# A METHOD USING GNSS LH-REFLECTED SIGNALS FOR SOIL ROUGHNESS ESTIMATION

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**KEY WORDS:** GNSS-R, Roughness model, Reflectivity, Surface roughness, Soil moisture, Bare soil

**ABSTRACT:**

Global Navigation Satellite System Reflectometry (GNSS-R) is based on the concept of receiving GPS signals reflected by the ground using a passive receiver. The receiver can be on the ground or installed on a small aircraft or UAV and collects the electromagnetic field scattered from the surface of the Earth. The received signals are then analyzed to determine the characteristics of the surface. Many research has been reported showing the capability of the GNSS-R technique. However, the roughness of the surface impacts the phase and amplitude of the received signals, which is still a worthwhile study. This paper presented a method can be used by GNSS-R to estimate the surface roughness. First, the data was calculated in the specular reflection with the assumption of a flat surface with different permittivity. Since the power reflectivity can be evaluated as the ratio of left-hand (LH) reflected signal to the direct right-hand (RH) signal. Then a semi-empirical roughness model was applied to the data for testing. The results showed the method can distinguish the water and the soil surface. The sensitivity of the parameters was also analyzed. It indicates this method for soil roughness estimation can be used by GNSS-R LH reflected signals. In the next step, several experiments need to be done for improving the model and exploring the way of the estimation.

## 1. INTRODUCTION

In the last two decades, Global Navigation Satellite System-Reflectometry (GNSS-R), has gained increasing interests as an efficient tool for remote sensing. It uses GNSS satellites as a source of the transmitter and the desired parameters are retrieved from the signals reflected from the surface. It can be taken as a bistatic radar system that the transmitter and receiver are not co-located. Several applications of GNSS-R have been extensively explored including the soil moisture content (Egido, 2012; Jia, 2016; Katzberg 2006; Larson 2010; Masters, 2004; Rodriguez-Alvarez, 2011; Small, 2010), vegetation biomass (Mironov, 2012; Ulaby, 1985), wave height (Alonso-Arroyo, 2015), snow depth (Jin, 2016; Larson, 2009), ice thickness (Yan, 2016) and so on (Garrison, 2014).

Since it has been shown that L-band signals are quite sensitive to the soil moisture in the top of 0-2 cm surface layers (Wang, 1980). Many efforts have been made to the GNSS-R soil moisture retravel on land application. For a smooth surface, the incident angle and the reflected angle are symmetric around the specular point, which the angular radiation pattern of the reflected wave is a delta function centered about. For the slightly rough surface in, the angularly reflected wave consists two components: a reflected component and a scattered component. The reflected component is again along the specular direction, with a magnitude of its power smaller than on the smooth surface. The specularly reflected component is referred to as the coherent component. The scattered component, also called incoherent or diffuse component, consists of power scattered randomly in all directions, with its magnitude is smaller than coherent component. The phase coherence of the incoherent component is deteriorated or even destroyed (Schanda, 2012).

As the surface roughness increases, the amplitude of the coherent power decreased and the incoherent power increased. Finally, for the very rough surfaces, that is only scattered component remains without any specular reflection. Therefore, the main power that contributes mostly to the reflected signals are co- and incoherent power, which originated by different scattering mechanisms that depend on the roughness of the surface.

The distribution of these power can be mapped as a function of delay and frequency, such as DDM. The signals were captured and sampled by GNSS receiver, e.g., antennas, and front-ends. Then the data were stored to process by an open loop approach for obtaining the DDM. Some scattering models give the help to the studies of modeling scattering components due to surface roughness. Then the bistatic equations were used to calculate the relevant information.

The rougher surface generates more incoherent power, which prevents the correct estimation of coherent power for soil moisture sensing. To investigate the effects of the roughness surface on soil moisture content retrieval, this paper first suggested a possible method estimating the roughness of the reflecting surface. Some preliminary results were reported and the results showed the huge potential for improving the accuracy of the soil moisture retrieval application.

## 2. METHODOLOGY

GNSS-R signals reflected from the ground are acquired by means of a commercial receiver. The raw data were sampled and digitalized, before being processed into Delay-Doppler Maps (DDMs) and Delay Waveforms (DWs) with an open loop scheme. The reflectivity ( $\Gamma$ ) was obtained by making the ratio of signal-to-noise ratio (SNR) of the left-hand reflected signal and the right-hand direct signal. the Fresnel reflection


https://doi.org/10.5194/isprs-archives-XLII-3-637-2018  

coefficient ( $R_{qp}$ ) can be expressed as linearly polarization modes, which $q$ and $p$ indicate the reflected and incident polarization, respectively (Zavorotny, 2000):

