Interactions of microwaves with forests: simulations at L-band

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Abstract

The potential of L-band in forest monitoring has been demonstrated in several studies: a good dynamics exists between backscattering from bare soil and the one from forests; forest radiometry has also recently received increasing attention, in view of future satellite missions aimed at monitoring underlying soil moisture; finally, the bistatic radar technique has been proposed in order to overcome the saturation effect, which could prevent operational use of microwave remote sensing for higher biomass values. On the other hand, it is recognized that modeling the interactions between forests and L-band microwaves is important for several objectives, since models may single out the contributions of single components and can be helpful to predict the performance of future systems. The electromagnetic model developed at Tor Vergata University is able to simulate the backscattering coefficient, the emissivity and the bistatic scattering coefficient using a unified approach, based on the radiative transfer theory. Comparisons between model simulations and measurements of emissivity and backscattering coefficient, at L-band, showed a fairly good agreement. The model was also used to predict the performances of an L-band radiometer in monitoring soil moisture under forests and to predict the trends of the specular scattering coefficient as a function of biomass.

1. Introduction

Modeling the interactions between forests and L-band microwaves is important for several objectives. The most common application, which has been the subject of several investigations, is the use of radar to monitor biomass. Some recent studies are also considering bistatic systems as a mean to monitor land properties. In particular, the performance of a bistatic system at L-band over forests is under evaluation [1] as it seems to be a promising tool to overcome the saturation limit of active systems. In the recent years, also the topic of L-band emission from soils covered by forests has received some attention. The main stimulus was related to the development of the Soil Moisture Ocean Salinity (SMOS) Project, with the launch of a satellite carrying an L-band radiometer on board. The objective of the mission over land is soil moisture monitoring but, since a significant fraction of land is covered by forests, it is important to simulate their emission.

It is recognized that these studies may benefit from model simulations. Models may single out the contributions of single components (e.g. soil and forest canopy) from the overall scattering or emission. Moreover, they can be helpful to predict the performance of future systems, when available experimental data are scarce. Models must be physically sound and, in order to describe the complexity of the interactions of electromagnetic waves with vegetation with acceptable accuracy, they need several inputs. Reasonable ways must be found to generate a reliable input data set when detailed ground data are not complete, or when there is a wide variability of forest properties within large pixels

This paper describes simulations of backscattering coefficient, emissivity and bistatic scattering coefficient of forests at L-band. To this aim, various versions of a basic discrete model are used [2]. A procedure is described, which generates the input data set when only general information is available, and which is founded on allometric equations given in the literature. Model outputs were compared with experimental data of backscattering coefficient and emissivity. Also the capability of radiometers in soil moisture monitoring and the performance of bistatic systems in estimating biomass were investigated by parametric studies.

2. The electromagnetic model

The model is based on the radiative transfer theory, and adopts a discrete approach. Vegetation elements, such as trunks, branches and leaves (or needles) are represented by means of canonical shapes, i.e. cylinders and discs. Extinction cross sections and bistatic scattering cross sections are computed using suitable electromagnetic theories. The electromagnetic properties of leaves or needles are simulated applying the Rayleigh-Gans approximation which is valid when one dimension of the scattering object is small with respect to wavelength. Trunks and branches are studied by means of the "infinite length" approximation which applies to cylindrical objects very long with respect to one wavelength.

Contributions of single elements are then combined by using a multiple scattering algorithm. The same algorithm is used to combine vegetation scattering with soil scattering, and the bistatic scattering coefficient is computed. The value in the backward direction gives the backscattering coefficient, while the emissivity is obtained by the energy conservation law. Details of the procedure are given in [2], and are not repeated here.

In the most recent version, also the contribution of the litter has been included. The soil is assumed to be overlaid by a dielectric layer, representing the litter, which is a mixture of air and dielectric material. The permittivity of the dielectric material is computed as a function of moisture, and the permittivity of the layer mixture is computed by means of the quadratic "refractive model" for mixtures. The overall reflectivity of this composite medium, made by soil and litter, is computed using the coherent multiple reflection model. Details about the procedure, which includes also roughness effects, are given in [3].

