

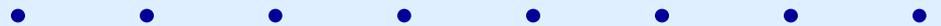
# 2018 Dragon 4 Symposium

## Soil Moisture Monitoring Using GNSS SNR Data: Proposing a Semi-empirical SNR Model

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# OUTLINES

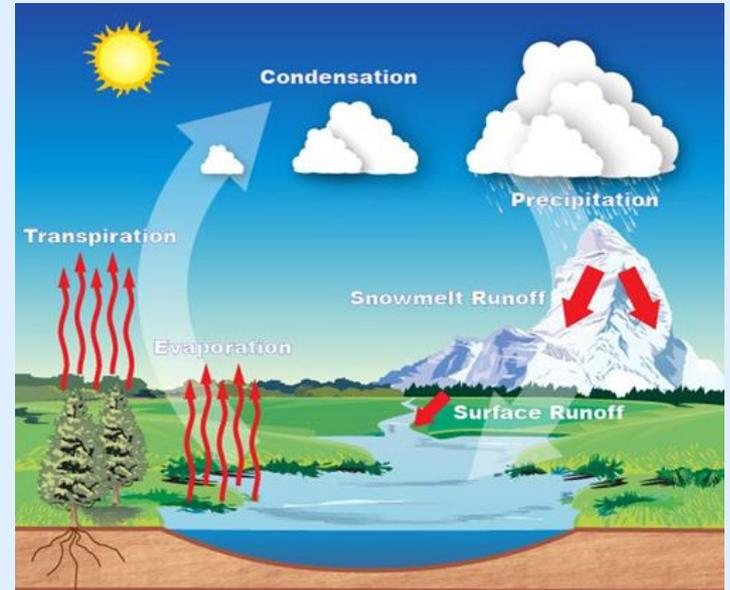
1. GNSS-IR FOR SOIL MOISTURE
2. SIMULATIONS
3. EXPERIMENTAL DATA VALIDATION
4. DISCUSSION AND CONCLUSION
5. FUTURE WORK



# 1. GNSS-IR FOR SOIL MOISTURE

**Soil moisture content (SMC) is an environmental descriptor that integrates much of the land surface hydrology.**

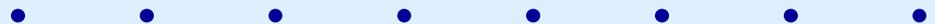
**It does play an important role in human life.**



**There are many methods for soil moisture measurement.**

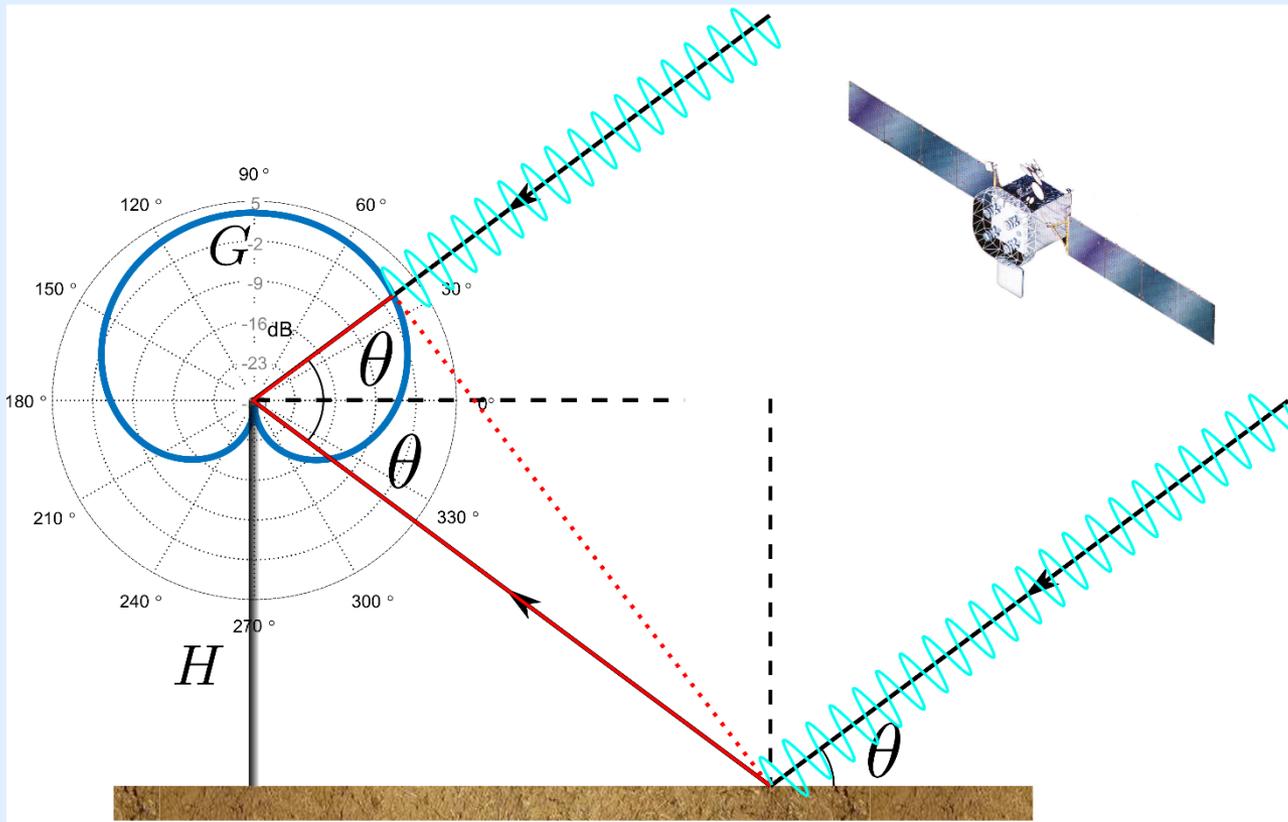
**GNSS-IR technique**

- **Economical**
- **Flexible**
- **Work all weather and all day**
- ...



