SEA SURFACE HEIGHT FROM SPACEBORNE GNSS-R: A DEMONSTRATION WITH TECHDEMOSAT-1 DATA

Maria Paola Clarizia[1], Christopher Ruf[1], Cinzia Zuffada[2] and Paolo Cipollini[3]
[1] University of Michigan, Ann Arbor, USA
[2] Jet Propulsion Laboratory, California Institute of Technology, Pasadena USA
[3] National Oceanography Centre (NOC), Southampton UK
* email: clarizia@umich.edu

INTRODUCTION

1. Overview

- ❖In this study we observe Sea Surface Height for the first time using spaceborne GPS-Reflectometry;
- ❖SSH is estimated using data from the TechDemoSat-1 (TDS-1) satellite , and compared with DTU10 Mean SSH;

2. GPS-R Concept

❖The difference in arrival time at the receiver between the direct and reflected GPS signal provides the SSH at the specular point;

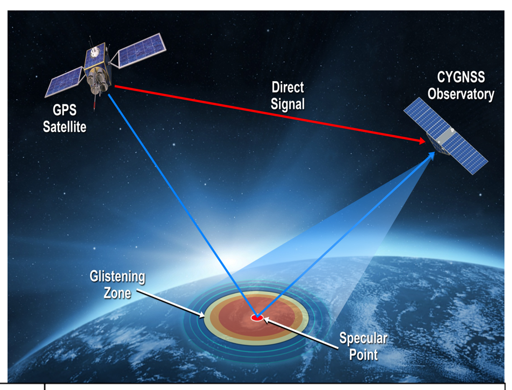


Table 1: TDS-1 Parameters

Orbit Parameters	*Altitude*: 635 km *Inclination*: 98.4° *Period*: 97.3 min *Eccentricity*: 0.00075 *LTAN*: 9:00 pm
Geometry/Sea Surface Conditions	*Incidence angle*: 0° - 52° *Wind speed*: 0 m/s – 24 m/s
GPS-R Receiver Parameters	*Sampling Rate*: 16.367 MHz *Center Frequency*: 1575.42 MHz (GPS L1) *Delay Pixels*: 128 *Delay Resolution*: 244 ns *Doppler Pixels*: 20 *Doppler Resolution:* 500 Hz *Filter Bandwidth:* 5 MHz *Receiver Peak Antenna Gain*: 13.3 dBi *Interpolation Method/Factor*: Spline/1000

