GNSS SIGNAL PROPAGATION IN SOIL AND REFLECTION ANALYSIS FOR SOIL MOISTURE MEASUREMENT

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ABSTRACT

The authors studied soil moisture measurement using the attenuation of GNSS (Global Navigation Satellite System) signals broadcasted from the navigation satellites launched by Europe, China and U.S. We aim to investigate thought experiment how different soil moisture and different soil depth affect the signal attenuation, hoping it can give better understanding of the sensing depth of GNSS-Reflectometry or GNSS-Interferometric Reflectometry technique. This experiment was recently carried out in Beijing, China from 23th of March 2019 to 11th of June 2019. This poster showed the initial results of this experiment.

INTRODUCTION

Soil moisture plays an important role in water cycle study. Modern remote sensing technology has demonstrated that L-band is very sensitive to soil moisture variation. With the design and implementation of the Global Navigation Satellite System (GNSS) which works on L-band as well, remote sensing using navigation signals could gain additional scientific interests. With two decades' development, two techniques based on signal reflection have been proposed including GNSS-R (GNSS-Reflectometry) and GNSS-IR (GNSS-Interferometric Reflectometry). More recently, some researchers tried to utilize the penetrating signal to measure soil moisture (Franziska Koch et al., 2016) and snow water equivalent (Franziska Koch et al., 2014 and Ladina Steiner et al., 2018).

OBJECTIVE

We aim to investigate thought experiment how different soil moisture and soil depth affects the signal attenuation, hoping it can give better understanding of the sensing depth of the reflected signal, which is related to estimating the Root-Zone soil moisture and Field Capability.

METHODS AND MATERIALS

The navigation signal propagation in soil and its reception by the antenna are illustrated in Figure 1. In GNSS receivers, the signal strength information was recorded in the form of Carrier-to-Noise Ratio (C/N0) which can be extracted from the Rinex file logged by the receiver. Assume that the C/N0 of the signal in air and soil is C/N0_a and C/N0_s, respectively. The signal received by the buried antenna was weaker compared with the signal in air, which results from refraction and attenuation in soil. The relationship between the two signals can be described as follows [3]:

\[ C/N_0_s = C/N_0_a + 10 \log(1 - R) - 10 \log(\epsilon_s) \]  

where \( R \) is the reflectivity of soil; \( \epsilon \) is Euler’s Number. \( l_s \) is the path length in the soil. According to the refraction theory, it relates to soil depth \( d \) through the following equation:

\[ l_s = \frac{d}{\cos(\theta)} \]  

where \( \theta \) is the refraction angle. In Equation (1), \( \kappa_s \) is the attenuation coefficient which can be modeled by [1]:

\[ \kappa_s = \sqrt{\epsilon_s^{-1} \epsilon_r^{-1} - 1} \epsilon_r \omega \]  

where \( \epsilon_r \) is the real part of the complex soil relative permittivity; \( \epsilon'_s \) is imaginary part of the complex soil relative permittivity; \( f \) is the signal frequency. Note that \( \theta \) is also a function of complex soil relative permittivity. Since the complex soil relative permittivity is mainly determined by the soil moisture, retrieval can be carried out according to Equation (1) with the aid of soil dielectric models developed by Dobson et al., Wang et al., Hallikainen et al. etc. In this study, the Hallikainen’s model was used.

For validation purpose, an experiment was recently carried out in Guocun Village of Beijing, China (116˚41ʹ23.1907E, 39˚41ʹ50.3315ʺN, Figure 2-3). About 70 days’ data was collected from 23th of March 2019 to 11th of June 2019 using two sets of GNSS receivers with identical hardware configurations including identical cables and antennas. One antenna was placed at the bottom of the one large plastic bag. Another one was fixed on the surface of the ground outside the bag. The two antennas were connected to two independently working receivers with 1-Hz sampling frequency. During the experiment period, we gradually increased the antenna (by burying soil to the bag (Figure 4)). Each time the burying depth was increased, the soil moisture was increased manually, and then let it to drop naturally. Three soil moisture sensors were buried horizontally in the soil with one sensor always staying at the bottom of the bag and the other two buried evenly in the vertical direction according to the soil depth.

RESULTS

Each phase’s data were processed individually. Table 2 showed the results of all the phases of different satellite systems using high elevation angle data for example. For the first three phases (3 ~ 10 cm soil depth), the correlation coefficient between retrieved and in-situ soil moisture is about 0.9, while for the later phases the correlation coefficient dropped to about 0.6. In order to give better understanding when the soil depth is greater than 10cm (Figure 5-6). As for the RMSE, the results varied between 0.02 and 0.19 cm³/cm³. However, since GPS system present more observations, its results were illustrated in Figure 7.

DISCUSSION AND CONCLUSION

This study confirmed the validity of soil moisture retrieval using the attenuation of GNSS signal of opportunity. In the current modeling, the soil was considered as homogeneous and single layer medium, which might cause large retrieval error encountered in this experiment.

REFERENCES