# 1. GNSS-IR FOR SOIL MOISTURE

## 1.1 Reflection geometry



$G$  : Antenna gain

$H$  : Antenna phase center height

$\theta$  : Satellite elevation angle

# 1. GNSS-IR FOR SOIL MOISTURE

## 1.2 Theoretical model

$$SNR = SNR_d + SNR_r + 2\sqrt{SNR_d \cdot SNR_r} \cos\left(\frac{4\pi H}{\lambda} \sin(\theta) + \phi\right)$$

$$\frac{SNR_r}{SNR_d} \approx \frac{G_r}{G_d} \cdot |\Gamma|^2$$

$$\Gamma = \frac{(1 - \epsilon_r) \cos^2 \theta}{\left(\sin \theta + \sqrt{(\epsilon_r - \cos^2 \theta)}\right) (\epsilon_r \sin \theta + \sqrt{(\epsilon_r - \cos^2 \theta)})}$$

$$\epsilon_r = 2.8603 + 3.7463 \cdot SMC + 119.1755 \cdot SMC^2$$

Where:

$SNR_d$  : SNR of the direct signal;  $SNR_r$ : SNR of the reflected signal;

$\lambda$ : carrier wave length;  $\phi$ : initial phase;  $G_d, G_r$ : antenna gain;

$\Gamma$ : reflection coefficient;  $\epsilon_r$ : relative permittivity ;  $SMC$ : soil moisture content;

# 1. GNSS-IR FOR SOIL MOISTURE

## 1.2 Semi-empirical SNR model development

$$SNR = SNR_d + SNR_r + 2\sqrt{SNR_d \cdot SNR_r} \cos\left(\frac{4\pi H}{\lambda} \sin(\theta) + \phi\right)$$

Let:

$$p^{n0}(\sin\theta) = \log_{10}(SNR_d),$$

$$p^{n1}(-\sin\theta) = \log_{10}(SNR_r)$$

Where:

$p^{n0}(\cdot)$  : 2<sup>nd</sup> order polynomial function

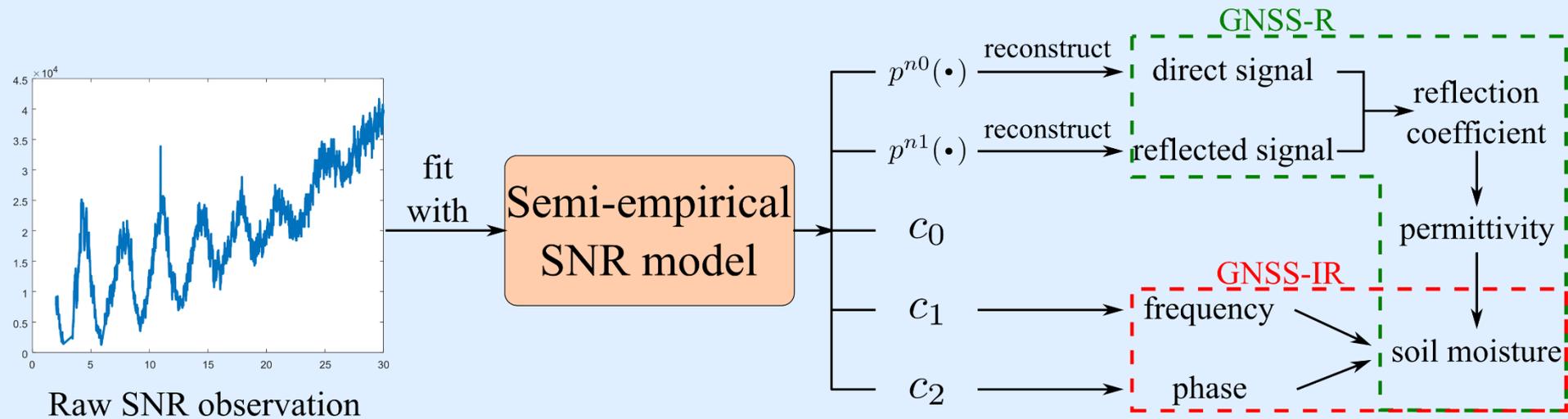
$p^{n1}(\cdot)$  : 4<sup>th</sup> order polynomial function

Finally:

$$SNR = c_0 \left[ 10^{\frac{p^{n0}(\sin\theta)}{10}} + 10^{\frac{p^{n1}(-\sin\theta)}{10}} \right]$$

# 1. GNSS-IR FOR SOIL MOISTURE

## 1.3 How this model can be used to retrieve SMC

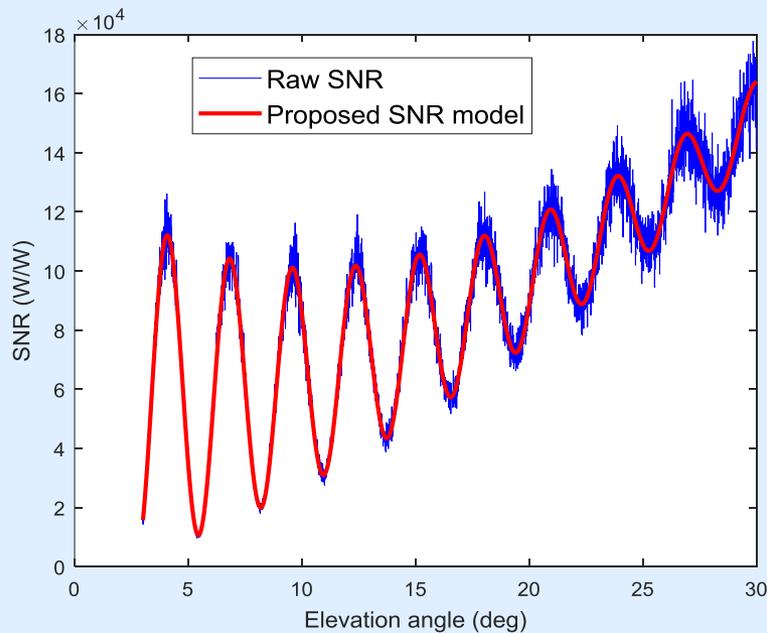


From the reconstructed signals, soil permittivity can be estimated, after which SMC can be retrieved using well established soil dielectric models on microwave frequencies.

