Comparison between Predicted Performances of Bistatic and Monostatic Radar in Vegetation Monitoring

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Radar response saturation sets limits in the use of active systems for monitoring forest biomass on a global scale. The possibility of widening the range of observable biomass is analyzed by considering a bistatic radar configuration.

INTRODUCTION

Synthetic Aperture Radar systems are being evaluated in view of their use to monitor the Earth's environment on a global basis. A number of spaceborne and airborne *SAR* experiments have been carried out to investigate the sensitivity of radar backscattering to various parameters of vegetation, both of agricultural type and of forests (Zebker *et al.*, 1991; Churchill and Attema, 1992) and several studies have shown a significant correlation between the backscattering coefficients at different polarizations and the biomass of forest stands (Hussin *et al.*, 1991; Dobson *et al.*, 1992). However, even at *P*-band, saturation is already observed for biomass values that are relatively low with respect to the range of values estimated for the world's forests (Imhoff, 1993), so that the usefulness of *SAR* to measure forest biomass on a global scale seems limited. Attempts to push the saturation point towards higher values can be made by lowering the radar frequency or the incidence angle.

In this paper the possibility of substantially widening the range of forest biomass values over which significant regression exists with radar scattering is analyzed by considering a bistatic radar configuration (Dunsmore, 1993).

A simulation analysis has been carried out by using the microwave scattering model of vegetated terrain developed at Tor Vergata University (Ferrazzoli *et al.*, 1991). This model considers the vegetation-terrain system as a canopy of discrete lossy scatterers overlying a homogeneous lossy half-space with rough interface. The electromagnetic properties of the scatterers, which model the plant constituents, are described by their absorption cross sections and bistatic scattering cross sections. Simple geometries, such as cylinders (which represent trunks, branches and twigs) and disks (which represent deciduous leaves) are considered. The electromagnetic properties of the soil are described by its bistatic scattering coefficient. To compute this latter, the Small Perturbation approximation is used at lower frequencies (e.g., at *L*-band), while the Geometrical Optics approximation applies for *X*-band and beyond. The cross sections of cylinders are obtained through the Infinite Length approximation. Disks are treated on the basis of the Rayleigh-Gans approximation at the lower frequencies, while the Physical Optics formalism is used at *X*-band and beyond. The dimensions of the scatterers are chosen according to the ones of the real plant elements, and their permittivity is evaluated from the moisture content.

In the present simulation the trees are subdivided into several horizontal layers containing scatterers of different shape and dimensions. The top layer is a canopy of randomly oriented disks, while the lower layers contain cylinders with dimensions increasing from top to bottom. Orientation is random in the upper layers (twigs), then suitable angular distributions are assumed for the branches and the prevailingly vertical trunks (Ferrazzoli and Guerriero, 1994). The scattering from the vegetation-terrain system is obtained by combining the scattering from the layers containing the various vegetation elements through the Matrix Doubling algorithm.

BISTATIC VS. MONOSTATIC RESPONSE

The results reported here refer to the simulated *L*-band radar response of a deciduous forest with varying woody volume (up to 900 m^3/ha). The parameters of the trees have been chosen according to the ground data collected on the Flevoland Dutch site on occasion of the MAESTRO-1 experiment (Droesen *et al.*, 1990). The total scattering is decomposed into the components contributed by the various relevant mechanisms, to gain a deeper insight in the electromagnetic behavior of the forest both in a monostatic and in a specular bistatic radar configuration.

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Fig. 1 shows the computed linearly polarized co- and cross-polar backscattering coefficients σ^0_{pq} of the forest as a function of the woody volume for a conventional monostatic radar configuration with an incidence angle $\theta = 45°$.

In this case the cross-polar response exhibits the highest dynamics, while the co-polar σ^0's vary less with the woody volume and, moreover, beyond about 200 m^3/ha present an ambiguous behavior, essentially due to the intervening quenching of the global contribution from the forest floor by the increasing density of the woody canopy.

Measurements on the same forest by a bistatic radar have been simulated in the case of an incidence angle equal to the one in the monostatic case ($\theta_i = 45°$), while the receiver has been assumed in the specular direction ($\theta_s = 45°$). This geometry allows the receiving section of the system to receive both the specular coherent reflected and the incoherent scattered components of the radar wave. The rather different behavior (Fig. 2) of the bistatic radar from the monostatic one is essentially due to the presence of these wave components.

Co-polar powers now behave monotonically and exhibit the larger dynamics. Their decreasing trend with increasing forest biomass derives from the the decrease of both the coherent and the incoherent components in the specular direction, which is not counterbalanced by the increase of the scattering from the vegetation. The curves show a rather mild saturation, which allows the bistatic system to maintain an appreciable sensitivity to forest woody biomass even at relatively high values. It should be noted that the absence of cross-polar coherent reflection reduces the usefulness of the cross-polar measurements, as opposed to the monostatic case.

CONCLUSIONS

The performance of an *L*-band bistatic radar in a specular configuration has been simulated to analyze its theoretical capability in monitoring forest biomass over an extended range. Both the specular coherent reflection and incoherent scattering by the forest floor act to enhance the potential of the bistatic configuration. Similar theoretical results have also been obtained at higher frequencies in case of agricultural fields. Calibrated experimental data are now needed to assess the actual performance of bistatic vs. monostatic radars in remote sensing.

