Soil Moisture Content Detection based on GNSS Reflected Signal and its applications

YANG Dongkai
School of Electronic and Information Engineering
BeiHang University
edkyang@buaa.edu.cn

OUTLINE

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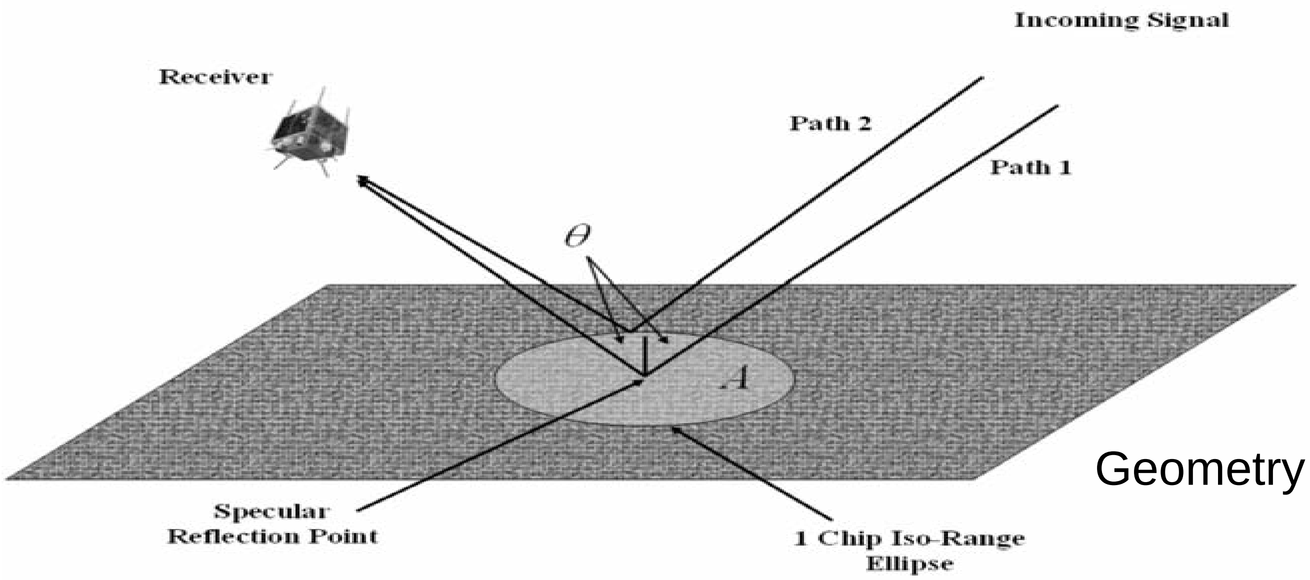
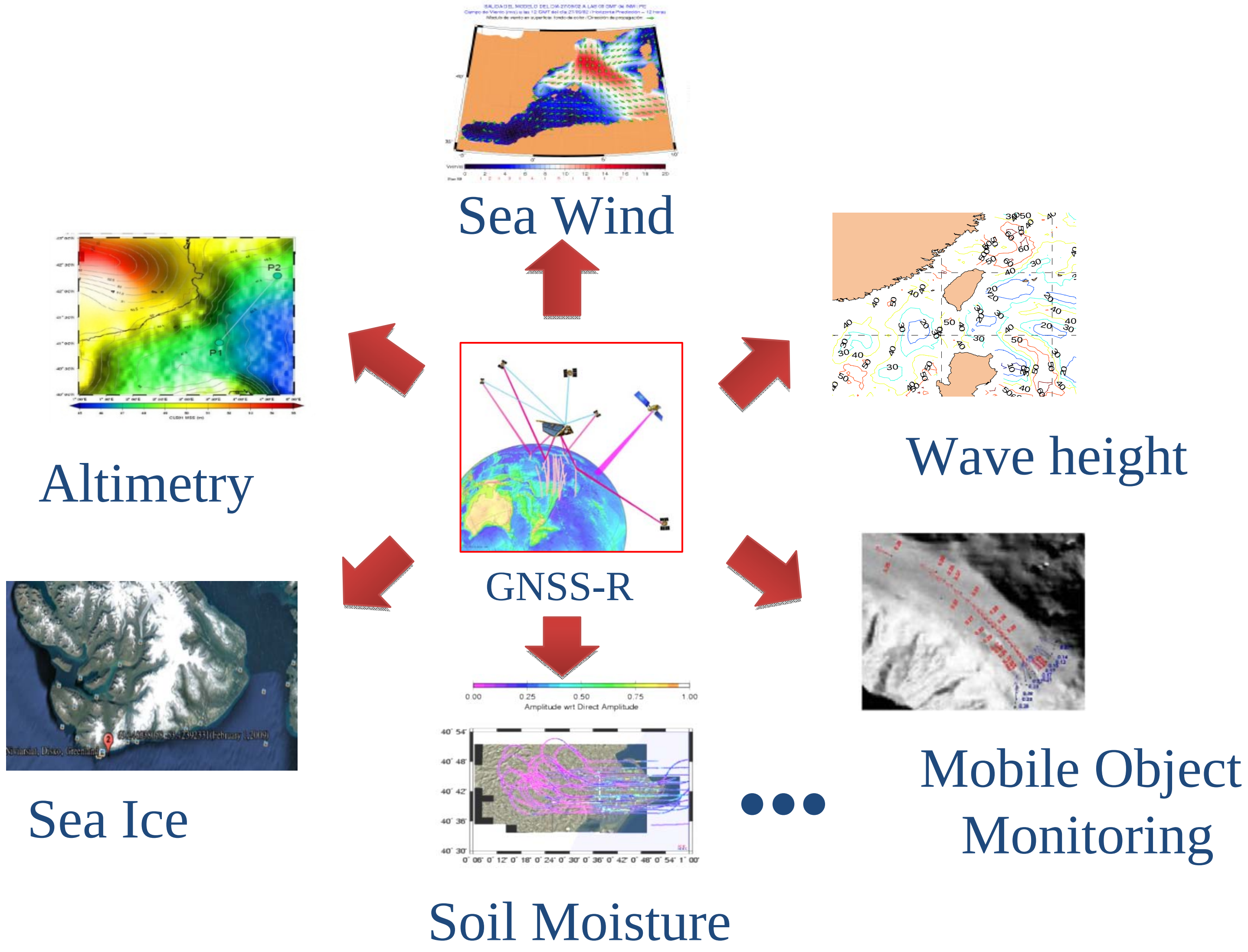
1. Introduction

