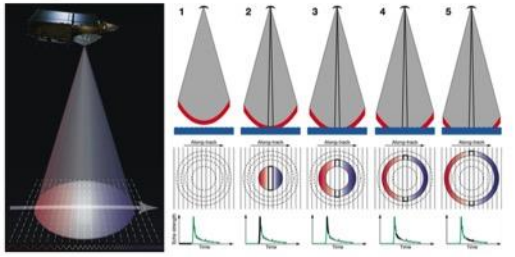

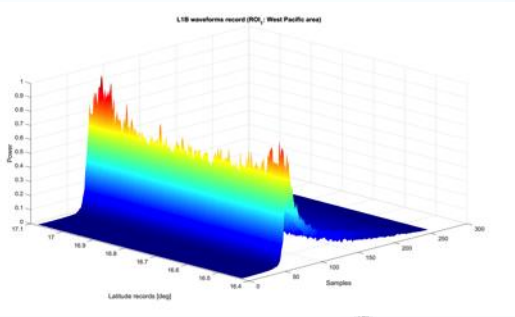

Improved Retrieval Methods for Sentinel-3 SAR Altimetry over Coastal and Open Ocean and recommendations for implementation: ESA SCOOP Project Results.

Marc Naeije, David Cotton, Thomas Moreau, Eduard Varona, Christine Gommenginger, Mathilde Cancet,

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esa

seom scientific exploitation of operational missions

SCOOP
OSTST Oct 2019

The SCOOP Project

- SCOOP (SAR Altimetry Coastal & Open Ocean Performance) project funded under the ESA SEOM (Scientific Exploitation of Operational Missions) Programme.
- Aim is to provide answers to the two questions:
  - ***What level of performance can we expect from Sentinel-3 SRAL data over the open ocean and coastal zone?***
  - ***Can we further enhance this performance with improvements to the processing schemes?***

Quickly evolving subject: A lot has happened in the last 3-4 years

Have achieved some of the expected improvements in terms of along track resolution and measurement precision, but not reached the level predicted by theory. Can we do better?

SCOOP Overview

1. **State of the Art Review**
   - A thorough review of the current knowledge of SAR altimetry – with **recommendations** on processing methods and algorithms.
   - **Report is available online** via SatOC SCOOP project page (www.satoc.eu/projects/SCOOP)
2. **Phase 1**
   - **Generate 1-year test data** set applying SRAL "Baseline" equivalent processing to CryoSat FBR data
   - **Evaluate expected performance of Sentinel-3** SRAL products over the open ocean and in the coastal zone
3. **Phase 2**
   - **Develop, implement and test modifications** to the SRAL "Baseline" processing algorithms
   - **Evaluate improvement** in performance from modified processing
4. **Scientific Road Map**
   - **Recommendations for further R&D and implementation** for Sentinel-3 and other future SAR altimeter missions

SCOOP Data Sets

SCOOP Test Data Set (TDS)

- **10 Regions of Interest**:
  - West, Central and Eastern Pacific; NE Atlantic, N Sea, Agulhas, N Indian Ocean, Indonesia, *Cuba (SARin)*, Harvest (California)
- 2012-2013; 01/12/2015 onwards for Harvest
- **TDS1: CryoSat FBR baseline C data – reprocessed** with Sentinel-3 SRAL baseline configuration. SAR L1B, SAR L2, RDSAR L2
- **TDS2: Modifications to TDS1:** SAR processing includes zero padding in range, and intra- burst Hamming windowing
- **Enhanced Wet Troposphere Correction** (U Porto): GPD+
- **Documented descriptions** of processing schemes and products at ***www.satoc.eu/projects/SCOOP***
- **Both TDS available** on request by email to ***scoop.info@esa.int***

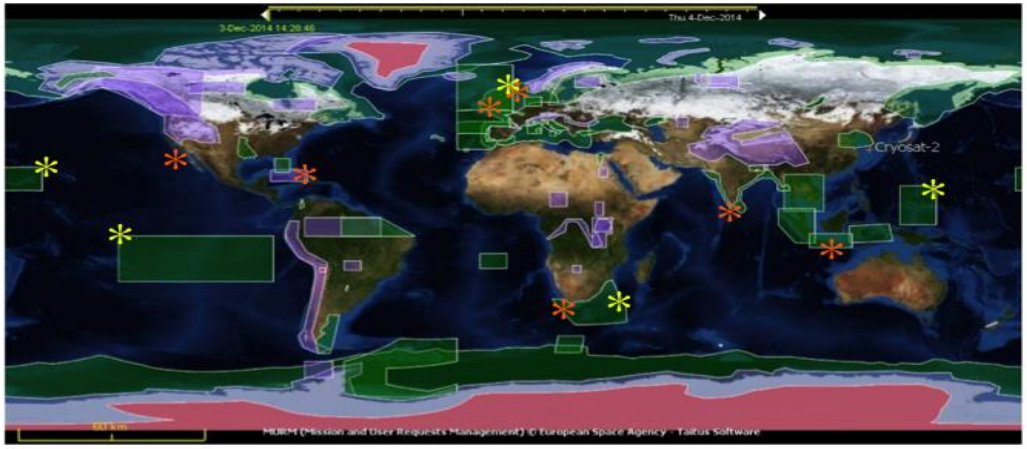


Image credit: ESA

SCOOP "Baseline" TDS Processing

SAR Mode Processing:

