Testing the Accuracy of Large-Scale GNSS-R Applications

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SUMMARY

Global Navigation Satellite System Reflectometry (GNSS-R) is a promising technology with a huge potential. Naming just few most interesting applications, remote sensing of the sea surface roughness and salinity, snow structures, and sea-ice characterization, we can realize the importance of GNSS-R. Due to a variety of possible platforms (satellites, aircrafts, helicopters, etc.) different resolutions are available for the final users, which imply, also, different scopes of the accuracy. In this paper we are testing the resolution and accuracy of a water surface level obtained by GNSS-R. We utilized a platform set to a pedestrian bridge, with two GNSS receivers. One of them is attached to the upper side of the platform, while the other is placed upside-down, directing to the water mirror. The upper GNSS will receive only the direct signals from the satellites, while the latter one will create its position only according to the „false "measurements, meaning the signals reflected from the water. Knowing the mutual positional relation between the two receivers, we can calculate the height of the water mirror and, after longer measuring sessions; monitor the change of the river level.

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1. INTRODUCTION

Global Navigation Satellite Systems (GNSS) are complex of satellite constellation from different countries and their agencies. Nowadays, GNSS is consisting of four main satellite constellations: United States' Global Positioning System (GPS), European Union's GNSS called Galileo, Russia's (GLObalnaya NAvigatsionnaya Sputnikovaya Sistema) GLONASS , and China's BeiDou Navigation Satellite Systems known as COMPASS. Significant contribution to world GNSS have Japan's GNSS Quasi Zenith Satellite System (QZSS) and India's Regional Navigation Satellite System (IRNSS) covering more regional areas (Shuanggen, 2010).

GNSS is relatively new and advanced space technology. The beginning of GNSS era starts in the second half of last century by US Department of Defense. The first satellite navigation system Transit was tested by US Navy in 1960. Couple year's later the Timation satellite was developed and launched which proved ability to place accurate clocks in space. In early seventies Defense Navigation Satellite System (DNSS) was formed and later renamed in Navstar related to its own Navstar satellites constellation and soon after was called GPS. Around same time Soviet Union developed the GNSS named GLONASS which was completed in 1995 by Russian Aerospace Defense System. Before its commercial use, both of these satellite constellations were used only for military purposes. The US GPS was globally used at all time by all users since mid-nineties. Nowadays GPS counts around 32 satellites in its own constellation while GLONASS space segment is composed of 24 satellites distributed over three orbital plates. In beginning of 20th century EU and European Space Agency (ESA) started Galileo positioning system which is expected to be completed in 2020 with its full constellation of 30 satellites. China is also developing its own GNSS called BeiDou Navigation System which will count 35 satellites mostly orbiting in Medium Earth Orbit (MEO) (Shuanggen, 2014). Together all of these navigation satellite systems can be described as highly precise, continuous, all-weather and near real time electromagnetic (L-band) techniques with the broadcast signals. GNSS satellites are continuously emitting two or more radio signals in different frequencies (1-2GHz) with the wavelength 20 cm in L –bands. Direct GNSS signals are used for navigation, positioning and timing while refracted and reflected signals are mostly used to image the Earth's surface environments (ocean remote sensing and land cover and its changes). Due to climate change effects (Stapleton and Hawley, 2013), increase of temperature, snow melting, sea level rise and more frequent extreme weather conditions, there is a need for its monitoring to prevent catastrophic consequences. In these cases, GNSS remote sensing tools play a major roll. Last year in city of Obrenovac, Serbia, a major flood event occurred with loss of human lives and material goods. The frequency and intensity of precipitation and the flood events has been raised dramatically in last couple years in Serbia and in the region. Therefore, monitoring water level in populated areas is important as a base of an early warning system (Löfgren et al., 2011a, Löfgren et al, 2011b). The satellite based altimetry offers highly precise water level results but with insufficient spatial and temporal resolution while gauging stations offer the high temporal resolution but only at the point of the location. It is shown that GNSS –Reflectometry can fill the gap between these two measurement methods. GNSS –R shows new perspectives in water level monitoring; it offers more freely available dual-frequency signals and dense coverage (Beckheinrich et al., 2014, Beckheinrich et al, 2013).

