Sea Level Monitoring Using a GNSS-Based Tide Gauge

Johan Löfgren, Rüdiger Haas, Jan Johansson
Department of Radio and Space Science, Chalmers University of Technology, Göteborg, Sweden
Email: johan.lofgren@chalmers.se

Introduction

- Global climate change is believed to cause melting of large masses of ice in the polar regions, and changing the sea level.
- More than 50% of the world's population live within 60 km of the coast and are potentially endangered by sea level rise.
- Monitoring of sea level change is thus important.
- Traditionally, sea level is observed by tide gauges, giving measurements relative to the Earth's crust.
- In order to improve the understanding of sea level changes, absolute measurements are necessary, i.e., measurements relative to the Earth's center of gravity.
- We thus propose a GNSS-based tide gauge that can give relative and absolute sea level measurements.

Figure 1. The experimental setup of the GNSS-based tide gauge at the Onsala Space Observatory (OSO).

Concept

- The GNSS-based tide gauge consists of two antennas, one zenith-looking right hand circular polarized (RHCP) and one nadir-looking left hand circular polarized (LHCP), mounted back-to-back on a beam over the ocean (see the experimental setup in Fig. 1).
- The RHCP antenna receives the GNSS-signals directly, whereas the LHCP antenna receives the signals reflected from the sea surface.
- The reflected signals change polarization from RHCP to LHCP.
- The reflected signals experience an additional path delay ($a+b=c$ in Fig. 2), implying that the LHCP antenna can be regarded as a virtual antenna located below the sea surface.
- When the sea level changes, the path delay of the reflected signal changes, thus the LHCP antenna will appear to change position.
- The vertical position change corresponds to twice the sea level change.

