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# A new soil roughness parameter for the modelling of radar backscattering over bare soil

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ABSTRACT

The characterisation of soil surface roughness is a key requirement for the correct analysis of radar backscattering behaviour. It is noteworthy that an increase in the number of surface roughness parameters in a model also increases the difficulty with which data can be inverted for the purposes of estimating soil parameters. In this paper, a new description of soil surface roughness is proposed for microwave applications. This is based on an original roughness parameter, *Zg*, which combines the three most commonly used soil parameters: root mean surface height, correlation length, and correlation function shape, into just one parameter. Numerical modelling, based on the moment method and integral equations, is used to evaluate the relevance of this approach. It is applied over a broad dataset of numerically generated surfaces characterised by a large range of surface roughness parameters. A strong correlation is observed between this new parameter and the radar backscattering simulations, for the HH and VV polarisations in the C and X bands. It is proposed to validate this approach using data acquired in the C and X bands, at several agricultural sites in France. It was found that the parameter *Zg* has a high potential for the analysis of surface roughness using radar measurements. An empirical model is proposed for the simulation of backscattered radar signals over bare soil.



## 1. Introduction

Soil moisture and roughness parameters play a key role in hydrological and climate studies. In recent years, various efforts have been devoted to the analysis of the backscattering characteristics of bare soils. Initially, different backscattering models (theoretical, semi-empirical and empirical) were developed (Chen et al., 2003; Dubois, Van Zyl, & Engman, 1995; Fung, Li, & Chen, 1992; Oh, Sarabandi, & Ulaby, 1992; Ulaby, Moore, & Fung, 1986; Zribi, André, & Decharme, 2008). More recently, several studies have proposed various approaches for the improvement of roughness descriptions (Bretar et al., 2013; Callens, Verhoest, & Davidson, 2006; Davidson et al., 2000; Li, Shi, & Chen, 2002; Mattia & Le Toan, 1999; Oh & Kay, 1998; Verhoest et al., 2008; Zribi, Ciarletti, & Taconet, 2000), which are essential to the accurate analysis and interpretation of backscattering behaviour and soil moisture estimation (Lievens, Vernieuwe, Alvarez-Mozos, De Baets, & Verhoest, 2009). An analysis based on a fractal representation has been proposed (Rouvier et al., 1997; Zribi et al., 2000) allowing a multi-scale description, which is not limited to the use of a single scale based on the correlation length parameter. Zribi et al. (2000) introduced fractal and Brownian approaches to describe the correlation function, whereas Li et al. (2002) proposed a general power law description of roughness spectra. Fung (1994); Shi, Wang, Hsu, O'Neill, & Engmann (1997) and Zribi, Baghdadi, Holah, Fafin, & Guérin (2005) have proposed different types of analytical correlation function, used to fit the experimental data. Although all of these studies have led to improvements in the direct backscattering simulations, the availability of a limited number of radar configurations makes it generally impossible to retrieve the volumetric soil moisture with all of the roughness parameters. In this context, Zribi & Dechambre (2003) introduced a description based on the parameter $Zs = s^2 / l$, where $s$ is the rms surface height and $l$ is the correlation length (Bretar et al., 2013; Lawrence, Wigneron, Demontoux, Mialon, & Kerr, 2013). Baghdadi et al. (2011, 2006); Baghdadi, Holah, & Zribi (2006);and Baghdadi et al. (2004) proposed an empirical correlation length, computed as a function of the rms height, radar frequency, incidence angle and polarisation, in order to obtain a better fit between integral equation model (Fung et al., 1992) simulations and radar observations. Lievens et al. (2011) show that roughness parameters differ between SAR acquisitions, as they are related to the observed backscatter coefficients and variations in local incidence angle. A statistical model was thus developed, to allow the effective roughness parameters to be estimated from microwave backscattering observations. Despite these contributions, the influence of roughness is still poorly modelled in currently known inversion techniques.

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In the present study, a new surface description is proposed, in which the analysis uses the moment method to numerically simulate the backscattering integral equations. Our paper is organised into five sections, of which Section 2 presents the principles of the numerical backscattering simulations, Section 3 discusses the influence of roughness on the backscattering simulations and introduces the new roughness parameter, *Zg*. Section 4 describes the potential of this parameter, through the use of experimental analyses based on different types of ground and radar measurements. Finally, our conclusions are presented in Section 5.

## 2. Numerical backscattering simulations — methodology

A numerical backscattering model based on the moment method is used to simulate radar signals over bare soils (Chen & Bai, 1990; Harrington, 1968; Johnson et al., 1996; Mattia, Le Toan, & Davidson, 2001; Soriano, Guérin, & Saillard, 2002; Zribi, Le Morvan, Dechambre, & Baghdadi, 2010). With this approach, the computations are made using simulated surfaces, with various roughness and soil moisture characteristics. The first step in this process thus involves the generation of soil roughness profiles.