- GNSS signals scattered from ocean, land and ice are affected by the reflecting surface, and the changes induced by the surface can be observed [1] .
- Understanding what exactly is being sensed and what accuracy will drive the future applications of this novel technique.



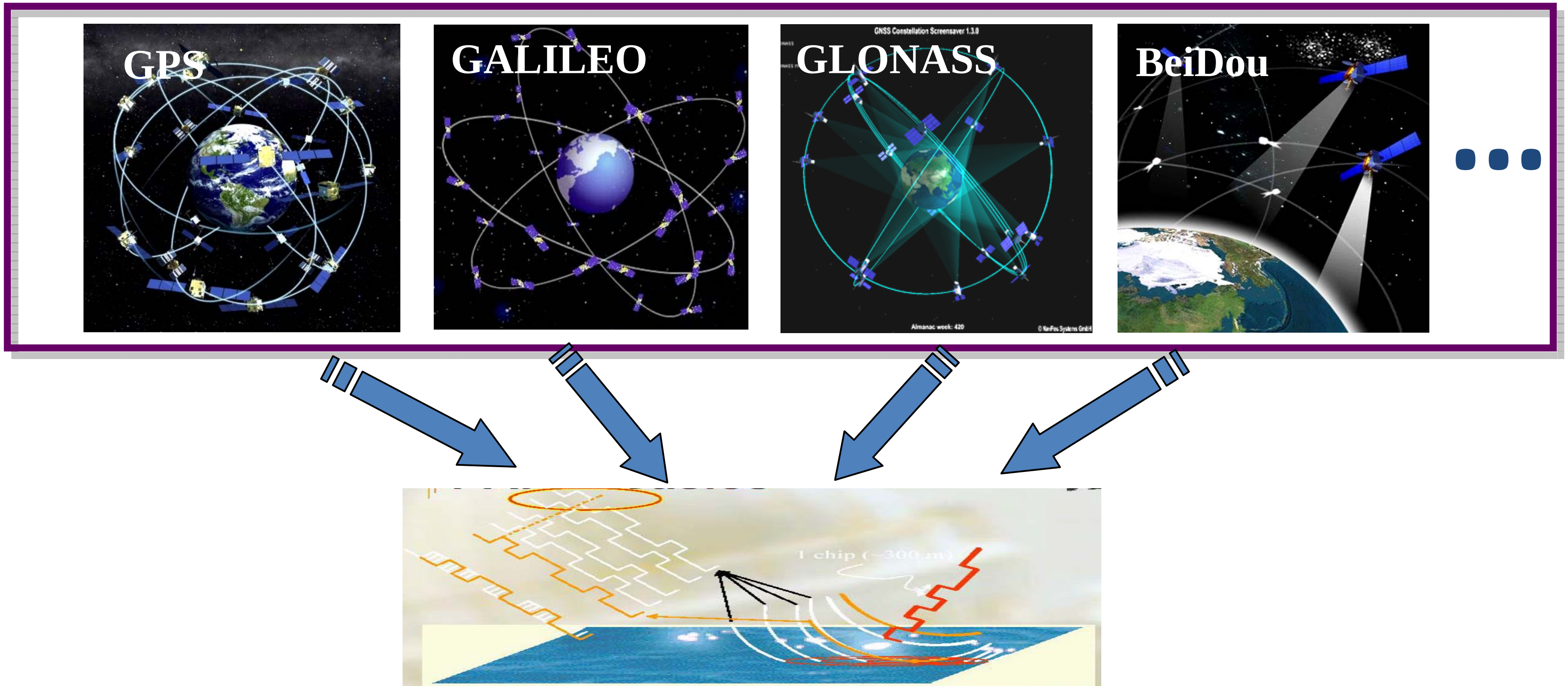
Geometry of GNSS-R [2]