2. BACKGROUND

2.1 Basic concept of GNSS Reflectometry

The work principles of GNSS-Reflectometry could be presented through a theory based on geometric elements.

The aim of GNSS-R technique is to collect the direct and the reflected signals from a GPS transmitter and interpret data as information of a river surface state.

The diffuse component of the reflection covers an area which is defined by the Fresnel surface. Conceptually, it is possible to separate the process of reflection into two contributions: the term (coherent) specular and the diffuse component (non-coherent), as shown in Fig. 1 (Roussel, 2012).

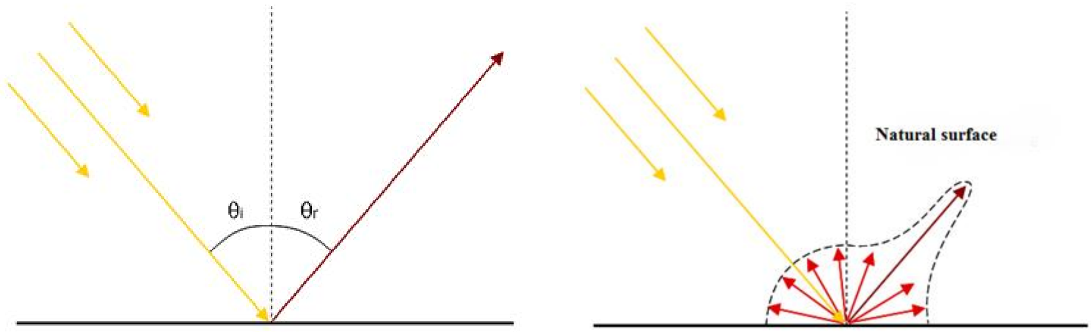

Figure 1: Specular (coherent) and diffuse (non-coherent) reflected signal in the specular point

The two receiver antennas based on the pedestrian bridge are mounted back to back on an axis. The antenna up looking, located on the top, picks directly transmitted signal from GPS, while the antenna of below down looking captures the signal that has been reflected on the surface. The signals are reflected from the zone named the glistening zone. The power of the reflected signals depends on the glistering zone and its physical parameters such us humidity and temperature. The stronger reflection will be cached from the specular point. The specular reflections will happen only in the case if the surface is absolutely flat. At the moment when signal is reflected from the wet surface, immediately changes its polarization from right hand circularly polarized (RHCP) to left hand circularly polarization (LHCP) (Fig. 2).

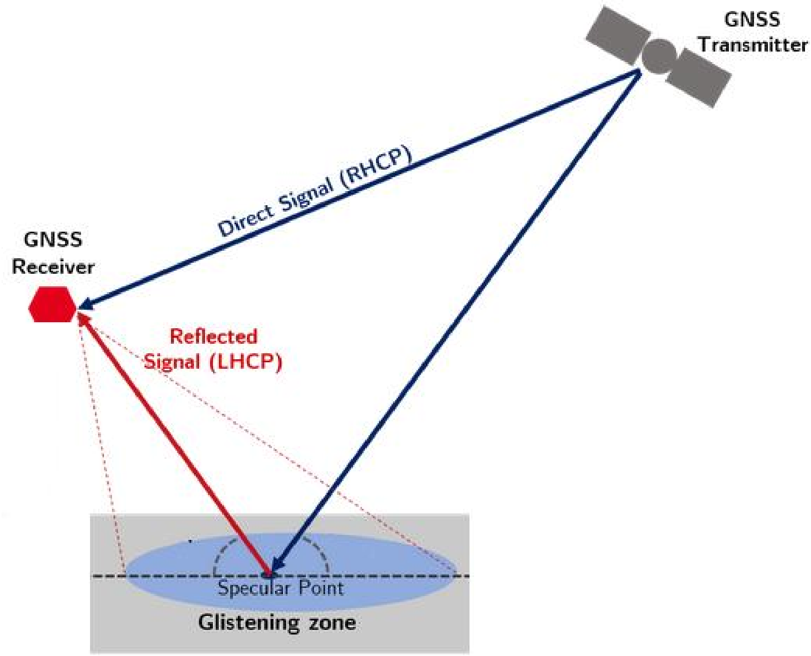

Figure 2: GNSS-R principles and geometry

The base of the calculation is to estimate the height of the antennas. This height of the antennas is calculated by simile of the delay between the direct and the reflected signals. This estimation is more precise during the calm weather condition, because of incoherent scattering in the case of the rough water surface (Fig. 3) (Langlay, 2010).

