Study of Altimetry Precision Using GNSS-R

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Abstract

This study presents an analysis and comparison of the performance of different algorithms to estimate sea surface height (SSH) from Global Navigation Satellite System Reflectometry (GNSS-R) data. The focus is on the use of two specific algorithms: the Leading-Edge Derivative (LED) algorithm [1] and the HALF algorithm [2], implemented in different ways. While these two algorithms have shown promising results for SSH, the assessment and comparison of their performance remains limited, especially with spaceborne data. These limitations are addressed in the present study, where the two algorithms are applied to both synthetic and real spaceborne data. We use in particular simulated data from the CYGNSS End-2-End Simulator (E2ES) and real data from TechDemoSat-1. It also provides results from inter comparision of different GNSS-R simulators to generate synthetic realistic GNSS-R waveforms. These simulators are JPL's GNSS-R simulator which generates waveforms using semicodeless approach and CYclone Global Navigation Satellite System (CYGNSS) End-to-End Simulator (E2ES) which uses Global Positioning System (GPS) Coarse Aquisition (C/A) code to generate waveforms. HALF algorithm is implemented for the inter comparison and applied to synthetic data. The achieved precision in the SSH for the different algorithms is assessed and compared.

Algorithm Comparison

Geometry Description

Multistatic Radar system where transmitters are existing GNSS satellites and receivers are in low orbit satellites. Signal path is between transmitter, the Earth surface and the receiver along the forward scattering direction.

Approach

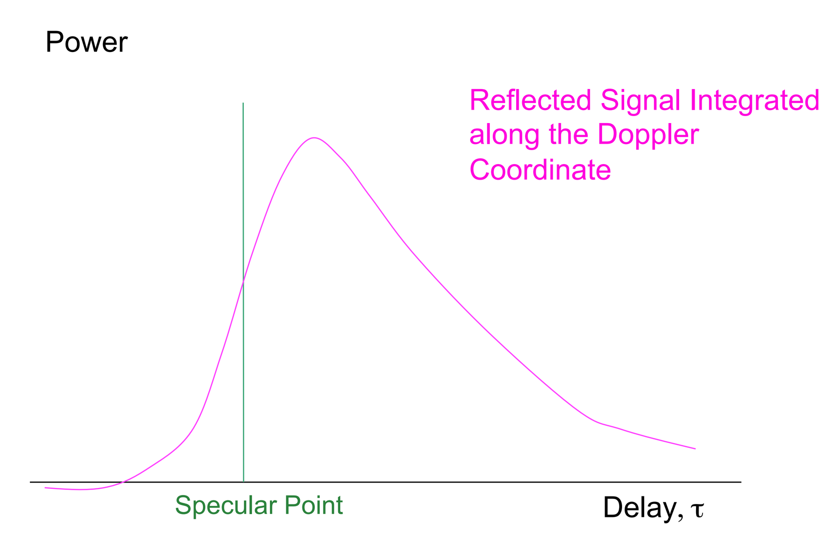
Determine the delay value (referenced to the arrival of the direct signal) corresponding to the specular point is key to measuring the range associated with reflection geometry, from which the SSH can be obtained.