Applications of GNSS-R



2. GNSS Signal Characteristics

- The full-time operation of radio navigation satellites system;
- Free, abundant global signal resources;
- Spread spectrum communication for flexible processing;
- Reflections theory of radio signals.



GNSS Signals[3]

System	Carrier	Modulation	Multiple Address
GPS	L1/L2/L5 L1C/L2C	BPSK/BOC/TM BOC/QPSK	CDMA
Galileo	E1/E5/E6 E5a/E5b	BOCc/CBOC Alt BOC BPSK	CDMA
GLONASS	L1/L2/L3	BPSK/QPSK	FDMA/CDMA
BeiDou	B1/B2/B3	MBOC/BOC Alt BOC QPSK	CDMA

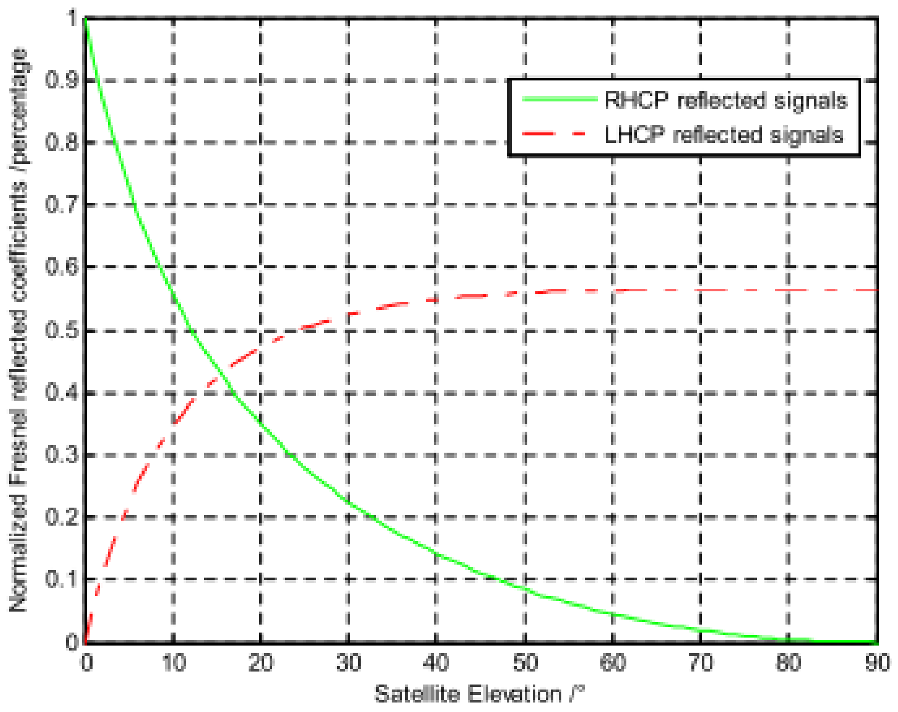
Polarization

➢Satellite signals direct to the earth

Designed as Right-Hand Circularly Polarized (RHCP).

➢Signals reflected from the earth

After scattering from earth surface, the polarization of navigation signal would be changed, where the Left-Hand Circularly Polarized (LHCP) component becomes the main one. And the LHCP component is increasing over the satellite elevation [4].



