Data analytics for TDS-1 GNSS-R Ocean Altimetry Using A "Full DDM" Retrieval Approach

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INTRODUCTION

GNSS-R for Ocean Altimetry

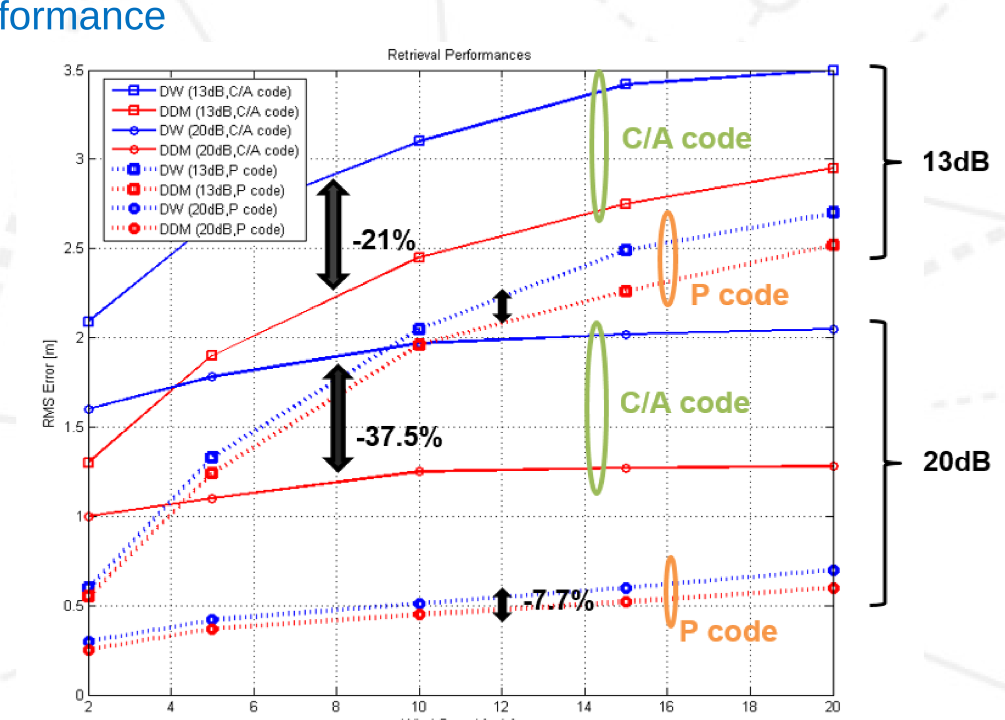
- GNSS-R (Global Navigation Satellite System-Reflectometry)
- Using reflected GNSS signal from the Earth's surface for geophysical remote sensing [1-2]
  - Altimetry and Scatterometry
  - Bistatic radar configuration
- Extensive ground and air-borne research reported; limited number of existing satellite demonstrations
- Multiple satellite missions (PARIS, GEROS, CYGNSS) in the planning phases

MOTIVATION

- TechDemoSat-1 (TDS-1) of Surrey Satellite Technology Ltd (SSTL) in orbit since July 2014
  - Provides opportunity to test GNSS-R sensing
  - TDS-1 dataset of onboard-processed Delay-Doppler maps (DDMs) has been made available to the science community
- Results reported to date have focused on ocean sensing
  - Wind speed [3]
  - Altimetry [4] using the delay waveform "leading-edge" method
- Altimetry from TDS-1 is very coarse due to use of C/A code only; high rms errors requiring significant time/space averaging even to see geoid
- Still of interest as a demonstration