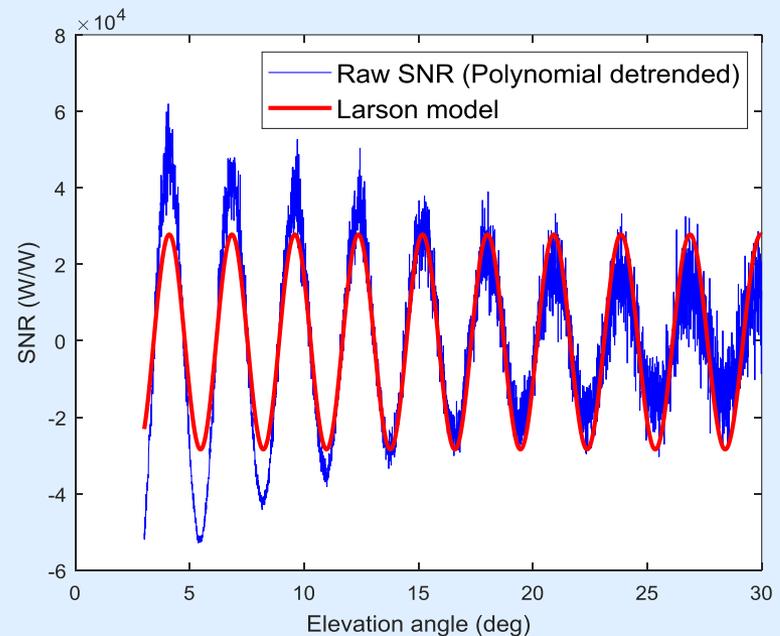
The estimated frequency and phase information can be used to study how they are related to soil moisture empirically as proposed by K. M. Larson et al.

# 2. SIMULATIONS

## 2.1 Fitting quality comparison



The goodness of fit is 94.95%

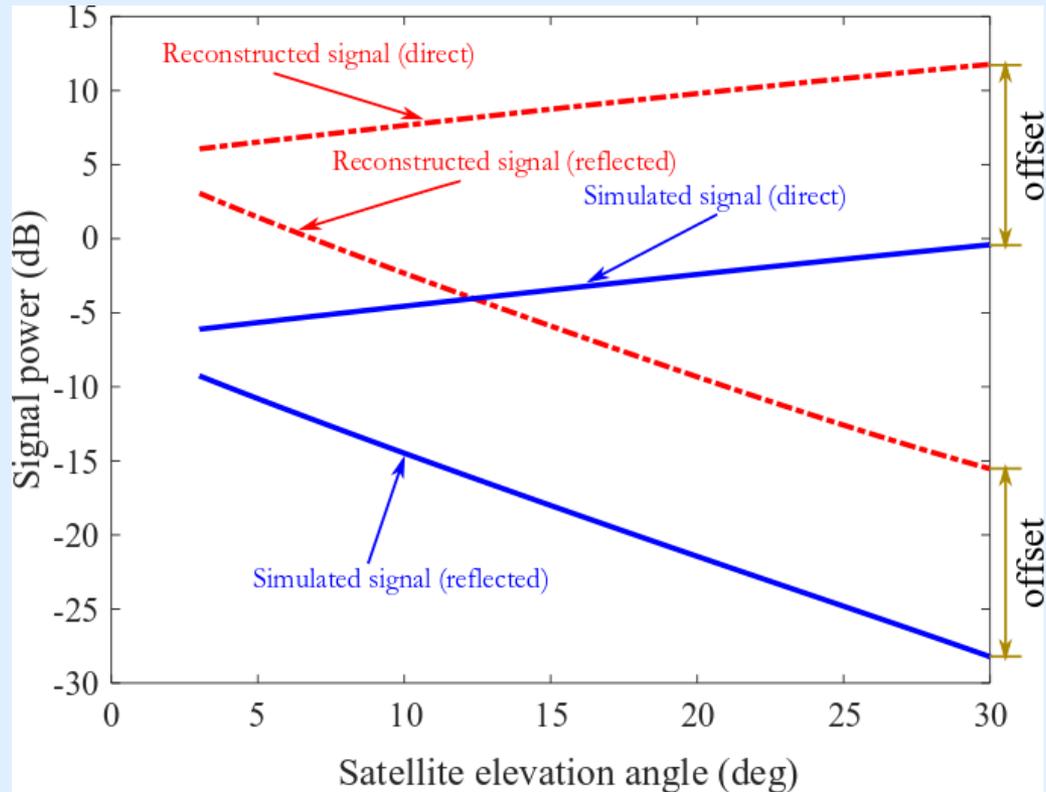


The goodness of fit is 55.80%

The “Quality of fit” of the proposed model is about 40% better than Larson model that uses polynomial de-trending followed by cosine modeling.