RHCP/LHCP components of Reflected Signal

Signal power

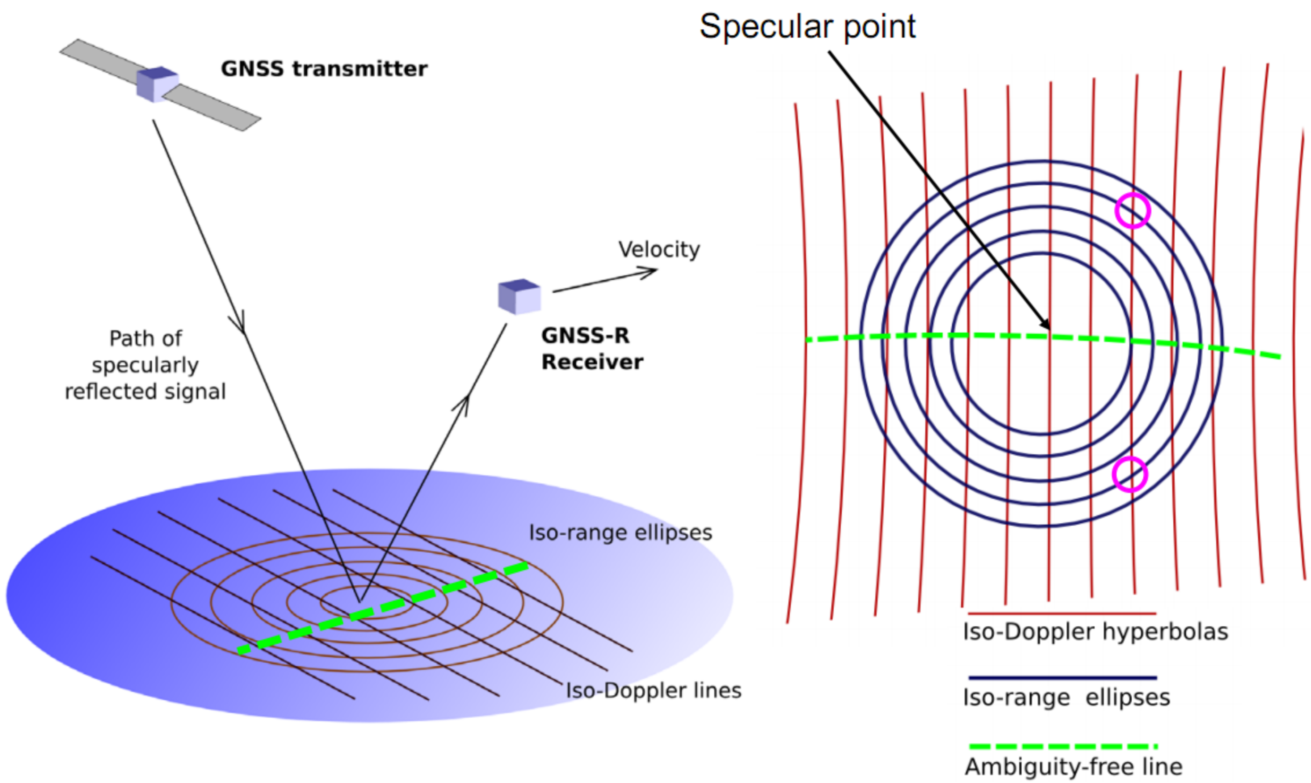
The reflections become very weak as the attenuation over the reflected area and propagation path. High gain antenna and accumulation would be necessary for the signal processing.

