SIMULATION STUDIES OF THE EFFECT OF FOREST SPATIAL STRUCTURE ON InSAR MEASUREMENTS

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ABSTRACT:

The height of scattering phase center retrieved from InSAR data is considered to be correlated with tree height and the spatial structure of the forest stand. Though some researchers have used simple backscattering models to estimate tree height from the height of scattering center, the effect of forest spatial structure on InSAR data is not well understood yet. A three-dimensional coherent radar backscattering model for forest canopies based on realistic three-dimensional scenes was used to investigate the effect. A fractal tree model (L-system) was used to simulate individual 3-D tree structure of different ages or heights. Trees were positioned in a stand in specific patterns resulting in a 3-D medium of discrete scatterers. The radar coherent backscatter model used the 3-D forest scene as input and simulated the coherent radar backscattering signature. Interferometric SAR images of 3D scenes were simulated and heights of scattering phase centers were estimated from the simulated InSAR data. The effects of tree height, and the spatial distribution patterns of trees on the scattering phase center were analyzed and discussed.

1. INTRODUCTION

The 3D radar backscatter model developed previously at UMD/GSFC (Sun and Ranson, 1995) was an incoherence model, in which backscattering components were incoherently summed together to get the total backscattering power from a pixel or target. This model was modified into a full coherent model by considering the positions of all scatterers within a tree crown (leaves and branches) and coherently adding the backscattering components together. The phase of the scattering component was determined by its position relative to a reference point. Different from other coherent models (Lin and Sarabandi, 1999; Thirion et al., 2004), the model used here has both the tree crown components (branches and leaves) and position of each tree in a stand explicitly specified. The explicit 3D physical model of the forest stands was generated using L-system. The scattering components considered in the model are the direct backscattering from a scatterer, the double-bounce between the scatterer and ground surface, and the ground-scatterer-ground scattering. The model was used in this study for margin difference between two antennas) is different for different scattering components, so does the phase center height of these components. The position of the scattering phase center of a pixel is a result of the coherent summation of these components. When the forest structure changes, the relative strengths of these scattering components change leading to the change of the scattering center.

2. COHERENT BACKSCATTER MODEL

The coherent radar backscattering model takes the 3-D forest scene as input and simulates the coherent radar backscattering signature. The model is a discrete scatterer model. Dielectric cylinders with finite length and dielectric thin disks are used to represent the trunks, branches and leaves. The radar scattering signal from trunks and branches is calculated using the infinite cylinder approximation, and that of the leaves employed the generalized Rayleigh-Gans (GRG) approximation (Karam et al., 1988). Furthermore, the attenuation of the microwave signal by the forest canopy, i.e. transmissivity matrix of the forest canopy, is estimated using Foldy's approximation. The tree crown is divided into multiple cells. Every cell is internally homogeneous. Using these approximations, the scattering matrix of every scatter is calculated, and added together coherently. In this study, only the first order coherent scattering was taken into consideration, and the higher order scattering and the near-field coupling between adjacent scatterers were omitted.

Within a forest stand or a radar pixel there are N scatterers. The ground plane can be considered as a half-space dielectric medium with a slightly rough surface. The total scattering field from a pixel can be evaluated from

$$E^s = \frac{e^{ikr}}{r}\left(\sum_r^N e^{i\phi_n} F_n\right)E^i \quad (1)$$

where φ_n is the phase compensation term which is the phase shift of the nth scatterers from local to global coordinate system. φ_n is given by $(\vec{k}_i - \vec{k}_s)\vec{r}_n$, where $\vec{k}_i$ and $\vec{k}_s$ are the direction of incidence and scattering wave. $\vec{r}_n$ is the coordinate vector of the nth scatterers in global coordinate system. Both E^s (scattering field) and E^i (incidence field) are vectors and can be denoted as $\begin{bmatrix} E_{hs} \\ E_{vs} \end{bmatrix}$ and $\begin{bmatrix} E_{hi} \\ E_{vi} \end{bmatrix}$, respectively. F_n is the complex scattering matrix of the nth scatterer above a dielectric plane:

