

## PRELIMINARY STUDY ON WAVELET DENOISING METHOD FOR INVERSION OF SNOW DEPTH IN GNSS-MR

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### ABSTRACT:

GNSS-MR technology inverts snow depth by using low-altitude SNR data. This information contains rich surface information. Due to the complex surface environment, the signal received by the receiver contains noise. during snow depth inversion, it is not possible to extract relatively "pure" snow information. Therefore, the wavelet denoising method is used to compare with the traditional polynomial. The results show that the snow depth RMSE of the polynomial inversion is 8cm and the error is 7cm. Wavelet denoising inversion The snow depth RMSE is 5cm and the error is 3cm. The experimental verification wavelet denoising method can better eliminate the systematic error and improve the inversion precision.

### 1. INTRODUCTION

The measurement of snow thickness is a key factor in estimating the moisture content of snow. In recent years, GNSS-MR technology has achieved a series of research results in the inversion of the surface environment [Ozeki, et al. 2012; Zhou et al. 2018; Ao et al. 2012; Larson et al. 2008; Cheng et al. 2014; Zhang et al. 2013]. However, the current inversion of snow depth using GNSS-R technology is mainly concentrated on the inversion method of each carrier or carrier combination. The noise of the signal is not processed. Therefore, based on the GPS L2 carrier, the wavelet analysis method is used to denoise the signal-to-noise ratio of the L2 carrier to verify the feasibility of wavelet analysis in inversion of snow depth. The GNSS-R technology inversion of snow depth mainly uses low-altitude SNR data, which is not only affected by the environment, but also by the receiver itself.

The receiving process contains more or less noise, so the observation data Denoising processing to obtain relatively "clean" snow information is beneficial to improve the accuracy of the inversion. The wavelet decomposition will produce the low frequency part and the high frequency part, and the original information is mainly concentrated in the low frequency part, so this paper only decomposes and reconstructs the low

frequency part. In this paper, the principle of NSSS-MR technology inversion of snow depth is firstly described. Then the traditional quadratic polynomial and wavelet denoising method are used to carry out snow depth inversion. The advantages of wavelet denoising method are verified by comparison with measured data. Because in the experiment, it is found that the difference between the denoising and the quadratic polynomial inversion results is very small. Therefore, the wavelet experiment in this paper directly uses the two-layer decomposition and reconstruction signal to invert the snow depth.

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## 2. GNSS-MR INVERSION SNOW DEPTH PRINCIPLE

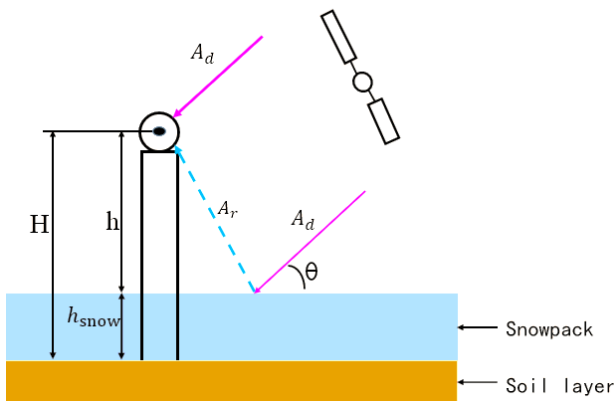


Figure 1. Schematic diagram of GNSS-MR inversion snow depth

As shown in Fig. 1, it is a schematic diagram of the inversion of snow depth by GNSS-MR technology. It can be seen from the figure that the receiver receives the direct signal and the reflected signal of the satellite at the same time, and the reflected signal enters the ground surface and then has a reflection effect before entering the receiver. Therefore, this paper mainly extracts the snow depth inversion experiment of the reflected signal. In the figure,  $H$  is the vertical reflection distance from the phase center of the receiver antenna to the soil surface layer, which is the known amount of actual measurement;  $h$  is the vertical reflection distance from the antenna phase center to the snow surface layer;  $h_{\text{snow}}$  is the snow thickness on the soil layer;  $\theta$  is the satellite elevation angle, that is, the incident angle at which the direct signal is reflected by the surface.