- Path Loss
  - the loss is being larger over the propagation distance

- Surface absorb
  - the surface absorb is changing with the different media

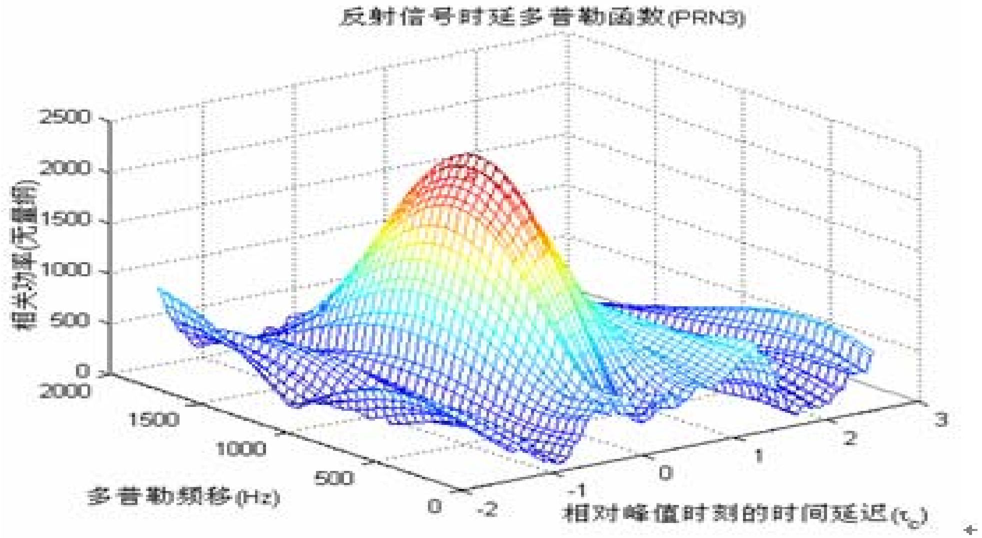
Geometry: Delay & Doppler shift

The delay at every point on the surface plot iso-range ellipse.
Similarly, Doppler frequency shift form iso-Doppler hyperbolas.



Correlation function

The properties of reflected GNSS signal can be described by DDM (Delay Doppler Map), which are the correlation values distribution of the reflected signal over a two-dimensional space, i.e. time delay and Doppler offset .



Scattering coefficient

$$\sigma_{soil} = \frac{P_r}{P_d}$$

$$\sigma_1 = \frac{P_{rRHCP}}{P_d}$$

$$\sigma_2 = \frac{P_{rLHCP}}{P_d}$$

GNSS scattering characteristics is the most uncertain factor in the observation system design, which directly impact on the engineering design of the GNSS-R receiver. The scattering characteristics of the GNSS radio wave with respect to the wave incident angle, dielectric constant, the antenna pattern, the roughness[5].

3. Soil Moisture Content Detection

- The GNSS reflect signal is sensitive to soil moisture, which means that GNSS-R has a potential in Soil Moisture Content (SMC) estimation. The specific values between the reflected and directed wave are used to calculate the soil moisture content.
- Widespread soil moisture monitoring using GNSS-R receiver network plays a crucial role in geophysical parameters retrieval.

Soil Moisture Detection: SMC model[6]

Traditional SMC model

reflectivity

↓

dielectric constant of soil

↓

SMC

$$\Gamma_{GPS} = P_r / P_d$$

Γ_{GPS} --reflectivity

P_r -- power of reflected signal

P_d -- power of direct signal

ε -- dielectric constant of soil

$$\Gamma = |R(\theta)|^2 \exp(-h\cos^2\theta)$$

$$h = 4k^2\sigma^2$$

$$\Gamma_{GPS} = |R(\gamma)|^2$$

$$R(\gamma) = \frac{1}{2}(R_v(\gamma) - R_h(\gamma))$$

$$R_v(\gamma) = \frac{\varepsilon\sin\gamma - \sqrt{\varepsilon - \cos^2\gamma}}{\varepsilon\sin\gamma + \sqrt{\varepsilon - \cos^2\gamma}}$$

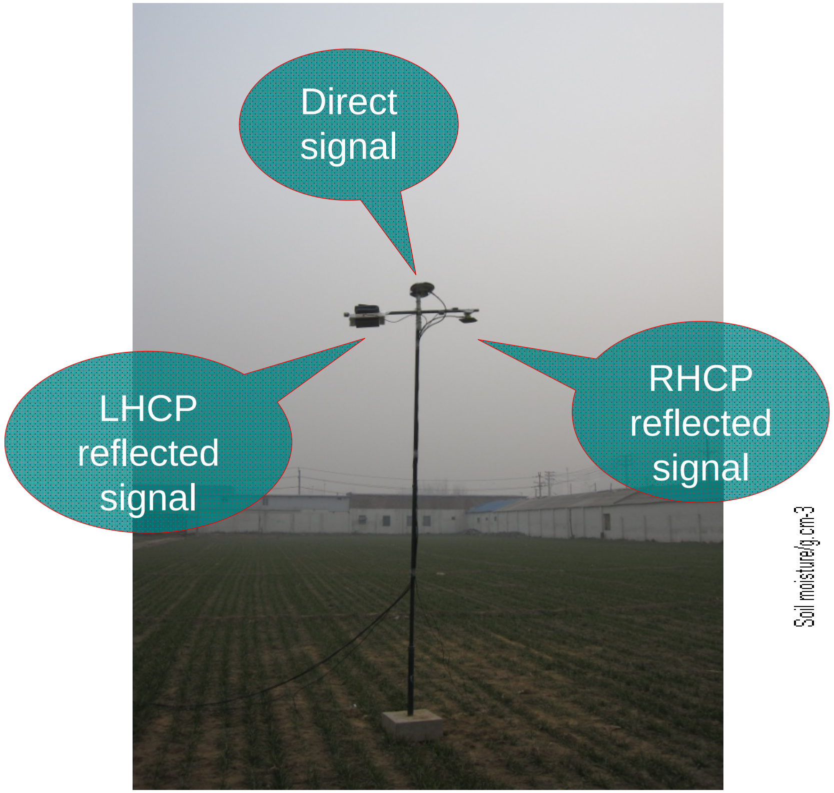
$$R_h(\gamma) = \frac{\sin\gamma - \sqrt{\varepsilon - \cos^2\gamma}}{\sin\gamma + \sqrt{\varepsilon - \cos^2\gamma}}$$