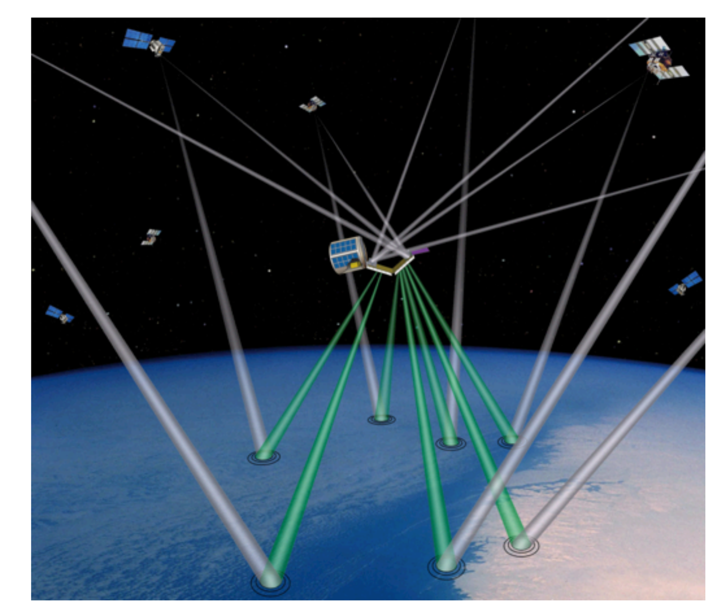
Algorithms Description

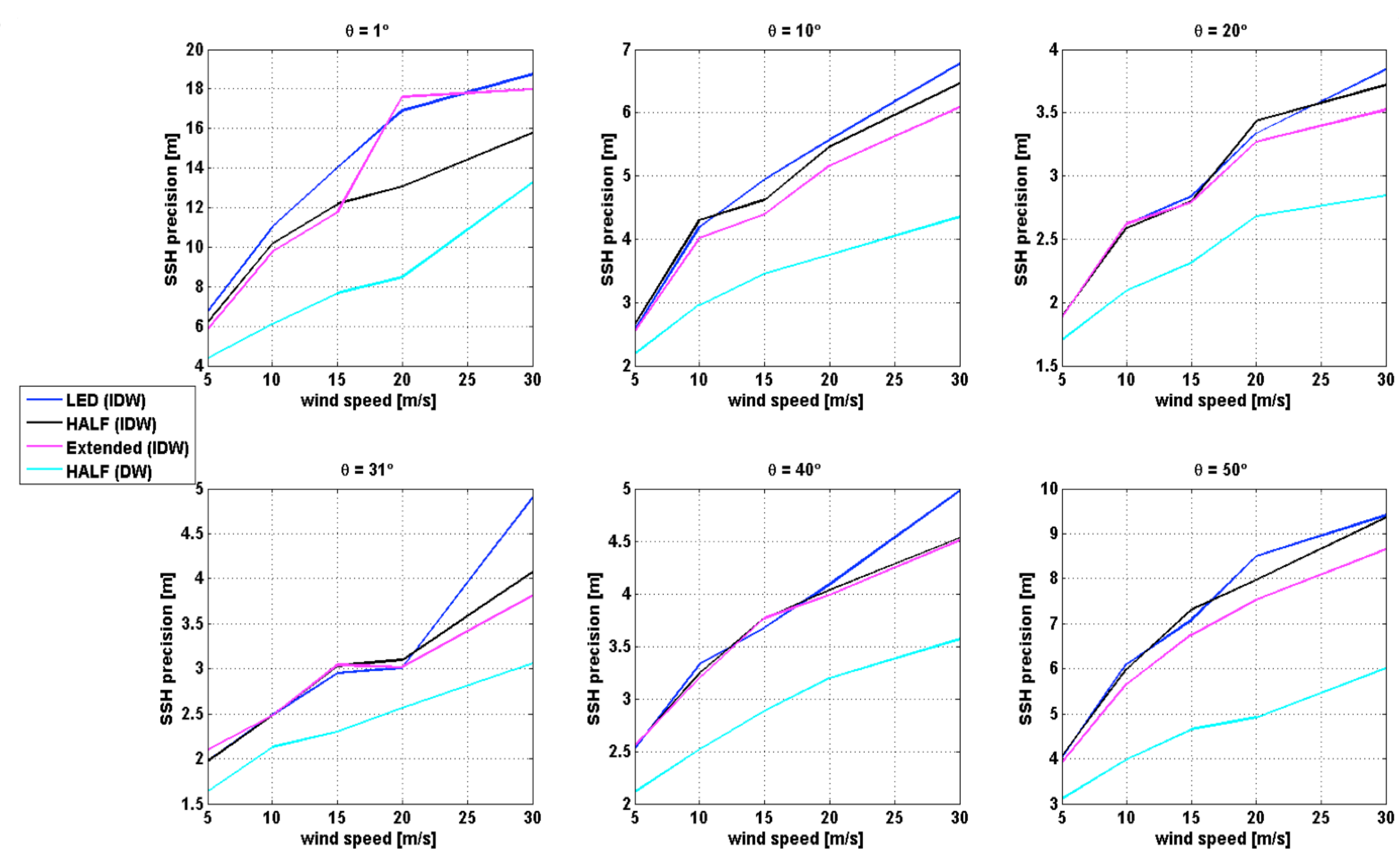
Leading Edge Derivative Algorithm: *The specular point delay corresponds to the location of the peak of the waveform first derivative along the leading edge*
HALF Algorithm: *The delay at which the power is a given fraction of the peak power corresponds to the specular point delay*

