On the absolute sea level at the Swedish west coast estimated by VLBI, GNSS, and tide gauges

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Introduction

The geodesy VLBI radio telescopes and the GNSS stations at the Onsala Space Observatory are all located within a few hundred metres from the Kattegat coastline.

Therefore, a collaboration begun with the Swedish Meteorological and Hydrological Institute (SMHI) to install a tide gauge station at the observatory (Figure 1). SMHI is responsible for the national observational network of sea level in Sweden and the data are available by open access. This station has been operational since June 2015 and its characteristics have been presented at an earlier EVGA meeting (Elgered *et al.*, 2019).

There is now a time series of the relative sea level for almost ten years. It is still a bit short to combine with geodetic height data to assess long term trends in the absolute sea level. However, the tide gauge station Ringhals, located 20 km south-south-east of Onsala has been operational since 1967. In the following we present data from these two stations and combine the results with recent estimates of the land uplift from VLBI and GNSS.

Onsala tide gauge

Hourly values of the sea level are archived and available open access via the SMHI web. The tide gauge station is equipped with several sensors (Elgered *et al.*, 2019). The official sensor is the CS476 radar. We show the complete time series, from 00 UT 24 June 2015 to 24 UT 28 February 2025, in Figure 2.

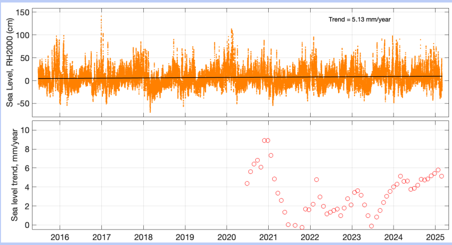

Figure 2. Sea level observations at Onsala (top). The estimated linear trend from the start to a specific date show that seasonal and yearly variability is significant (bottom).

Comparison: Sea level at Onsala and Ringhals

We use the existing simultaneous data (from June 2014 to February 2025) to assess the question of how representative the Ringhals tide gauge station is for the one at Onsala.

The Onsala and Ringhals stations provide 84,819 and 84,329 data points, respectively. This corresponds a coverage of 99.86 % and 99.29 %, respectively.

Before the comparison is done, we select only data points that are acquired on the same hour resulting in 84,235 data points, corresponding to 99.2 % of the total period.

The sea level observations at Ringhals are shown in Figure 3. When comparing figures 2 and 3 we see an overall agreement but a difference in the trends of about half a mm/year.

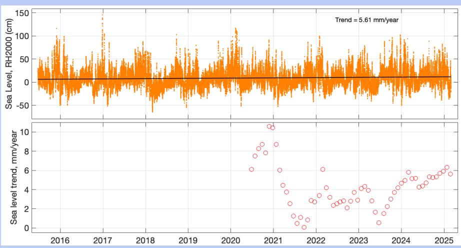

Figure 3. Sea level observations at Ringhals, c.f. Figure 2.

Figure 1. The tide gauge station at the Onsala Space Observatory.

The mean sea level averaged over this time period is 7.1 cm at Onsala and 9.0 cm (RH2000) at Ringhals. The observations are shown together with their differences in Figure 4. We note that occasionally during high sea level the difference is large with higher values at Ringhals.

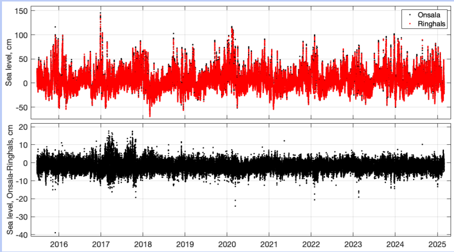

Figure 4. Sea level observations at Onsala and Ringhals (top) and their differences (bottom).

This effect is studied further using Van de Casteele diagrams in Figure 5. The horizontal error bars in the right graph indicate the formal uncertainty assuming a white noise distribution.

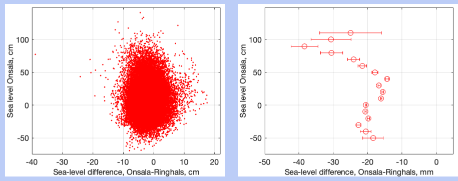

Figure 5. Van de Casteele diagrams showing the differences in sea level at Onsala and Ringhals. Individual observations are shown in the left graph and mean values for 10 cm intervals in the sea level at Onsala are shown in the graph to the right.

The reason for the differences during high sea level is not known. The high sea levels occur during storms, and we may speculate that the local environment, *i.e.,* the location of the tide gauge station relative the shape of the coastline, plays a role during these occasions, see Figure 6. We estimated the sea level trends also by ignoring values of the sea level at times when one or both sites observed a sea level above a certain level. However, we find that the difference of the half mm/year remains in all cases.

Figure 6. Location of the tide gauge stations at Onsala and Ringhals.

The absolute sea level

There are several geodetic reference markers in and around the Onsala tide gauge well. Levelling of the markers in the well relative to those in the bedrock are carried out roughly on a yearly basis. All markers are, however, not visited every time. The reference markers 827, a, b, c, and d, are located on the mounting plate of the main radar sensor CS476. They show a standard deviation of typically 0.6 mm relative to the the reference marker 822, in the bedrock close to the well.

The complete time series of the relative sea level at Ringhals is shown in Figure 7. The linear trend estimated from these data is 0.54 mm/year. We also note a slight increase in the rate when including the data from the last ten years. This in agreement with the higher rates observed at Onsala and Ringhals using the observations from 2015 to 2025.

Geodetic observations as summarized in ITRF2020 (Altamimi *et al.*, 2023) give an estimated uplift of:

- 2.7 mm/year using GNSS data (1994–2020)
- 2.9 mm/year using VLBI data (1980–2020)

It is reasonable to believe that these values are rather constant over a few decades.

Assuming that the sea level measured at Ringhals, during the 57 years of operation, is representative also for Onsala, and that the uplift at Onsala is approximately equal to that at Ringhals, means that an overall linear trend of the regional absolute sea level has been approximately 3.3 mm/year averaged over the period 1967–2025.

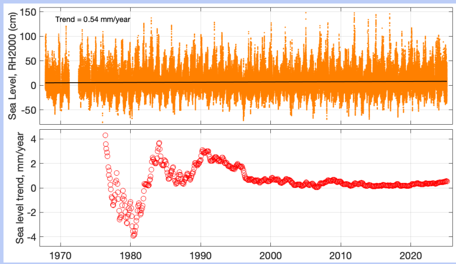

Figure 7. All observations of the sea level at Ringhals.

Conclusion

The sea level at a specific site or region show large variations, depending on the weather conditions, compared to the long-term trend. Therefore, stable and reliable values for any trends can only be obtained by averaging over a very large area or over a long time. The absolute sea-level rise from 1967 to 2025 in the Onsala / Ringhals area of Kattegat has been 3.3 ± 0.2 mm/year. We also see an indication that there is an acceleration towards the end of the time series. If this is true it is consistent with recent results for the global sea level trend (Hamlington *et al.*, 2024).

References

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