- **Cryosat FBR "à la Sentinel-3"**

  Implementation through the ESA GPOD facility: http://gpod.eo.esa.int

- **Cryosat FBR to L1B – Delay Doppler Processing**

  Cryosat calibrations applied according to Baseline-C

- **L1B to L2 Echo Modelling / Re-tracking**

  SAMOSA 2 model

  Application of a Look-Up Table (LUT) for the selection of a variable Point Target

  Response (PTR) width as a function of SWH.

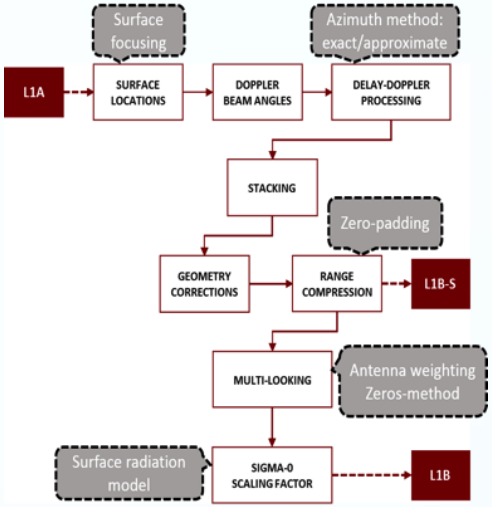


Image credits isardSAT

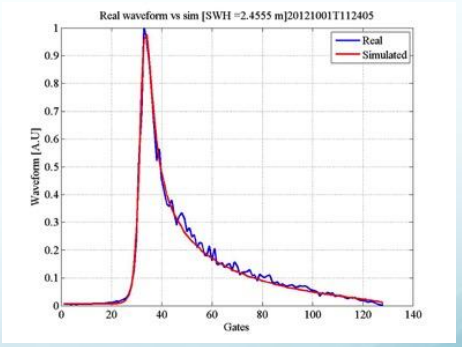


Image credits Starlab

RD SAR Processing:

New code written for SCOOP to be equivalent to Sentinel-3 processing

Wet Troposphere Correction:

Enhanced GPD+ Wet Troposphere Correction (GPD+)

SCOOP Phase 2 SAR Test Data Set

SAR Mode Test Data Set 2

- L1B processing :
  - Zero-padding (factor 2) in range
  - Intra-burst windowing (Hamming)
  - Approximate beamforming (azimuth processing)
  - Cut of stack edges (keeping looks $-0.6 < \theta_{look} < 0.6$)
  - No intra-burst alignment
- L2 processing:
  - In-house isardSAT implementation of SAR ocean retracker (based on *Ray et al. 2015*)
  - Adapted to L1B processing modifications (consistency L1B-L2)
  - Fixed PTR setting (not SWH dependent), σ0 bias applied