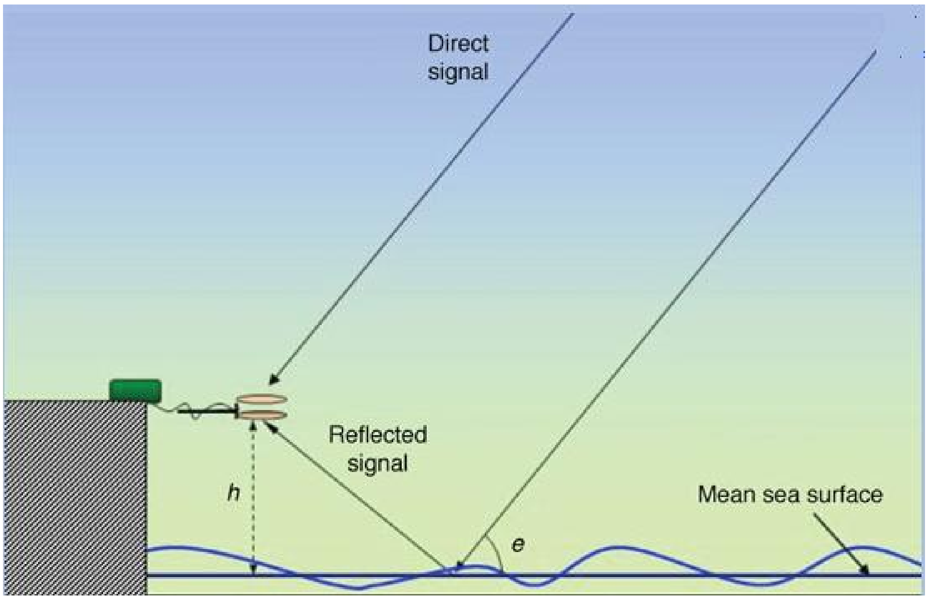

Figure 3: Coastal altimetry principle; estimation the height of receiver antennas

The equation (1) are used to calculate the height of antenna as a function of time (t), where (τ) is a lapse between time of the reflected and the direct signals, (h) is the estimated height, (θ) is the elevation angle of the satellite and (b) is the bias (Langley, 2010; Tay, 2013)

$$\tau(t) = \mathrm{d}_r - d_d = 2h\sin\theta(t) + \mathrm{b} \tag{1}$$

The altimetry (h) could be measured in two ways:

1. Measurement by the altimetry code: the code is used to calculate the distance between the direct and reflected signal.
2. Measurement altimetry by measuring the phase

For reflected signal, it is necessary to take into account the dispersion and the model of the resulting waveform, but for the received signal it must be correlated with a replica directly and the wave C/A will have a well-defined triangular shape.

Fig. 4 presents the block diagram of the principal work of GNSS-R technique for wet surface monitoring. The RHCP and LHCP antennas feed the direct and the reflected signals to a radio frequency (RF) receiver than in turn feeds a software (SW) (GPS slave and master) and process the data received (Langlay, 2010).