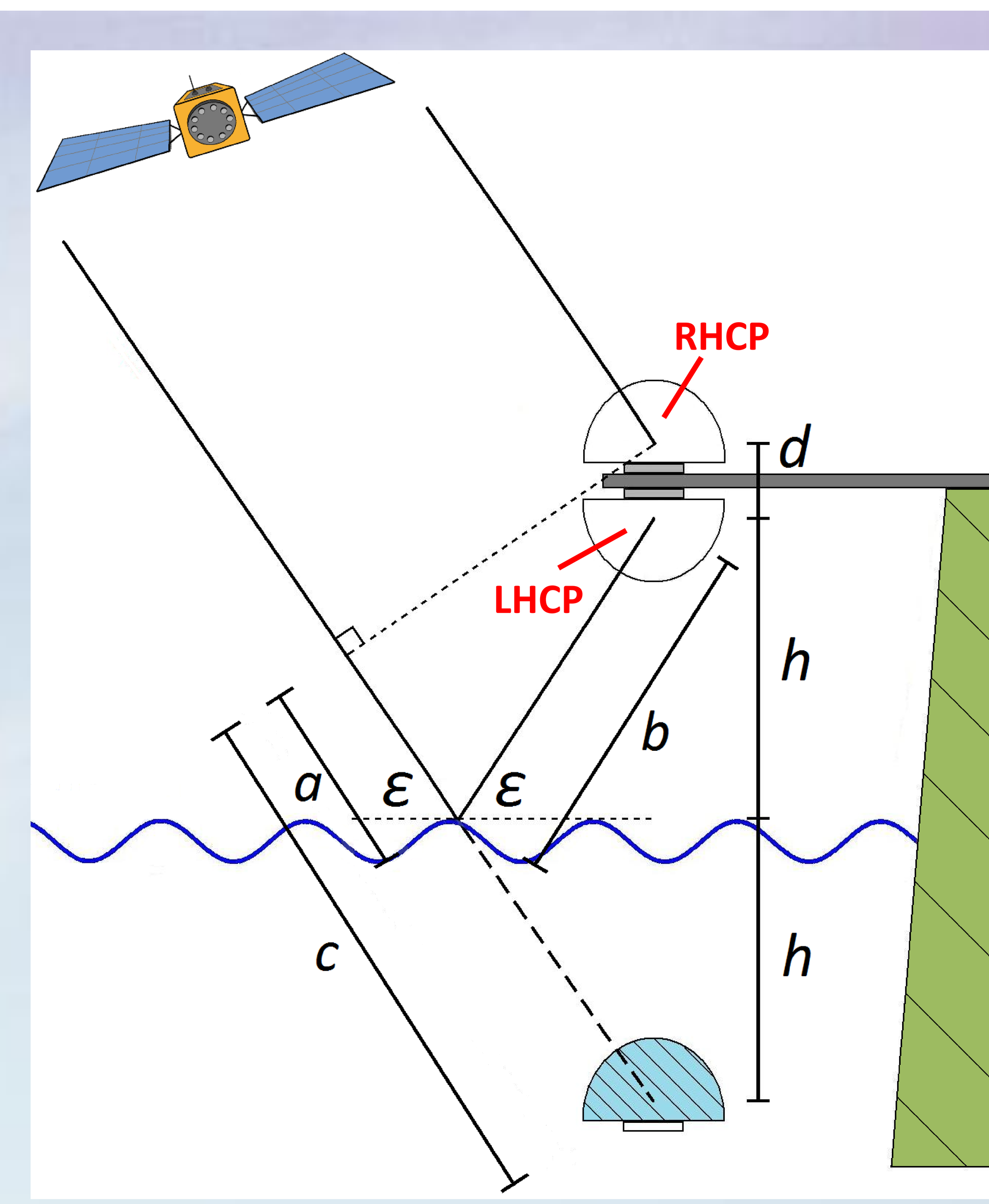

Figure 2. Schematic drawing of the GNSS-based tide gauge installation and the signal geometry.