# 2. SIMULATIONS

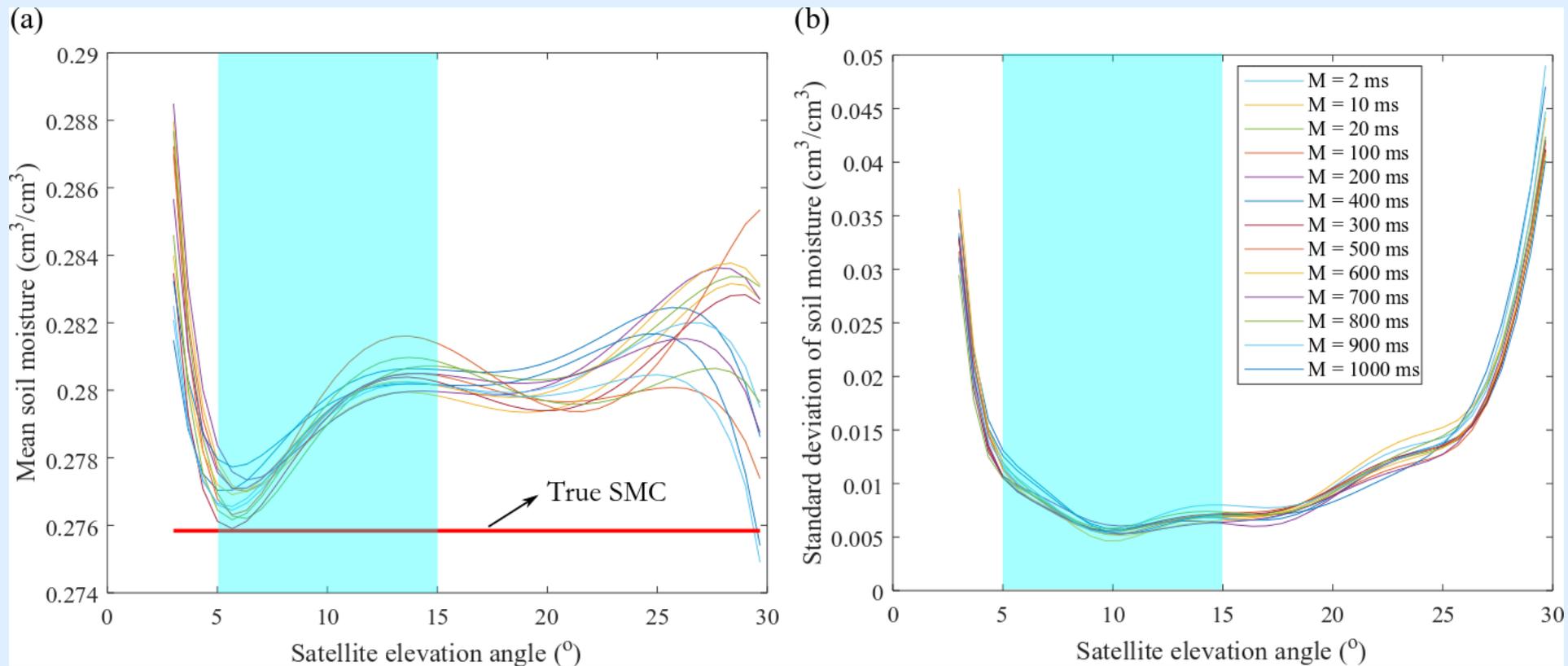
## 2.2 Signals reconstruction



The proposed model cannot reconstruct the signals absolutely. However, since the offset is nearly the same on both the reconstructed direct and reflected signal, it can be cancelled in the subsequent processing.

# 2. SIMULATIONS

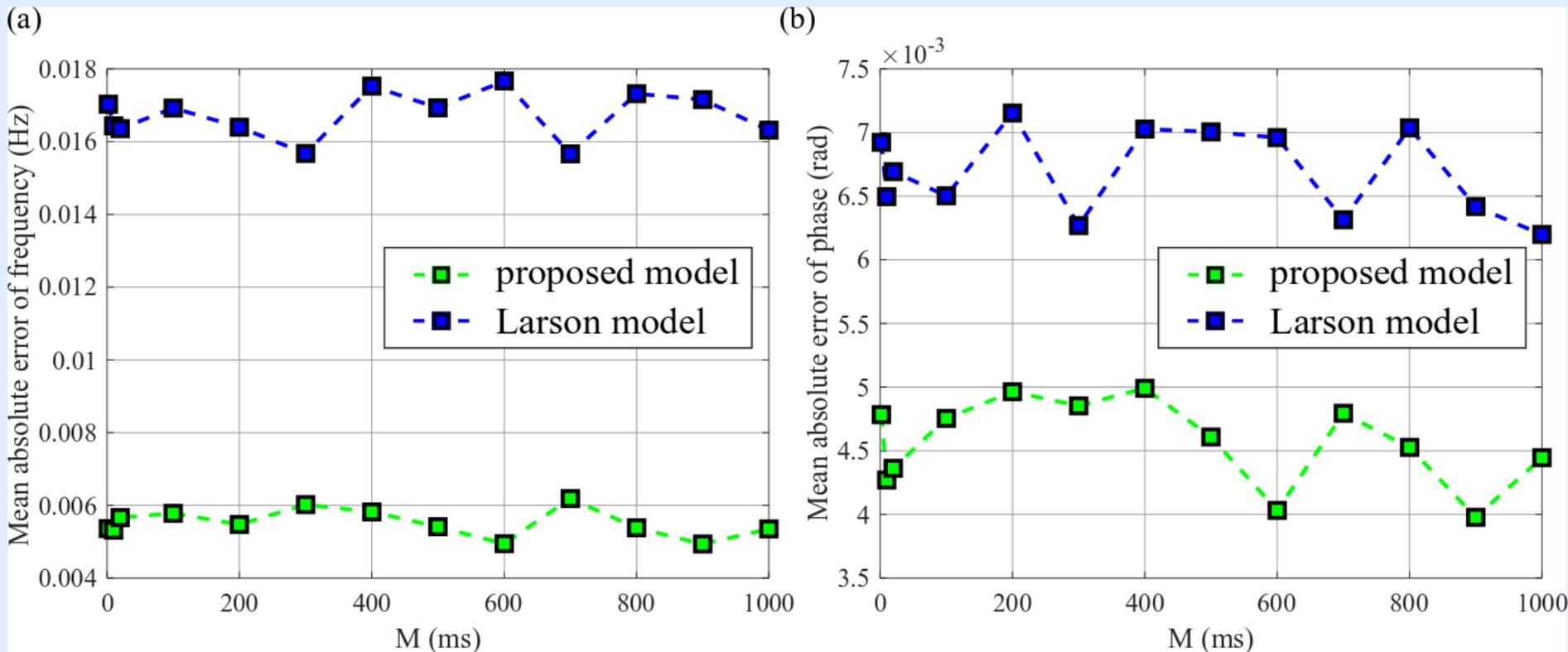
## 2.3 SMC retrieval from reconstructed signals



The SMC retrieval is more satisfactory when the satellite elevation angle is **between 5 degrees and 15 degrees** regarding the mean estimation error (a) and standard deviation (b). M is the number of coherent accumulation used in simulating SNR data.