m_v -- soil moisture content

$$\varepsilon = (a_0 + a_1S + a_2C) + (b_0 + b_1S + b_2C)m_v + (c_0 + c_1S + c_2C)m_v^2$$

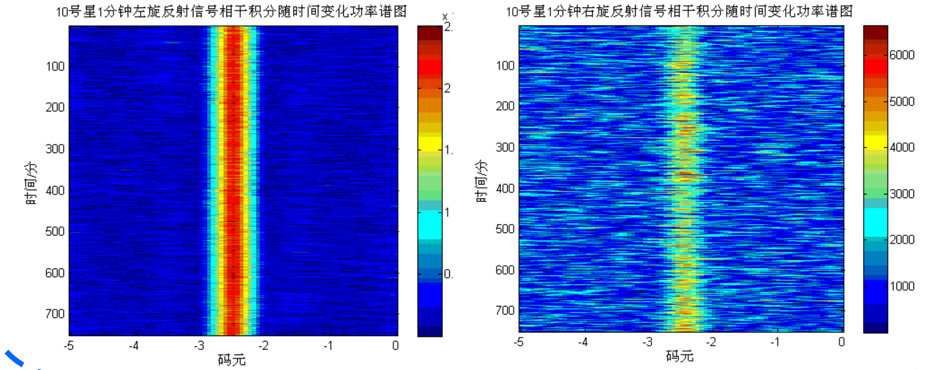
Instrument and Experiment: Case 1 [2]

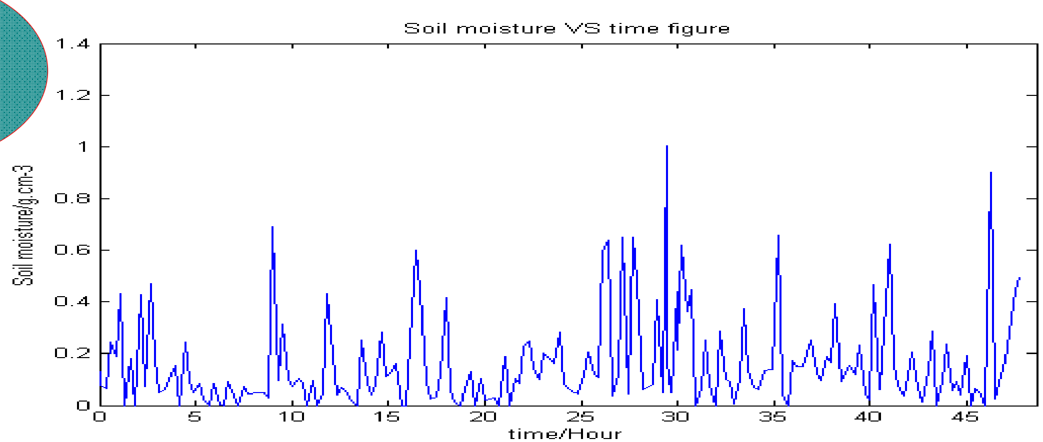
Soil moisture GNSS-R remote sensing experiment by using NSSC GNSS-R Software receiver



20ms Signal correlation power

nadir-pointing LHCP antenna **nadir-pointing RHCP antenna**



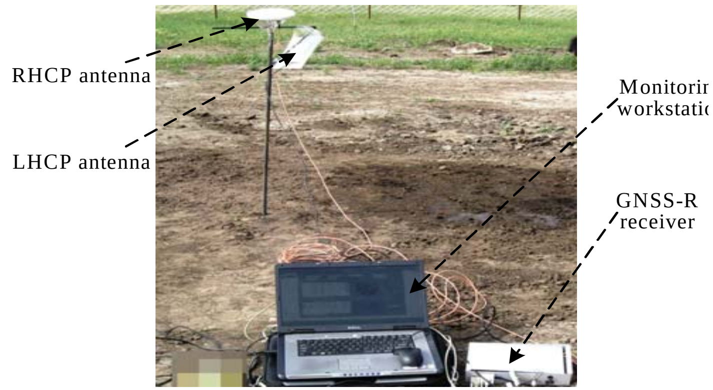


48hours Soil moisture result

Case 2 [6]

