# Experience with the GNSS-Based Tide Gauge at the Onsala Space Observatory

*Johan S. Löfgren, Rüdiger Haas*

**Chalmers University of Technology, Department of Earth and Space Sciences**

**Onsala Space Observatory, SE-439 92 Onsala, SWEDEN**

## THE GNSS-BASED TIDE GAUGE

- Two antennas: one zenith-looking Right Hand Circular Polarized (RHCP) and one nadir-looking Left Hand Circular Polarized (LHCP) mounted back-to-back over the ocean, see Fig. 1a.
- The RHCP antenna receives the GNSS-signals directly, whereas the LHCP antenna receives the signals reflected from the sea surface.
- The reflected signals experience an additional path delay (see Fig. 1b), 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.
- Since the height of the LHCP antenna over the sea surface is directly proportional to the sea surface height and the RHCP antenna is directly proportional to the land surface height, the installation monitors changes in local sea level.


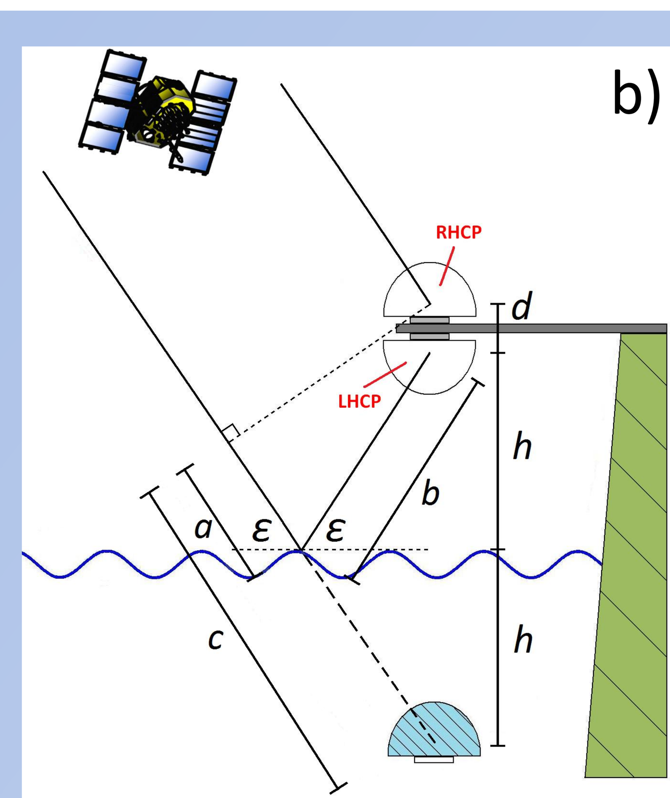


*Figure 1. a) The experimental setup of the GNSS-based tide gauge at the Onsala Space Observatory with the radome of the 20 m geodesy/astronomy radio telescope in the background. b) Schematic drawing of the GNSS-based tide gauge. The RHCP antenna receives the direct signals and the LHCP antenna receives the signals reflected from the sea surface.*