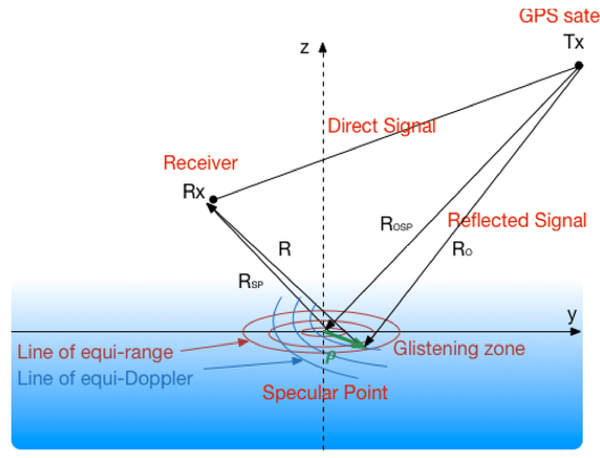
Previous Studies

- Fixed Geometry, varying wind speed, C/A and P code, using only the delay waveform (DW) or full DDM in retrieval [5]
- [5] showed full DDM outperforms DW only; C/A code rms SSH error ~ 3 m or more for a 1 sec product
- Results from previous simulations suggest that Full DDM approach may yield improvements in SSH retrieval performance

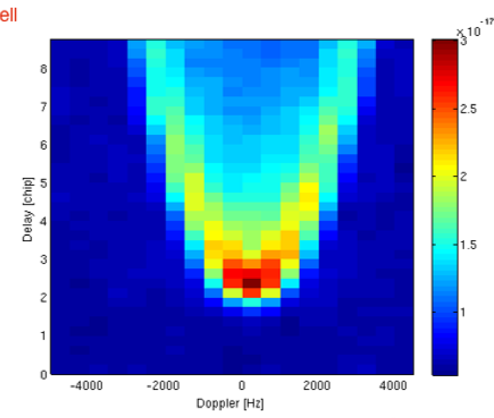


Goals for this Study

- Perform TDS-1 altimetry using the "Full DDM" approach
- Requires forward model: modified CYGNSS E2ES



GNSS-R Geometry

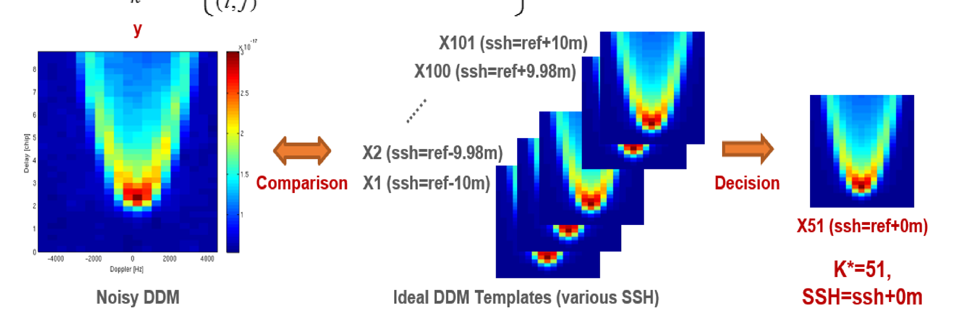


Noisy DDM Example (1ms with 1000 looks)

Maximum Likelihood (ML) Retrieval

- For given geometry and known wind speed, generate set of noise free 'templates' of varying SSH from -100 m to 100 m in 101 steps (2m resolution)
- Compare between noisy DDM and templates and find closest one [5,6] : Retrieved SSH index is

$$k^* = \arg\min_k \left\{ \sum_{(i,j)} \left| y(i,j) - x_k(i,j) \right|^2 \right\}$$,where k = template index



- Thermal noise estimated and removed by averaging data free areas
- Additional spatial and temporal averaging can be used post-retrieval to 'beat down' TDS-1 retrieval errors

CYGNSS End-to-End Simulator (E2ES)

- CYGNSS (Cyclone Global Navigation Satellite System) Mission: launch Oct 2016 [7]
- 8 small satellites in low Earth orbit (LEO) at 35° inclination w/ C/A code only
- CYGNSS E2ES developed for mission simulations
- E2ES modified to allow studies of altimetry