# 2. SIMULATIONS

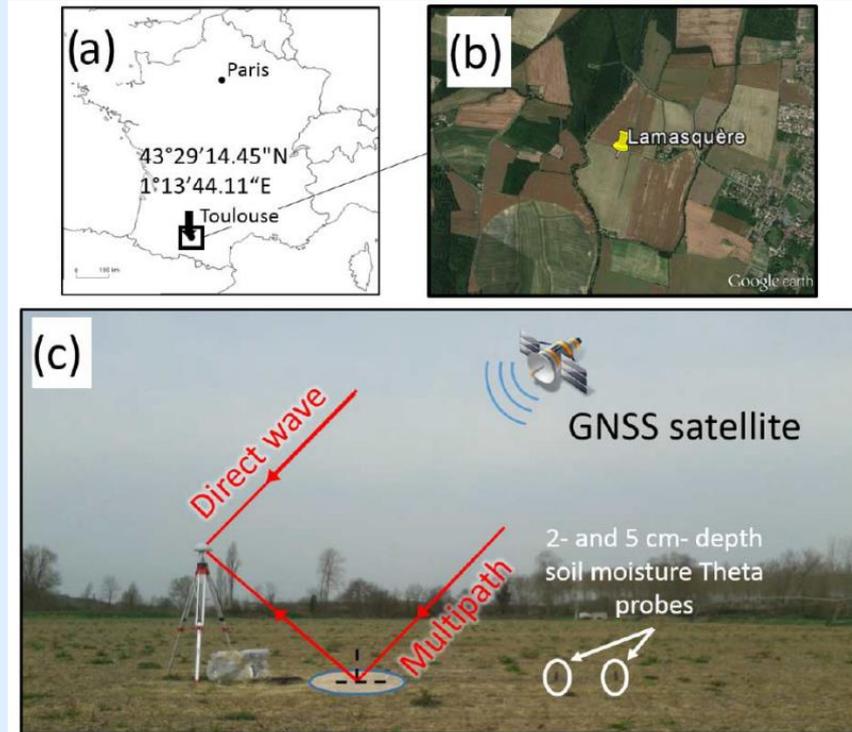
## 2.3 Frequency and phase estimation



Both the frequency (a) and phase (b) estimation error obtained from the proposed model were reduced. **However, the extent of reduction is different. The improvement on phase estimation can be neglected using the proposed model (figure b).**

# 3. EXPERIMENTAL DATA VALIDATION

## 3.1 Data set description



Time span: 5th of February 2014 ~  
15th of March 2014

Location: Lamasquère, France

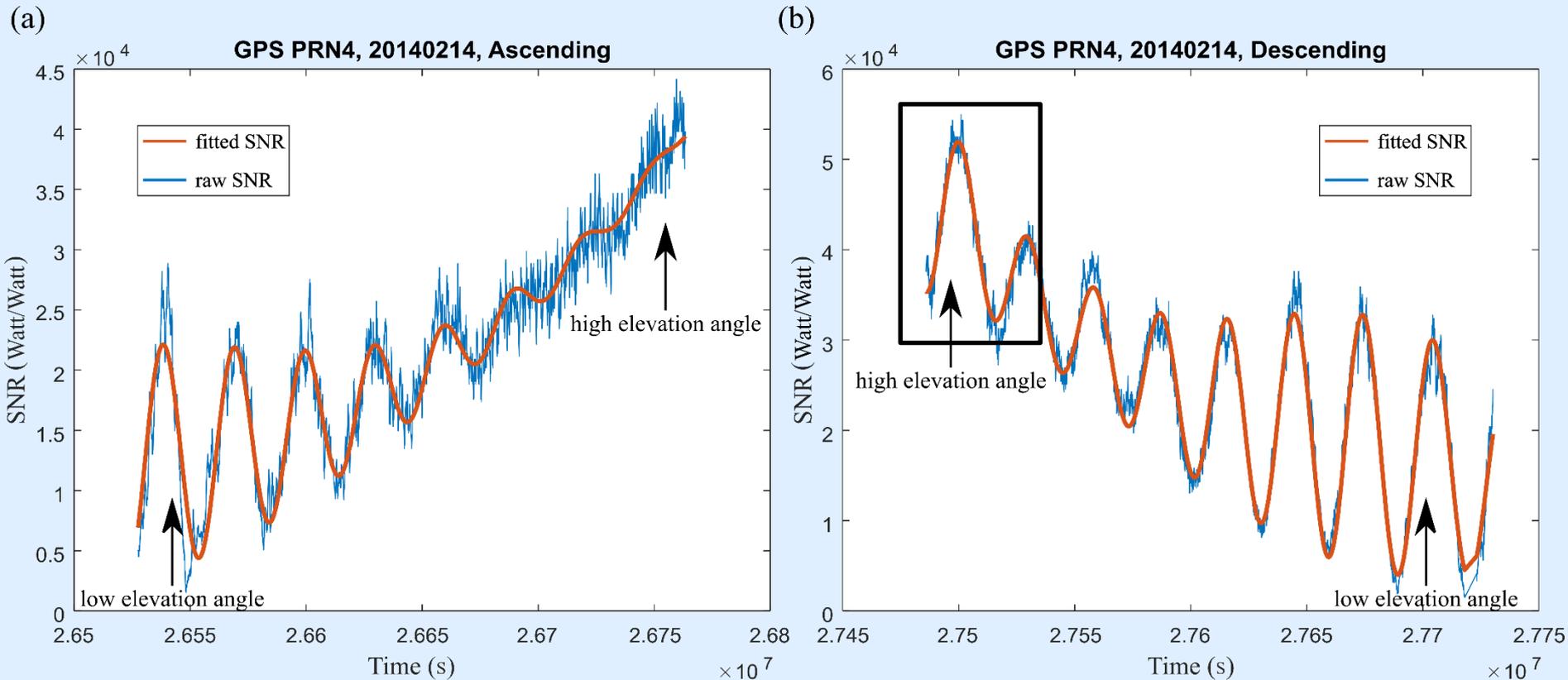
Soil type: silt clay (18% sand, 41%  
clay and 41% silt)

