Estimation of Canopy Attenuation at L-band by a Time Domain Analysis of Radar Backscatter Response

M. Kurum¹, R. H. Lang¹ and P. E. O’Neill²

¹George Washington University
Washington, DC 20052 USA
kurum@gwu.edu, lang@gwu.edu

²NASA Goddard Space Flight Center
Greenbelt, Maryland 20771 USA
peggy.e.oneill@nasa.gov

Abstract

A new technique for determining the canopy attenuation that uses the measured stepped frequency radar backscatter response is proposed. It makes use of the details found in a transient solution where the canopy (volume scattering) and the tree-ground (double interaction) effects appear at different times. A coherent scattering model, based on a Monte Carlo simulation, is developed to calculate transient response from distributed scatterers over a flat surface such as a forested terrain. The influence that the different backscattering contributions have on the expected time-domain response of a forest stand is then described through numerical simulations. The proposed technique is based on separating the backscattering sources within a forest canopy in the time response. The frequency correlation functions (FCF) of the separated contributions are generated for difference frequencies in the bandpass of the radar system. The ratios of volume scattering to double interaction return for an array of difference frequencies over the system bandpass are computed to eliminate system characteristics such as antenna gain. It is shown that these ratios provide a system of equations depending only on the canopy thickness, the canopy attenuation and 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 L band data collected over deciduous trees to verify that the algorithm results match the simulated data.

1. Introduction

Soil moisture is a basic parameter that integrates much of the land surface hydrology and provides a basic link between the earth’s surface and the atmosphere through its effect on surface energy and moisture fluxes. Soil moisture is thus a key variable in the hydrologic cycle. To understand the role of land surface hydrology in regional and global processes, the distribution of soil moisture under a variety of surface conditions must be mapped accurately. Microwave remote sensing offers great potential for accurate soil moisture estimation on a global basis because the primary physical property that affects the microwave measurement is directly dependent on the amount of water present in the soil. This potential, coupled with advances in microwave sensor technology, has given rise to new satellite missions with L-band passive microwave radiometers, such as SMOS, Aquarius, and SMAP. It is expected that these missions will significantly increase the capability of monitoring Earth’s soil moisture globally.

Although L-band is preferable for soil moisture sensing due to its great sensitivity to the moisture content of the first 5 cm of soil, the pixel size expected from L-band spaceborne radiometers is on the order of several tens of kilometers. As a result, one expects that the surface within a large radiometric footprint will be a mixture of different surface and vegetation types. Forests for example will fill many pixels partially or completely in the future spaceborne radiometric images of emitted microwave radiation since forests cover a considerable portion of the Earth’s land surface. An important question is whether, in light of this coarse limit on resolution, the spaceborne instruments can make meaningful measurements of average soil moisture over landscape partially or completely covered with forest canopy. The forest canopy masks the soil moisture signal and reduces the radiometric sensitivity to soil moisture [1]. Therefore, to
correct vegetation effects for accurate soil moisture retrievals through forest canopies, proper characterization of scattering and attenuation in tree canopies is needed. A new technique for determining the canopy attenuation that uses the measured stepped frequency radar backscatter response is proposed. The proposed technique is based on separating the backscattering sources within a forest canopy in the time response. In order to validate the proposed technique and to understand its sensitivity to various physical conditions and incidence angles, NASA’s ComRAD (for Combined Radar/Radiometer) active/passive microwave truck instrument system has been used [2]. Data are acquired over deciduous Paulownia trees under the leaf-drop and the full-canopy conditions at ComRAD angles (15°, 25°, 35°, and 45°).