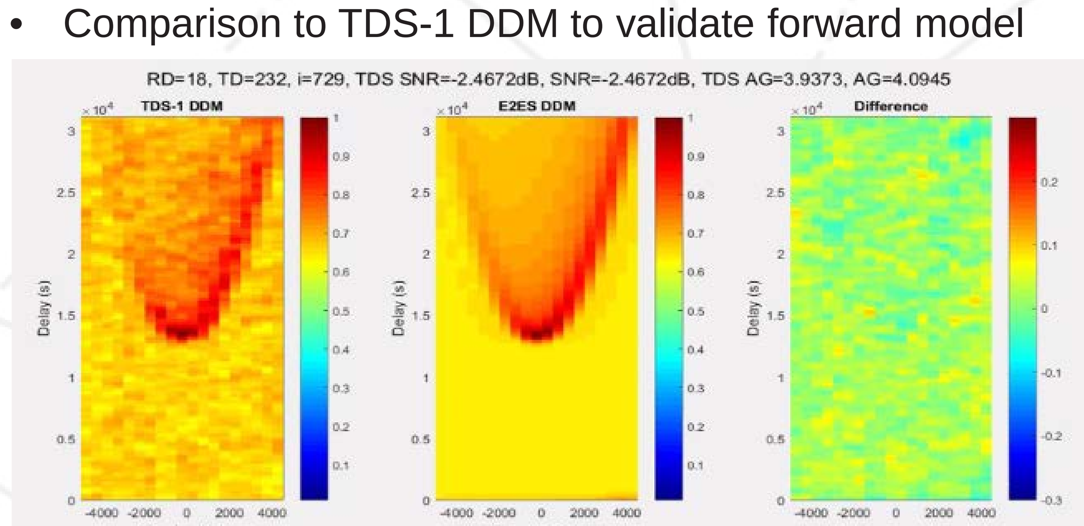
Conventional E2ES components

- Dynamic orbit propagators for GPS and CYGNSS constellations
- Signal generation by GPS transmitter satellites
- Free space propagation to the specular reflection point on the Earth surface
- Bi-static forward scattering from the wind driven, roughened ocean surface using Nature Run data
- Receive antenna gain pattern projected onto the Earth surface
- Link budget for received signal strength
- Fading and thermal noise statistics of received signal
- Accuracy, precision and resolution of Delay Doppler Map data product
- Wind speed retrieval algorithm

+ New E2ES components for altimetry

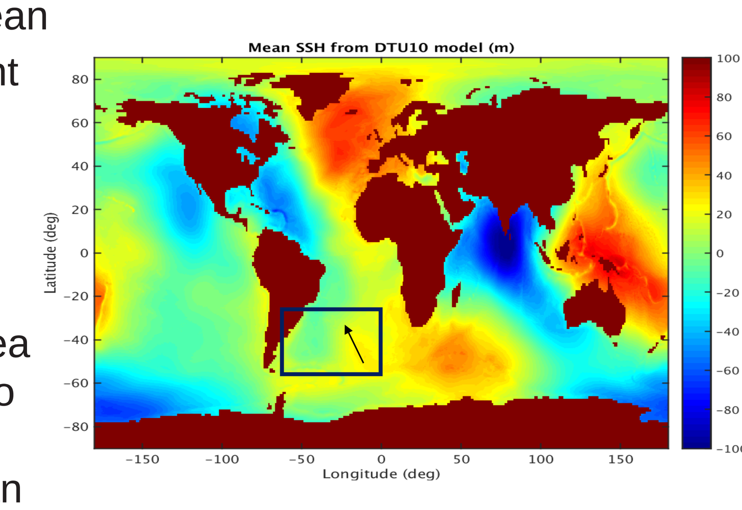
- Incorporate SSH variations in forward model
- SSH retrieval algorithm
- Altimetry performance analysis

