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

Dongkai, Yang[1](edkyang@buaa.du.cn); Mutian, Han[1](hanmutian@buaa.edu.cn) 1. Beihang University, China

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 techinique. 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 technique 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 signal of opportunity gained wide 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 recievers, the signal strength information was recorded in the form of Carrier-to-Noise Ratio (C/N_0) data, which can be extracted from the Rinex file logged by the receiver. Assume that the C/N_0 of the signal in air and soil is $C/N_{0,a}$ and $C/N_{0,s}$, 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]:

$$C/N_{0,s} = C/N_{0,a} + 10\log_{10}(1-R) - 10\kappa_s l_s \log_{10}(e) \quad (1)$$

where, R is the reflectivity of soil; e is Euler's Number. l_s is the path length in the soil. According to the refraction geometry, it relates to soil depth d_s through the following equation:

$$l_s = \frac{d_s}{\cos(\theta_t)} \quad (2)$$

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

$$\kappa_s = \sqrt{\frac{\mu_0}{\varepsilon'_{r,s}\varepsilon_0}} \cdot \varepsilon''_{r,s}\varepsilon_0 2\pi f \quad (3)$$

where $\varepsilon'_{r,s}$ is the real part of the complex soil relative permittivity; $\varepsilon''_{r,s}$ is imaginary part of the complex soil relative permittivity; f is the signal frequency. Note that R 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.

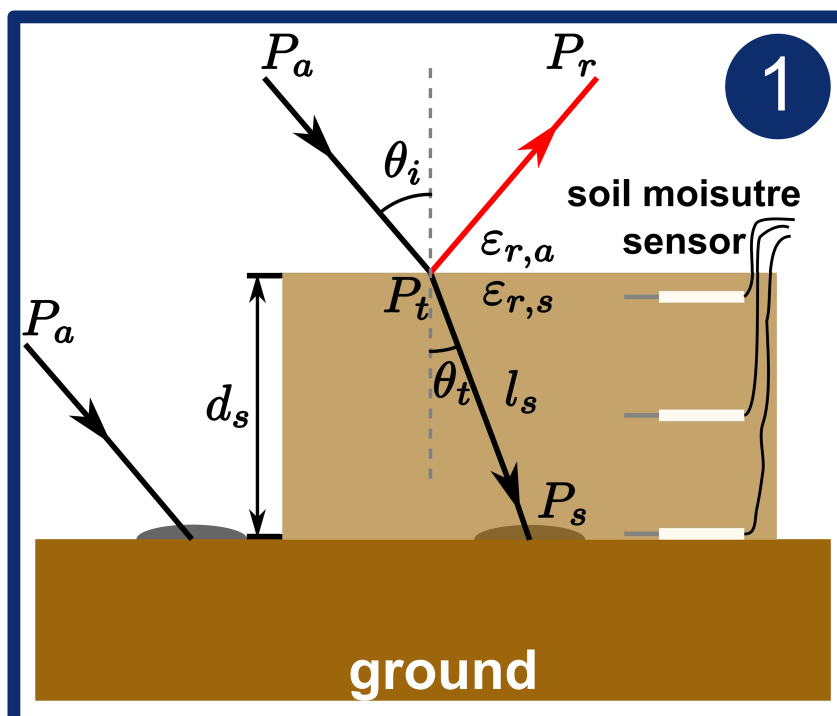
For validation purpose, an experiment was recently carried out in Guocun Villiage of Beijing, China (116°41'23.1907E, 39°41'50.3315"N, Figure 2-3). About 70 days' data was collected from 23th of March 2019 to 11th of June 2019 using two sets of GNSS receivers with identical hardware configurations including 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 burying depth by adding 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.

