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An experimental study on the effect of antenna orientation on GNSS-IR

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ABSTRACT

Signal to noise ratio (SNR) data provided by the Global Navigation Satellite Systems (GNSS) receiver indicates the power of the received signal. Estimation of the quantities related to the reflection surface by analysis of the SNR data is called GNSS Interferometric Reflectometry (GNSS-IR). When a geodetic receiver is oriented to a direction, it receives stronger signals from the direction it is looking. In this study, two-day observations for a total of four days with zenith-looking (ZL) and horizon-looking (HL) receivers were performed. The data were analyzed comparatively in terms of amplitude and reflector height estimations. According to the reflector height estimations, it was seen that it is more appropriate to use HL receiver for elevation angles greater than 20°, while there is no significant difference from low elevation angles. Furthermore, since HL receivers receive reflected signals stronger than ZL receivers, the amplitudes of fluctuations in SNR data are found to be higher for HL receivers. Therefore, it can be said that it may be more appropriate to use HL receiver in GNSS-IR studies to determine quantities such as soil moisture to which SNR amplitude is sensitive.

1. INTRODUCTION

Multipath is the interference between direct signals from the satellites and those reflected before received by the antenna especially at low satellite elevation angles. Although as originally, GNSS was developed for accurate positioning facilities for various purposes while depending on eliminating this effect, recently several studies for novel applications using multipath have been introduced. Global Navigation Satellite System Interferometric Reflectometry (GNSS-IR) using the advantages of the reflected signals has been implemented in various applications such as soil moisture estimation (Han et al. 2020; Larson et al. 2010; Roussel et al. 2016; Zhang et al. 2017), snow depth retrieval (Gutmann et al. 2012; Larson et al. 2009; Ozeki and Heki 2011; Tunalioglu et al. 2019), sea-level changes (Anderson 2000; Xi et al. 2018) to extract features where the signals were reflected since it has been first proposed in 1993 by Martin-Neira (1993). The method can be classified as non-geometrical and geometrical in which amplitude or the power of signal, and range difference of the direct and reflected signals are considered, respectively (Yang et al. 2019) depending on the application characteristic.

The aim of this article is to apply GNSS-IR technique to two types of oriented GNSS receivers that have the same antenna gain pattern, which are established as zenith-looking (ZL) and horizon-looking (HL) and to investigate whether the orientation affects the gain of the signals or not in terms of amplitude, phase, and reflector height changes.

2. METHOD

The signals transmitted by GNSS satellites can be reflected from one or more surfaces before arriving at the GNSS receiver. Receivers record direct and reflected signals simultaneously. These signals interfere at the antenna phase center of the receiver. The power of the composite signal resulting from the interference can be obtained by the C/N_0 data provided by the receiver.

C/N_0 data were considered approximately equal to the SNR, which can be expressed by the following equation,

$$SNR^2 = {A_d}^2 + {A_m}^2 + 2A_d A_m \cos\Delta\varphi \quad (1)$$

where A_d is the amplitude of the direct signal, A_m is the amplitude of the reflected signal, $\Delta\varphi$ is the phase of

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the composite signal. The changes in the received angle of the GNSS signal due to the movement of the satellite alter the reflection geometry that result in oscillations in the power of the composite signal, i.e. SNR data. To find the contribution of the reflected signals to the SNR data, i.e. to eliminate the contribution of the direct signals, it is appropriate to fit a quadratic polynomial to the SNR data. By removing the trend from the data, detrended SNR (dSNR) is obtained. dSNR can be expressed by the following equation,

$$dSNR = A_m cos(2\pi f \sin\varepsilon + \Delta\varphi) \quad (2)$$

where f is the frequency of the multipath signal, ε is the satellite elevation angle. Since dSNR data is a function of the sine of the satellite elevation angle, it is sampled irregularly. In this study, Lomb Scargle Periodogram (LSP), which is the commonly used method to determine the frequency of irregularly sampled data, was used to compute the dominant frequency.