$$F(\theta_i,\phi_i;\theta_s,\phi_s) = \begin{bmatrix} f_{hh}(\theta_i,\phi_i;\theta_s,\phi_s) & f_{hv}(\theta_i,\phi_i;\theta_s,\phi_s) \\ f_{vh}(\theta_i,\phi_i;\theta_s,\phi_s) & f_{vv}(\theta_i,\phi_i;\theta_s,\phi_s) \end{bmatrix} \quad (2)$$

where $f_{\alpha\beta}(\theta_i,\phi_i;\theta_s,\phi_s)$ is the scattering amplitude from direction (θ_i,ϕ_i) in α polarization to direction (θ_s,ϕ_s) in β polarization.

F_n is mainly made up of four components:

1) $F_n{}^t$ denotes direct scattering matrix from scatterers;

2) $F_n{}^{gt}$ denotes scattering matrix from the scatterer specular reflected from ground;

3) $F_n{}^{tg}$ denotes scattering matrix from specular reflection of the ground by the scatterer;

4) $F_n{}^{gtg}$ denotes ground-scatterer-ground scattering matrix.

The bistatic scattering coefficient in a pixel of area A is

$$\sigma_{\alpha\beta}(\theta_i,\phi_i;\theta_s,\phi_s) = \frac{4\pi}{A}\left|f_{\alpha\beta}(\theta_i,\phi_i;\theta_s,\phi_s)\right|^2 \quad (3)$$

3. SIMULATION OF 3D FOREST STAND STRUCTURE

Field measurements or a forest growth model provide information of forest species composition and tree sizes in certain growth phases. A fractal tree model (L-system) was used to simulate individual 3-D tree structure of different ages or heights. Trees were positioned in a stand in certain patterns resulting in a 3-D medium of discrete scatterers. The radar coherent backscatter model takes the 3-D forest scene as input and simulates the coherent radar backscattering signature. Fig. 1-3 show the 3D structure of forest stands with different spatial distribution patterns of trees. These forest stands consists of 36 birch trees. Fig. 1 is a clumped distribution of trees (5 clump centers). Fig. 2 shows the random distribution of trees. Fig. 3. shows a regular 6 by 6 matrix of trees.

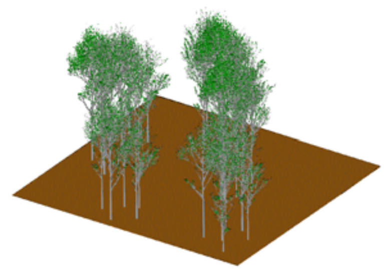

Fig.1. Clump distribution

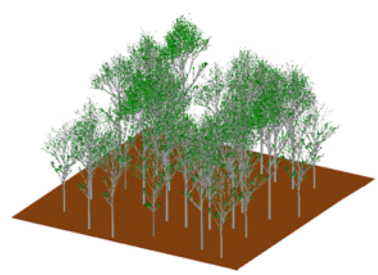

Fig.2. Random distribution

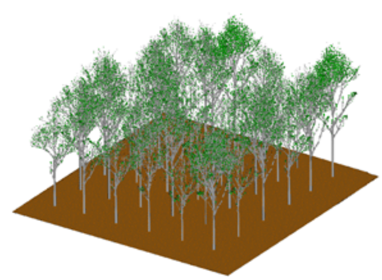

Fig.3. Regular distribution

4. InSAR SIMULATION

Two coherent radar images were simulated using coherent radar scattering model. The height of the scattering phase center was estimated using the following equations (Zebker et al, 1992):