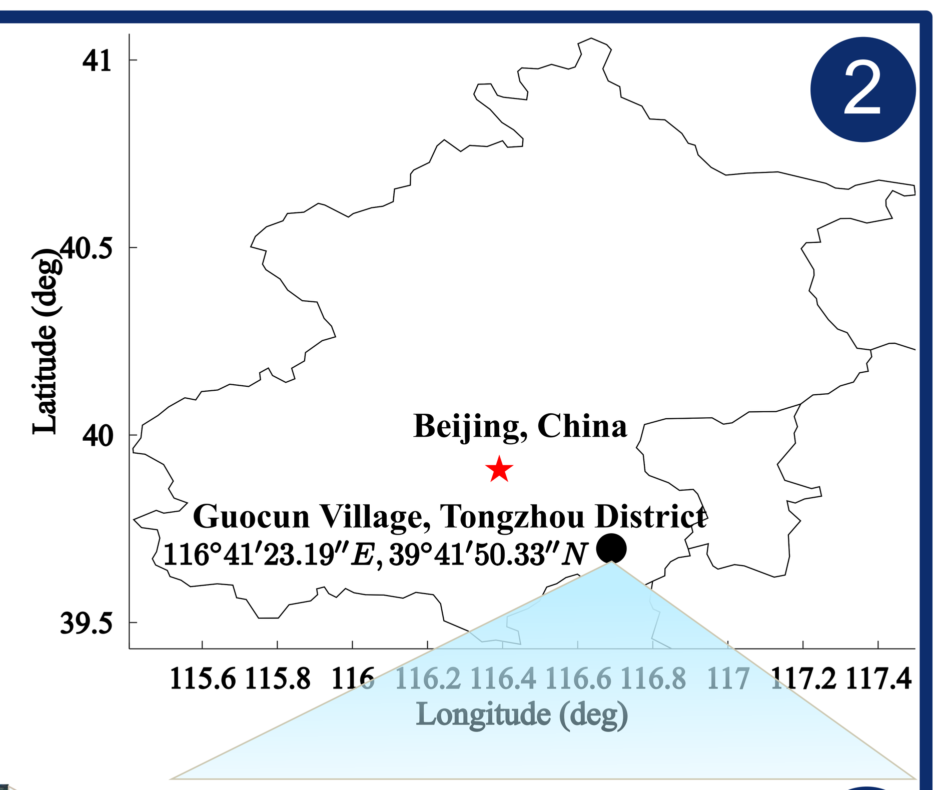
RESULTS

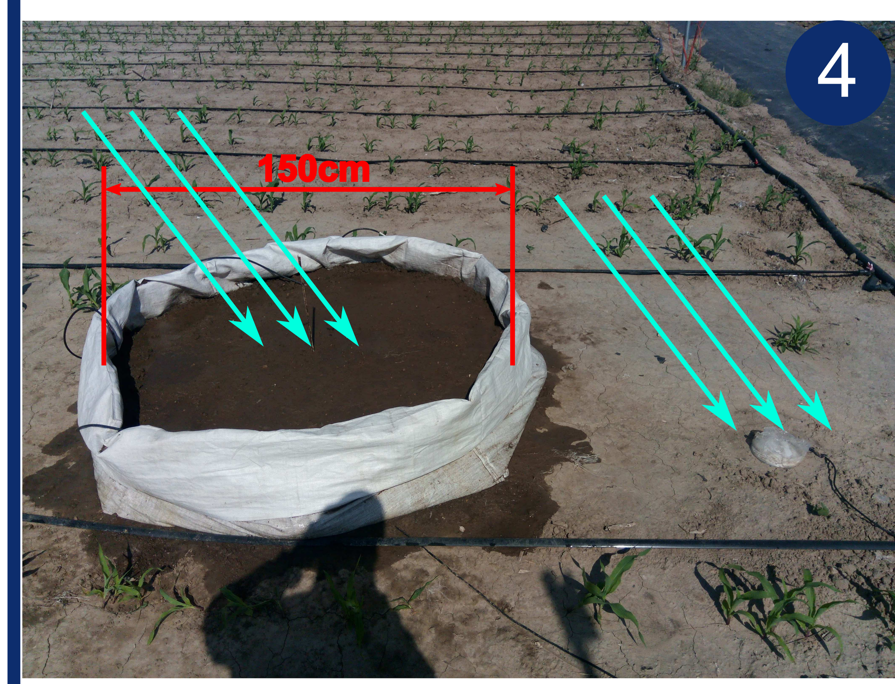
Each phase's data were processed individually. Table 2 showed the results of all the phases of different satellite systems using high elevation angle data for example. For the first three phases (3 ~ 10 cm soil depth), the correlation coefficient between retrieved and in-situ soil mositure is about 0.9, while for the later phases, the correlation coefficient dropped to about 0.8 until no signal could be recieved because of serious attenuation when the soil depth is larger than 18cm (Figure 5-6). As for the RMSE, the results varied between 0.02 and 0.19 cm³/cm³. However, since GPS system gave more observations, its results were illustrated in Figure 7.

