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Forest biomass monitoring with GNSS-R: Theoretical simulations

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Abstract

GNSS-Reflectometry (GNSS-R) is a remote sensing technique which performs bistatic measurements of the earth surface scattering. This paper presents some theoretical simulations of the specular scattering coefficient of a forested area, with the aim of demonstrating the potentiality of GNSS-R in monitoring forest biomass. The study is performed by means of an electromagnetic model developed in the past years and tested over several vegetation covered sites in its active and passive version. Here, after showing a comparison between model results and measurements over a forest site in the monostatic configuration, and after summarizing other previous validations, the extension to the specular configuration, typical of GNSS-R systems, will be presented. Namely, simulations are carried out at circular polarization and a sensitivity analysis of the received power in the specular configuration to some soil and forest parameters is shown.

In the GNSS-R configuration, the theoretical response of vegetation shows a decreasing trend with increasing biomass, due to the increasing attenuation by the plant canopy which reduces the coherent scattering from the soil. The latter, however, remains higher than incoherent scattering even when forest biomass is large, especially at RL polarization and low incidence angle. Consequently the magnitude of the received power is sensitive to the forest biomass without exhibiting the typical saturation of radar backscattering measurements, and it may thus allow biomass retrieval.

Keywords: Electromagnetic models; Bistatic scattering; Vegetation; Soil moisture

1. Introduction

GNSS-Reflectometry is gaining increasing interest in the remote sensing community, due to the bistatic nature of the microwave scattering measurements (Jin and Komjathy, 2010). This technique exploits the L-band Global Navigation Satellite System (GNSS) signal as an opportunity source, with the consequent advantages of a limited cost and a potential high time resolution when performed from a spaceborne platform (Ruffini, 2006). Most of GNSS-R activities, both theoretical and experimental (Zavorotny and Voronovich, 2000a; Hajj and Zuffada, 2003; Martin-Neira et al., 2001; Gleason et al., 2005) concern oceans, as the high conductivity maximizes the reflected signal amplitude. Although most works considered the altimetric application, aimed at estimating the delay between direct and reflected signals, also the scatterometric mode is gaining interest. The latter measures the power coming from the sea surface, with the objective of estimating the reflection properties of the observed area which, on their side, are related to the sea state and wind speed over the ocean.

Recently, the scatterometric mode has been proposed for land applications also, i.e., soil moisture monitoring (Masters et al., 2004) since, according to the well established Fresnel formulas, the reflection coefficient of a flat surface depends on its permittivity which, in the case of land, is dependent on its moisture content. Semi-empirical permittivity models indicate L-band to be well sensitive to this parameter, so that an appreciable sensitivity of GNSS-R to soil moisture is expected. In the last decade some experimental campaigns were carried out to demonstrate that GNSS-R power waveforms can be detected over land, and their parameters are correlated to soil moisture content

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(Zavorotny et al., 2003; Masters et al., 2004; Gleason, 2006). Most of the pioneering study were devoted to a qualitative interpretation of the land waveforms, while most recent works proposed inversion algorithms relating power value of the waveforms to the Fresnel reflectivity (Katzberg et al., 2006; Egido et al., 2008). The sensitivity to soil moisture of the GPS reflected signal was proved also by means of a different approach: the Interferometric Pattern Technique (Rodriguez-Alvarez et al., 2009), which is based on the coherent addition of the direct and reflected fields.

A theoretical study was performed by Zavorotny and Voronovich (2000b) who extended a previous model, based on the Geometrical Optics approximation and concerning GPS scatterometry over ocean, to the case of a bare soil with rough surface. The work in Pierdicca et al. (2008) also analyses the sensitivity to soil moisture of bare soil bistatic scattering, showing that at L-band the specular configuration exhibits a high sensitivity.

