the vegetation layer is derived by using the transmission matrix within that layer. Finally, the different scattering mechanisms are combined by adding the three scattering contributions [2], [3].

TABLE I

EXAMPLE OF INPUT PARAMETERS

Frequency(GHz)	1.26 (L-band)	Small branch length (m)	1.21
Frequency(MHz)	480 (P-band)	Small branch radius (m)	0.01
Incidence angle(deg)	40	Small branch density	0.3
Dielectric constant	(15.0,3.0)	Small branch orientation (deg)	70
Height (m)	4.0	Leaf diel	(32,4)
Radius (m)	0.06	Leaf density	0.03
Canopy height (m)	8.00	Leaf radius (m)	0.0015
Large branch diel	(32,4)	Leaf density	700
Large branch length (m)	1.58	Trunk diel	(36,2)
Large branch radius (m)	0.015	Trunk length (m)	7.33
Large branch density	0.3	Trunk radius (m)	0.0650
Large branch orientation (deg)	80	Trunk density	0.3
Small branch diel	(32,4)	Soil diel	(29.89,2.23)
Soil height (m)	0.024		

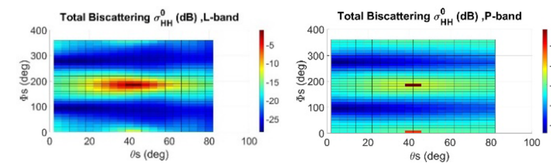

Fig. 3. Co-polarization total bistatic scattering RCS from forest at L-band and P-band.

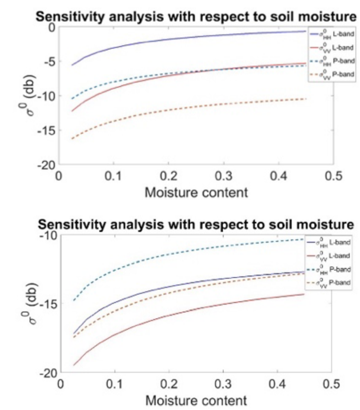

Fig. 4. RCS sensitivity analysis with respect to soil moisture in backscattering (top) and specular (bottom) directions.

IV. Conclusion

The proposed model advances the state of the art in coherent radar scattering models from monostatic to fully bistatic case. This development gives the opportunity to benefit from the measurements of scattered fields from vegetated landscapes in arbitrary directions, e.g., in GNSS reflectometry applications. Furthermore, since there is more sensitivity to soil moisture in the specular direction than the backscatter direction, much better soil moisture retrieval results are expected as well as retrievals over a larger range of soil moisture values.

References

[1] Rodriguez-Alvarez, Nereida, et al. "Land geophysical parameters retrieval using the interference pattern GNSS-R technique." *IEEE Transactions on Geoscience and Remote Sensing* 49.1 (2011): 71-84.

[2] Burgin, Mariko, et al. "A generalized radar backscattering model based on wave theory for multilayer multispecies vegetation." IEEE Transactions on Geoscience and Remote Sensing 49.12 (2011): 4832-4845..

[3] Durden, Stephen L., Jakob J. Van Zyl, and Howard A. Zebker. "Modeling and observation of the radar polarization signature of forested areas." *IEEE Transactions on Geoscience and Remote Sensing* 27.3 (1989): 290-301.