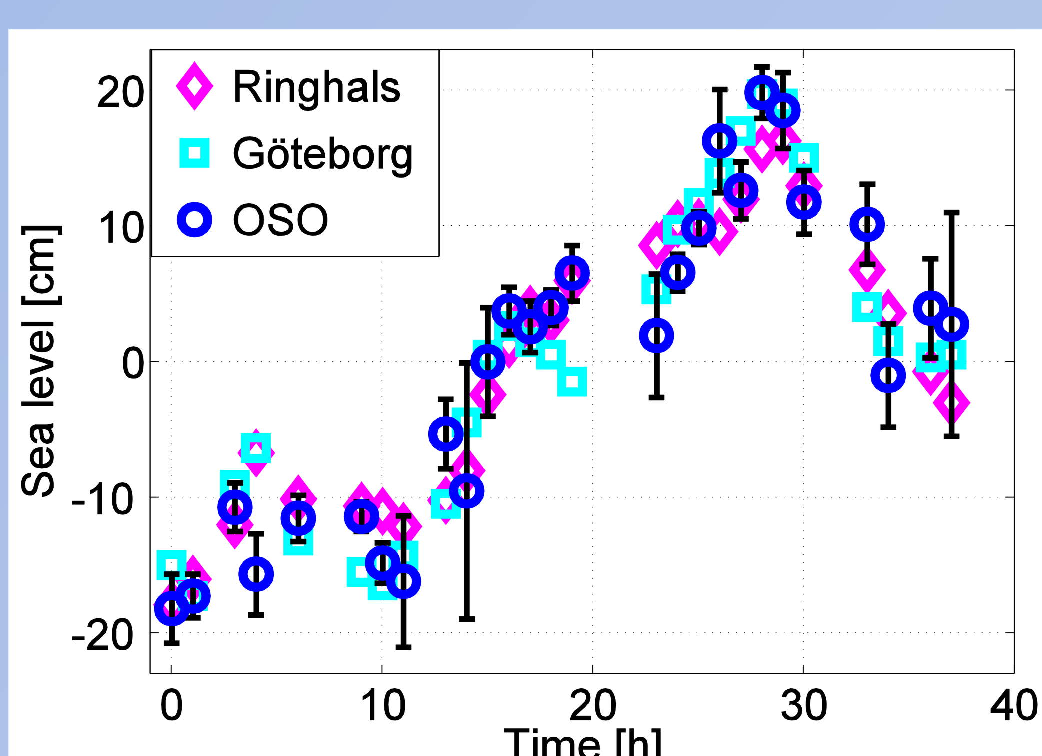


*Figure 2. GNSS-based tide gauge results compared to sea level from two stilling well gauges at Ringhals and Göteborg located about 18 km and 33 km away from OSO, respectively. The mean is removed from each time series.*

## COMPARISON WITH STILLING WELL GAUGES

- Relative positioning using single differenced GPS L1 phase data.
- Solutions with 20 minutes of data (1Hz) around every full hour.
- Least-squares estimation of differences in: local vertical components (every interval), receiver clock differences (every epoch), and phase ambiguity differences (every interval).
- Comparison with sea level from two stilling well gauges at Ringhals and Göteborg, 18 km south of and 33 km north of Onsala Space Observatory (OSO), respectively, in 2008 show an RMS agreement of better than 4 cm (see Fig. 2).
- Maximum difference < 9.3 cm (7.5 cm for the stilling well gauges), which mostly depends on different locations and averaging techniques.
- Possible to measure local sea level in mild sea state conditions.

## DIFFERENT TEMPORAL RESOLUTIONS

- Relative positioning using single differenced GPS L1 phase data (1 Hz) done in two steps.
- Firstly, determination of float phase ambiguities with the same processing as for the results in Fig. 2.
- Secondly, the determined ambiguities were inserted as knowns into a second processing estimating receiver clock differences (every epoch) and vertical baseline for the desired number of epochs.
- Solutions with temporal resolution of 5, 30, 60, 120, and 240 seconds are consistent with each other and show finer variations, see Fig. 3.
- The overall negative trend is similar to the negative trend from the stilling well gauges at Ringhals and Göteborg.

