Retrieving sea surface heights by inverse modeling of GNSS SNR data

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Introduction

Since it was demonstrated that reflected Global Navigation Satellite Systems (GNSS) signals can be used to monitor local sea surface heights, the concept has been attractive as it is relatively inexpensive and easy to deploy and operate. So far, the method has been much less precise than traditional tide gauges, limiting their usefulness. However, here we present a new method for retrieving the sea surface height with increased precision.

The method is based on inverse modelling the oscillations of the SNR that come from multipath interference, in order to deduce the sea surface height. The SNR is modelled as a function of reflector height, h, and satellite elevation, ε:

$$\delta\mathrm{SNR} = A \sin\left(\frac{4\pi h}{\lambda}\sin(\varepsilon) + \varphi\right) \times \exp\left(-4k^2\gamma\sin^2(\varepsilon)\right)$$

A, φ, γ and h are fitted using non-linear least-squares algorithms. To facilitate a varying surface height, h is implemented as a B-spline function. Inverse modelling the SNR allows for using signals from multiple sources simultaneously, sharing the same reflector height in the data analysis.

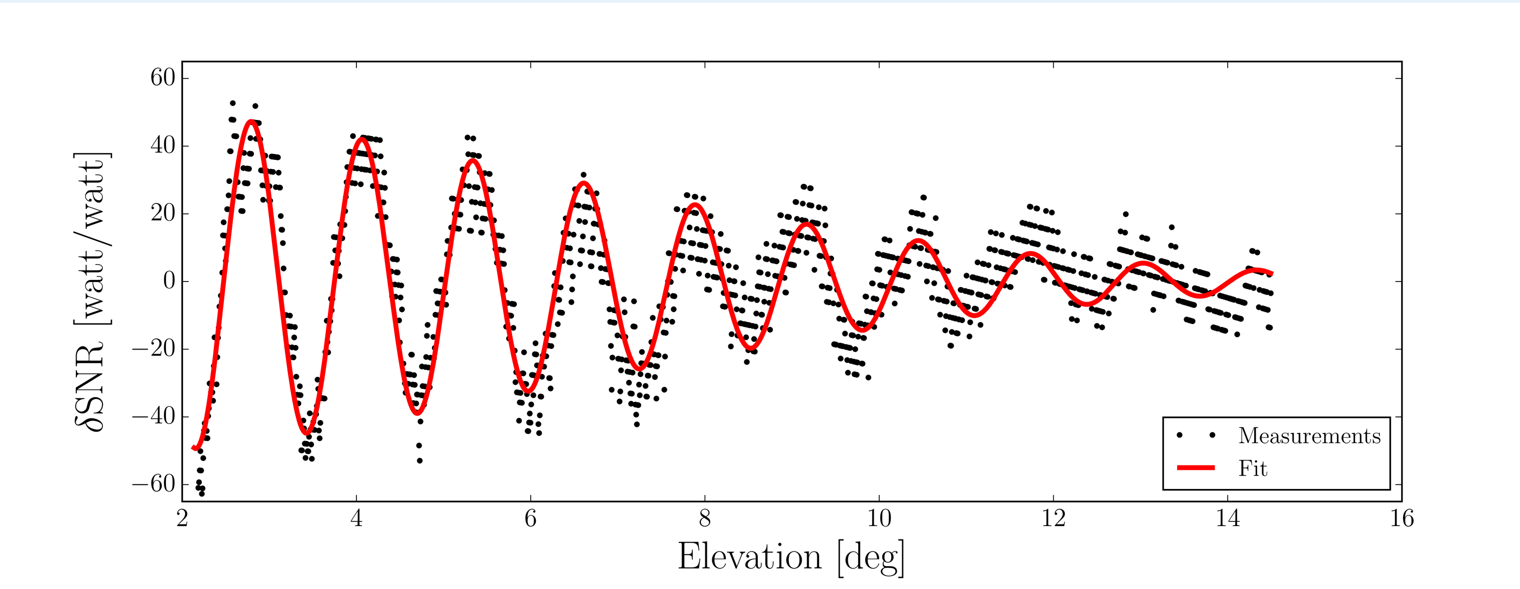

Figure 1 : SNR measurements and the fitted model. The fit is done using data from one day of GNSS-R observations.