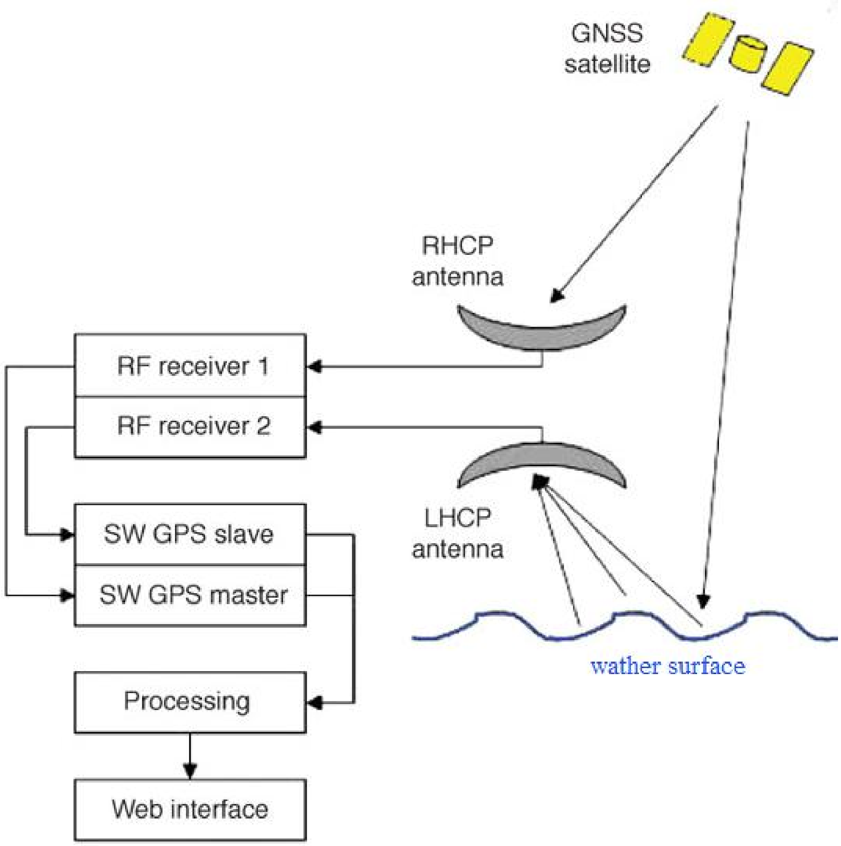

Figure 4: Basic concept of GNSS-R technique

The reflected GNSS signals on the wet surface can be modelled by a geometrical optics model, where the fundamental physical process is the reflection on the facets. The reflected signals are managed by the data such as the radius of the curvature and the probability density of the slopes of the surface. This probability density can inform us about the interaction between the atmosphere and the wet surface (time, energy, gas) (Tay, 2013).

2.2 **Test field**

The pedestrian bridge across the river Sava in Sremska Mitrovica, Republic of Serbia, built during the period of 1986-1991 (Fig. 5).

The bridge structure consists of the Main bridge structure with spans of 35 m + 192.5 m + 35 m = 262.5 m, and Aproach structure on the left bank with the span of 35 m, (Fig. 6).

The main structure is cable supported structure with two concrete pilons height of 37 m (at columns S-3 and S-4) above the structural steel-conrete beam.

The bridge level is circular arch, and the instrumentation was installed at highest point of the bridge, close to a bridge mid-point.

Figure 5: Pedestrian bridge in Sremska Mitrovica across the river Sava – downstream view