3. The generation of input data set

The discrete model requires several geometrical and physical parameters as input. These are: absolute distributions of trunk dimensions and branch dimensions, leaf dimensions, distributions of branch orientations and leaf orientations, permittivity of trunks, branches and leaves. Moreover, soil moisture and soil roughness parameters are required, as well as litter parameters defined in the previous section. The adopted procedure assumes soil moisture and soil roughness to be known, by measurements or realistic assumptions. Also the biomass and the forest category are assumed to be known a-priori. The other inputs are obtained by using allometric equations or other information available in the literature, as indicated below.

For a single tree, the diameter at breast height (dbh) is a fundamental parameter which controls several tree variables. Allometric equations given in [4] allow us to compute the overall dry biomass of the single tree and its subdivision into trunk, branch and leaf components, as a function of dbh. Other important information provided in [4] concerns the subdivision of total biomass. Indeed, another set of allometric equations allows us to assess how the total biomass is subdivided into components. The equations are available for both hardwood and softwood trees.

Over an extended forest area, a wide variability of tree dimensions is present. The electromagnetic model requires absolute distributions as input, including total number of trees per unit area. The passage from "single tree" level to forest level requires two fundamental steps. First of all, a distribution of dbh is taken. Typical distributions are available in the literature. The average value increases with biomass (t/ha), while the range of the distribution must be increased when pixels are large, as in the case of spaceborne radiometers. Then, the total biomass is used to convert from relative dbh distributions into absolute dbh distributions, i.e. number of trees per unit area with dbh within given intervals. Other allometric equations of [4] give the component subdivision as a function of dbh. Dry biomass values for trunk, branch and leaf are in this way computed as values per unit of underlying surface.

A different approach can be applied for large scale applications, where only the *Leaf Area Index (LAI)*, instead of the overall biomass, is available. In this case, the problem can be solved by using the previously described procedure, but including also empirical relationships relating *LAI* to leaf dry biomass. Details of the procedure are given in [5] and [1],

The procedure described previously gives the biomass of forest components [t/ha] for each dbh interval. Since the electromagnetic model needs geometrical dimensions and moistures as input, a suitable conversion procedure must be established. Volumes of leaves, branches and trunks, per unit of underlying area, are computed as a function of vegetation moisture. Realistic values of this variable are available in the literature. Trunk height can be obtained from stem volume by means of equations given by [4]. For branches, the overall volume is subdivided into cylindrical elements of different diameters. The relationship between maximum branch diameter and dbh can be taken by literature, for both Hardwood and Softwood species. As far as leaves are concerned, the model uses as input LAI and geometrical parameters, i.e. radius and thickness for broadleaf, radius and length for needleleaf. These parameters are available in the literature for various species.

4. Comparison with experimental data

In the past, several campaigns were carried out with the NASA/JPL AIRSAR in order to study the correlations between radar backscatter and forest parameters. They were accompanied by ground measurements such as those performed in Hawaii [6]. Backscattering measurements at L-band were compared with model simulations. The SAR observation angle ranged between 40° and 50°, and in our simulations it was fixed to 45°. The observed site was an evergreen broadleaf forest in Hawaii. Simulated sigma0's were in general agreement with the regression curves reported in [6]. Results of the comparison were reported in [1]. The major discrepancies were observed at the lower biomass, where the soil parameters have the highest impact. Consequently, for the low biomass the model slightly underestimates backscattering, especially at HH polarization. At the higher biomass values, the correspondence improves for the three polarizations.

Simulated values of emissivity were compared with results of various experiments. A multitemporal set of brightness temperatures was collected during the "Bray 2004" experiment in Les Landes forest [7]. Measurements were carried out by the EMIRAD radiometer, operating at 1.41 GHz and horizontal polarization, between July and December 2004. The radiometer antenna looked downward from a 40 m tower towards a 34 years old Maritime Pine forest, with an average tree height of 22 m. Soil and litter variables were measured on ground and simulations covered various soil conditions. A good agreement between simulations and measurements was obtained, with an overall rms error of about 2.5 [3].