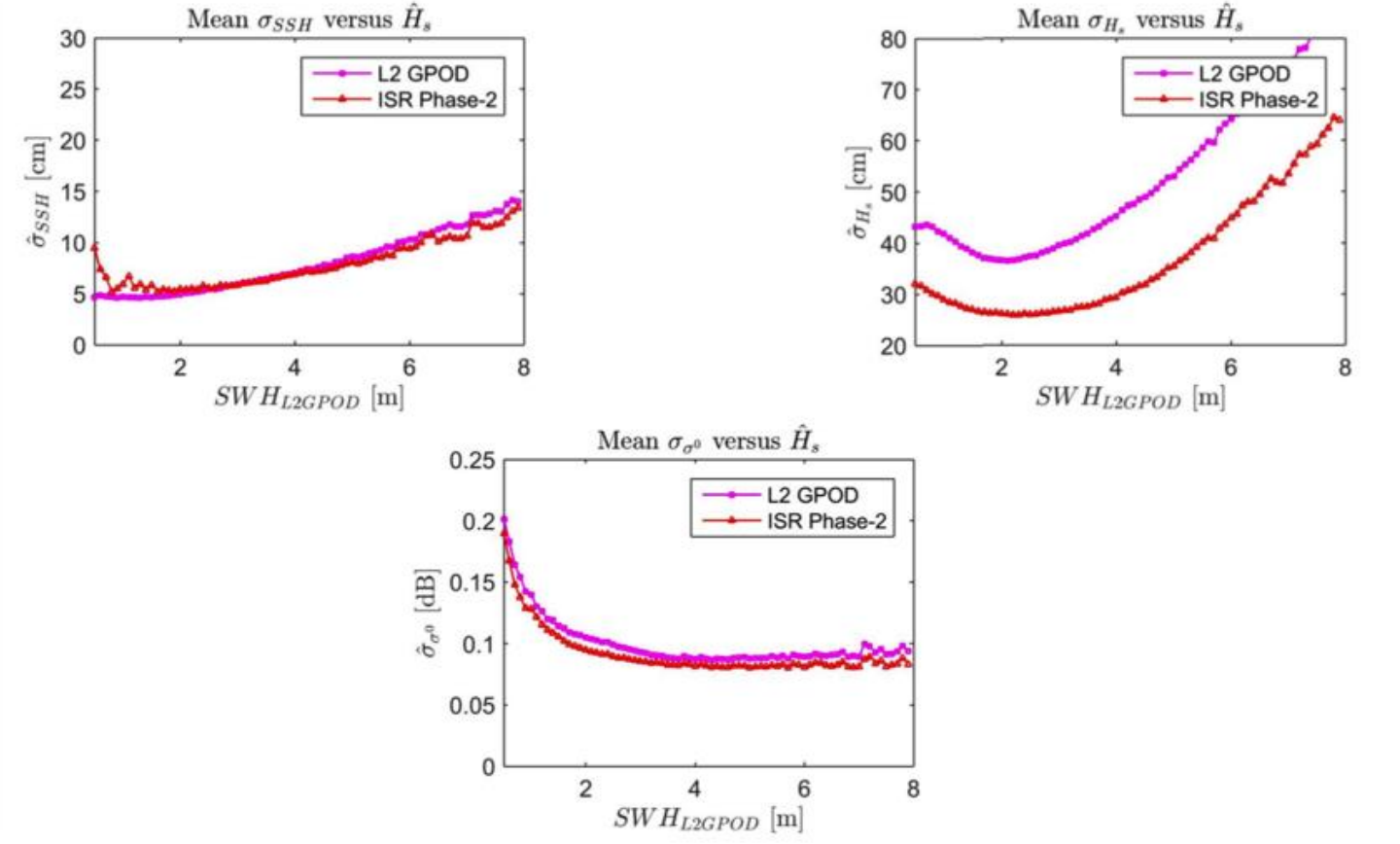
RDSAR Test Data Set 2

- Waveform processing as for TDS1
- Latest (RADS) corrections, orbit based on GDRE standards
- Extra test data set with MLE4 retracker

SCOOP Data Sets – Performance Analyses

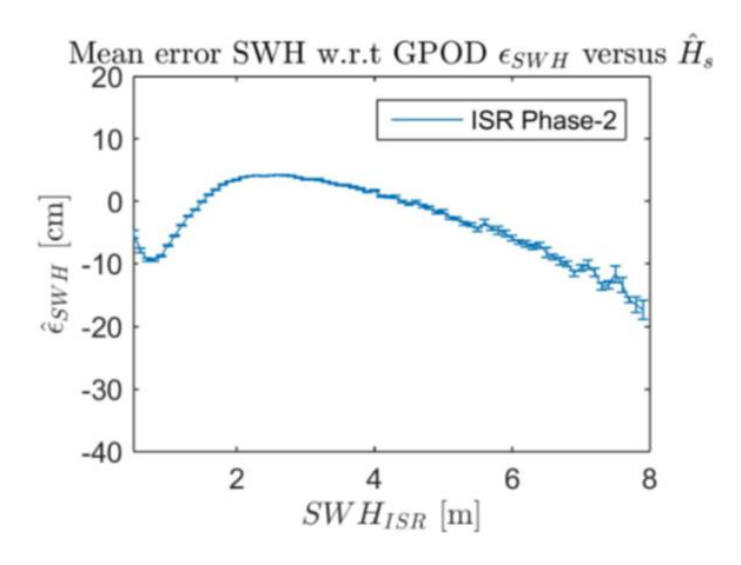
Open Ocean

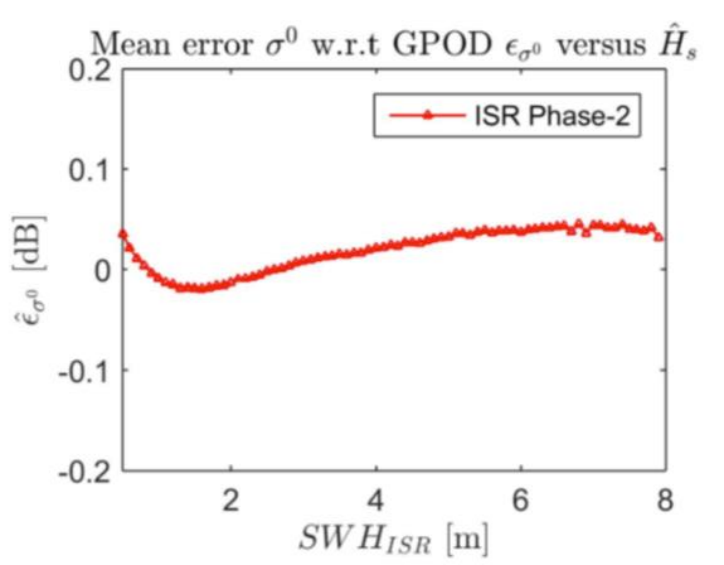
TDS 2 Precision: Noise performance SSH, SWH & sigma-0 (by isardSAT)



- SSH: TDS2 noisier than TDS1 at low SWH, but better performing at high SWH
- SWH: TDS2 improved on TDS1 for all SWH (10cm lower std)
- σ0: TDS2 slightly lower noise than TDS1 for all SWH.

