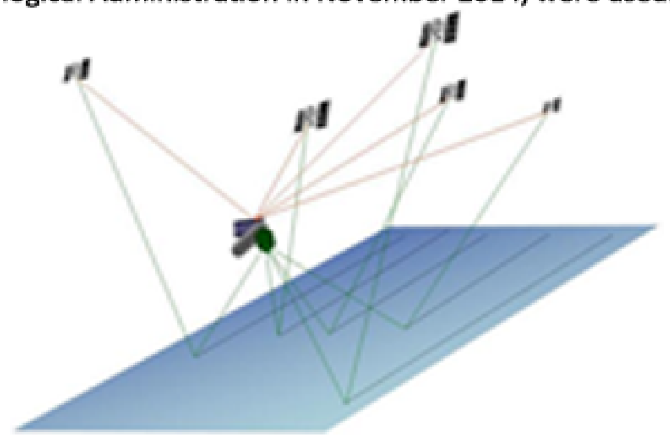
Soil Moisture Remote Sensing Using GNSS-R Technique

Introduction

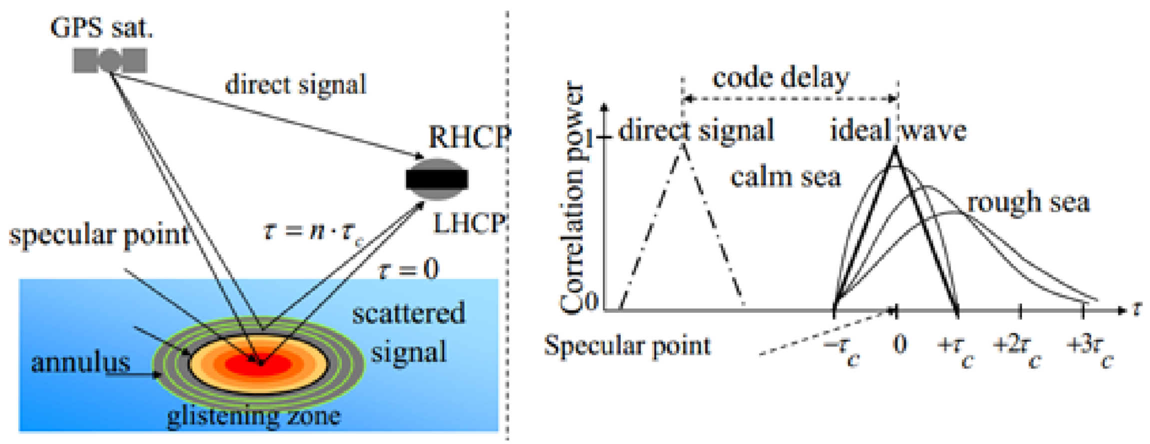
Understanding the natural processes and the effects of human intervention in our planet is of great importance to guarantee a prosperous and sustainable living for human beings. Soil moisture is a key parameter for this purpose. It has an influence on many processes in ecological cycle like climate change. Especially, it is well known as a major relevance in the agricultural sector. As a consequence, it is significant to measure this parameter with the appropriate accuracy and resolution requirements. Nowadays the most common way to measure soil moisture is with in-situ sensors. These techniques have high measurement reliability but remain inappropriate to cover regional and global scales given the vast amount of resources that would be necessary to perform such campaigns. In order to bridge this gap, remote sensing methods have been proposed for soil moisture remote sensing, which is based on the large contrast of the dielectric properties of et and dry soils throughout most of the electromagnetic spectrum.

Global Navigation Satellite System Reflectometry (GNSS-R) was proposed as ocean altimetry firstly during 1990s and it has been applied to soil moisture remote sensing since 2000s. When GNSS signals impinge on the Earth, the scattering surface leaves its imprint on the reflected signal. In 2000, NASA & University of Colorado made the first experiment to monitor soil moisture based on GNSS-R – SMEX 02-03. Since then, many researches on soil moisture remote sensing using GNSS-R technique were conducted (e.g. Egido et al., 2008; ESA, 2010; Larson, 2010; Egido et al., 2012; Egido, 2013; Yin et al., 2015). A lot of scientific literature about the GNSS-R technical fundamental and its advantages, general idea of soil moisture remote sensing using GNSS-R technique is available. Nevertheless, there is a lack of
scientific literature about GNSS IF signal data processing using MATLAB to estimate the soil moisture and performance analysis, including the sensitivity and accuracy.