$$R_{lr} = R_{rl} = \frac{1}{2}(R_{vv} - R_{hh}), \quad (1)$$

$$R_{rr} = R_{ll} = \frac{1}{2}(R_{vv} + R_{hh}). \quad (2)$$

Then, a semi-empirical roughness model concerned with the reflectivity of soil (Wegmuller, 1999) was applied:

$$\Gamma_{hh} = \Gamma_{h,fre} \cdot \exp(-(k \cdot s)^{\sqrt{0.10 \cdot cos\theta}}), \quad (3)$$

$$\Gamma_{vv} = \Gamma_{hh} \cdot (\cos\theta)^{0.655}, \text{ when } \theta \leq 60°, \quad (4)$$

$$\Gamma_{vv} = \Gamma_{hh} \cdot (0.635 - 0.0014 \cdot (\theta - 60^{o})), \text{ when } 60° \leq \theta \leq 70°, \quad (5)$$

where k is the wavenumber, which is defined as $2\pi / \lambda$ ( $\lambda$ is the wavelength, $c / f$ ), and $s$ is the standard deviation of the surface height. The Eq.1 was combined with Eq.4 or Eq. 5 to obtain the $\Gamma_{hh}$ numerically, depending on different incident angles ( $\theta$ ). Then the standard deviation of surface height ( $s$ ) can be obtained by solving the Eq.3.

Firstly, instead of using the data from experiments. this method was tested by obtaining the reflectivity in specular reflection condition ( $s = 0$ ), where $R_{vv}$ and $R_{hh}$ are the Fresnel coefficients for horizontal and vertical polarization (Stutzman, 1993):

$$R_{hh}(\theta) = \frac{\cos\theta - \sqrt{\varepsilon_r - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon_r - \sin^2\theta}}, \quad (6)$$

$$R_{vv}(\theta) = \frac{\varepsilon_r \cos\theta - \sqrt{\varepsilon_r - \sin^2\theta}}{\varepsilon_r \cos\theta + \sqrt{\varepsilon_r - \sin^2\theta}}, \quad (7)$$

where $\theta$ is the incident angle. $\varepsilon_r = \varepsilon / \varepsilon_0 - j60\lambda\sigma$, in which $\varepsilon$ is the dielectric constant of the surface, $\varepsilon_0$ is the dielectric constant of the air, $\lambda$ is the wavelength of the signal, $\sigma$ is the electric conductivity. Most of the natural surface can be modeled by a Gaussian height distribution. Thus, the reflectivity $\Gamma_{lr}$ can be written as

$$\Gamma_{lr}(\theta) = \left|R_{lr}(\theta)\right|^2 e^{-h(\cos\vartheta)^2}. \quad (8)$$

We can assume the roughness surface is zero ( $h = 0$ ) obtaining the reflectivity by Eq. 1,6,7,8. After this, the method we proposed were used to test if the surface is flat as the assumption.

## 3. RESULTS

### 3.1 Flat surface

Here we presented some preliminary results, showing roughness estimation obtained by applying the above model. We assumed the surface is flat and the permittivity of the soil are 10, 20, 30, 40, 50, respectively. The reflectivity was obtained by Eq. 6, 7, 8 and calculated in the range of 0.18-0.58 as shown in the top plot of figure 1. The surface roughness estimation results were given in the bottom plot of figure 1. With all different permittivity, the estimated roughness are all zeros, which corresponds to the flat surface assumption.

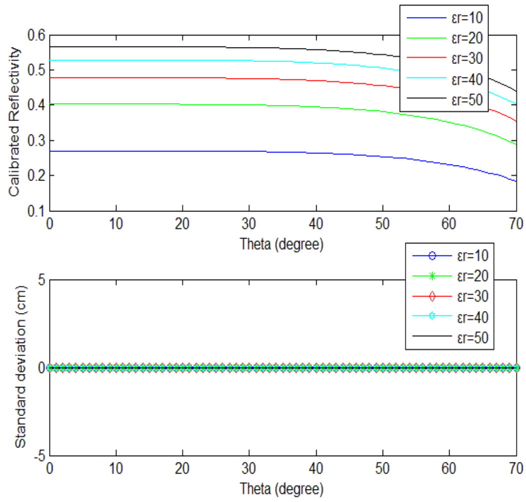


Fig. 1. The estimation of soil surface roughness for a flat surface.

### 3.2 Variation of the surface roughness

This method was also applied to random surfaces. In the testing stage, we used the MATLAB software generating random numbers as surface relativities in the range of 0-1 for simulating the variation of the surface roughness. The results were shown in the Fig. 2 and 3 with two cases, permittivity = 15 (land soil), 78 (lake), respectively.