There is a relationship between the reflector height and the frequency of the multipath signal as follows,

$$h = f\lambda/2 \quad (3)$$

where h is the reflector height, λ is the wavelength of the GNSS signal.

2.1. Study Area and Experimental Setup

The study area is a stadium located in Yildiz Technical University Davutpaşa Campus with a wide flat surface and open sky view. The experiment was carried out on 4 days with the CHC i50 geodetic GNSS receiver. The receiver was established on DoY (Day of Year) 267 and 268 by being oriented towards the zenith (ZL). The antenna was oriented towards the horizon (HL) on the DoY 275 and 276 (Figure 1).

Figure 1. Study area and experimental setup

In-situ measurements of reflector heights are 2.127 m for ZL receiver and 2.025 m for HL receiver.

2.2. Data and Analysis

The duration of daily observations was set to 5 hours. The data-sampling interval is set to 1 second. SNR signals at L1 frequency (S1C, S1X, S1I) transmitted from all satellite systems (GPS, GLONASS, Galileo, BeiDou) were evaluated. The range of 0°-20° where the number of multipath signals increases was selected as the satellite elevation angle range. Data with a range of at least 10° elevation angles were evaluated, other than these, were excluded. The SNR trend has been removed using a 2nd order polynomial. The dominant frequency and amplitude of the dSNR were estimated by LSP. The reflector height was obtained by using Eq. (3).

Four different ways have been used to remove the defective ones from the estimated reflector heights. In the first three of these, the MAD (Median Absolute Deviation) value and its different coefficients were used. In the last one, the estimations that the maximum amplitude of the dSNR is not greater than 4 times of the background noise were accepted as an outlier. Besides, the results in which all measurements were evaluated, were also shared. The analyses were carried out in two different ways in plane: for data from all directions (0°-360°), and only for the direction range where the horizon line is open (200°-300°).

3. RESULTS

The usual setup of geodetic GNSS receivers is such that the maximum gain of the antenna is oriented to the zenith. When the receiver is set up in this way, the antenna has the maximum gain for signals from the 90°, while the minimum gain for the signals coming from the 0° or below satellite elevation angles. Depending on the antenna gain pattern of the receiver, the power of the received signal changes depending on the satellite elevation angle.

When the receivers are oriented in a direction parallel to the surface, the angle at which the strongest signal received changes by the same amount. In this study, on DoY 275 and 276, the receiver was setup oriented to 250° in azimuth. When the receiver is setup in this way, the antenna has the maximum gain for signals from the 0°, while the minimum gain for the signals from the 90° satellite elevation angle. Since the multipath effect is more intense at low elevation angles, when the antenna is oriented in this way, it receives the reflected signals with high gain like direct signals. This means that this antenna orientation can be used in GNSS-IR studies.

Figure 2 shows the satellite elevation angles and logarithmic display of the SNR data from the G04 satellite on DoY 268 and 276. On DoY 268, at low elevation angles where multipath is intense, the mean SNR starts from ~35 dB and increases with the elevation angle. On DoY 276, the mean SNR starts from ~50 dB at low elevation angles and decreases as the elevation angle increases.