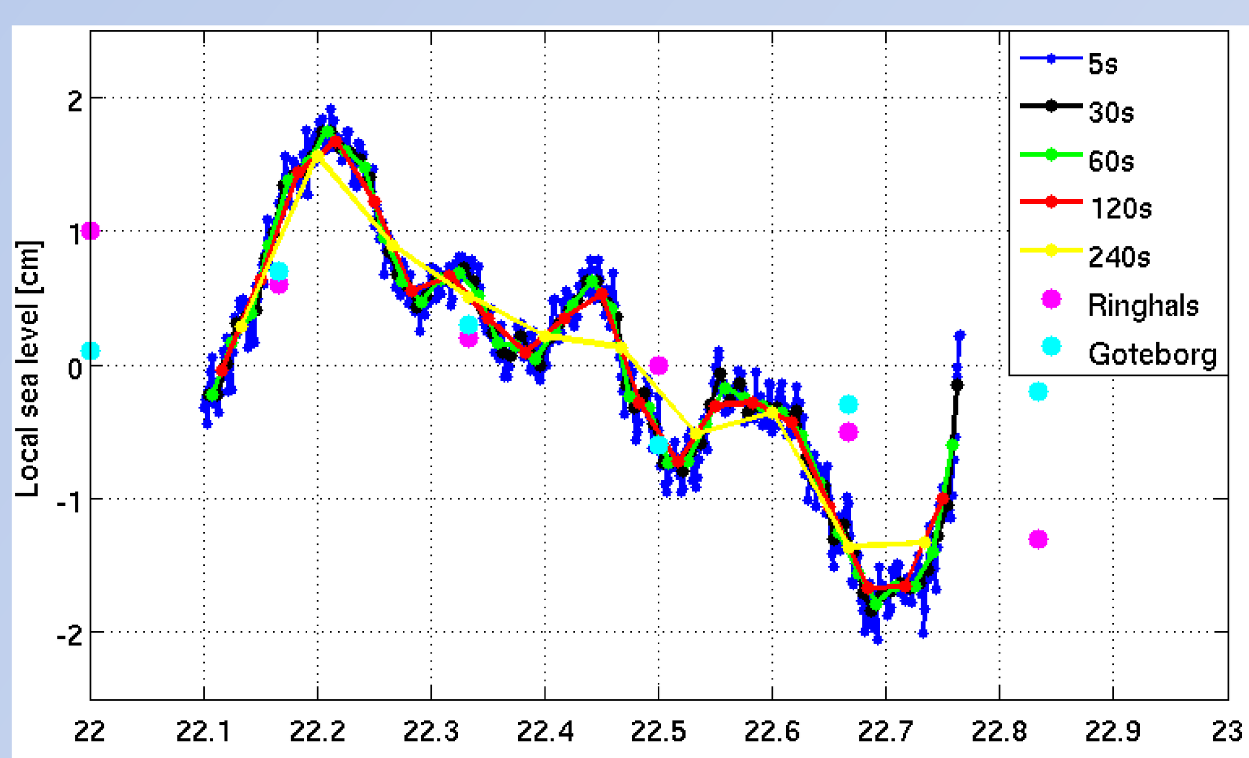


*Figure 3. Time series of local sea level with the temporal resolution of 5, 30, 60, 120, and 240 seconds together with sea level measurements from stilling well gauges at Ringhals and Göteborg with the temporal resolution of 600 seconds. The mean is removed from each time series.*