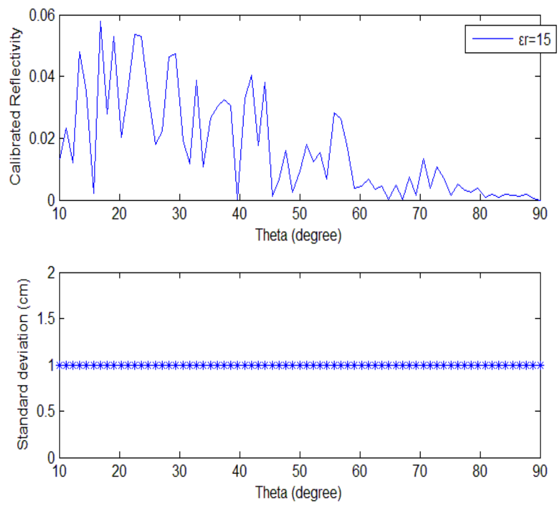


Fig. 2. The estimation of soil surface roughness for random surface (soil).

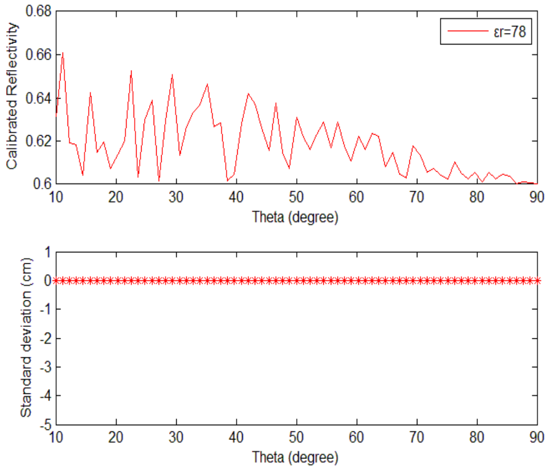


Fig. 3. The estimation of soil surface roughness for random surface (lake).

In the soil case (Fig. 2), the land of permittivity 15 corresponds with very low reflectivity (random numbers) ranging from 0 to 0.06. Theta is the incident angle. The results of the estimated standard deviation are all ones, which are not accurate as a random land surface. In the water case (Fig. 3), the permittivity 78 is shown with higher reflectivity (random numbers) ranges from 0.6 to 0.66. The results of the estimated standard deviation are all zeros which correspond to the lake surface.

Therefore, for the random surfaces testing, it was observed that the model was able to distinguish the land and the water surface. Moreover, in order to obtain precisely the variations of the land surface, huge experiments and analysis need to be done to modify and improve the model.

### 3.3 Parameters sensitivity analysis

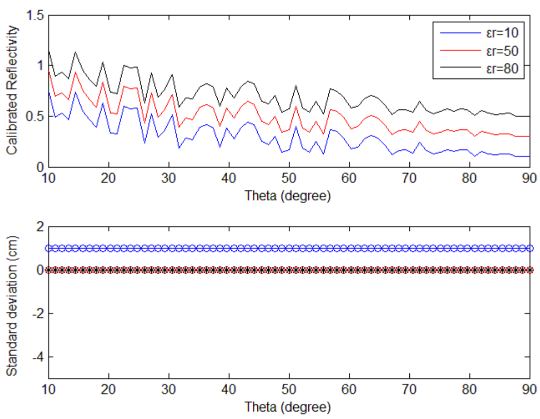


Fig. 4. The estimation of soil surface roughness for random surface (lake).

On the other hand, the sensitivity of parameters was analyzed in the following. The permittivity was defined as 10, 50 and 80. Then the simulated calibrated reflectivity showed different behaviors as in the top plot of figure 4. After applying the model, the standard deviation was calculated respectively with all zeros and ones indicated by two curves (the bottom plot of figure 4). The standard deviation of permittivity 50 (red) and 80 (black) are all zeros and the permittivity 10 (blue) is all ones. The results proved that the model can distinguish the water and the land soil. Moreover, it showed that the permittivity is not the main parameters affects the standard deviation estimation, while the calibrated reflectivity is quite sensitive to the roughness estimation.

## 4. CONCLUSIONS

The GNSS-Reflectometry (GNSS-R) technique has been widely used in many fields. Due to its unique characteristics, the GNSS-R provides low-cost, portable, and all-weather monitoring conditions, which plays a key role for sensing the soil moisture content. In this paper, a method was proposed to estimate the standard deviation of surface roughness. This method bonded the GNSS-R reflection coefficient and semi-empirical reflectivity models for bare soils, to investigate the probability and sensitivity of the surface roughness estimation. The results showed this method can predict the surfaces of water and soil land. Moreover, for the sensitivity of the parameters, it was shown that the surface reflectivity plays the main role in the roughness estimation. It will be applied further to various experiments for modifying and improving the roughness estimation.

## ACKNOWLEDGMENTS

This work was supported by N.S.F.C. No.41401480, NUPTSF Grant NY217152, and NY213105.

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