A GNSS-BASED TIDE GAUGE FOR LOCAL SEA LEVEL MONITORING

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1. INTRODUCTION

It is important for human society to continuously monitor the sea level, since more than 50% of the world's population live within 60 km of the coast [1]. Moreover, global climate change is believed to result in the melting of large masses of ice in Polar Regions. This will bring freshwater into the ocean [2] and thus change the sea level [3]. The traditional way to observe sea level is with tide gauges which results in measurements relative to the Earth's crust [4]. However, the Earth's crust is continuously moving and in order to fully understand sea level change processes, measurements of sea level in relation to the Earth's center of gravity, are necessary. The motion of the Earth's crust in relation to the center of gravity can be determined using satellite techniques [5], e.g., Global Navigation Satellite Systems (GNSS). A GNSS-based tide gauge was therefore proposed [6], which can obtain both relative and absolute sea level variations, by observing reflected GNSS-signals. Presented here, as a proof of concept, are results from the experimental installation compared with data from traditional tide gauges. Moreover, we anticipate to present new results at the IGARSS 2010 conference with long time series (weeks to months) of sea level from the permanent GNSS-based tide gauge installation that is currently under construction at the Onsala Space Observatory (OSO).

2. CONCEPT OF THE GNSS-BASED TIDE GAUGE

The GNSS-based tide gauge installation consists of two antennas mounted back-to-back on a beam over the ocean (see Fig. 1). One antenna is right hand circular polarized (RHCP) and zenith-looking, receiving the direct GNSS-signals, whereas the other antenna is left hand circular polarized (LHCP) and nadir-looking, receiving the signals that are reflected from the sea surface. When the signals are reflected in the sea surface, they change polarization from RHCP to LHCP. Compared to the directly received signals, the reflected signals experience an additional path delay ($a + b = c$). This means that the LHCP antenna can be regarded as a virtual antenna located below the sea surface (see the blue antenna in Fig. 1). The height of the LHCP antenna over the sea surface (h) is presented in Eq. 1.

$$h = \frac{a+b}{2\sin\varepsilon} - \frac{d}{2} \tag{1}$$

Here ε is the elevation of the transmitting satellite, $a + b = c$ is the additional path delay of the reflected signal, and d is the vertical separation between the phase centers of the RHCP and the LHCP antennas. When there is a change in the sea surface, the path delay of the reflected signal changes, which means that the height of the LHCP antenna over the sea surface also changes. Hence, the LHCP antenna will appear to change vertical position. From the geometry in Fig. 1 the vertical difference in position between the RHCP and virtual LHCP antenna, related to the height of the LHCP antenna over the sea surface, is obtained as $\Delta v = 2h + d$. As a result the installation monitors changes in sea level, because the height of the LHCP antenna over the sea surface is proportional to the the sea level. Furthermore, a vertical position change corresponds to half the change in sea level. Using multiple satellites the estimated change in sea level will represent the change of an average sea surface formed by the reflection points of the GNSS-signals.

3. DATA PROCESSING

The experimental setup of the GNSS-based tide gauge was installed at OSO during three days in December 2008. The installation was mounted towards the south with open sea water in a south-southeast direction. The antennas used were a Leica AT504 GG choke-ring antenna (RHCP) and a Leica AR25 multi-GNSS choke-ring antenna (LHCP), and both antennas were protected

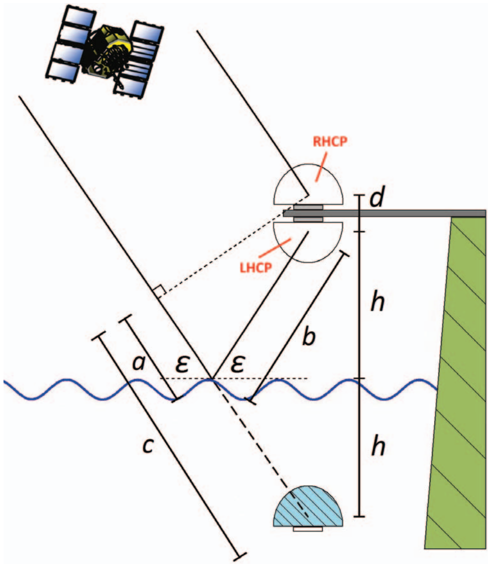

Fig. 1. Schematic drawing of the GNSS-based tide gauge installation.