For the geodetic GPS receiver antenna, the main function is to suppress the multipath observation error. The amplitude of the direct signal and the reflected signal have the following relationship:

$$A_d \gg A_r \quad (1)$$

From Figure 1, the SNR and signal amplitude are as follows [Dai et al. 2016]:

$$\text{SNR}^2 = A_c^2 = A_d^2 + A_r^2 + 2A_d A_r \cos\theta \quad (2)$$

Combining equation (1), the influence of multipath effect on signal-to-noise ratio is mainly due to the satellite elevation angle, that is,  $A_d$  and  $A_r$  differ greatly in numerical value, and low-order polynomial is usually used to eliminate trend term  $A_d$ . The research shows that the low-altitude multipath effect has the greatest influence on the SNR residual sequence, which

provides important data for multi-path inversion of surface parameters. The amplitude of the multipath reflected signal can be expressed as:

$$A_r = A_d \cos\left(\frac{4\pi h}{\lambda} \sin\theta + \varphi\right) \quad (3)$$

As shown in Fig. 1, in equation (3),  $\lambda$  represents the carrier wavelength,  $\theta$  represents the satellite elevation angle,  $h$  represents the vertical reflection distance, and  $t = \sin\theta$ ,  $f = 2h / \lambda$ , then equation (3) can be simplified to The standard cosine function expression is:

$$A_r = A_d \cos(2\pi f t + \varphi) \quad (4)$$

In the formula (4), the frequency  $f$  contains the vertical reflection distance parameter  $h$ . If the spectrum analysis is performed on the equation (4), the frequency  $f$  can be obtained. Because the Lomb-Scargle algorithm (LS) [Cao et al. 1986] transform can not only effectively extract the weak periodic signal from the time domain sequence, but also can reduce the false signal generated by the uneven time domain sequence to some extent, so the LS spectrum is used in this paper. Analytical method for spectrum analysis. By performing L-S spectrum analysis on the SNR residual sequence, the frequency  $f$  of the GPS multipath reflected signal can be obtained, and the vertical reflection distance  $h$  can be obtained by  $f=2h/\lambda$ . Referring to Figure 1, the thickness of the snow can be calculated by the formula  $h_{\text{snow}}=H-h$ . Thereby, snow depth measurement using SNR observations is achieved.

### 2.1. Wavelet Analysis Theory

The signal-to-noise ratio data is affected by various factors such as the condition of the measuring instrument and the surrounding environment of the tracking station, so that the signal received by the receiver will contain various noise effects and cover the actual situation. Therefore, the wavelet theory is introduced to reduce the signal. Noise processing. In practical engineering applications, wavelet analysis is mainly to reduce noise in data. Most of the actual signals we obtain are non-stationary signals. The traditional Fourier analysis method can only observe the signal in the time domain or the frequency domain separately. For the deficiency of this method, the wavelet transform method emerges as the times require, and the adaptive ability of the method to the signal Strong, and well obtained time-frequency domain characteristics of non-stationary signals.

The essence of wavelet transform [Guo et al. 2014] is to

represent any function  $f(t)$  in  $L_2(\mathbb{R})$  space as having a different scaling factor  $a$  and a translation factor  $b$  in  $\Psi_{a,b}(t)$ . The superposition of the projections on the top. It maps the one-dimensional time domain function to the two-dimensional "Time-Scale" domain. By changing the scaling factor  $a$  and the translation factor  $b$ , wavelets with different time-frequency widths can be obtained to match the original signal. The position satisfies the requirements for time-frequency localization analysis of the signal.

### 3. EXPERIMENT AND ANALYSIS

The GPS-MR technique mainly extracts the signal-to-noise ratio residual sequence in the reflected signal and performs L-S spectral analysis to obtain the inversion snow depth value. Therefore, an important indicator for selecting a suitable wavelet base is the wavelet's ability to cancel. Wu Zhicheng [Wu et al.2013] and other four wavelet basis functions of sym10, coif3, bior3.5 and haar were selected to extract the trend term by comparing the ability of different wavelet basis functions. The results show that sym10 wavelet has the best ability to eliminate. Therefore, this paper uses sym10 wavelet base. Since the low frequency signal retains more original information, the high frequency part is seriously affected by

noise. Therefore, this paper only decomposes and reconstructs the low frequency part.

The experimental data source of this paper is the L1 band data of the GPS continuous observation of the Yel2 ( $62^\circ 28' 51.9''$  N,  $114^\circ 28' 50.9''$  W) station from January 1st to April 10th, 2016 provided by IGS. The measured snow depth data is provided by the National Climate Data Center (<https://www.ncdc.noaa.gov/>). The wavelet base used in this experiment is db4, and the number of denoising layers is 2. As shown in Figure 3 below,  $a$  and  $b$  are the signal-to-noise residual sequence and the corresponding LS spectrum of the No. 8 satellite using the quadratic polynomial to remove the trend term. In Figure 4,  $c$  and  $d$  are wavelets and the wavelet is analyzed. The low frequency signal (the signal to noise ratio residual sequence after the trend term is removed) and the corresponding LS spectrum.