TDS2 Accuracy: SWH & σ0 compared to TDS1 (isardSAT)

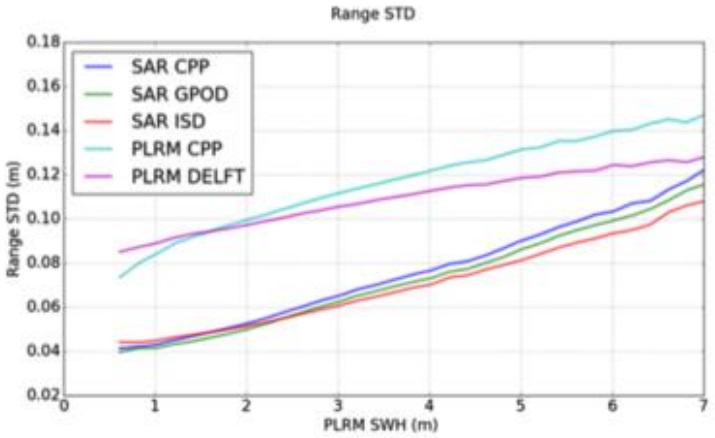




- SWH dependent error in SWH estimation. Significant at low SWH (< 1.5m)
- Small SWH dependence in σo estimation (< 0.05 dB)

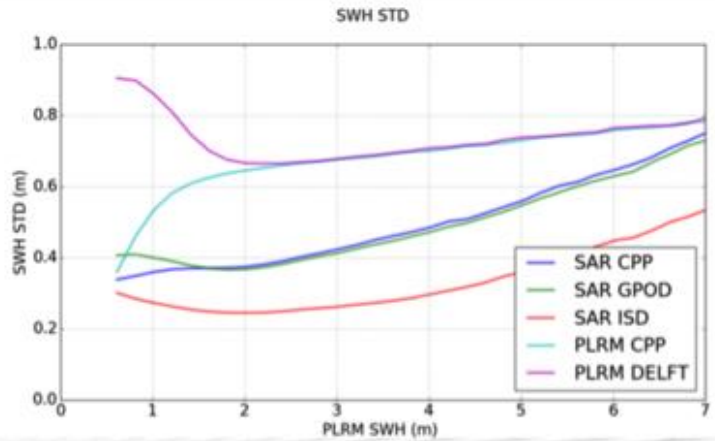
  No dependency on radial velocity (was seen in earlier data sets)

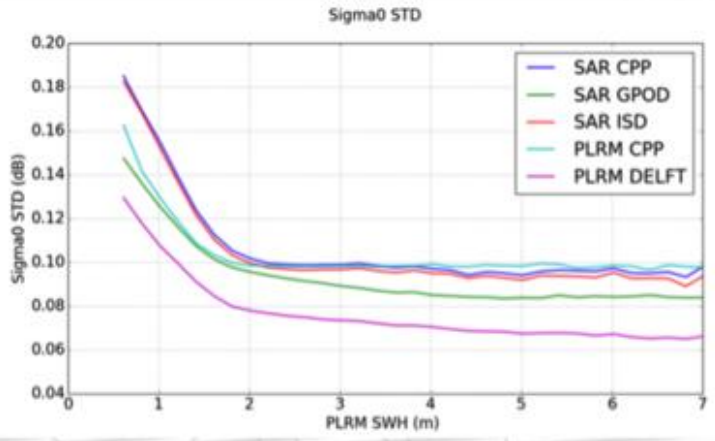
TDS 2 Open Ocean Performance (by CLS)