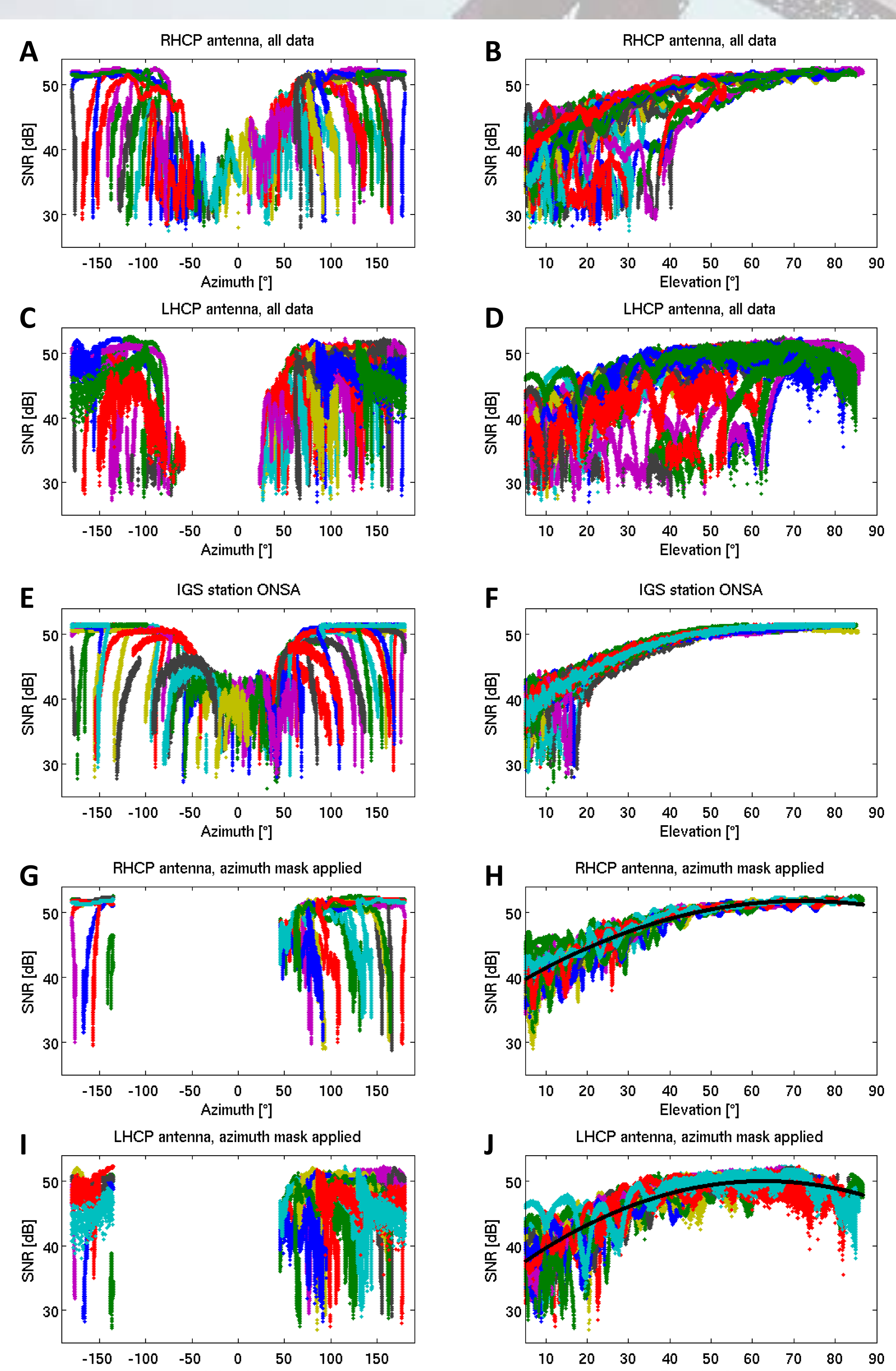

Figure 3. SNR versus azimuth (left column) and elevation (right column) during 12 hours. Values are presented for all data received with the RHCP antenna (A and B) and LHCP antenna (C and D), the IGS station ONSA (E and F) as a comparison, and for the RHCP antenna (G and H) and LHCP antenna (I and J) after the azimuth mask is applied. The polynomial fit to the SNR is also shown (H and J).

Signal evaluation

- 40 hours of continuous 1 Hz data.
- A data quality check was done using the signal-to-noise (SNR) ratio as determined by the two receivers for 12 hours (see Fig. 3A, 3B, 3C, and 3D).
- The reflected signals are noisier than the direct signals, however the SNR of the reflected signals is always above 25 dB.
- When comparing the SNR of the RHCP antenna to the SNR of the IGS station ONSA (see Fig. 3E and 3F) a similar decrease is seen for northern azimuth angles, but the IGS station has higher SNR for low up to intermediate elevations.
- The surrounding to the north of the GNSS-based tide gauge consisted of coastline and a boathouse, while all other directions were open sea. To avoid influences of unwanted signals we used an azimuth mask.
- The SNR of the remaining data (Fig. 3G, 3H, 3I, and 3J) resembles the IGS station SNR, meaning a significant increase in SNR above 20° elevation.
- A second order polynomial was fitted to the SNR of each antenna (see Fig. 3H and 3J). The average difference between the two SNR polynomials was between 1.0 and 3.4 dB.

Data analysis

- An elevation and azimuth mask was applied to the data (keeping data above 20° elevation and within 45° to 225° azimuth) to avoid unwanted reflections (see Fig. 4A and 4B).
- The 1 Hz data were analyzed with an in-house developed software in MATLAB.
- The software used L_1 phase delays for relative positioning to perform a least-squares estimation of
  - differences in the local vertical components
  - receiver clock differences
  - phase ambiguity differences
- Each solution was made using 20 minutes of data every full hour during 40 hours.
- The resulting time series of the sea level change was compared to data from two traditional tide gauges operated by the Swedish Meteorological and Hydrological Institute at Ringhals and Göteborg, about 18 km south of and 33 km north of OSO, respectively (Fig. 5).
- The root-mean-square (RMS) agreement between the time series is better than 4 cm (see Tab. 1).

Table 1. RMS agreement between the time series.