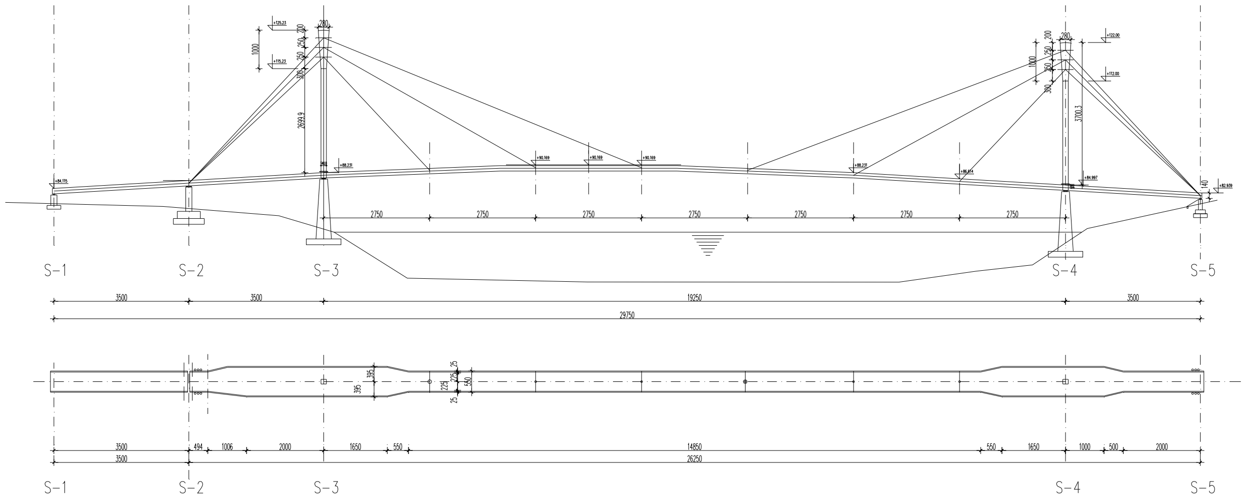

Figure 6: Layout of the pedestrian bridge in Sremska Mitrovica across the river Sava

3. RESULTS AND DISCUSSION

3.1 Experiment set-up

The experiment was performed during 24th December, 2014. We constructed a five meters long iron track with two arms, with a platform on one end, mounted to the arms. The other end was constructed as a stand for weight, which served as a balance. The platform contains two standard screws for mounting tribrachs, one at each side. The screws are set in one line, perpendicular to the platform.

We used two Trimble 5700 GPS receivers, with Zephyr antennas. Before placing and positioning the track, we mounted two GPS antennas using the screws on the platform, and connected them to the receivers with 5 m long antenna cables. We have chosen such set-up in order to (1) make the whole construction lighter, and (2) to have the receivers themselves in the safe environment, on the bridge floor, instead over the river.

Both sides (upper and lower) of the platform were covered with a non-reflective material, in order to avoid the multipath reflection from the construction. The position and the orientation of the screws were calibrated before the measurement session, to assure that the screws belong to the same line, and that the line is perpendicular to the horizontal construction (platform with the arms).

3.2 Measurements and results

During our measurement session, the upper receiver was tracking 9 to 11 satellites, while the reverse oriented receiver was tracking up to 0 satellites, with several loss of lock, where less than four satellites were found.

The measuring session lasted for 1 h 47 min. It was a rather short time for drawing conclusions about the long-term changes in water mirror level. On the other hand, it was quite enough for a static baseline solution. Therefore, we calculated the coordinate differences between the direct and inverted antenna and obtained the following results:

$$dN = 0.209\,\mathrm{m} \pm 7.3\,\mathrm{mm}$$
$$dE = 0.933\,\mathrm{m} \pm 5.0\,\mathrm{mm} \quad (2)$$
$$dH = 36.554\,\mathrm{m} \pm 6.4\,\mathrm{mm}$$

The vertical distance *dH* is negative, because the upper receiver was used as the reference one. The solution was fixed, and measurement uncertainties showed that no extreme changes in experiment conditions occurred during the session. The horizontal distance between two antennas is, therefore:

$$d_{hor} = \sqrt{dN^2 + dE^2} = 0.938\mathrm{m} \quad (3)$$

It was expected to obtain value close to zero for the horizontal distance, since the mounting construction was calibrated before the session. However, since the vertical distance was 36,665 m, obtained horizontal distance is only 2.56% of the vertical one. Measured *dH* is a virtual height difference, because it is the result of longer path of the signals coming to the inverted receiver. The real height difference between two antennas was 0.245 m. We calculated the real horizontal distance between them, assuming the 2.56%, which gives the difference in horizontal position of 6.3 mm. That value resulted from the imperfection of the platform construction and the non-horizontality of the platform, caused by the traffic during our experiment.