$$Z(y) = h - r\cos(\theta)$$

$$\cos\theta = \cos\alpha\cos(\alpha-\theta) + \sin\alpha\sin(\alpha-\theta)$$

$$\sin(\alpha-\theta) = \frac{(r+\delta)^2 - r^2 - B^2}{2 \cdot r \cdot B} \approx \frac{\delta}{B}$$

$$\delta = \frac{\lambda\Delta\phi}{2\pi}$$

where $\Delta\phi = \angle(E_1^* E_2)$ represents the phase difference between two simulated radar signals E1 and E2. Fig. 4 shows the height of phase center for various scattering components. The phase center of a pixel is the combined effect of the components included in the pixel. The JPL TOPSAR configuration (platform height 8500m, baseline 2.6m, α=62.77°) (Zebker et al., 1992) was used in the simulation of the InSAR images.

5. RESULTS

Dependence of phase center height on stand structure

The InSAR signature from entire stands shown in Figs. 1-3 were simulated and the height of the phase center were calculated from the simulated data. The tree height changes from 6m to 15m. Table 1 shows L-HH and L-VV InSAR results, respectively.

Table 1. Height of phase center for different stands with 36 trees from simulated LVV InSAR (bottom) and LHH InSAR (top) data. Clumped – trees were clumped into 5 clusters, 6X6 – regularly planted, and random – randomly planted.

LHH	Tree Height (m)		
Stand Type	6	10	15
Clump	3.79	6.54	9.53
6*6	4.21	7.20	10.39
Random	4.72	7.81	10.76
LVV	Tree Height (m)		
Stand Type	6	10	15
Clump	3.79	6.54	9.53
6*6	4.21	7.20	10.39
Random	4.72	7.81	10.76

The height of phase center of the direct backscattering from all branches and leaves equals the height of the scatterer itself. The phase center of the total direct backscattering should be in a place within the tree crown. Since the backscattering from the ground surface was not included in this simulation, and the ground-scatterer-ground scattering was very week, the double-bounce is a major factor to lower the phase center of a forest stand. Table 2 shows that when the tree distribution is clumped, the double-bounce scattering is strong, so the phase center in this case is lower than other distributions.

Table 2. Percentage of backscattering power (L-HH) from double-bounce scattering for three different tree distribution patterns.

	Clump	6*6	Random
Double-bounce	59%	24%	32%

Simulation of high-resolution images

Fig. 4 shows a L-HH backscattering coefficient image of the stand shown in Fig. 2. Rader incidence angle is 45°. Image pixel size is 0.5m. Fig. 5 is the corresponding power image of Fig. 4.

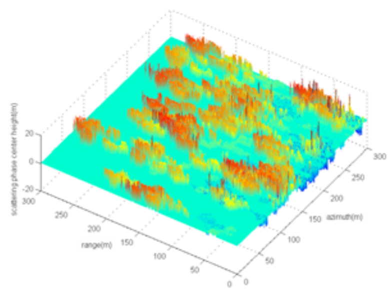

Fig. 4. The height of scattering phase of a simulated birch forest stand. L-band HH

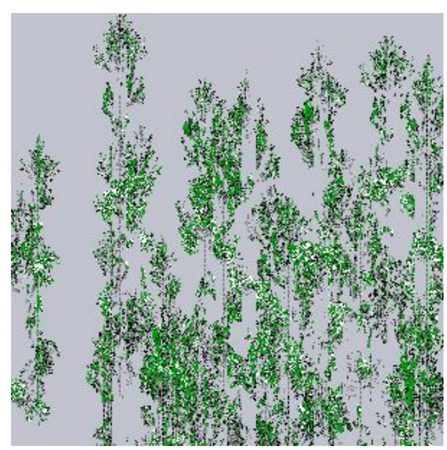

Fig. 5 is the correspondent power image of Fig. 4

6. CONCLUSION

The simulation results have shown that the location of backscattering phase center from a forest stand is influenced by the spatial structure. We will verify the results using field measured forest structure and InSAR data in our future work.

7. ACKNOWLEDGEMENT

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