2. Time Domain Analysis of Radar Backscatter Response

A coherent scattering model, based on a Monte Carlo simulation, is developed to calculate transient response from distributed scatterers over a flat surface such as a forested terrain. Using the single scattering approximation, the total backscattered field in the frequency domain is obtained from the coherent sum of individual scattering from each discrete scatterers embedded in the mean medium and illuminated by an aperture antenna with an arbitrary radiation pattern. The effect of attenuation and phase change of the coherent wave, propagating in the random medium, is taken into account by calculating the mean field within the medium [3]. This frequency domain solution is then calculated at $N_f$ discrete frequency points in the operating bandwidth of the radar. The formulation accounts for the spread of the beam within the medium and for the variation of the attenuation and the phase with the propagation direction. The time domain response is produced by performing an inverse discrete Fourier transform (IDFT) on this backscattered field. This follows closely the data acquisition and signal processing technique employed by network analyzer-based radars (stepped frequency measurements). An average time domain response is obtained by a sufficient number of realizations of trees through Monte Carlo simulations. From an intuitive and data analysis point of view, it is desirable to have time domain information. With the time domain information, one acquires the ability to locate spatially the individual backscattering sources within the forest canopy [4, 5, and 6]. For example, the volume scattering and the double interaction contributions appear at different times in the transient solution. This time difference results from the fact that these two scattering mechanisms have different path length.

Good agreement is observed between the average simulated and measured backscatter transient responses of Paulownia trees under leaf-drop (November 24th) and the full-canopy (October 22nd) conditions at 45° for $HH$ and $VV$ polarizations. The comparison between the measured and the simulated transient responses is given in Fig.1. This comparison indicates that it is possible to distinguish the characteristics of the forested terrain from L-band stepped frequency signals as a function of depth by utilizing different arrival times of the components of the transient response. The volume scattering and double interaction contributions of the measured data can be separated successfully with the use of a temporal bandpass filter in time. Each contribution can then be used as a means for obtaining additional information about layer.

3. A New Technique to Measure Canopy Attenuation

A new technique to determine canopy attenuation from stepped frequency measurements over trees is proposed. The algorithm for the estimation of canopy attenuation is based on separating the canopy and the trunk-ground returns. Once these backscattering sources are identified in time domain and are isolated with a gating filter, the frequency correlation functions (FCF) for each backscattering contribution are generated for difference frequencies in the bandpass of the radar system [7]. The individual response of the tree components has a slight variation with frequency while the total backscatter response from the canopy decorrelates. As a result, the FCF in stepped frequency radar observations are related to structure and geometry of a forested terrain [8]. 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, the canopy attenuation and 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 agreement obtained between the transient responses of the measured and the simulated data as seen in Fig. 1 suggests that the simulated data can be used to evaluate the technique’s success.

The results show that the extracted attenuation values from the measured data are highly correlated with the estimated values from the simulated data. As expected, lower attenuation values are observed for the defoliated trees than that of foliated trees. As the incidence angles are increased from 15° to 45°, it is observed that attenuation values are increased due to the increase in the path traveled. At higher angles of incidence, the rate of increase in the attenuation values for VV polarization is observed to be higher than that for HH polarization due to the vertically oriented structure of the trees. At lower incidence angles, however, both HH and VV polarizations experience similar attenuations. The results obtained here at 45° are similar to the results at 40° reported by Ulaby et al [9]; he has used completely different approach but similar instrument configuration.

4. Conclusions

A mathematical formulation characterizing the time domain radar backscatter response of a distributed medium over a flat surface such as a forested terrain has been developed. The transient response due to the plane wave spectral components that are excited by the antenna is found. The results are then used to
develop a Monte Carlo procedure for simulating the time domain radar backscatter response. Using this procedure, time domain analysis for various cases has been carried out to understand backscattering sources within the forest canopies and their effects on the transient response of the backscattered field. It has been shown that it is possible to distinguish the characteristics of a forested terrain as a function of depth by utilizing different arrival times of the components of the transient response. The volume scattering and double interaction contributions of the measured data have been separated successfully with a proper choice of a gate filter. A new technique for determining the canopy attenuation, using the measured stepped frequency radar backscatter response, has been proposed based on the normalization of the FCF of tree-ground return to the FCF of canopy contribution. It is shown that this ratio is independent from radar system parameters. It is only a function of vegetation and ground parameters such as extinction coefficient, layer depth, and soil moisture. The technique has been applied to truck based L-band multi-angle stepped frequency radar data collected over stands of deciduous Paulownia trees under various physical conditions. The canopy attenuation is successfully retrieved.

5. Acknowledgments

The authors would to thank 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