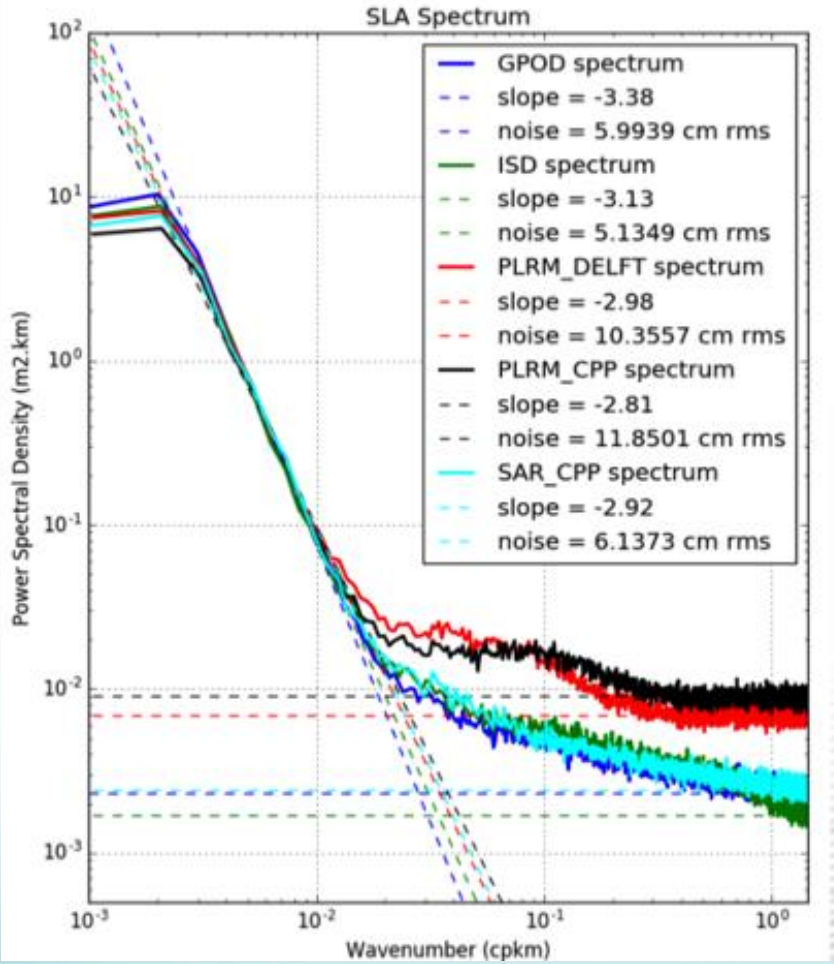
Alternative SARM algorithm:

- Range STD: improvement brought by Hamming window at medium/large wave height (but degraded at low swh)
- High noise reduction in SWH (> 35% @2m) better than CY2 Baseline B/C (also including zero-pading x2 and azimuth window)
- No improvement for sig0





TDS 2 Open Ocean Performance (by CLS)

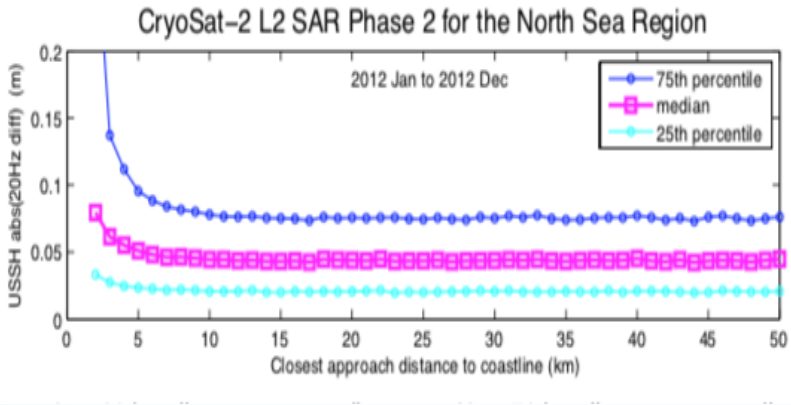


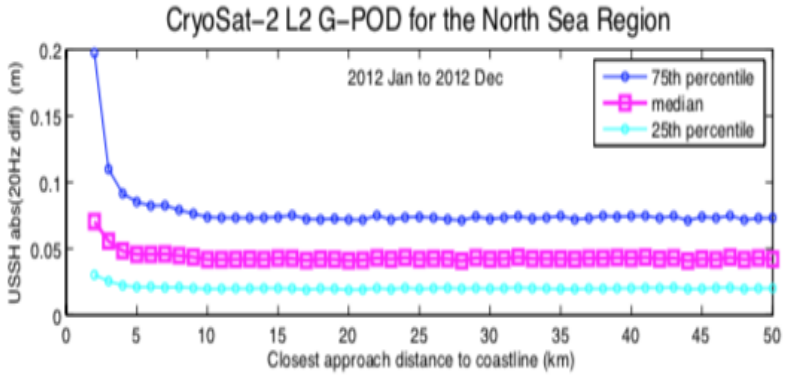
- Same behavior on large scales
- Short wavelength correlated errors (*bump*) affecting conventional altimetry from 7 to 50 km
  A little hump also observed in PSD from alternative SARM data most probably linked to Hamming window (that creates low spatial correlation between samples)
- Swell-induced effects (*red noise*) at sub-mesoscales (from 30 km to smaller scales) affecting SAR altimetry
- Large noise reduction on HF content brought by SAR mode (➔ better observability of small scale oceanic signals)