The presence of vegetation can make the soil moisture retrieval a difficult task, since it attenuates and scatters the GNSS signal before it impinges on the ground and after it is reflected to the receiver (Katzberg et al., 2006). On the other hand, this may suggest another application of GNSS scatterometry, i.e. vegetation monitoring. It is well known that the biomass dependency of the radar backscatter varies as a function of radar wavelength and polarization, though reaching saturation after a certain biomass level. In Ferrazzoli et al. (2000) model simulations were carried out at L- and C-band with the aim of assessing the relevant features and the potential of the bistatic technique, and to investigate the possibility to overcome the limitations of monostatic radar in monitoring the crop biomass. Although the work was not strictly related to the use of GNSS-R, it considered specular scattering, so that its results at L-band may be taken as a first example of the potentiality of this technique. The theoretical study, carried out by means of a discrete Radiative Transfer model, showed that the biomass range over which an appreciable measurement dynamics is maintained can be widened by the specular bistatic configuration (Ferrazzoli et al., 2000). In particular, it was shown that the co-polar linear responses of a sunflower crop exhibits a decreasing trend with increasing biomass, since scattering in the specular direction is dominated by the soil coherent component, while all incoherent contributions are several dB's lower than total specular scattering.

In this paper, we extend the previous study on specular scattering focusing on GNSS-R applications to biomass monitoring of forests. The latter covers a very important role within the global monitoring objectives of remote sensing, such as carbon modelling, greenhouse gas emission inventories and deforestation control. Collection of GNSS signal reflections over land may represent a valuable tool to monitor the vegetation biomass, complementing the already well assessed capability of GNSS-R over the sea surface.

In Section 2 the discrete electromagnetic model which has been used to carry out this study will be recalled, and the equations adopted to estimate the variables required by the model will be shown. In Section 3, previous validations of the model will be summarized. Also, a specific forest site for which radar measurements were made available by literature will be considered (Imhoff, 1995) and a specific validation in the monostatic configuration will be carried out. The specular scattering coefficient of the same forest site will be then simulated at VV and HH polarizations. In order to take into account the polarization properties of the GPS signal, in Section 4 we will simulate the circular polarized scattering coefficient using a simplified version of the model. Finally, parametric simulations will be carried out using the typical GNSS parameters, in order to estimate the potentialities of GNSS-Reflectometry.

2. Model description

2.1. The electromagnetic model

The model developed at Tor Vergata University, which has been used in this study, is a discrete model, i.e., it represents the vegetated surface by means of a rough surface covered by an ensemble of lossy dielectric elements of simple shape. In the development of a discrete model, the first step consists in identifying the elements composing the vegetation structure, and assigning them realistic locations within the canopy. Then, simplified geometrical shapes are selected and associated to vegetation elements, in order to describe their scattering and absorption properties by means of analytical expressions developed on the basis of electromagnetic theories. Thus, in the case of forests, the considered elementary scatterers are cylinders, able to model trunks and branches, disks to model broad leaves, and needles, when conifer leaves are present. In the Tor Vergata model, the bistatic scattering properties of cylinders are simulated applying the Infinite Cylinder approximation (Karam and Fung, 1988), while the Generalized Rayleigh Gans (Eom and Fung, 1984, 1986) or the Physical Optics (Le Vine et al., 1983) approximations are applied for disks and needles, depending on the object size with respect to the wavelength. These are the canonical approximations currently applied in microwave active models (Liang et al., 2005).

The layer containing the ensemble of scatterers lies on a lossy dielectric homogeneous half space (representing the soil) with a rough interface. In the case of forests, soils are often covered by litter and/or understory vegetation that may modify soil properties. Following the procedure described in Della Vecchia et al. (2007), the whole soil–litter medium is reduced to a unique homogeneous half-space of given permittivity, which is usually lower than that of soil – except in the case of very dry soil. On its side, understory is represented as an absorbing layer.

A detailed description of the Tor Vergata model can be found in Ferrazzoli and Guerriero (1995), where it is shown how the scattering and extinction properties of each scatterer are combined using the Matrix Doubling algorithm. This method allows to take multiple scattering into account