- Comparison to TDS-1 DDM to validate forward model



Test Regions and Ground Truth

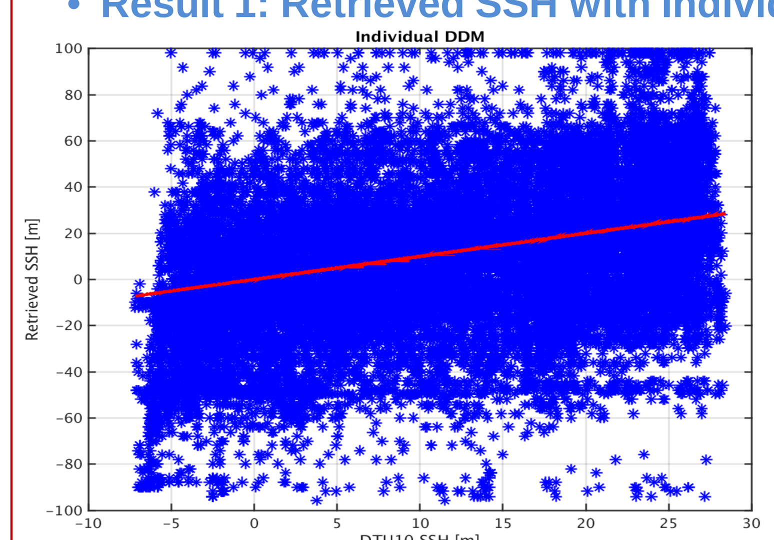
- Test Region: South Atlantic (Lon: -60~0, Lat: -60~-30 degree)
- Quality Control Filter
  - Antenna gain > 5 dBi
  - Night ascending tracks to reduce ionosphere
- Retrieved L2 Wind speeds in TDS-1 metadata are used
- Gridded DTU10 Mean Sea Surface Height (MSSH) used as 'truth' to evaluate performance (1min resolution)
- Geoid with mean sea level good model to see effects of big signals in the ocean



RESULTS

- Total number of test DDMs : 27827
  - 15247 DDMs for 01/26/15 ~ 02/21/15 (RD16~RD19)
  - 12580 DDMs for 03/16/15 ~ 04/18/15 (RD23~RD27)

Result 1: Retrieved SSH with Individual DDM



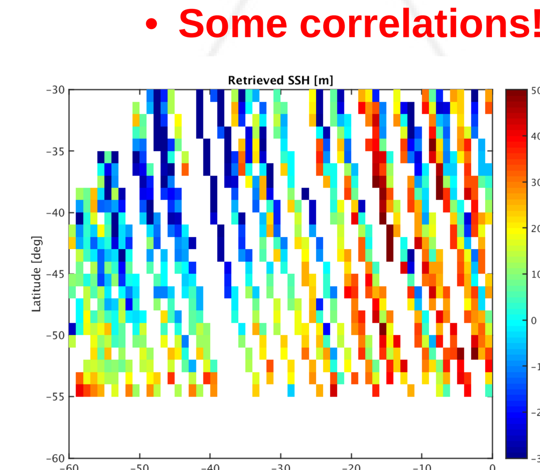
RMSE=29.3244m

Poor Performance likely due to model mismatch, wind speed error and instrument effects

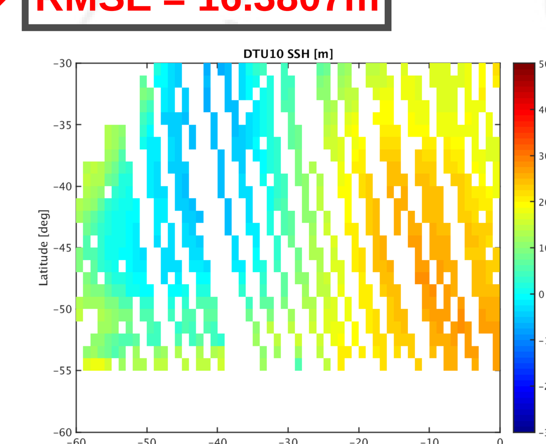
RMSE 2.5m from previous simulation study

Result 2: Retrieved SSH after averaging in time and space

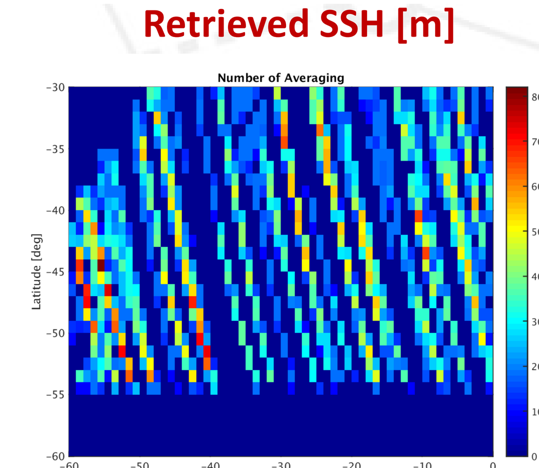
- Averaging SSH in 1-degree longitude and 1-degree latitude area
- Some correlations! → RMSE = 16.3807m