SMC variation: 24.08~29.78% (5 cm)  
10.46~15.85% (2 cm)

*Roussel, N.; Frappart, F.; Ramillien, G.; Darrozes, J.; Baup, F.; Lestarquit, L.; Ha, M.C. Detection of Soil Moisture Variations Using GPS and GLONASS SNR Data for Elevation Angles Ranging From 2° to 70°. IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. 2016, 9, 4781–4794.*

# 3. EXPERIMENTAL DATA VALIDATION

## 3.2 Fitting results

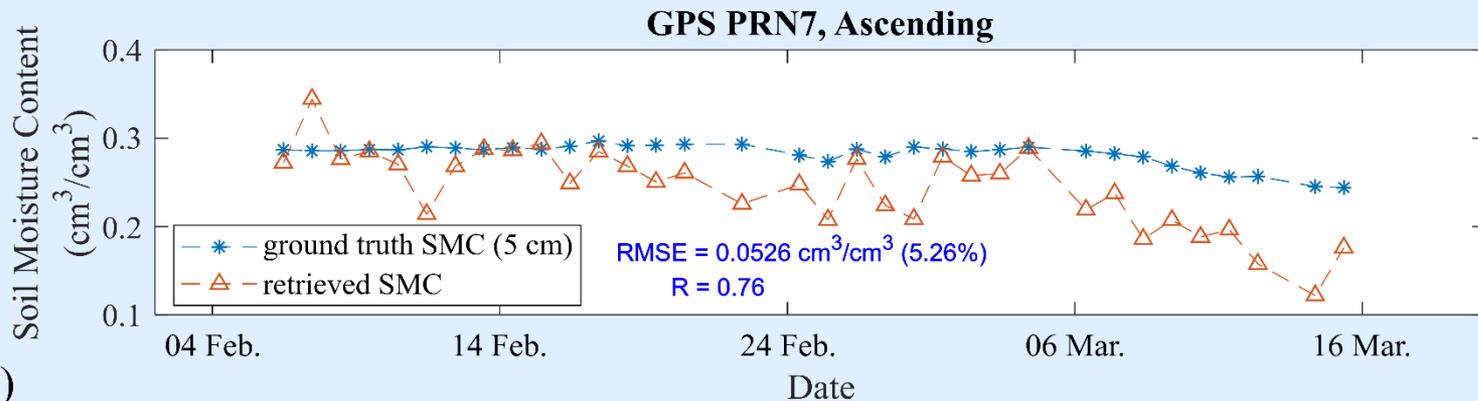


The quality of fit is 91.23% (a) and 93.92% (b), respectively. Note that in figure (b), irregular variation happened at high elevation angle since the interference amplitude suddenly increased. The proposed model could track this irregular variation adequately.

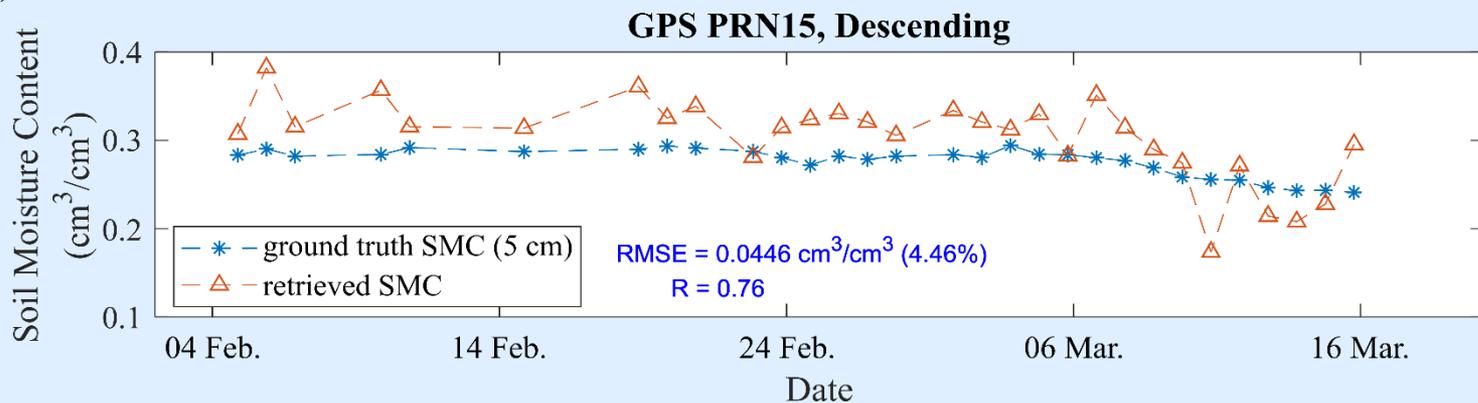
# 3. EXPERIMENTAL DATA VALIDATION

## 3.3 SMC retrieval from reconstructed signals

(a)



(b)



The results with best RMSE was given after antenna gain and soil roughness correction were applied. The elevation angle we used was  $10^\circ$ .