SCOOP Data Sets – Performance Analyses

Coastal Zone

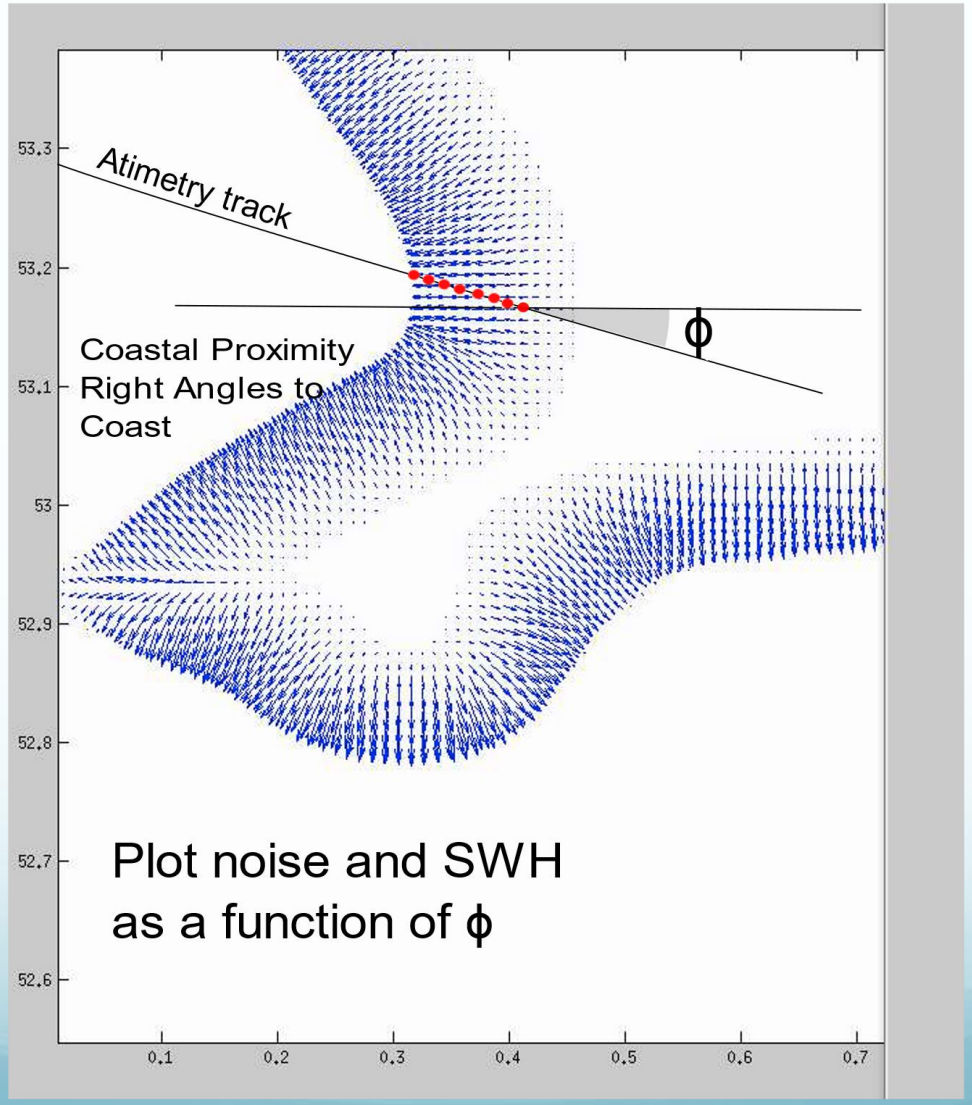
TDS 2 Coastal Performance (by SKYMAT)



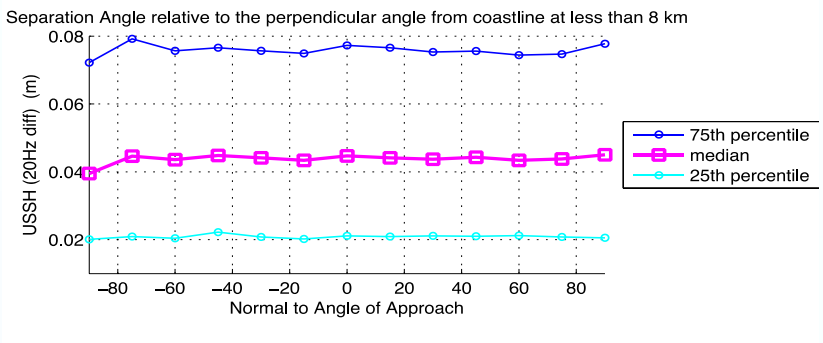


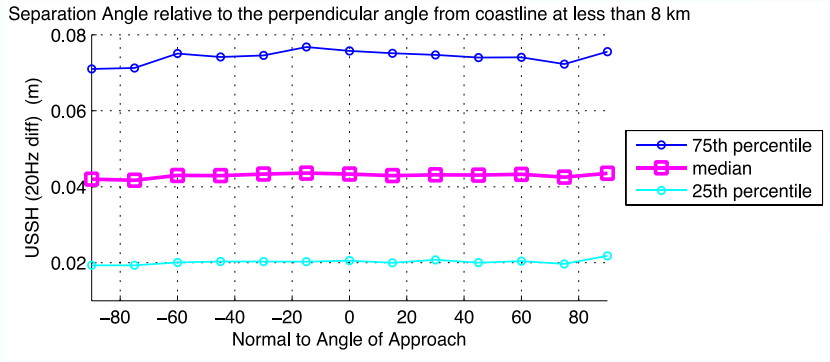
- Data filtered using waveform misfit < + 3
- Performance in terms of "noise" in SSH very similar between two test data sets.