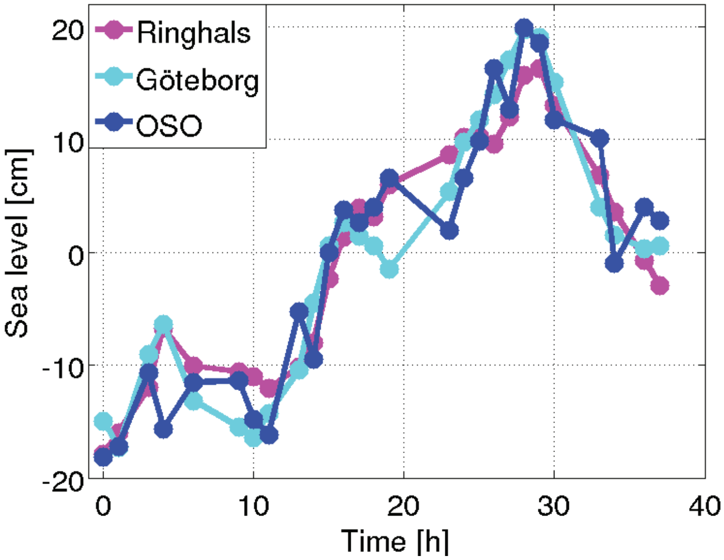

Fig. 2. Sea level observations from the GNSS-based tide gauge at OSO and from two traditional tide gauges at Ringhals and Göteborg.

by hemispherical radomes. Each antenna was connected to a Leica GRX1200+ receiver and data were collected during three days, recording 40 hours of continuous data with 20 Hz sampling.

Because the surrounding to the north of the installation was dominated by bedrock from the coastline and the fact that the signal-to-noise ratio, as determined by the receivers, was low for low elevation angles, an elevation and azimuth mask was applied to the data. The mask removed data below 20° elevation and outside the south direction -135° to +45° azimuth. Since the LHCP antenna was positioned approximately 1 m over the sea surface and the elevation and azimuth mask was applied, the area of the reflection points on the surface (with a radius of about 2.5 m) was approximately 9.8 m^2.

After decimating the data to 1 Hz data, for faster processing, using the Translation, Editing, and Quality Check (TEQC) software [7], an in-house developed software in MATLAB was used to produce hourly estimates of sea level height for comparison with other independent data sets. The software used L1 phase delays, with data from 20 minutes around every full hour, and satellite orbits from IGS ephemerides [8], to estimate the topocentric relative position between the antennas for the 20 minute period, receiver clock differences every epoch, and phase ambiguity differences between all satellites. The differences in relative vertical position of the antennas, Δv, was then converted into time series of sea level.

4. RESULTS AND OUTLOOK

In order to evaluate the sea level obtained from the GNSS-based tide gauge, the time series was compared to data from two traditional tide gauges. The traditional tide gauges are located at Ringhals and Göteborg (about 18 km south and 33 km north of OSO, respectively) and are operated by the Swedish Meteorological and Hydrological Institute (SMHI). The comparison is presented in Fig. 2, where the mean values of each time series were removed since the three sensors have different references levels. The GNSS-derived sea level observations agrees well with the two traditional tide gauges, indicating that the GNSS-based tide gauge gives valuable results for sea level monitoring. The pairwise root-mean-square differences between the three time series are better than 4 cm.

A permanent installation of the GNSS-based tide gauge is currently under construction at the OSO and is planned to be ready in early 2010. We anticipate to present long time series (weeks to months) of sea level at the IGARSS 2010 conference. Additionally, we plan to do tidal analysis to derive tidal constituents (amplitude and phase) and compare them to theoretical models.

5. REFERENCES

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