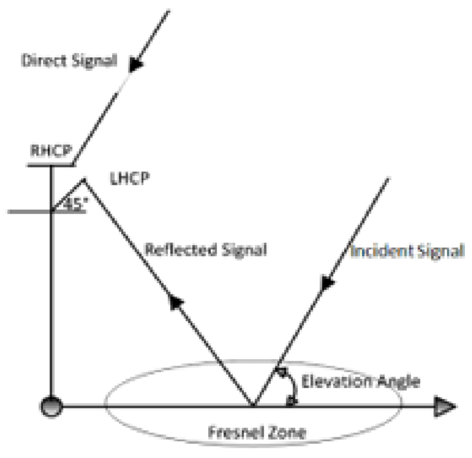
In this project we proposed a methodology of GNSS signals processing in soil moisture remote sensing application using MATLAB and per formance analysis. 3-day BeiDou and GPS IF data, from November 26, 2014 to November 28, 2014, collected by Shandong Taian Meteorological Administration in November 2014, were used.



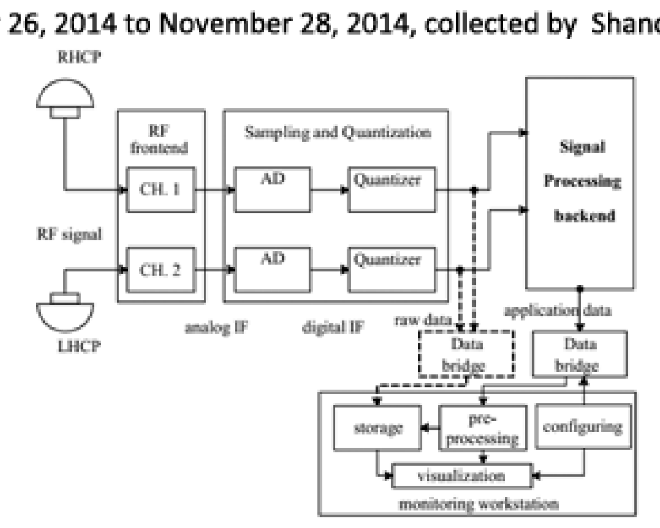
Egido (2013)



Yang (2013)



Liu et al. (2014)



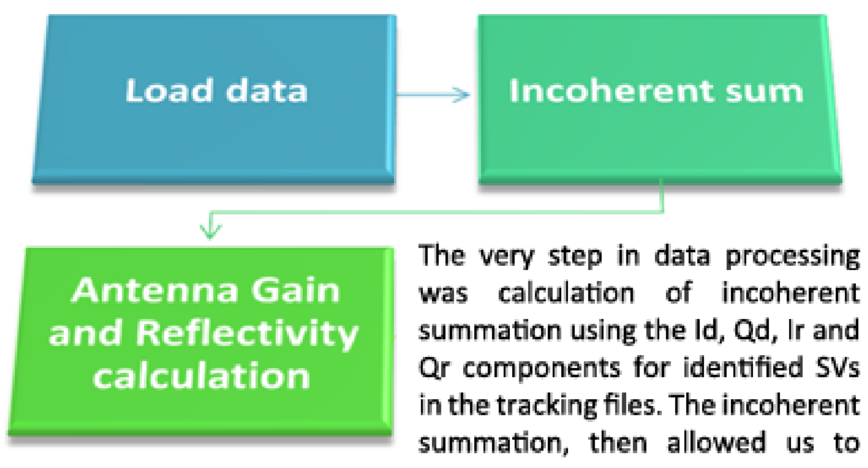
Yang (2013)