### 2.1. Roughness profile generation for different types of correlation function

In this section, it is proposed to generate soil surfaces with different correlation functions $\rho(x) = \exp\left(-\left(\frac{x}{l}\right)^{\alpha}\right)$, in which the parameter α can range between 1 and 2 (Li et al., 2002), with these extremes corresponding to exponential and Gaussian functions, respectively (Fung & Chen, 1985). The approach described by (Fung & Chen, 1985) is used as follows.

The surface heights are written as:

$$h(k) = \sum_{i=-M}^{i=M} W(i)X(i+k) \quad (1)$$

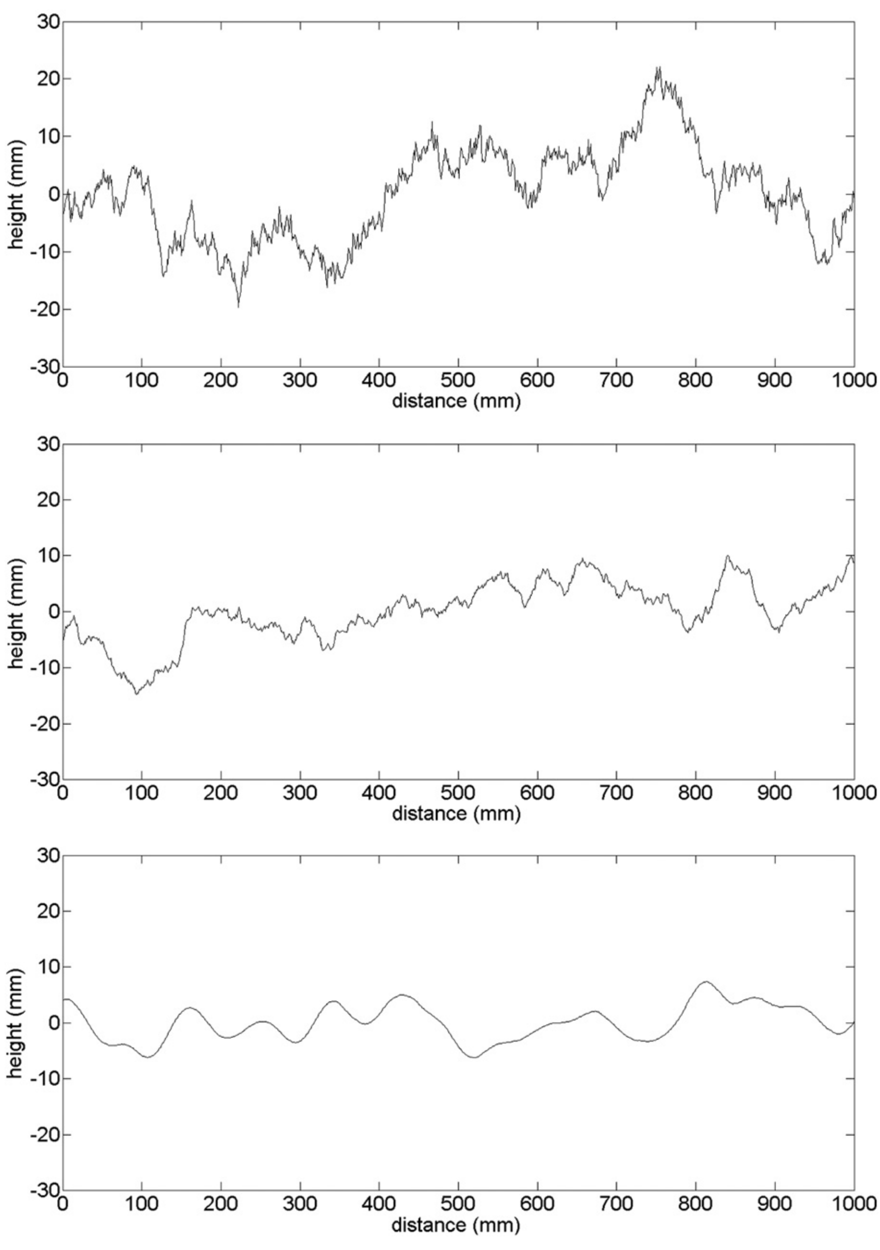


**Fig. 1.** Three synthetically generated surface profiles, with rms height = 0.6 cm, correlation length = 6 cm, and a) $\alpha = 1$, b) $\alpha$= 1.5 and c) $\alpha$= 2.