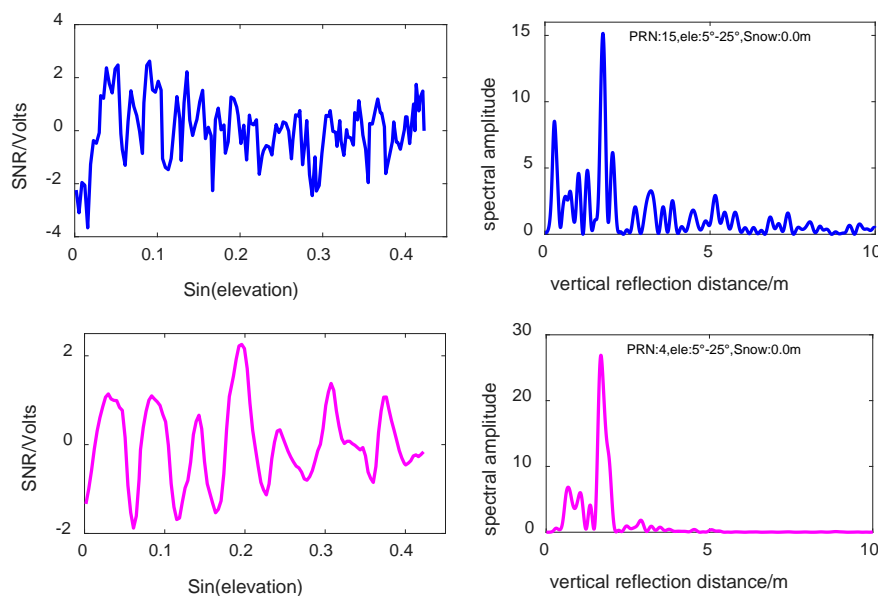


Figure 2 L1 band SNR residual sequence and L-S spectrum

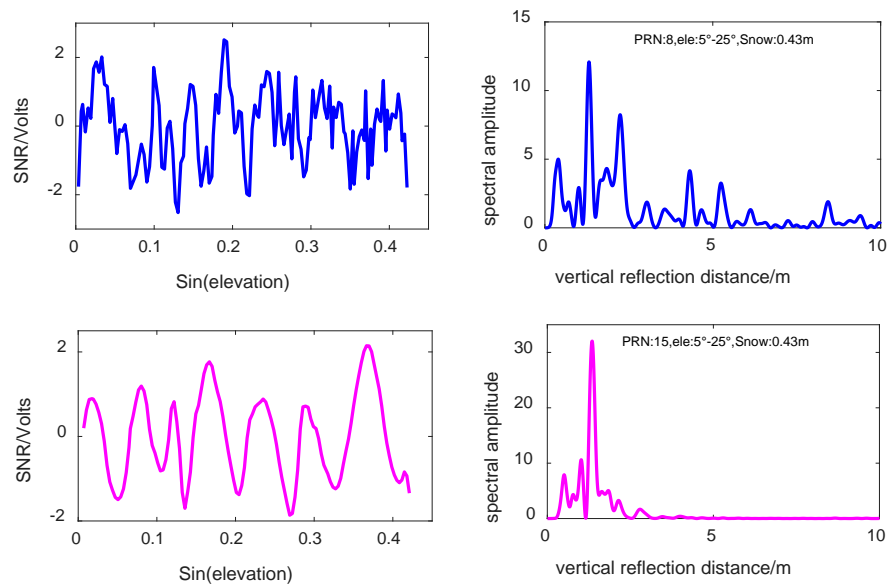


Figure 3 L1 band SNR residual sequence and L-S spectrum

It can be seen from figure 2 and figure 3 that, through L-S spectrum analysis, the SNR residual sequence extracted by polynomial and wavelet denoising is related to snow depth change. The oscillation of SNR residual sequence extracted by polynomial is more obvious than db4 wavelet base, one of the reasons is that the SNR residual sequence extracted by polynomial contains more noise. It can be seen from the SNR residual sequence diagram that the amplitude of the signal after noise reduction is smaller than that of the quadratic polynomial, which retains more useful information about snow cover and reduces the loss of effective energy. The snow depth value analyzed by L-S spectrum is closer to the actual value. After noise reduction, the signal band width decreases, the frequency resolution is improved, and the smoothness is good. In the L-S spectrum analysis figure 2 and figure 3, the horizontal axis represents the distance from the phase center of the antenna to the snow-covered top layer. The vertical axis represents the L-S spectrum amplitude of each frequency of the input SNR reflection signal. The peak amplitude of the L-S spectrum corresponds to the effective vertical reflection height  $h$ , which is determined by  $f = 2h/\lambda$ . Finally, the inversion value of the snow depth can be obtained by  $h_{\text{snow}}=H-h$ . In order to further

compare the accuracy of polynomial and wavelet decomposition in snow depth inversion, as shown in figure 4, it is a comparison diagram between the inversion snow depth result of quadratic polynomial and wavelet analysis and the measured snow depth value. In the figure, the x-coordinate represents the inversion date, and the y-coordinate represents the inversion snow depth value of db4 wavelet 2-layer decomposition SNR data, respectively. It can be seen from the figure that the inversion value of wavelet analysis and quadratic polynomial fluctuates around the actual value. It can also be seen that the snow depth value used for snow depth inversion after wavelet denoising is closer to the actual value. By calculation, RMSE value of polynomial inversion snow depth is 8cm with an error of 7cm, and RMSE value of wavelet de-noising inversion snow depth is 5cm with an error of 3cm. In the snow-free stage, the inversion value of the two methods fluctuates greatly with the actual value, which may be due to the arrival of summer, when the temperature gradually increases, leading to snow melt and little or no snow on the surface. Therefore, the inversion values of the two methods need to be verified.