Model outputs were also compared against experimental data collected during the autumn 2004 in the Jülich site (Germany). The L-Band 1.4 GHz radiometer ELBARA was installed in the upward-looking direction below the crown of a mixed hardwood forest, for observations at both vertical and horizontal polarization, and at various angles [8]. The average height of trees was about 20 meters, and the leaf fall process was monitored. Measured crown brightness temperatures were about 180-190 K, and decrease by about 10 K during the defoliation process. The model reproduced with a quite good accuracy the absolute brightness values and the defoliation effects [9].

Airborne radiometric measurements over forests were carried out in Tuscany in summer 1999 and winter 2001. Measurements included L-band, 40°, V pol. configuration [10]. The observed forest sites included both broadleaf and coniferous species. During the campaign several ground data were collected: in particular LAI, trunk diameter, basal area, plant density, height and woody volume. In the simulations, measured woody volume was used as input for the growth model, in order to get all the variables necessary for the description of the crown, and the measured LAI value was used for leaves. A comparison between simulated and measured emissivities was shown in [1]. For two samples both winter measurements (lower emissivity) and summer measurements (higher emissivity) were available. The model reproduced well the absolute values, as well as the effects of biomass and seasonal variations.

5. Parametric study

In this section, parametric simulations are described for the case of broadleaf forests. Height standard deviation and correlation length of soil was assumed to be equal to 1.5 cm and 5 cm, respectively. Simulations were made at L-band, and for two applications: sensitivity of emissivity to soil moisture beneath forest and sensitivity to biomass variations for a bistatic specular system.

The trends of emissivity vs. soil moisture content, for various values of LAI, from 1 to 6 were shown in [9]. The emissivity trends were obtained for an incidence angle of 25° at both vertical and horizontal polarization. Some sensitivity to soil moisture is observed for LAI values lower than 2-3. As expected, increasing LAI (biomass) produces an evident reduction in the slope of the trends, due to increasing attenuation of both the standing vegetation and the litter.

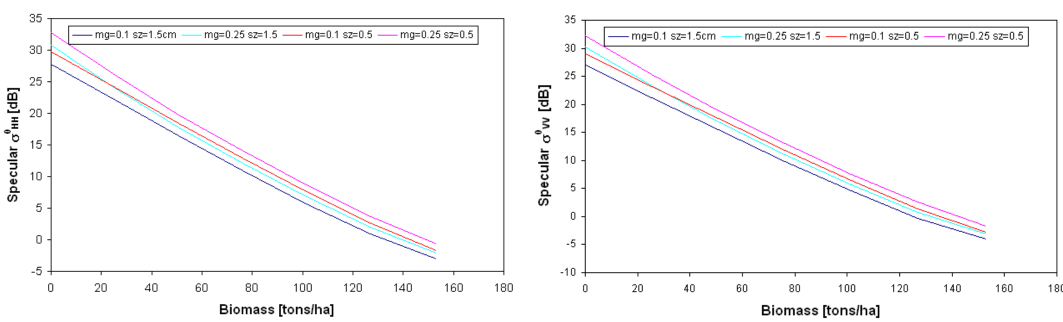

Fig. 1 Specular scattering coefficient at theta=20° vs. the biomass of a forest. The curves correspond to different soil conditions as indicated in the legend. On the left HH polarization, on the right VV polarization.

The specular bistatic scattering at 1.2 GHz and 20° was computed as a function of dry biomass (fig.1). The predicted dynamic range of the co-polar coefficients is good (i.e. higher than 20 dB), because of the high coherent specular scattering from soil which is not completely attenuated by the forest. The bare soil coherent contribution was simulated for a receiving antenna with a 3° beamwidth at about 800 Km height. Effects due to soil parameters variations are present, but are low when compared with the overall dynamic range. Of course this promising result must be verified by experiments and the feasibility of a spaceborne specular system must be carefully investigated.

6. Conclusion

A discrete model, which simulates microwave interactions with forests, has been refined to give the input data set by using allometric equations and include litter effects. Comparisons with L band experimental data are good for emissivity and backscattering coefficient at high biomass. Some discrepancies are observed for backscattering coefficients at low biomass. Parametric investigations indicate that the L-band emissivity of sparse broadleaf forests shows some sensitivity to soil moisture, which is reduced for higher biomass values. Model simulations predict a good sensitivity to biomass for an L-band bistatic system in the specular configuration.

8. References

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