Calculation the height of the water mirror *h* was performed using the model desribed by the equation (1). Here we are giving two graphs, showing the change in the height of the water surface *dw*, for the satellites SV#4 (Fig. 7) and SV#6 (Fig. 8), respectively. Tracking of SV#4 lasted for cca 1000 s, while the time interval during which SV#6 was locked was seven times longer. Both graphs were calculated as deltas of *dw* respective to the first epoch, so both graphs started from zero. Time interval between two consecutive measuring epochs was 15 s, which is displayed as x axis in Fig. 7 and Fig. 8.

However, analysing Fig. 7, a smooth change of *dw* can be noticed, while the figure of the changes calculated from the SV#6 measurements showed sudden jumps in the time series. Further investigation of the raw measurements resulted in finding a number of cycle slips for SV#6.

SNR is also an important factor for SV locking. Fig. 9 shows the SNRs for directed (SNRd) and reflected (SNRr) signals received from SV#4. Strengths of both signals fall within the optimum values. The reason for the cycle slips in the raw data received by SV#6 could be found in low SNR for the reflected signal (Fig. 10).

Two extreme examples are shown in this study case. Similar graphs can be produced for all satellites involved in the solution presented.

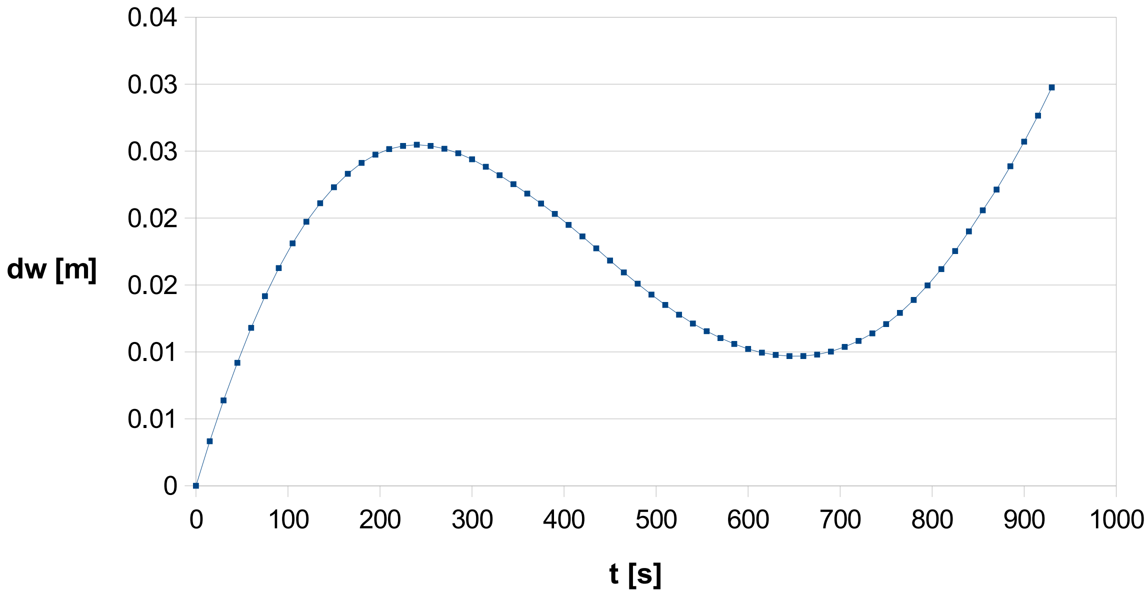