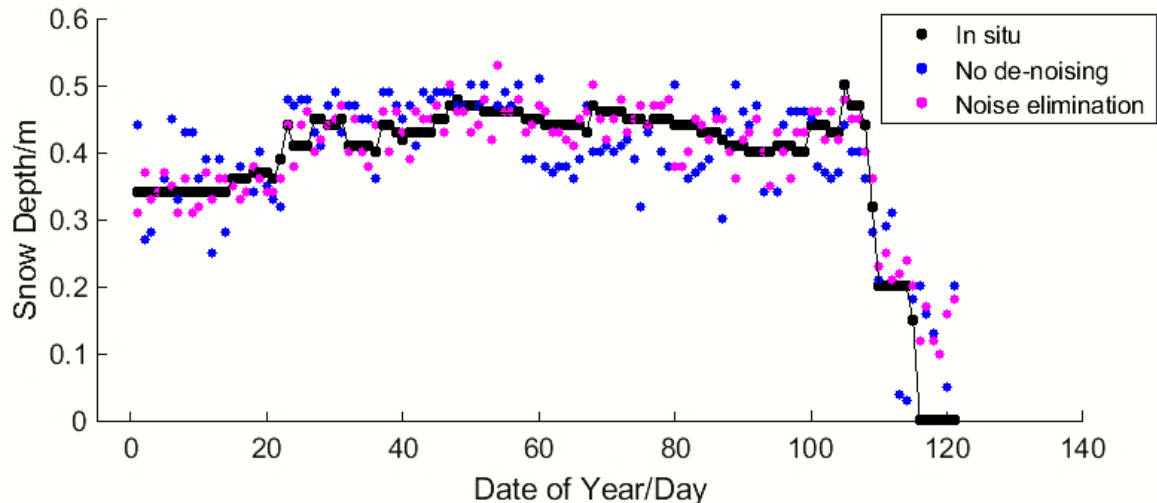


Figure 4 comparison diagram of  $5^{\circ} \sim 25^{\circ}$  polynomial, wavelet denoising and actual value

#### 4. CONCLUSION

From the experiments in this paper, the inversion accuracy of wavelet denoising method is better than polynomial. Appropriate elimination of noise can improve the accuracy of inversion snow depth, but wavelet denoising will also eliminate some useful information of snow, so the number of wavelet decomposition layers is how much more appropriate, and still have to continue experimenting. In this paper, only the low-frequency signal is decomposed and reconstructed. In the following research, the high-frequency signal will be decomposed and reconstructed, and the snow depth will be combined with the low-frequency signal.

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#### REFERENCES

Ao min si, hu youjian, liu yadong, et al. Soil moisture variation trend inversion of GPS signal-to-noise ratio observations [J]. *Journal of Surveying and Mapping Science and Technology*, 2012, 29(2):140-143.

Cao qingyuan. Fresnel integral calculation formula and its application [J]. *Wuhan University Journal·Information Science Edition*, 1986, 11(2): 57-64.

Cheng penggen, zheng shouzu, Chen xiaoyong, et al. Application of GNSS-R technology in sea ice inversion [J]. *Surveying and mapping engineering*, 2014, 23(4):1-5.

Dai kaiyang, zhang shuangcheng, li zhenyu, et al. Study on snow depth monitoring based on SNR observations of GPS [J]. *Geodesy and geodynamics*, 2016,3 6(6):525-528.

Guo jixin. Application research of wavelet analysis and time series combination model in deformation monitoring analysis and prediction [D]. Chang 'an university, 2014.

Larson K M , Small E E , Gutmann E D , et al. Use of GPS receivers as a soil moisture network for water cycle studies[J]. *Geophysical Research Letters*, 2008, 35(24):851-854.

Ozeki M. Heki K.GPS snow depth meter with geometry-free linear combinations of carrier phases[J]. *Journal of Geodesy*, 2012, 86(3):209-219.

Wu zhicheng, wang chongyang, ren aijun. Study on wavelet base optimization method for eliminating signal trend [J]. *Journal of Beijing institute of technology*, 2013, 33(8):811-814.

Zhang yun, Guo Jian Jjing, yuan guo liang, et al. Study on sea ice detection based on GNSS reflection signal [J]. Global positioning system, 2013, 38(2).