Results

The data used for testing and verifying the algorithm has been collected from GTGU at Onsala Space Observatory, Sweden, and SPBY in Spring Bay, Australia, where co-located tide-gauges.

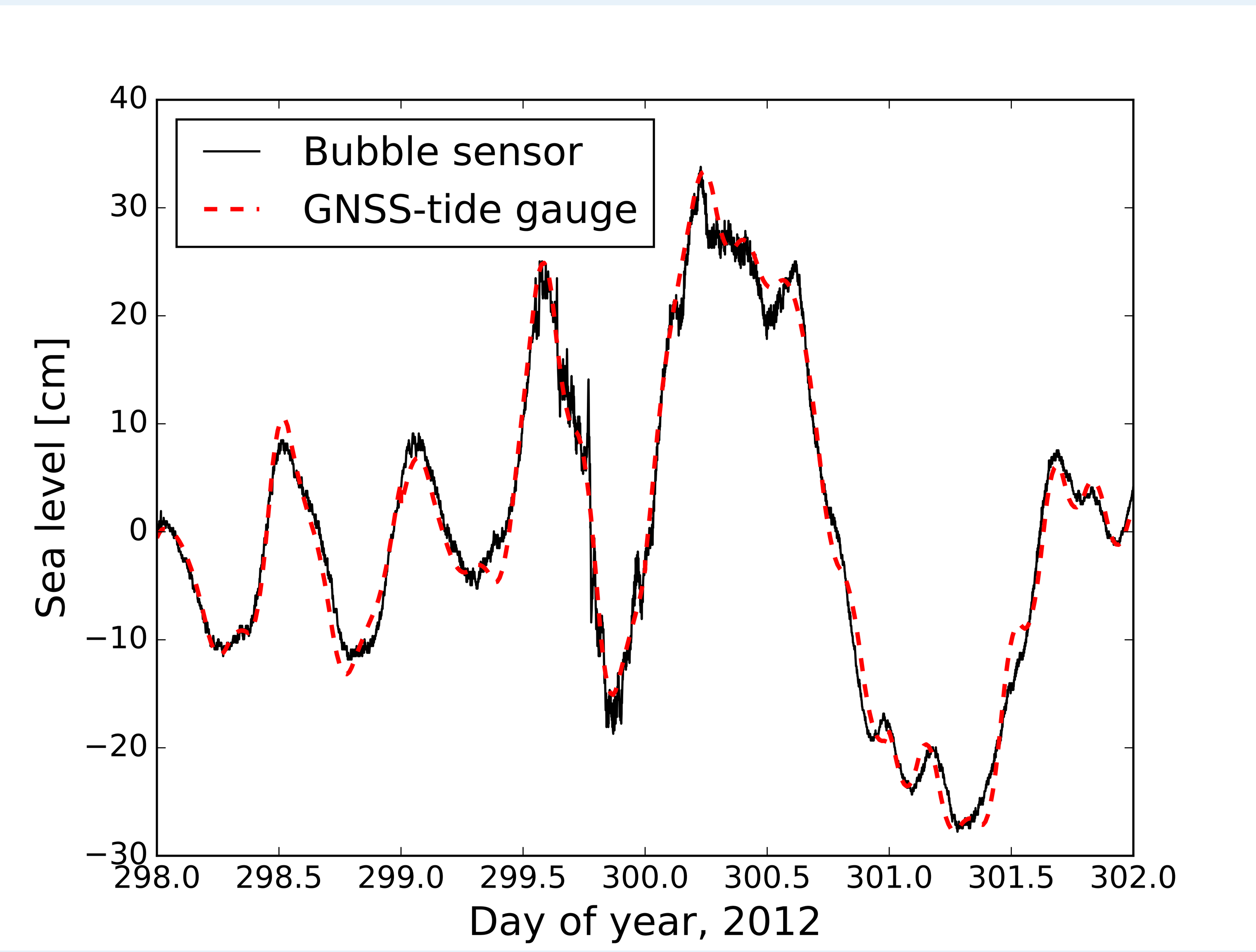

Figure 2 : Measurements from the bubble tide gauge at Onsala Space Observatory and the B-spline solution from the inversion algorithm.