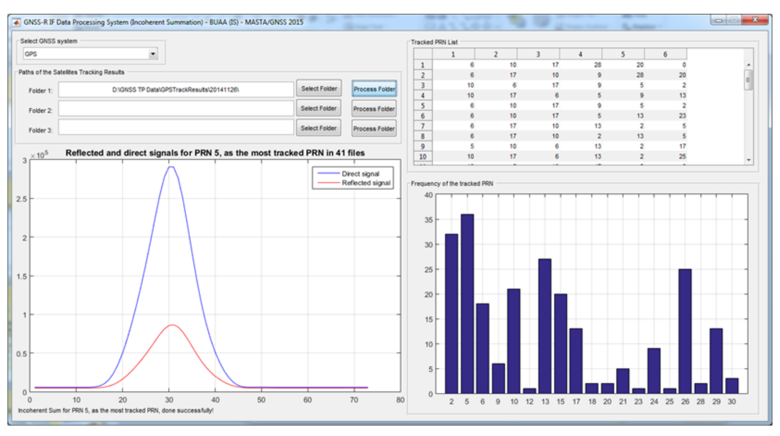
Methods and results - LS1525215

In this project we used BDS/GPS IF data previously collected by Shandong Taian Meteorological Station Administration from November, 26, 2014 to November, 28, 2014. A brief summary of BDS/GPS tracking correlation values is provided in the below.

	BDS			GPS			Total
	2014.11.26	2014.11.27	2014.11.28	2014.11.26	2014.11.27	2014.11.28	3 days
From	9:55:18	9:00:54	8:55:41	10:00:31	9:06:07	9:00:54	---
To	17:03:05	17:00:50	16:55:37	16:57:32	16:55:37	17:00:50	---
Duration	7:07:47	7:59:56	7:59:56	6:57:01	7:49:30	7:59:56	---
Tracking Results (.mat files)	42	47	47	41	46	47	270
Tracking Interval	0:10:26	0:10:26	0:10:26	0:10:26	0:10:26	0:10:26	---
Total Data Size (GB)	8.68	9.69	9.78	20.6	22.6	23.6	94.95

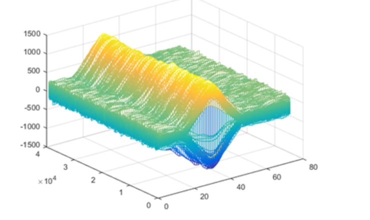
Furthermore, we got also the BDS/GPS satellites azimuth and elevation angles data for the 3days and Soil Moisture (SM) True Values, measured hourly in the ground directly, from 10h to 17h. Measured SM values include percentage of SM in weight and volume.

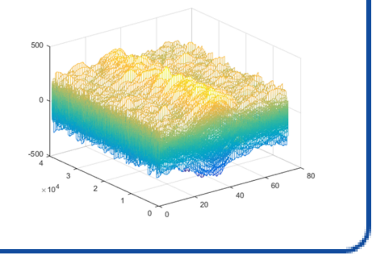




The very step in data processing was calculation of incoherent summation using the Id, Qd, Ir and Qr components for identified SVs in the tracking files. The incoherent summation, then allowed us to calculate the reflectivity and gain for the RHCP and LHCP antennas. The formula used to calculate incoherent summation is presented below. The RHCP and LHCP antennas gain was calculated using pre-written matlab functions. Done this step, the next one was calculation of soil relative permittivity and then soil moisture.

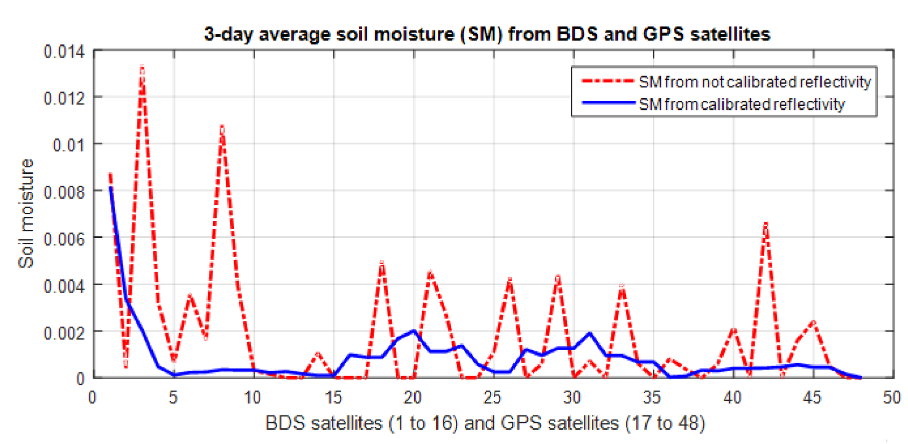
$$\mathrm{Incoh\_Sum} = \frac{\max(I_r^2 + Q_r^2)}{\max(I_d^2 + Q_d^2)}$$