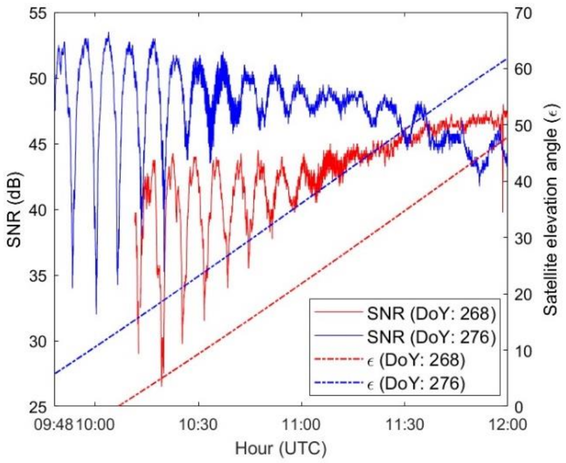

Figure 2. SNR plots and elevation angles of G04 satellite on DoY 268 and 276

In Figure 3, the dSNR data of the G04 satellite for all observation days are shown. The amplitude of the dSNR data on the days when the receiver is HL is ~4 times greater than the days when the receiver is ZL. However, in the 30°-60° satellite elevation angle range, it is seen that there is no significant sinusoidal signal in the dSNR data of the ZL receiver, while there are oscillations in the data of the HL receiver due to reflected signals. LSP analyses of these dSNR data are given in Figure 4. Accordingly, it can be said that the background noise increases with the amplitudes in the HL receiver and there is no improvement in determining the dominant frequency compared to the ZL receiver.

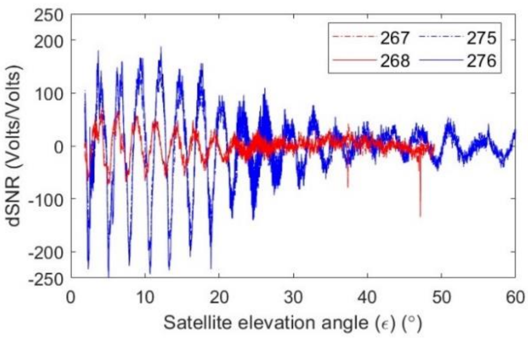

Figure 3. dSNR plots for the 0°-60° satellite elevation angle range of G04 satellite for all observation days

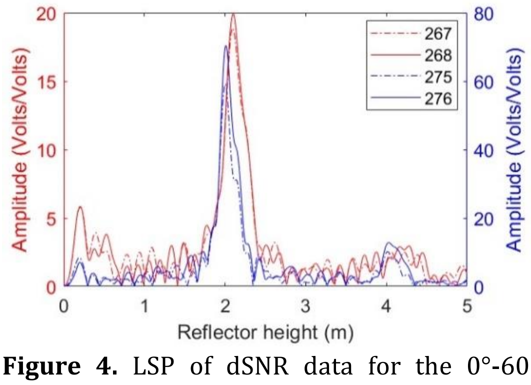

Figure 4. LSP of dSNR data for the 0°-60° satellite elevation angle range of G04 for all observation days

In Figure 5, the mean amplitudes of dSNR data obtained from satellites with sufficient number of common observations in four days in the 0°-20° elevation angle range are given. It is seen that installing the antenna horizon-oriented increases the mean dSNR amplitude for all satellites.

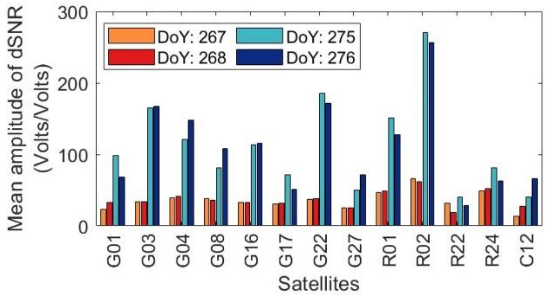

Figure 5. Mean amplitudes of dSNRs obtained from the data of common satellites for all observation days

The data were evaluated in two different ways, for the azimuth range of 0°-360° and 200°-300°. In Table 1, the analysis results of the signals coming from the 0°-360° azimuth range (i.e. from all directions) are given. The results obtained for different coefficients of MAD are given in the table. 4BG indicates that estimations where the maximum amplitude is less than four times the background noise are removed. RMSE1 means the standard deviations of the estimates from the in-situ reflector heights (i.e. accuracy), and RMSE2 means the standard deviations from the means of the estimates (i.e. precision).