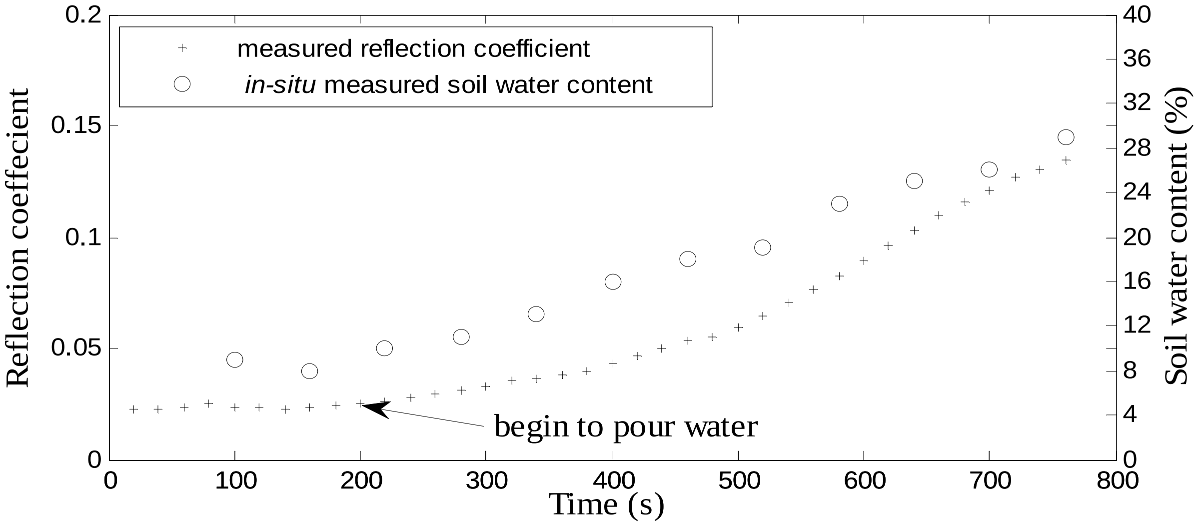
- Data collection in Hailaer Inner Mongolia, May 2009

- Experiment was performed on bare land



System installation during the ground-based experiments

Data processing results show that the GNSS reflection signal changes over the soil moisture, which has the same trend with the hygrometer



Comparison between reflection coefficient and *in-situ* measured water content

4. Applications of SMC

- Monitoring network is aimed to be established in specific area
- The BeiDou, GPS, GLONASS and GALILEO signals would be used
- Data fusion could be used for high precision detection of Soil moisture
  - Multiple constellations data fusion
  - Multiple satellite data fusion within one constellation, i.e. one GNSS system