DISSCUSSION AND CONCLUSION

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







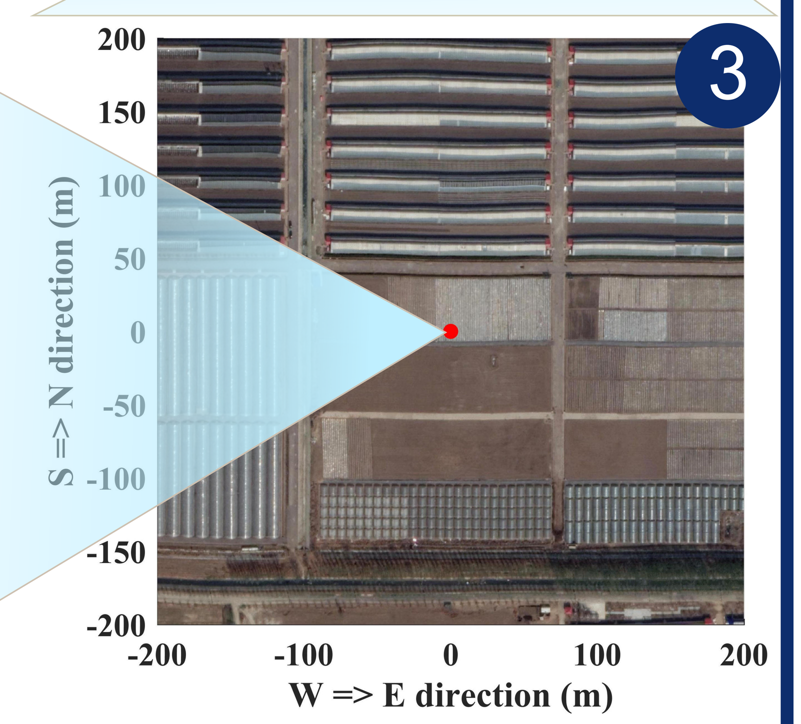
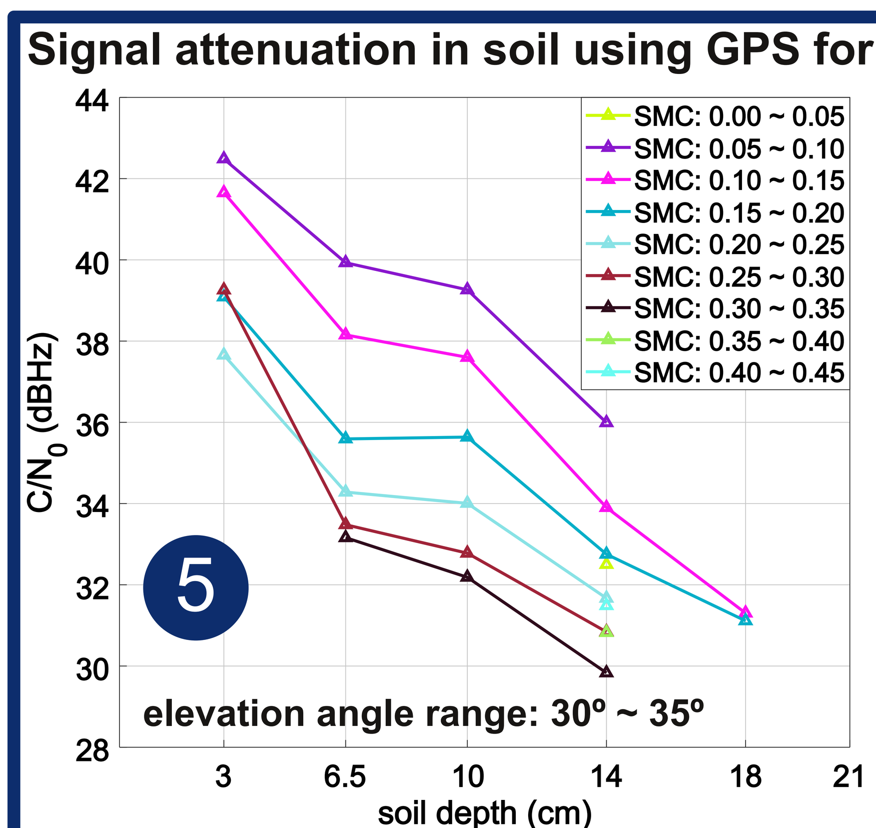