Figure 7. Change of the water mirror height for SV#4

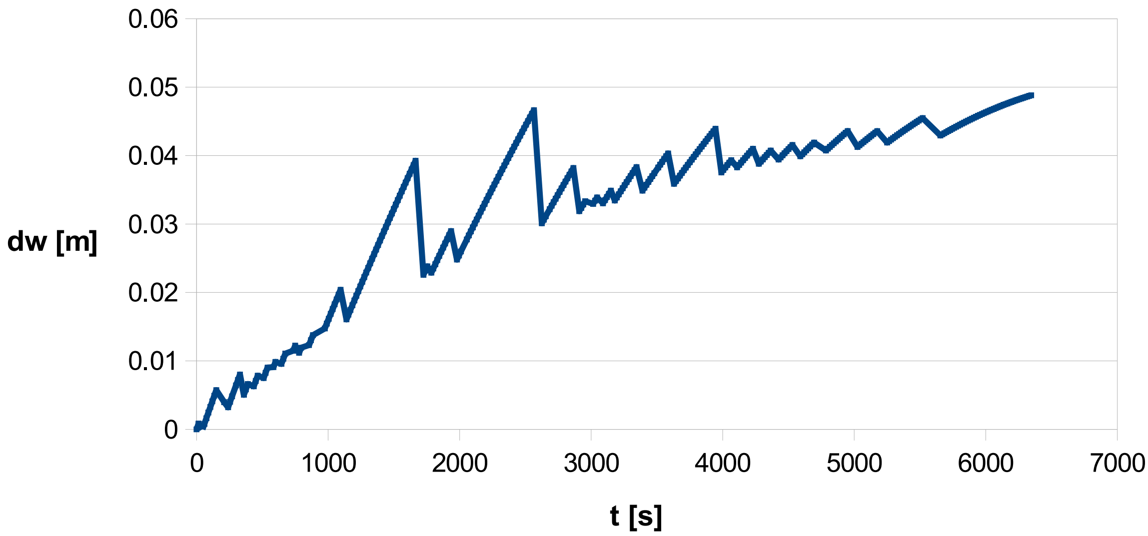

Figure 8. Change of the water mirror height for SV#6

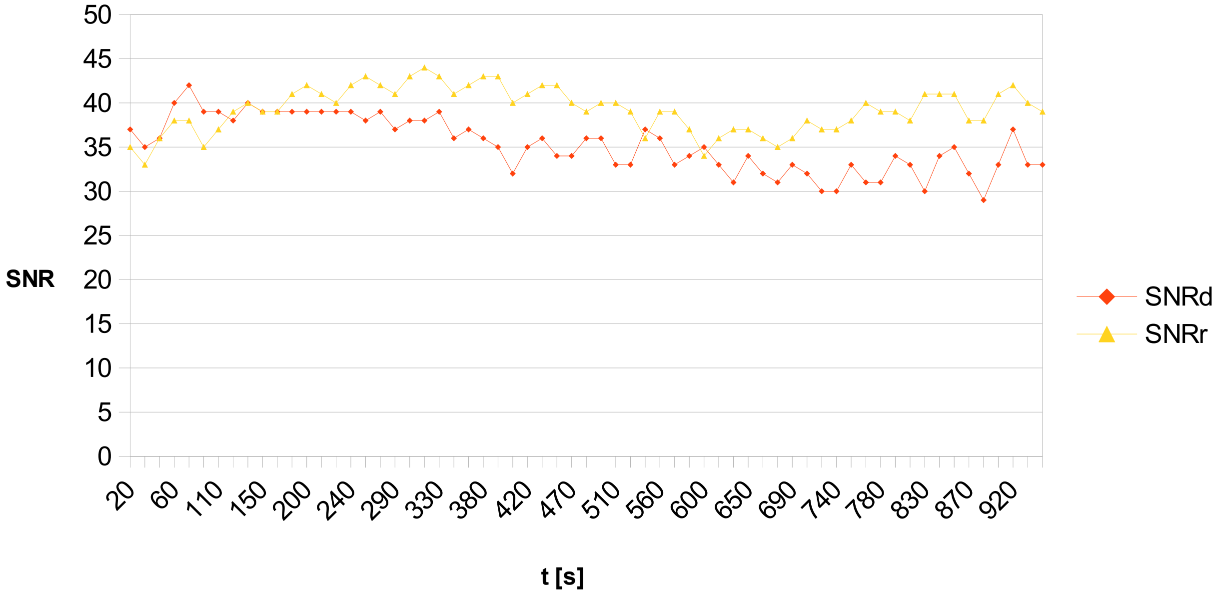

Figure 9. SNR for SV#4

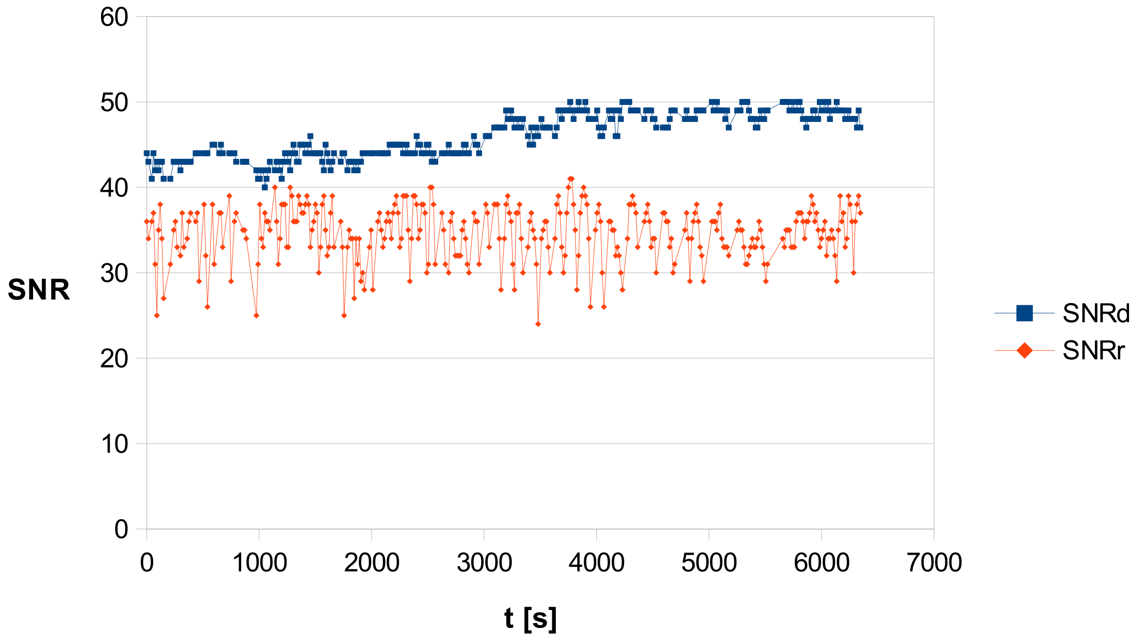

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Figure 10. SNR for SV#6

4. CONCLUSION AND REMARKS

GNSS, an established technology, finds its new applications in the number of fields more or less related to geodesy. One of the challenges for the future is using GNSS reflectometry as a tool for remote sensing applications.

Here we presented the experiment intended to find the possible usages of this promising technology in the areas that other instrumentation solutions are still involved. Economic issues certainly represent a benefit for GNSS-R, since the price of this equipment is getting more and more affordable to a broad scope of the users.

We showed that GNSS-R can be used for the large scale applications, for example, monitoring water level changes. This application can be extremely important in the case of natural disasters, where a quick response is needed. Permanent monitoring stations are relatively cheap to install, especially having in mind the benefit for the community.

The accuracy of the system depends much on the facility set-up. Since one of the antennas receives only the reflected signals, all issues applicable to the standard GNSS applications, here become more important and delicate.

Our further experiments will be directed to the multi-instrumental, long-term applications. To accomplish that, in the future we will work on cooperation both with the ministries and federal agencies for environmental protection, to support the actions like this.

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BIOGRAPHICAL NOTES

Prof. Dr. Vukan Ogrizović, born in 1970. Graduated in 1996 as Dipl.-Ing. in Geodesy and earned a doctorate degree in 2007, both from Belgrade University, until 1997 teaching assistant at Belgrade University. Since 2008 Assistant Professor and 2013 Associate Professor. Research fields: Earth Gravity Field and Reference Geodetic Networks

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Jasna Kolašinac, born in Split, Croatia in 1974. Graduated in 2007 as Dipl.-Ing in Geodesy from Civil Engineering University of Belgrade, Serbia. Earn Master's Degree in Civil and Environmental Engineering from Portland State University (USA) in 2014. Worked as student contractor for U.S. Geological Survey for Hydrology Department from 2009-2014. Earn Certificate of Completion in Summer Space Program 2014 from International Space University in Montreal, Canada.

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