3. Description of Data

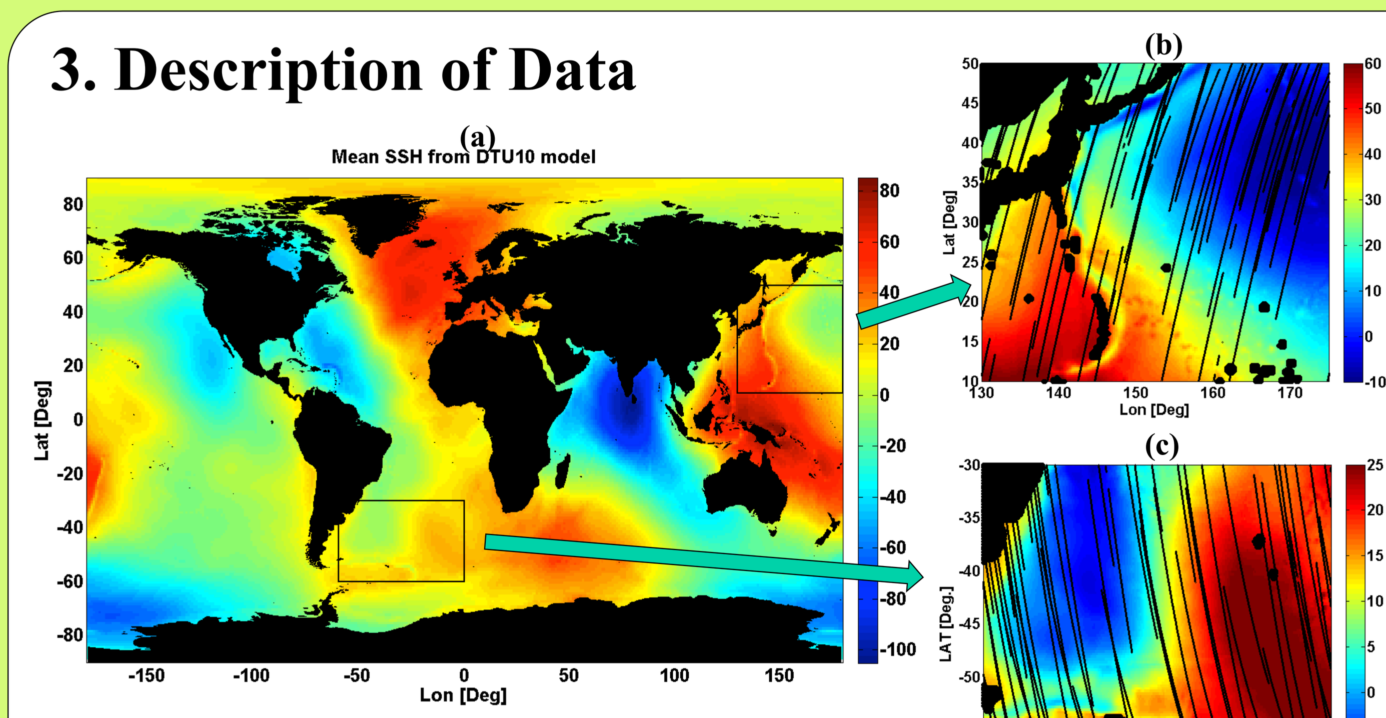


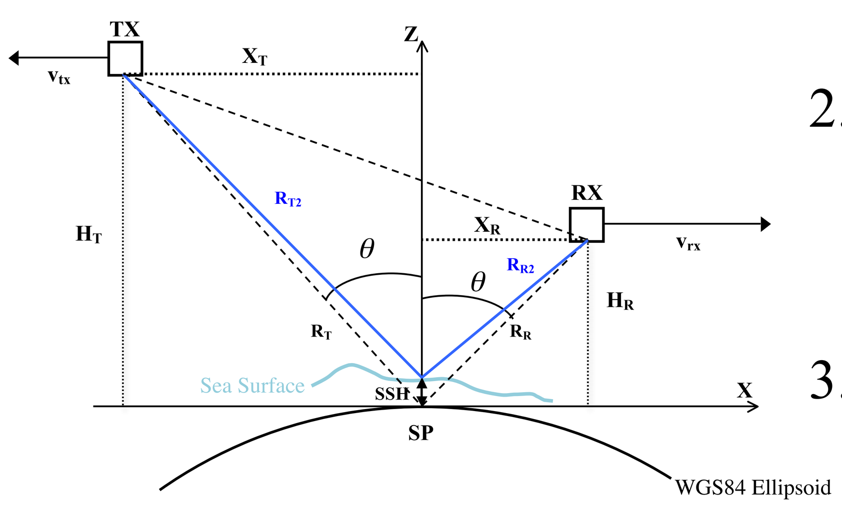
Figure 1. (a) global map of MSSH from the DTU10 model, with test areas highlighted as black boxes. (b) zoomed version of the MSSH for the South Atlantic region, (c) zoomed version of the MSSH for the North Pacific region;

The dataset consists of Delay-Doppler Maps (DDMs) collected between September 2014 and February 2015, plus metadata;

The data are very sparse in space and time, so we combine all the Specular Point (SP) tracks (shown in fig. 2b-2c) over the 6-month period;

SEA SURFACE HEIGHT RETRIEVAL

4. Along-Track SSH



$$c\Delta\tau = (R_T + R_R) - (R_{T2} + R_{R2})$$
$$SSH = H_T - \sqrt{R_{T2}^2 - X_T^2}$$
$$SSH = H_R - \sqrt{R_{R2}^2 - X_R^2}$$

➡ Solve for R_{R2}, R_{T2} and SSH

Figure 2. SSH measurement geometry. The time delays τ_2 and τ_1 are represented respectively by the blue and the black reflected minus direct path. It is assumed that the transmitter, specular point and receiver are in the *x*-*z* plane.