The output of the algorithm is a B-spline solution for the sea surface height that can be evaluated at any time. To evaluate the performance, the solution is evaluated at the time epochs of measurements of the co-located tide gauges.

Results, cont.

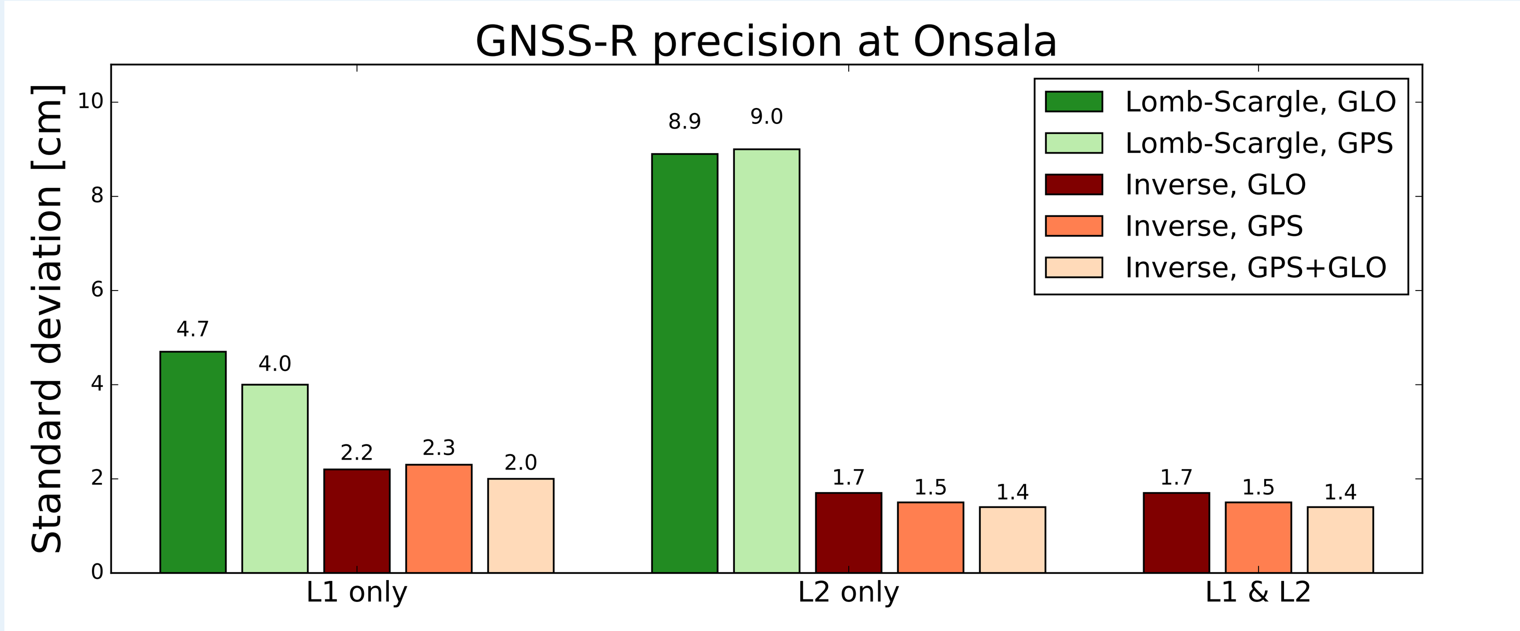

Figure 3 : Standard deviation of the difference between the sea surface heights retrieved by Lomb-Scargle analysis and our inversion algorithm, and the sea level measured by the tide gauge at Onsala Space Observatory.