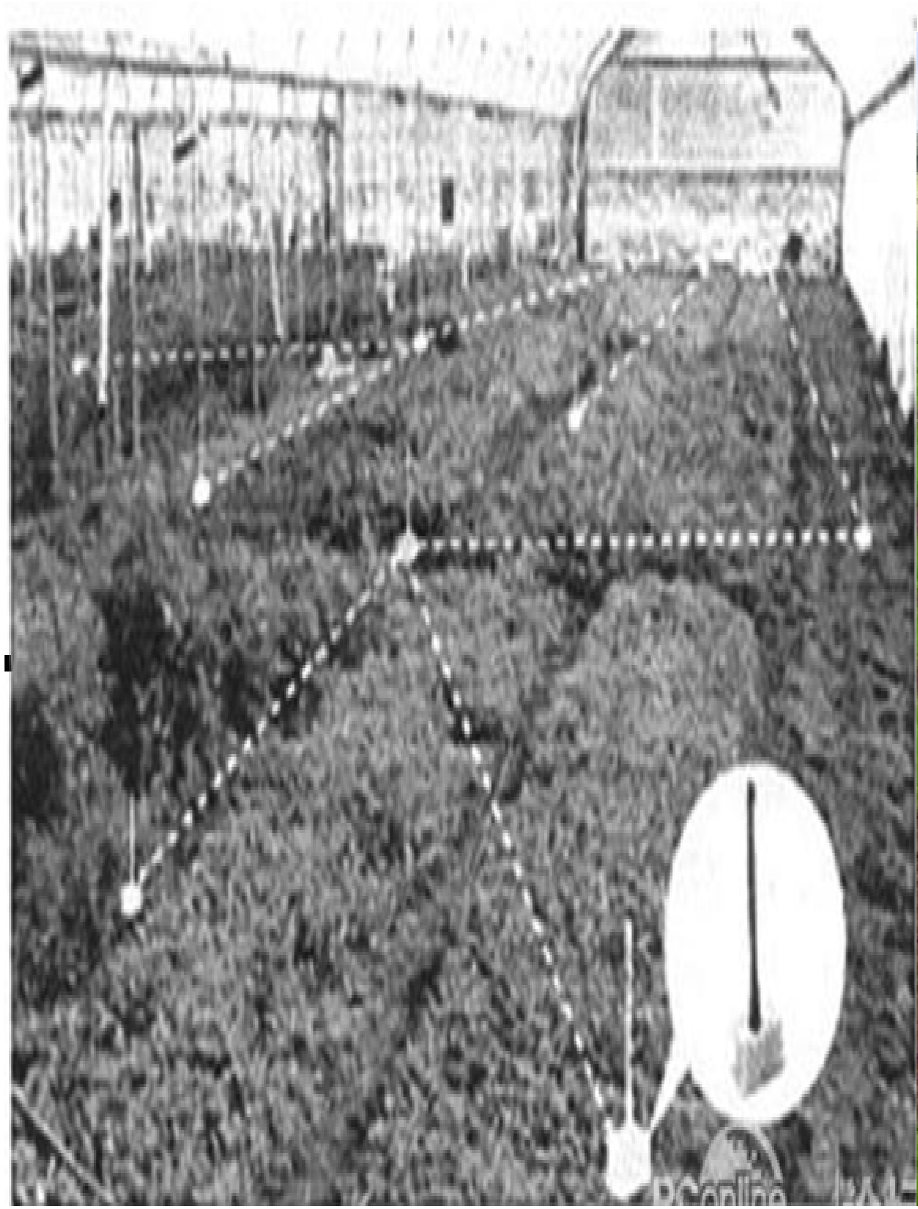
Research applications

- The existing research has shown that GNSS remote sensing has the potential to give environmental scientists a low-cost, wide-coverage measurement network that will greatly increase our knowledge of the Earth’s environmental processes[7].

- All of the previous work taken together makes a promising case for the future of this technology, and still in need of much further study.

Case 1: Climate Changes

Case 2: Precise agriculture



5. Summary

➢GNSS-R could be used for the soil moisture content monitoring

➢The GEO, IGSO and MEO constellations from BeiDou system are quite useful for the specific area observation on the earth

➢Soil Moisture Content (SMC) could be used for the scientific applications such as climate changes analysis, precise agriculture and even the environment protection.

Reference

[1]Eni G. Njoku , Dara Entekhabi, Passive microwave remote sensing of soil moisture [J] Journal of Hydrology ,1996,184 : 101-129

[2]M. Martin-Neira, P. Colmenarejo, G. Ruffini, C. Serra, "Ocean Altimetry using the Carrier Phase of GNSS Reflected Signals," Proceedings of Ocean Winds 2000, Plouzane, France, CERSAT News, Issue 11, November 2000.

[3]B Hofmann- Wellenhof; Herbert Lichtenegger; Elmar Wasle, GNSS ---global navigation satellite systems : GPS, GLONASS, Galileo, and more[M] Wien ; New York : Springer, 2008:232-307

[4]S.T. Gleason, S. Hodgart, S. Yiping, C. Gommenginger, S. Mackin, M. Adjrad and M. Unwin. Detection and Processing of Bistatically Reflected GPS Signals from Low Earth Orbit for the Purpose of Ocean Remote Sensing.[J] IEEE Transactions on Geoscience and Remote Sensing, Vol. 43, No. 6, June 2005 pp. 1229-1241.

[5]Long, Maurice W. Radar reflectivity of land and sea [M] Artech House, Boston, London, 2001

[6] Song Xuezhong, Xu Aigong,Yang Dongkai , Soil Moisture measuring application on the basis of GNSS Reflected Signals[C] Lecture Notes in Electric Engineering--China Satellite Navigation Conference 2012 Proceedings, Guangzhou, 2012,05

[7] Egido.A, Ruffini .G. Soil moisture monitorization using GNSS reflected signals.[J] IEEE Transactions of Geoscience and Remote Sensing ,2008, 7(3)：53—56.

Thank you!

YANG Dongkai

edkyang@buaa.edu.cn