Site 1	Site 2	RMS [cm]
Ringhals	OSO	3.7
Göteborg	OSO	3.7
Ringhals	Göteborg	3.3

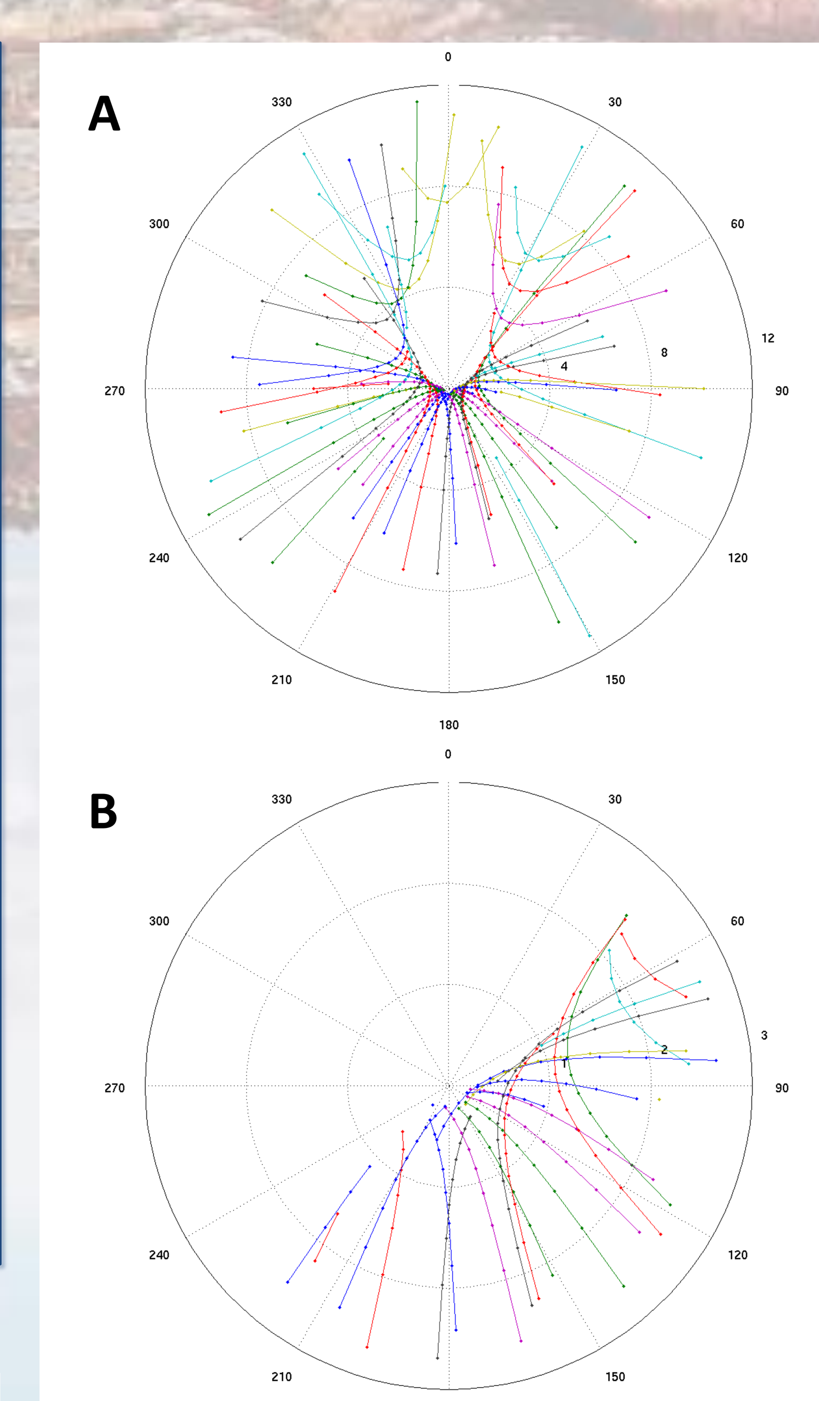

Figure 4. Reflection points on the sea surface during 12 hours for satellites above 5° elevation (A) and after the azimuth and elevation mask was applied (B).