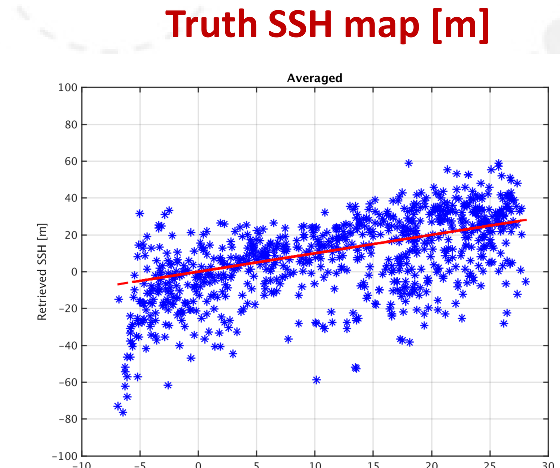
Retrieved SSH [m]



Truth SSH map [m]



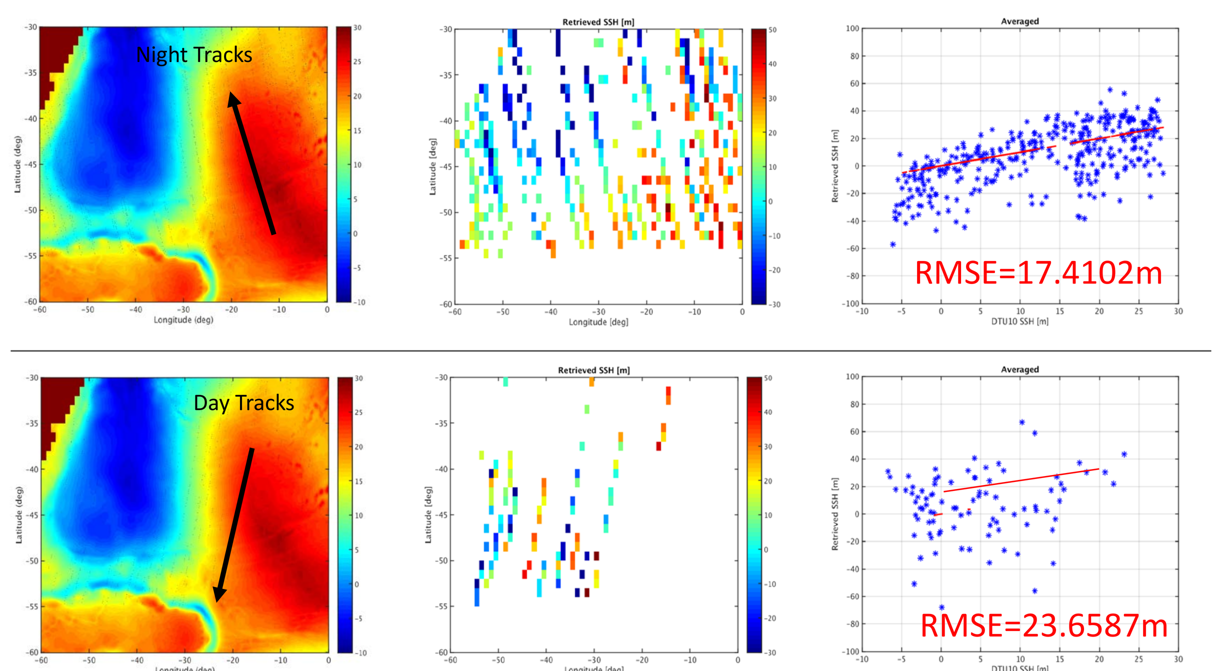
Number of Averaging



Scatter Plot

Result 3: Comparison between night tracks and day tracks

- Number of averaging : 20~40
- Ionosphere delay effects the performance for the day tracks



CONCLUSIONS

- Study performed of TDS-1 altimetry
  - Modification of current CYGNSS E2ES
  - TDS-1 DDM Generation using CYGNSS E2ES
- Sea surface height retrievals using
  - DTU10 SSH as a ground truth
  - Quality control filters (i.e. high AG, night track)
- Results
  - RMS error is large with individual DDM only
  - Large geophysical signals are observable given sufficient time and space averaging
- Future work
  - Attempts to reduce the model mismatch
  - Analyze impact of other error sources
  - Preparation for the CYGNSS Altimetry

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