1. A QC filter is applied to data (receive antenna gain > 5 dBi, and ascending night tracks only);
2. the Delay Waveform (DW) is selected from the DDM at zero Doppler frequency, and interpolated to improve SSH resolution;
3. The Leading Edge Derivative (LED) algorithm [1] is applied to estimate the delay difference τ_2 between direct and reflected signal;
4. The predicted delay difference τ_1 between direct and reflected signal is estimated using metadata information;
5. The delay difference $\Delta\tau = (\tau_1 - \tau_2)$ is converted to SSH with knowledge of the measurement geometry [2];

5. Gridded SSH

- ❖Some outliers in SSH estimates are removed using a standard criterion [2];
- ❖A gridded SSH map is obtained for the two regions, with a ¼ degree latitude/longitude resolution, using a smoothing procedure with a Gaussian kernel of Full Width at Half Maximum (FWHM) equal to 250 km;
- ❖FWHM = 250 km reduces the RMS difference between the smoothed versions of TDS-1 SSH and MSSH (see figure 3a) while not changing too much the original MSSH (figure 3b);
- ❖The TDS-1 SSH are finally converted into anomalies with respect to the DTU10 MSSH, by removing an overall bias relative to the DTU10 values;

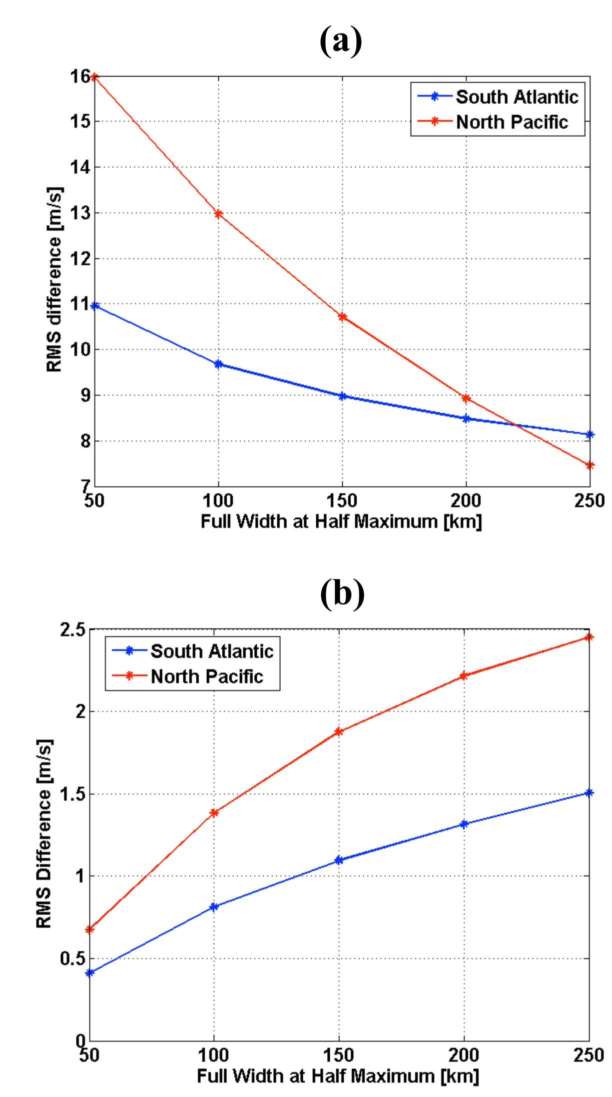
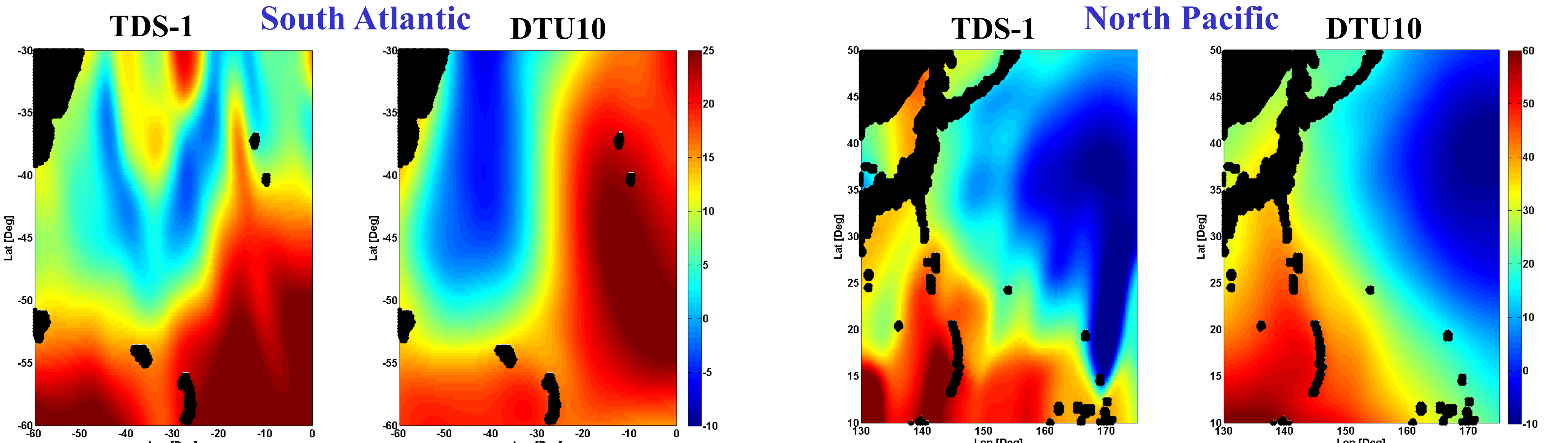