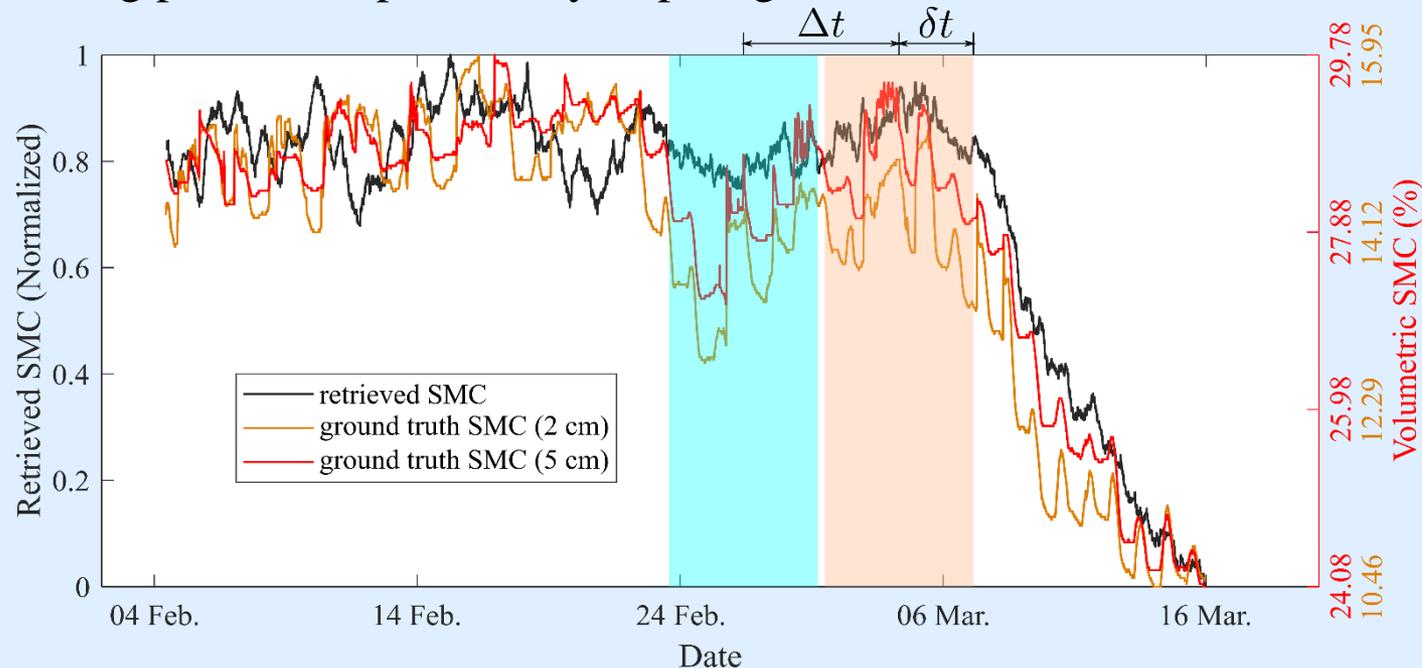


$$R(\theta) \approx \frac{p^{n1}(\sin \theta)}{p^{n0}(-\sin \theta)} \cdot \frac{G_d(\theta)}{G_r(-\theta)} \cdot \exp\left(\frac{16\pi^2}{\lambda^2} \sigma^2 \sin^2 \theta\right)$$

# 3. EXPERIMENTAL DATA VALIDATION

## 3.4 Further comparison

Further comparison were carried out by normalizing all the satellites' retrievals, then combining them into a time series, and finally using a moving window to smooth the results. The smoothing process is specified by step length  $\Delta t$  and half window width  $\delta t$ .