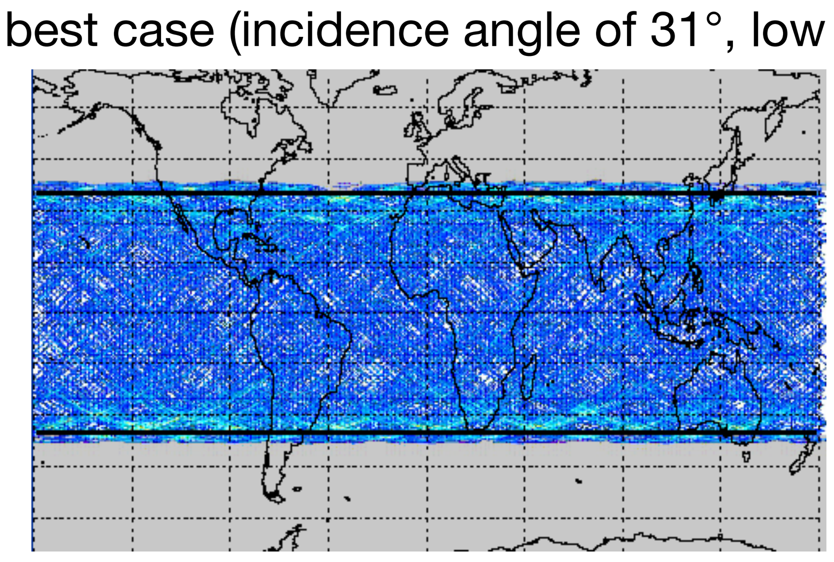
Waveforms were generated using the CYGNSS end-to-end simulator, to test what kind of altimetry would be possible with a constellation not designed for altimetry

HALF algorithm applied to DWs delivers the best performance for SSH precision, which for a system like CYGNSS can be as good as 1.6 m, in the best case (incidence angle of 31°, low wind speed of 5 m/s)



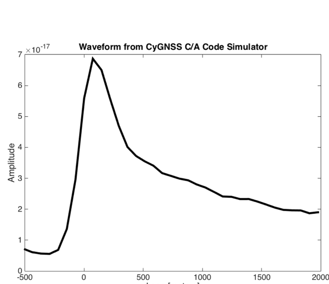


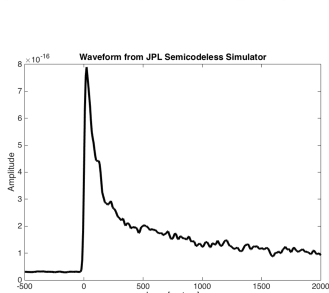




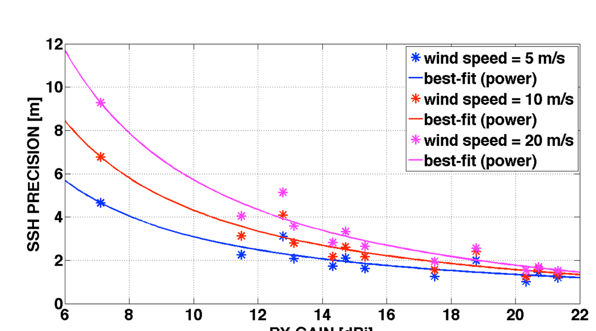
24 hour CYGNSS coverage shows density of tracks. This would provide improved precision when many 1 sec SSHs are averaged over spatial scales of order of 100 km, complementing traditional altimetry

Simulator Comparison

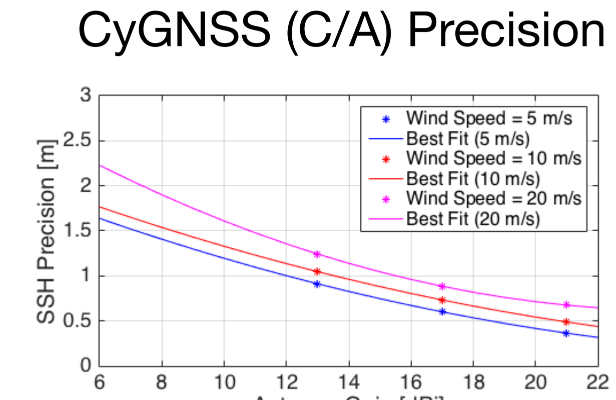




- Example of 1 sec altimetry waveforms from Wind speed: 10 m/sec, Incidence Angle: 30°, Antenna Gain: 20.3 dBi
- Simulators with different code :
  CYGNSS (C/A), JPL (semicodeless P(Y))
- Precision in SSH Estimation:
  - C/A Code 1.6 m, Semicodeless: 43 cm
  - P(Y) has larger bandwidth that C/A which translates into higher precision in semicodeless