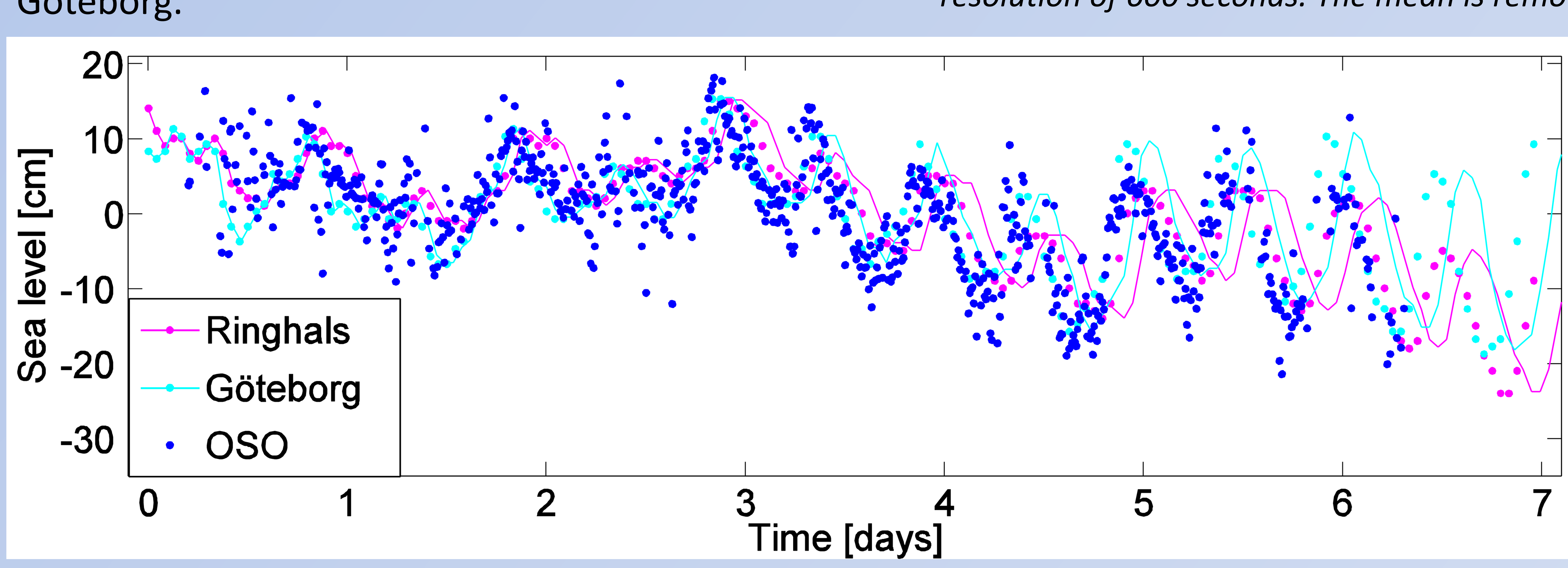


*Figure 4. GNSS-based tide gauge results from OSO compared to sea level from two stilling well gauges at Ringhals and Göteborg. Data are from 7 days in 2010 between September 26 and October 2. The mean is removed from each time series.*

## LONGER TIME SERIES

- Relative positioning using single differenced GPS L1 phase data for 1 week of 1Hz data, see Fig. 4.
- Similar processing as for the results in Fig. 2, but the vertical baseline is estimated every 10 minutes when possible.
- Comparison with sea level from two stilling well gauges at Ringhals and Göteborg show an RMS agreement of the same order as the RMS agreement of the two stilling well gauges with each other, see Tab. 1.
- Spectral analysis of the GNSS-derived sea level time series show a significant (>99.5%) M2-tide of 5.6 cm at Onsala.

*Table 1. Pairwise mean, maximum, and RMS differences in local sea level between the GNSS-based tide gauge at OSO and two stilling well gauges at Ringhals and Göteborg.*

| Site 1 | Site 2 | Mean (cm) | Max (cm) | RMS (cm) |
|---|---|---|---|---|
| OSO | Ringhals | 4.2 | 19.0 | 5.3 |
| Göteborg | OSO | 3.4 | 15.9 | 4.5 |
| Ringhals | Göteborg | 4.1 | 13.3 | 5.0 |

## RESULTS

- A first comparison of the results from the GNSS-based tide gauge at the Onsala Space Observatory (OSO) with two stilling well gauges at Ringhals (18 km south) and Göteborg (33 km north), show an RMS agreement of better than 4 cm.
- Solutions with high temporal resolution (5 s) are consistent with solutions of lower temporal resolution (30, 60, 120, 240 s).
- The different temporal resolutions show a similar overall trend as the observations from two stilling well gauges at Ringhals and Göteborg.
- Time series of 1 week derived from the GNSS-based tide gauge show an RMS agreement with the two stilling well gauges on the same order as the stilling well gauges with each other.
- Spectral analysis of the GNSS-derived time series of 7 days show a significant M2-tide of 5.6 cm at Onsala.

## CONCLUSIONS

- It is possible to observe and analyze high-rate data with the GNSS-based tide gauge and to derive local sea level with different temporal resolutions that are consistent with sea level observations from the closest stilling well gauges.
- The local short-time sea level variations at OSO cannot be represented by observations with low temporal resolution 18 km to 33 km away.
- It is possible to derive tidal constituents from the longer GNSS-derived sea level time series.

## FUTURE WORK

- Install the GNSS-based tide gauge permanently in a shielded location at OSO.
- Install a pressure sensor based tide gauge at the same site at OSO in order to further evaluate the GNSS-based tide gauge.
- Develop strategies for real-time local sea level monitoring.
- Continue to derive tidal constituents (amplitude and phase) and compare them to theoretical models.
- Process the GNSS data with existing GNSS softwares if possible. Otherwise further develop our own algorithms.
- Analyze high-rate (20 Hz) observations in post-processing.

**Workshop on GNSS Reflectometry: GNSS-R 2010, 21-22 October, Barcelona, Spain**