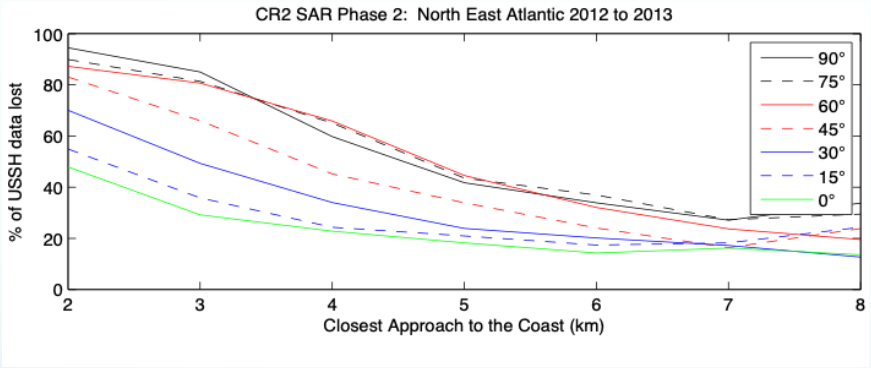
SCOOP SAR TDS2 Coastal Performance – Angle of Arrival

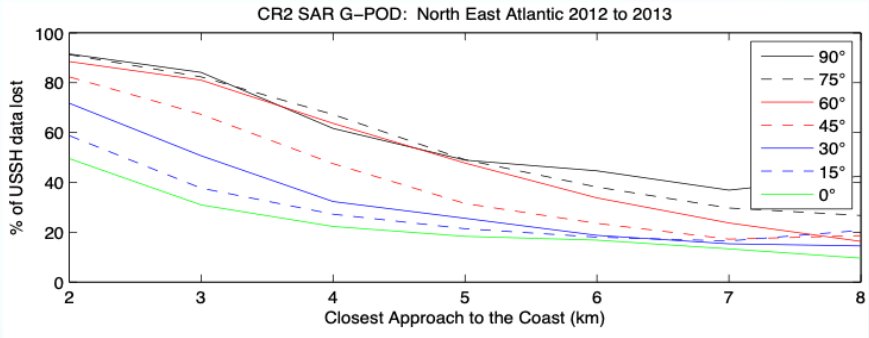


SCOOP SAR TDS2 Coastal Performance – Angle of Arrival



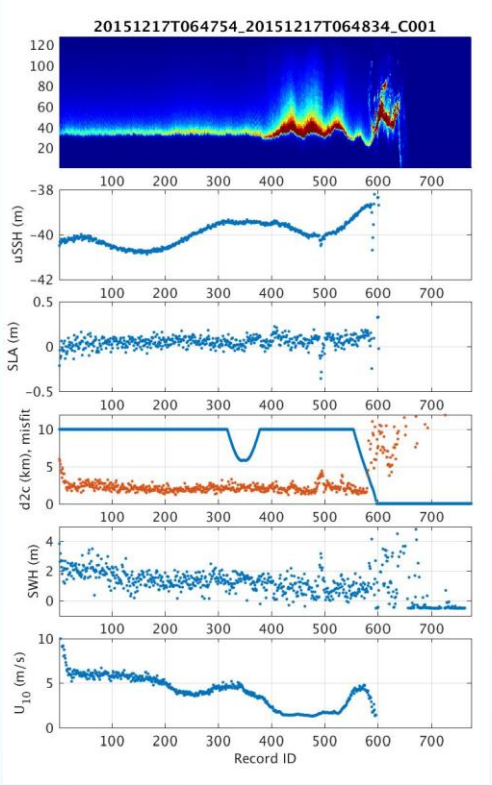


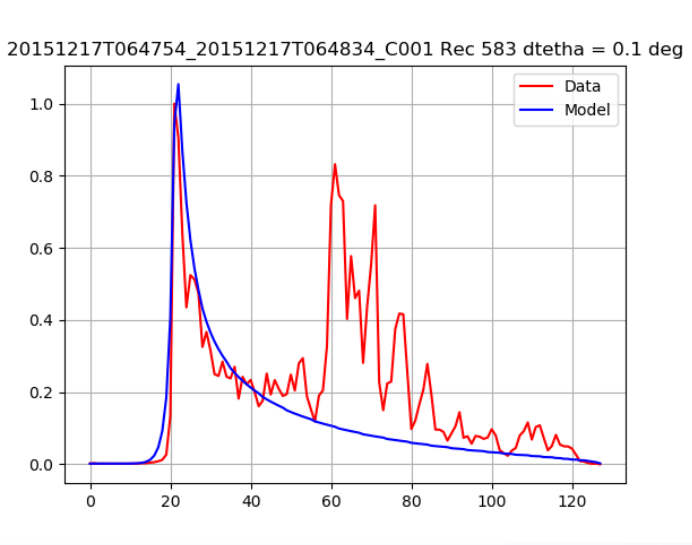




- No dependence of SSH “noise” on angle of arrival
- Much greater loss for oblique angles of arrival (> 80% lost AoA > 45°)
- Data filtering doing its job
- No significant differences between TDS1 and TDS2
- Can coastal processing, e.g. waveform stack selection, retrieve more data?