Figure 3. RMS difference between (a) Gaussian-smoothed versions of TDS-1 and DTU10 SSH, and (b) original and smoothed DTU10 SSH.

RESULTS

Figure 4 (from [2]): Comparison of TDS-1 (left panel) and DTU10 (right panel) SSH for the two regions considered.



- ❖The RMS difference between TDS-1 SSH and DTU10 SSH is 8.1 m in South Atlantic and 7.4 m in North Pacific (see fig.3a); These numbers are larger than the predicted precision of ~5 m, estimated in literature with simulations [3];
- ❖The GPS-R instrument onboard TDS-1 is very sub-optimal for SSH estimations:
  - A) the receiver bandwidth (see Table 1) is very narrow, and an SSH uncertainty on the order of several meters is expected even after the interpolation;
  - B) Some sensors parameters (antenna gain, sampling rate) are worse than those assumed in [3];
  - C) There is uncertainty on the information about the TDS-1 orbit;
  - D) Our errors represent the combined precision and accuracy, since no standard altimetry corrections are applied here;

CONCLUSIONS & FUTURE POTENTIAL

- ✧ **The ability of spaceborne GPS-Reflectometry to provide SSH is demonstrated for the first time;**
- ✧ One limitation of this analysis is the sparse availability of data, but with the launch of CYGNSS in 2016, the space-time coverage will become dense over +/-35° latitude (fig.5);
- ✧ GNSS-R receivers are low in cost/weight/power, so they can easily be launched to form constellations or piggybacked on other satellites;
- ✧ The very different sampling of GNSS-R altimetry may provide valuable data complementary to nadir altimeters, filling the space between altimetry tracks, and improving observations of mesoscale circulation;

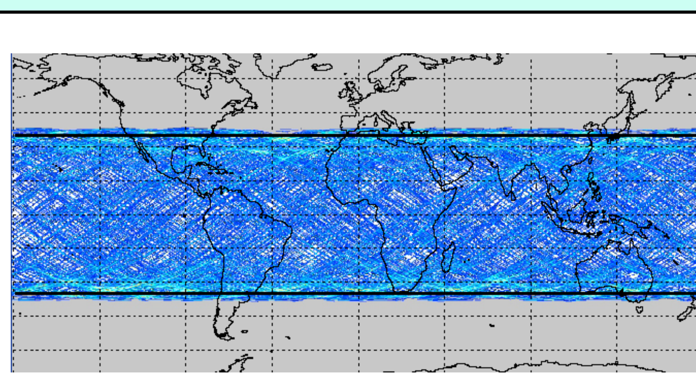


Figure 5. Coverage achieved by the CYGNSS Constellation in 24 hours.

REFERENCES
[1] Hajj, G.A., and C. Zuffada (2002), "Theoretical description of a bistatic system for ocean altimetry using the GPS signal", *Radio Science*, 38(5).
[2] Clarizia, M.P., Ruf C., Cipollini P. and Zuffada C. (2015), "First Spaceborne Observation of Sea Surface Height using GPS-Reflectometry", submitted to *Geophysical Research Letters*.
[3] 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,* 52(8), 4992-5004.