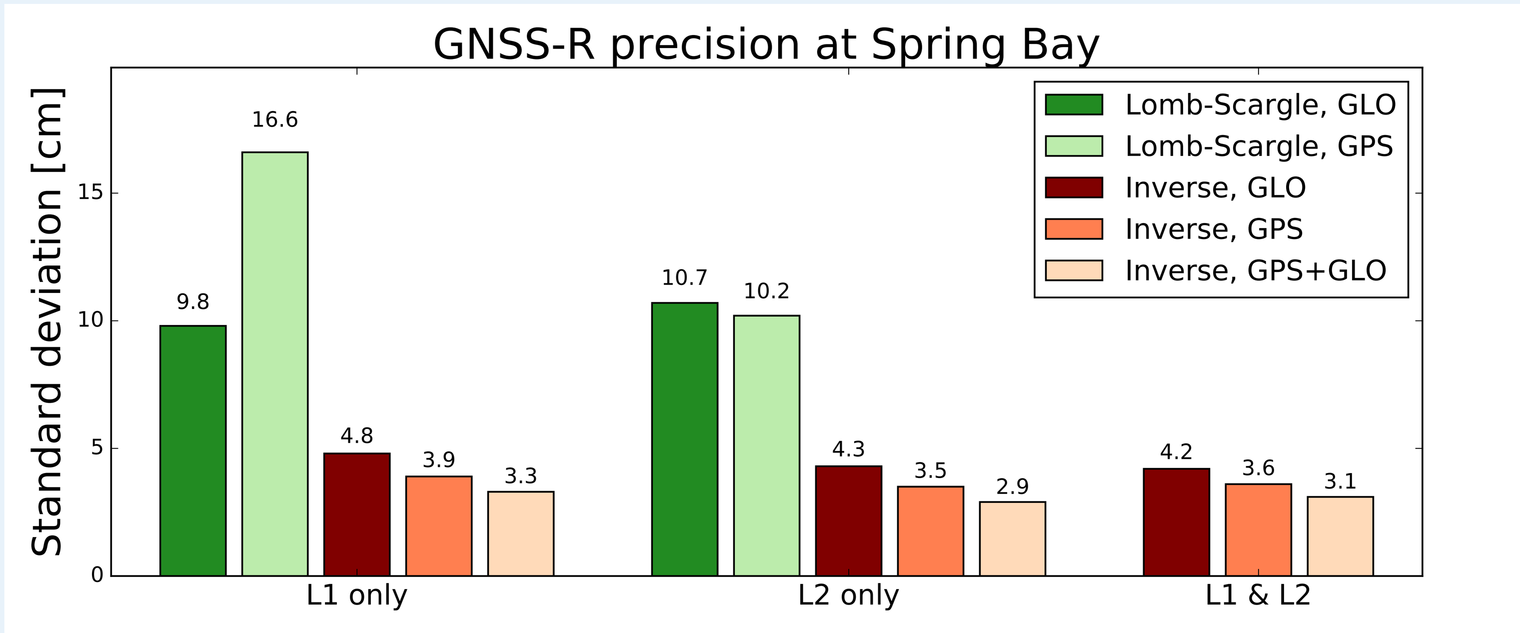

Figure 4 : Standard deviation of the difference between the sea surface heights retrieved by Lomb-Scargle analysis and our inversion algorithm, and the sea level measured by the tide gauge at Spring Bay.

Results from both Onsala in Sweden (Fig. 3), and Spring Bay in Australia (Fig. 4) confirm that the inverse modelling method has higher precision than the Lomb Scargle analysis. In Lomb-Scargle analysis, frequency shifts due to tidal sea level variations must be corrected for after retrieving an initial solution. In contrast, our method intrinsically handles varying sea surface heights.

It is also seen that combining data from both GPS and GLONASS decreases the standard deviation further. Including multiple sources increase the available data, and also increases the temporal and spatial distribution of the measurements, stabilising the solutions.

Conclusions

- Inverse modelling performs 2-3 times better than Lomb Scargle.
- Combining different satellite navigation systems leads to more precise measurements.

With better accuracy, dedicated GNSS-R stations becomes a more attractive option as they can also directly tie the measurements to the international terrestrial reference frame. Also, as the model can be expanded with other effects, such as tropospheric effects, inverse modelling will likely give even more types of measurements in the future.

References

[1] J. Strandberg, T. Hobiger, and R. Haas. Improving gnss-r sea level determination through inverse modeling of snr data. *Radio Science*, 51(8):1286–1296, August 2016.