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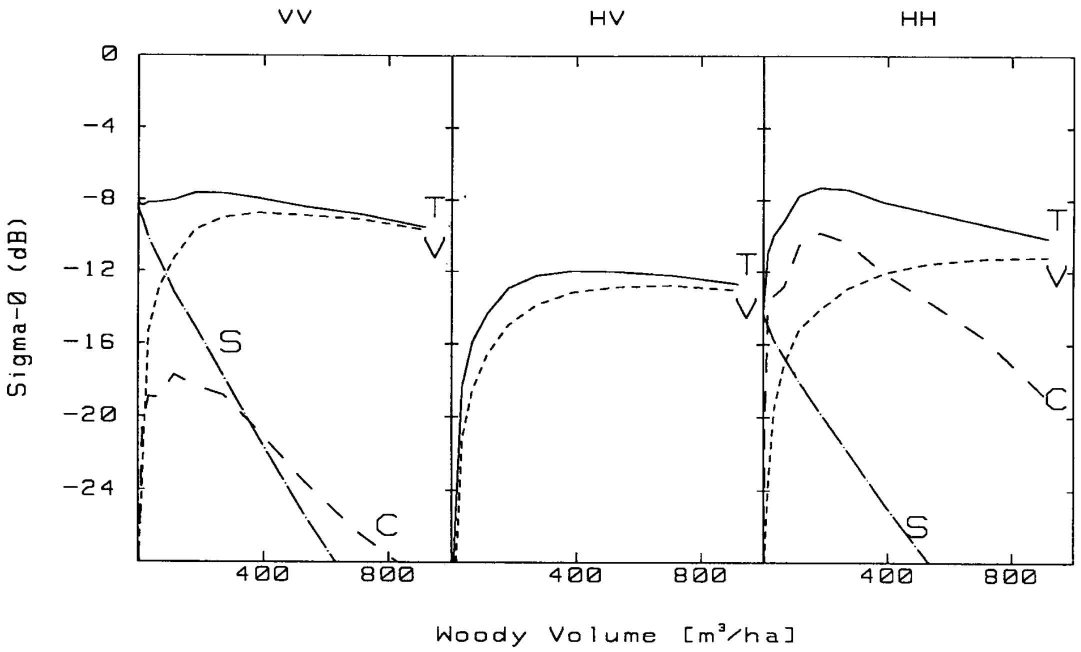

Figure 1: Linearly polarized co-polar (σ^0_{hh} and σ^0_{vv}) and cross-polar (σ^0_{hv}) backscattering coefficients for a monostatic radar as functions of the woody volume of a deciduous forest at 1.2 GHz, at an incidence angle $\theta = 45°$. Curves show both the total scattering (T) and the contributions by the principal scattering mechanisms: V, contribution by leaves, branches and twigs; S, from soil; C, from trunk-soil interaction (corner effect).

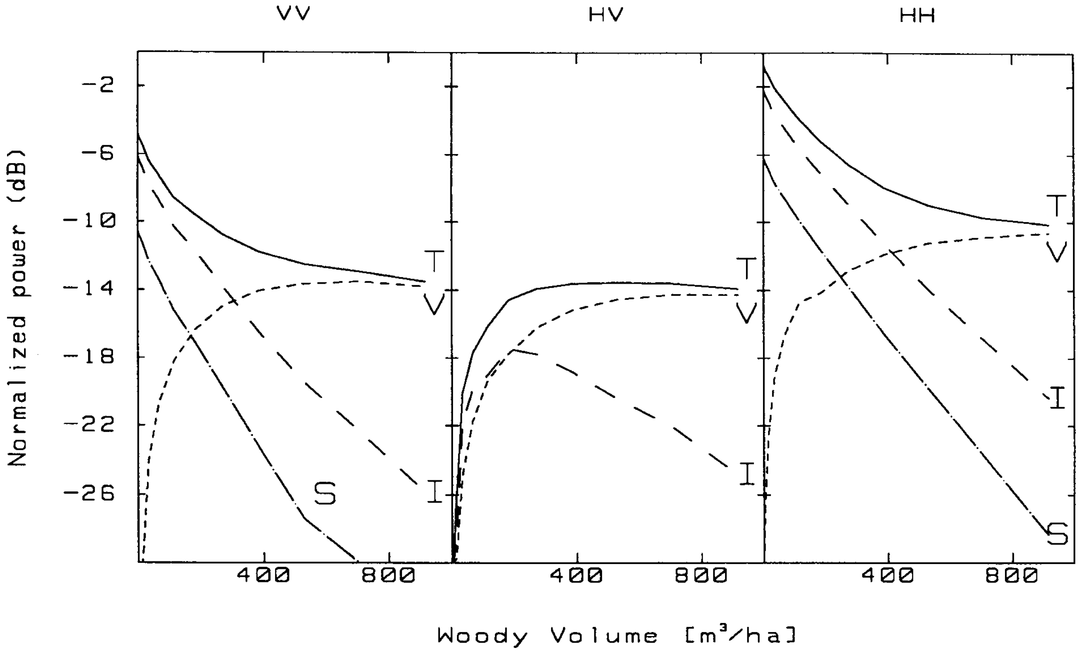

Figure 2: Co-polar and cross-polar normalized powers received by a bistatic radar in a specular configuration ($\theta_i = \theta_s = 45°$) as functions of the woody volume of a deciduous forest at 1.2 GHz. Curves show both total received power (T) and different contributions (V, contribution by leaves, branches and twigs; I, incoherent scattering by soil and soil-vegetation interaction; S, coherent reflection from soil).