Table 1:Experiment phases (divided according to the soil depth)

phase	date	soil depth (cm)	soil moisture (cm³/cm³)
1	2019.03.23 ~ 2019.03.30	3	0.0615 ~ 0.2557
2	2019.04.04 ~ 2019.04.19	6.5	0.0723 ~ 0.3829
3	2019.04.19 ~ 2019.05.06	10	0.1276 ~ 0.3378
4	2019.05.06 ~ 2019.05.22	14	0.1169 ~ 0.4431
5	2019.05.22 ~ 2019.06.02	18	0.1706 ~ 0.4252
6	2019.06.02 ~ 2019.06.11	21	0.1577 ~ 0.3394

Signal attenuation in soil using GPS for example:



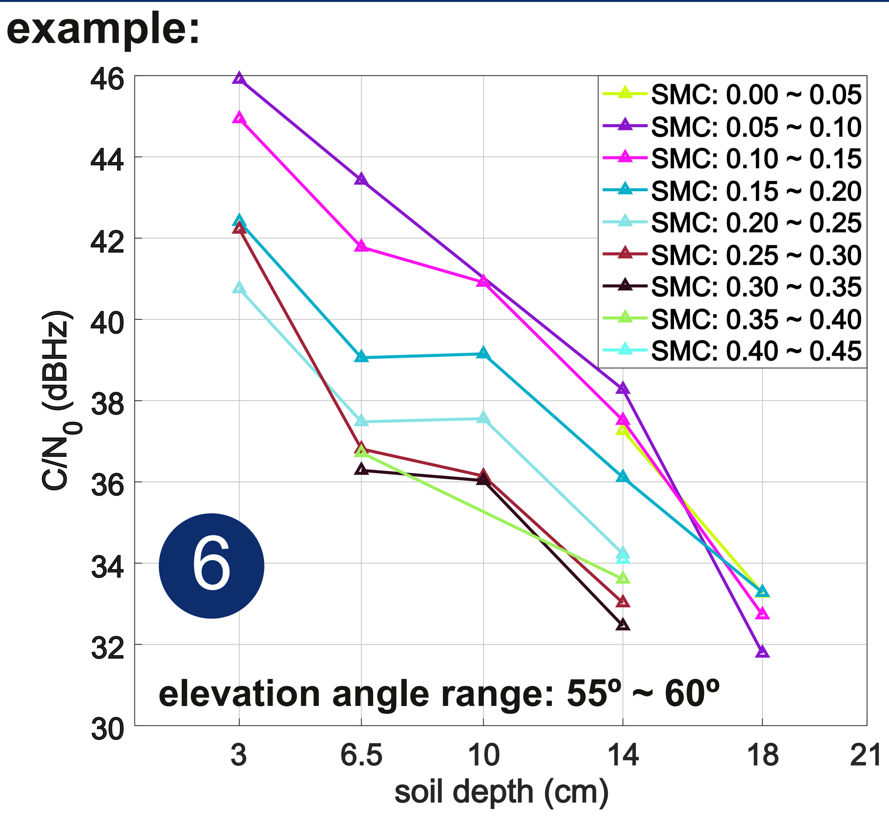
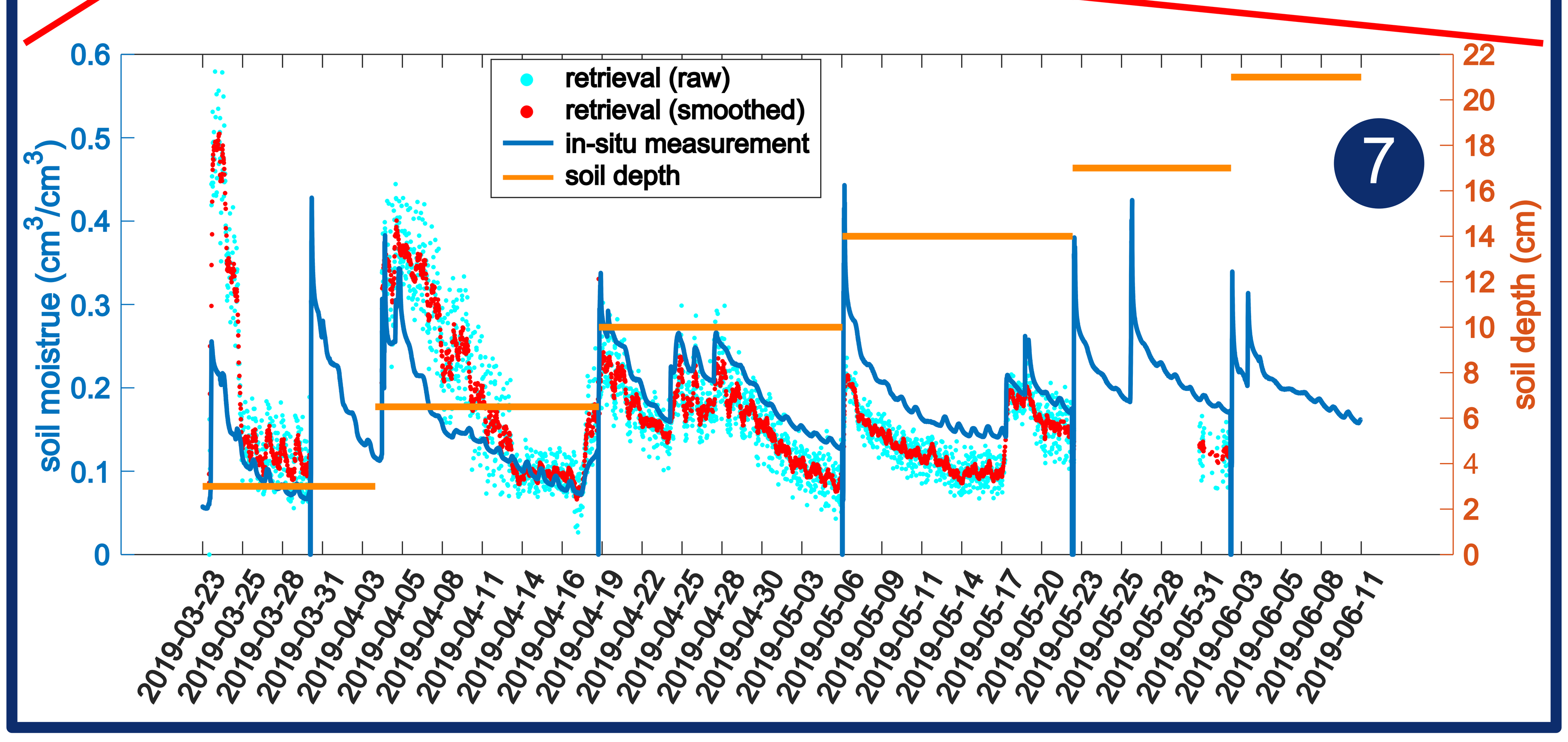


Table 2: Soil moisture retrieval results of three navigation systems (55° ~ 60°)

phase	GPS			GALILEO			BDS		
	number of observations	R	RMSE (cm³/cm³)	number of observations	R	RMSE (cm³/cm³)	number of observations	R	RMSE (cm³/cm³)
1	336	0.95	0.1193	180	0.93	0.1292	71	0.84	0.1846
2	730	0.93	0.0698	366	0.92	0.0786	127	0.92	0.1487
3	833	0.94	0.0431	225	0.93	0.0334	125	0.93	0.0177
4	782	0.79	0.0565	98	0.90	0.0523	287	0.88	0.0190
5	55	0.01	0.0521	NaN	NaN	NaN	NaN	NaN	NaN
6	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN



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