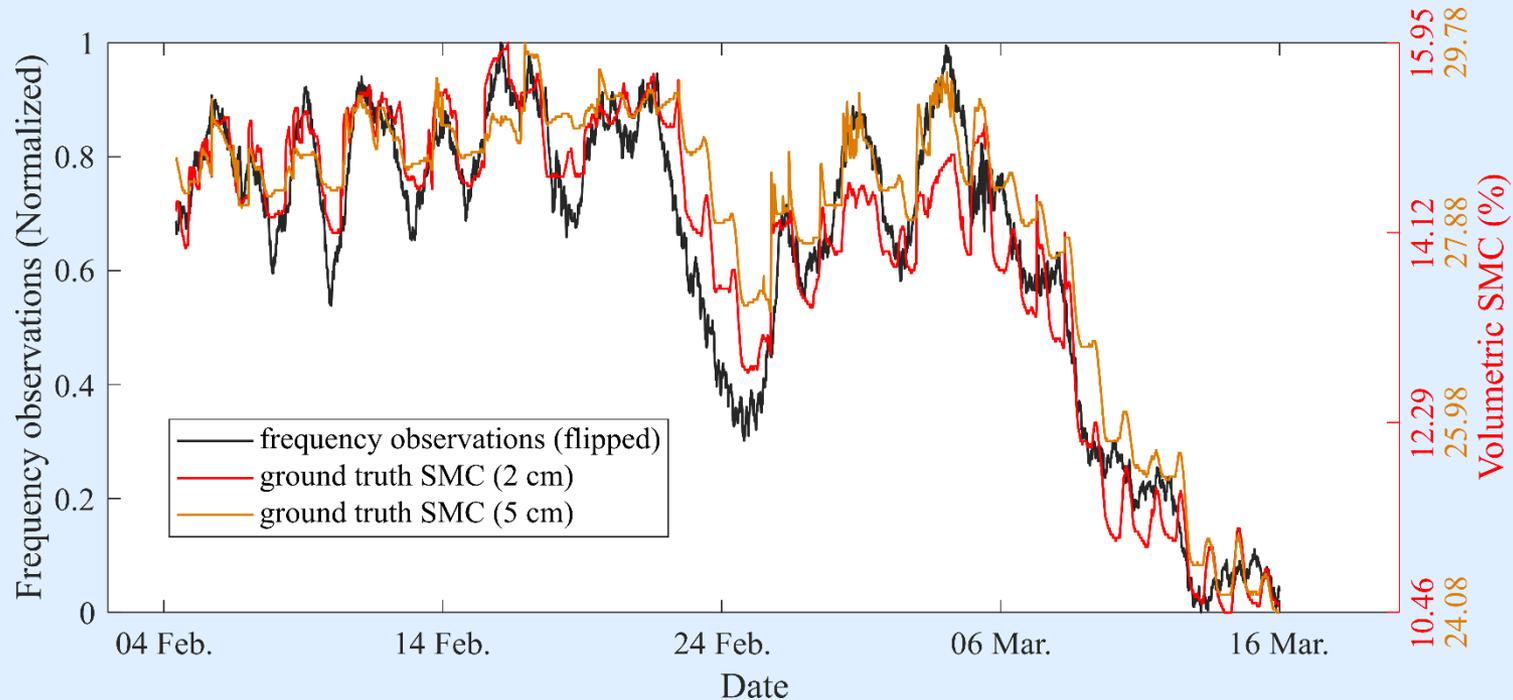


The resulting correlation coefficient with 5-cm SMC was 0.9370, while the correlation coefficient with 2-cm SMC was 0.8824 ( $\Delta t = 10$  min,  $\delta t = 20$  h). **The result was improved** compared with that obtained using Larson model which was 0.72 ( $\delta t = 55$  h, 2-cm SMC).

# 3. EXPERIMENTAL DATA VALIDATION

## 3.5 Correlation between SMC and frequency/phase estimation

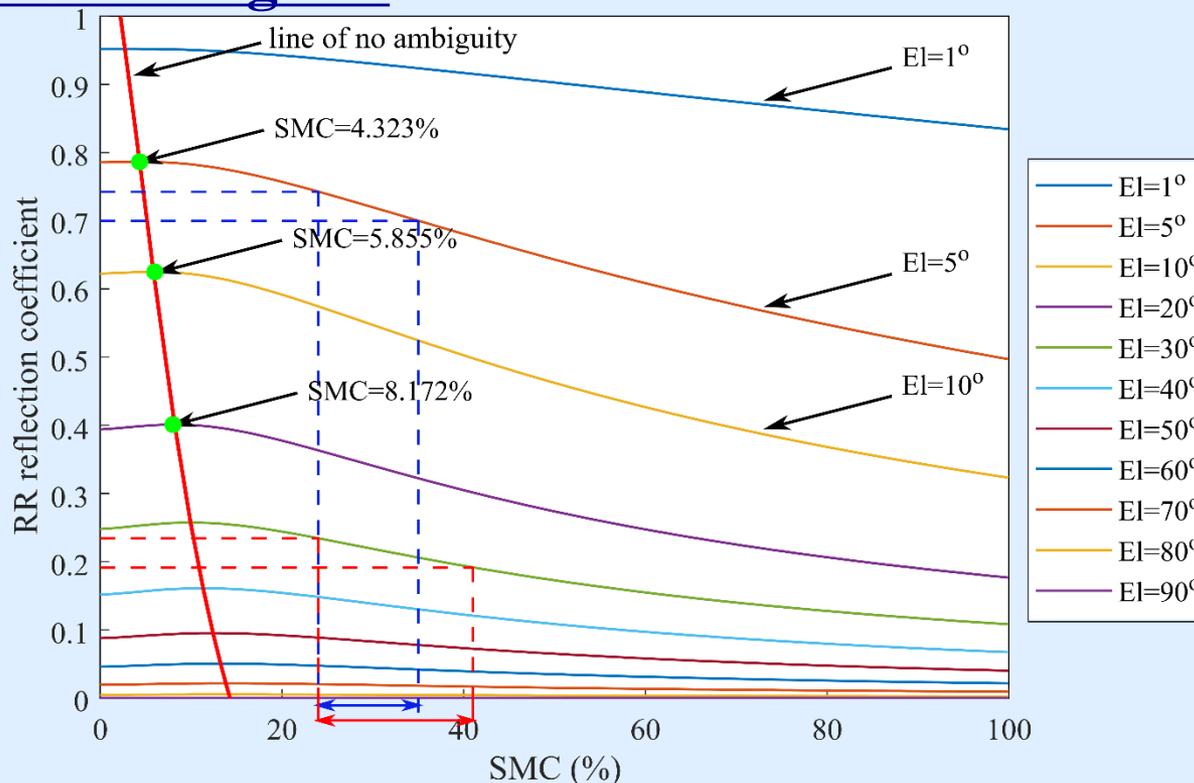
Same strategy was applied to frequency/phase Estimation according to section 3.4.



The correlation coefficient between frequency observations and 2-cm SMC was improved to 0.9548 (absolute value,  $\delta t = 11$  h) as compared with previous work which was 0.90 ( $\delta t = 11$  h, 2-cm SMC). However, The correlation coefficient regarding phase estimation was 0.9301 with  $\delta t = 8$  h, which was slightly degraded compared with the result from previous work, which was 0.95 ( $\delta t = 8$  h, 2-cm SMC).

# 4. DISCUSSION AND CONCLUSION

## 4.1 Retrieval ambiguity and error sensitivity using reconstructed signals



- The relationship between RHCP-RHCP reflection coefficient and SMC is not monotonic regardless of the elevation angle.
- The error sensitivity is dependent on elevation angle. The sensitivity is high on both ends of the elevation angle range.

# 4. DISCUSSION AND CONCLUSION

## 4.2 Conclusion

- By using this proposed SNR model, the quality of fit can be improved with little prior knowledge needed. It could ensure good fitting quality even in the case of irregular SNR variation. This advantage also results in better estimation of the frequency and phase information. However, we found that the improvement on phase estimation could be neglected.
- SMC could be retrieved from reconstructed signals. The results were satisfactory when the satellite elevation angle is between 5 degrees and 15 degrees. Additionally, the soil moisture calculated from the reconstructed signals was about 15% closer in relation to the ground truth measurements. However, the retrieval suffer from ambiguity problem, and are very sensitive to estimation errors.

# 5. FUTURE WORK

- **Further effort should be focused on improving the QoF even under more complicated irregular SNR variation through fitting function design.**
- **More accurate corrections and calibrations should employed.**
- **Since this proposed SNR model could capture high-order nonlinear SNR variation, it might be used to monitor vegetation in the future.**

Thanks for your attention!