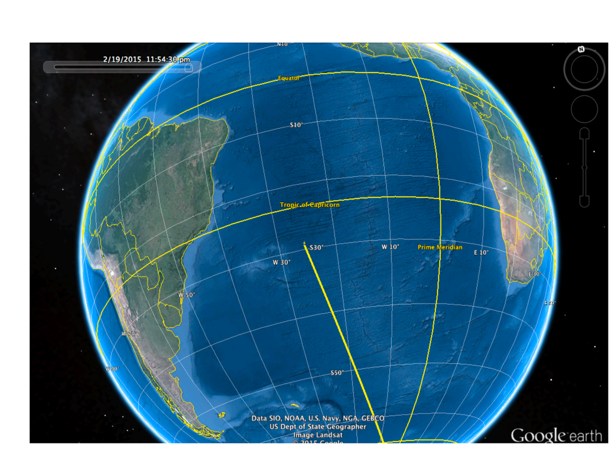


CyGNSS (C/A) Precision

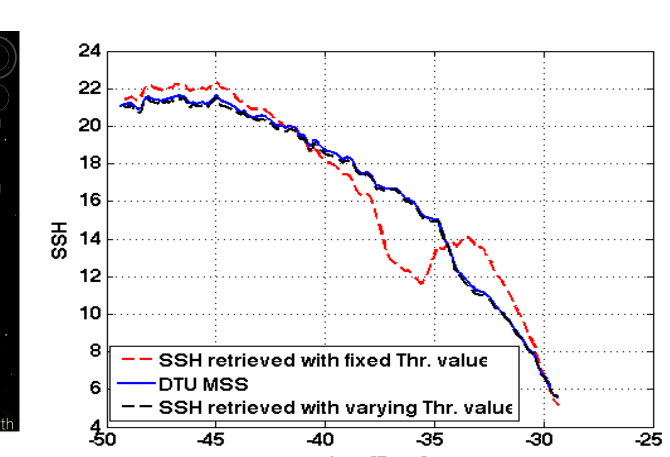


JPL (semicodeless P(Y)) Precision

Analysis of TDS-1



Example transect TD204 of TDS-1 used as case study



Estimated SSH

Mean sea surface of TD204 (blue), used to generate high-resolution DWs with the CYGNSS E2ES, along with SSH (red) estimated using a fixed peak fraction and a variable (geometry-dependent) peak fraction (black), for DWs with a delay resolution of 1/20 chip.

Summary

- Among the algorithms analyzed here, the HALF algorithm delivers the best performance;
- The best SSH precision using C/A code and CYGNSS simulations is ~1.6 m and using semicodeless code and JPL simulations is ~0.4 m, with an incidence angle of ~30°.
- Overall the SSH precision tends to increase with increasing gain of the receiver, but it tends to reach a plateau after a certain gain value, which is an evidence that the C/A code still poses limitations to the maximum achievable SSH precision.
- All these algorithms produced a biased SSH estimator. The bias needs to be characterized and removed. The bias seems to exhibit less variability with increasing gain of the receiver antenna.
- The agreement between TDS-derived SSH and mean sea surface is encouraging for one of the test cases, but much more work is needed to fully assess the possibility to retrieve any meaningful SSH information from TDS-1 data.
- Future investigations into how well the absolute delays in TDS-1 DDMs are known, since this is essential for SSH analysis, are needed.
- A better, more robust retrieval algorithm based on full waveform fitting (similar to standard altimetry) to estimate multiple parameters (i.e. wind speed, SSH, SWH) at the same time is needed.
- Continued availability of TDS-1 data, including corrections, is key to making progress.
  - More information on TDS-1 Analysis to retrieve SSH can be found **at Poster Number CVL_10 titled Sea Surface Height from Spaceborne GNSS-R: a Demonstration with TechDemoSat-1 Data**

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References: [1] Hajj, G.A., and C. Zuffada, Theoretical description of a bistatic system for ocean altimetry using the GPS signal, Radio Science, 38(5):1089, 2003.
[2] Cardellach, E., Rius, A., Martín-Neira, M., Fabra, F., Nogués-Correig, O., Ribó, S., Kainulainen, J., Camps, A., D Addio, S. (2013), Consolidating the Precision of Interferometric GNSS-R Ocean Altimetry using Airborne Experimental Data, IEEE Transactions on Geoscience and Remote Sensing, 2013, doi:10.1109/TGRS.2013.2286257.
[3] Rius, A., Cardellach, E., Martín-Neira, M., Altimetric Analysis of the Sea-Surface GPS-Reflected Signals, IEEE Transactions on Geoscience and Remote Sensing, 48, 4, pp. 2119 - 2127, 2010, Apr., 10.1109/TGRS.2009.2036721.
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