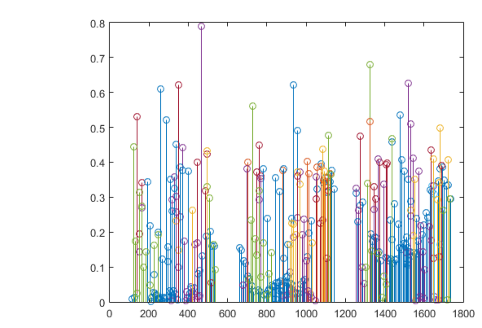


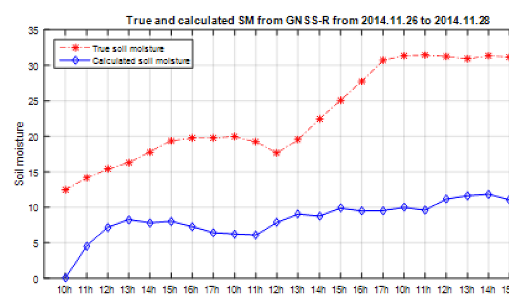


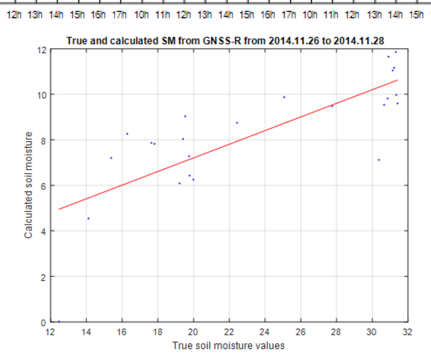
Methods and results - LS1525228

After calculating reflectivity, in the previous step, soil relative permittivity and soil moisture were calculated using non-calibrated reflectivity values. Then, reflectivity values were calibrated for antenna gain and soil roughness, and relative soil permittivity and soil moiture calculated again. The picture below shows a comparison between the soil moisture values calculated with (green line), without (magenta line) calibration and the error is shown in a red dashed line.









The formulas to calculate the soil relative permittivity and soil moisture are presented below:

$$\Gamma_{rl} = \frac{(\varepsilon_r - 1)^2 \sin^2\theta (\varepsilon_r - \cos^2\theta)}{\left(\varepsilon_r \sin\theta + \sqrt{\varepsilon_r - \cos^2\theta}\right)^2 \left(\sin\theta + \sqrt{\varepsilon_r - \cos^2\theta}\right)^2}$$

$$\varepsilon_r = 3.1 + 17.36 \cdot SM + 63.12 \cdot SM^2 + j \cdot (0.031 + 4.65 \cdot SM + 20.42 \cdot SM^2)$$

Conclusions

Studying GNSS-R for the first time was a great challenge and meanwhile interesting where a good knowledge has been obtained about GNSS-R principles and GNSS-R IF data processing for soil moisture calculation using matlab. Soil moisture sensitivity is generally regarded good for microwave signals at 1.4 Ghz. Basically soil moisture sensitivity is impacted by temperature, density of water and vegetation canopy, and some meteorological events such as rain.

Traditionally, GNSS-R data collection uses two antennas, RHCP for direct signals and LHCP for reflected signals. Nevertheless, nowadays there are some research works on GNSS-R applications using 3 antennas, one up-looking, to receive direct signals and two down-looking, to receive reflected signals. The data used in our project were collected using two antennas.

Some publications about GNSS-R application in soil moisture remote (SM) sensing use SM models based on a flat surface. However, if high accuracy concerns our work, we should consider different factors in the SM model such as soil surface roughness, vegetation canopy and system noise in order to refine our results.

References

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Internation School
GNSS
MASTA
2015
Beijing, China
June 2016

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