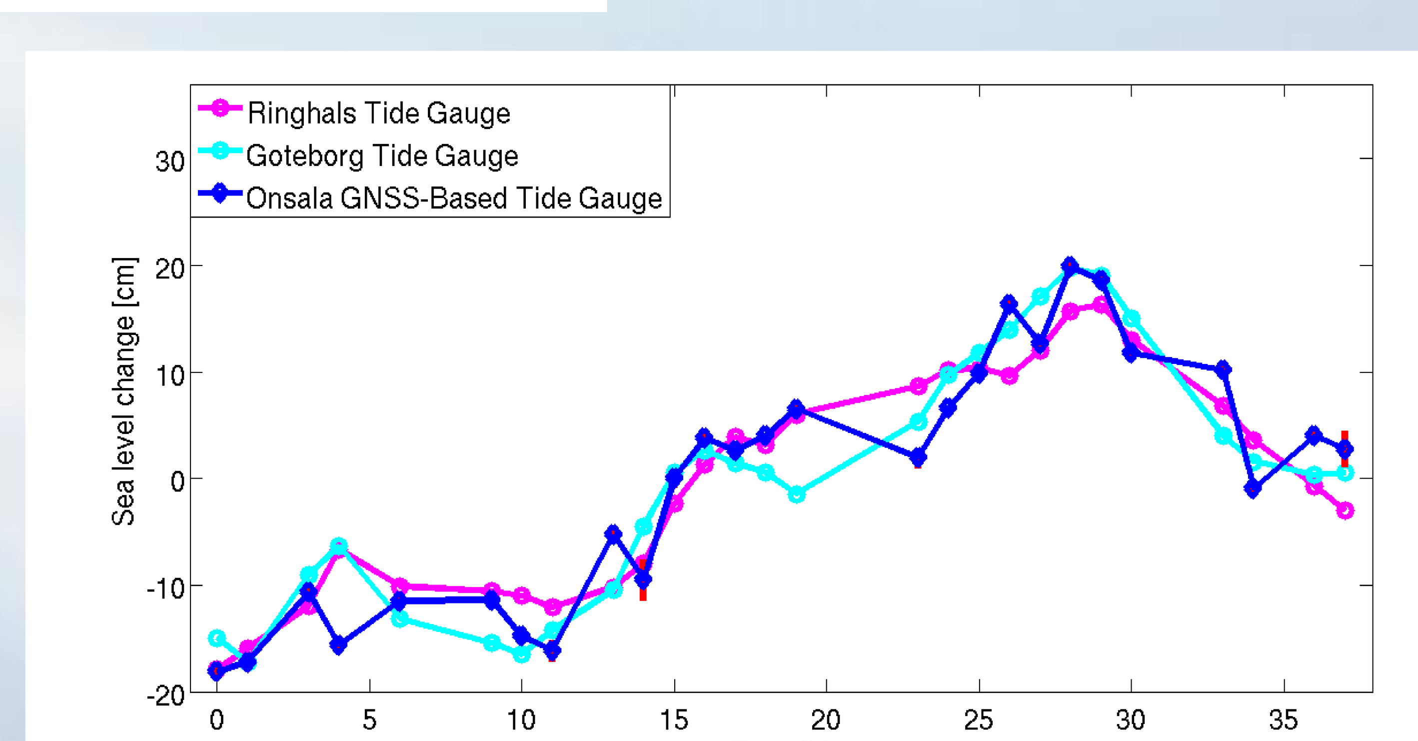

Figure 5. Sea level change from the GNSS-based tide gauge at OSO and from two traditional tide gauges at Ringhals and Göteborg. The mean of each time series is subtracted.

Conclusions and outlook

- The reflected signals were noisier than the direct signals and the noise was higher at low elevations.
- The maximum average reduction in SNR of the LHCP antenna as compared to the RHCP antenna was 3.4 dB.
- The GNSS-derived sea level change resembles reasonably well the independently observed sea level changes from two traditional tide gauges.
- The RMS agreement is better than 4 cm, indicating that the GNSS-based tide gauge gives valuable results for sea level monitoring.
- We plan to install the GNSS-based tide gauge permanently at OSO and to develop strategies for real-time sea level monitoring.
- Furthermore, our plan is to install additionally a traditional tide gauge at the same site for comparison purposes.
- We want to analyze high-rate (20 Hz) observations in post-processing, which might allow us to derive parameters that describe the sea surface roughness, as well as sea water properties.