Table 1. Results of 0°-360° azimuth angle range

	DoY:	267	268	275	276
Num. of Est.	NONE	41	44	33	33
	1MAD	23	26	19	23
	2MAD	34	37	24	29
	3MAD	36	40	27	31
	4BG	26	29	28	26
RH Est. (m)	NONE	2.097	2.080	2.032	2.033
	1MAD	2.135	2.125	2.057	2.055
	2MAD	2.127	2.130	2.062	2.053
	3MAD	2.123	2.123	2.053	2.044
	4BG	2.121	2.127	2.042	2.056
RMSE1 (cm)	NONE	8.7	18.2	5.6	6.5
	1MAD	1.5	1.7	3.4	3.9
	2MAD	3.3	2.9	4.3	4.7
	3MAD	3.7	3.8	4.3	5.3
	4BG	3.3	2.6	5.4	5.8
RMSE2 (cm)	NONE	8.3	17.8	5.6	6.6
	1MAD	1.3	1.6	1.2	2.5
	2MAD	3.3	2.9	2.1	3.8
	3MAD	3.7	3.8	3.2	5.0
	4BG	3.3	2.6	5.1	4.6

According to the results in Table 1, using 1MAD to remove bad estimates decreases the number of estimates, but increases accuracy and precision. In Table 2, the analysis results of the signals coming from the 200°-300° azimuth range where the horizon direction is open are given.

Table 2. Results of 200°-300° azimuth angle range

	DoY:	267	268	275	276
Num. of Est.	NONE	12	17	15	14
	1MAD	10	10	9	11
	2MAD	11	14	11	14
	3MAD	12	16	14	14
	4BG	11	17	15	14
RH Est. (m)	NONE	2.132	2.130	2.055	2.057
	1MAD	2.131	2.130	2.060	2.055
	2MAD	2.130	2.127	2.063	2.057
	3MAD	2.132	2.127	2.061	2.057
	4BG	2.132	2.130	2.055	2.057
RMSE1 (cm)	NONE	1.4	2.0	4.0	3.8
	1MAD	1.0	0.7	3.6	3.4
	2MAD	1.0	1.1	3.9	3.8
	3MAD	1.4	1.6	3.9	3.8
	4BG	1.4	2.0	4.0	3.8
RMSE2 (cm)	NONE	1.3	2.1	2.7	2.1
	1MAD	0.9	0.7	0.5	1.7
	2MAD	1.0	1.2	0.8	2.1
	3MAD	1.3	1.7	1.6	2.1
	4BG	1.4	2.1	2.7	2.1

According to Table 2, more accurate and precise estimates were made by using 1MAD.

4. DISCUSSION

In Tables 1 and 2, it is seen that the accuracy and precision values are very close to each other for the estimates of DoY 267 and 268, while there are differences in the estimates of DoY 275 and 276. Additionally, considering the final reflector height estimates, it is seen that the estimates of DoY 267 and 268 (2.131 m and 2.130 m) are close to the in-situ height (2.127 m), while there is a difference of approximately 3 cm between the in-situ height (2.025 m) and estimates of DoY 275 and 276 (2.060 m and 2.055 m). These results show that the in-situ measurement for the HL receiver may have an offset. However, to strengthen this inference, more daily observations should be performed. In this initial study, we will be content with stating that there is a high probability of such an offset for CHC i50, and we will leave it to further studies to verify this with longer experiments.

5. CONCLUSION

According to the precision values, it can be concluded that establishing the receiver ZL or HL does not make a significant difference in the precision of reflector height estimation for low elevation angles (0°-20°). However, we can infer from the dSNR plot shown in Figure 3 it is appropriate to use a HL receiver for higher elevation angles (e.g. 30°-60°). Besides, as seen in Figure 5, it can be said that setting the receiver HL collects the reflected signals stronger and is particularly suitable for use in GNSS-IR studies to determine the quantities related to dSNR amplitude (e.g. soil moisture).

In future studies, a better modeling of the dSNR signal of the HL receiver can be developed. In addition, the observations of a nadir-looking receiver can be examined similarly.

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