SCOOP SAR TDS2 Coastal Processing (NOC)





Fit SAMOSA2 model with reduced stack +/- 0.1°

- Many interesting features in L1B-S stack data in coastal zone
- Land contamination signals in the stack appear first at high gates
- Reducing stack has strong impact on the waveform peakiness and the toe of the leading edge
- Reduced stack waveforms have been re-tracked with SAMOSA2 model
- Sub-waveform/ALES for SAR ?

Recommendations

SAR Mode Processing

- The use of the innovative SARM processing (Zero-padding and Hamming window) for Sentinel-3 mission is recommended to improve ocean altimetry products
- In situ measurements are needed to fine tune and calibrate the PTR settings.
- SSB correction dedicated to the SAR SSH is needed to compute accurate SSH.
- Further studies should be carried out into the development of coastal re-trackers for SAR mode echoes.
- Other approaches should (continue to be) developed and evaluated:
  - Stack characterisation / selection; Amplitude and Dilation Compensation (ACDC); Fully Focussed SAR processing; effect of vertical motion of wave particles...

RDSAR Processing

- Coastal re-trackers should be applied for coastal data sets.
- Further tests on MLE4 re-tracker on the RDSAR product should be carried out.

Wet Troposphere Correction

- The GPD+ correction clearly outperforms the ECMWF operational model-derived correction.
- The composite correction present in Sentinel-3 products is not suitable for use. The GPD+ WTC would be an added value for Sentinel-3A products

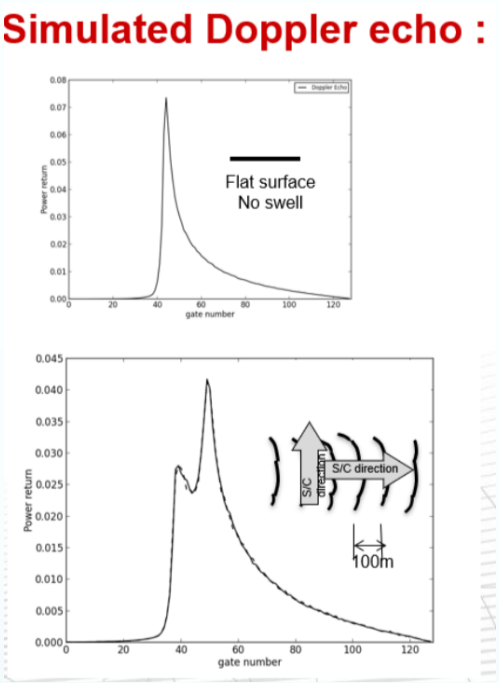
See SCOOP Scientific Roadmap for full recommendations

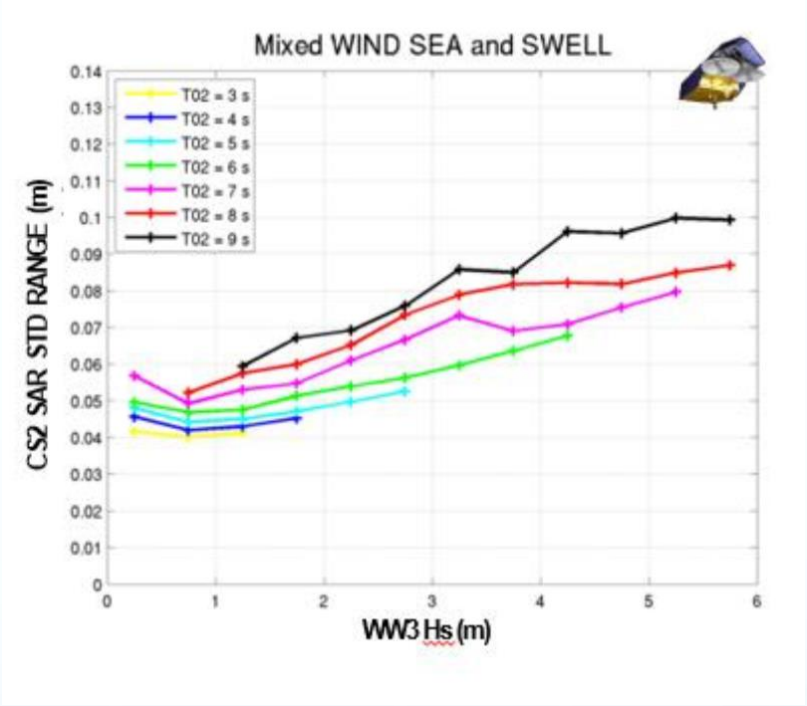
Thank you!
http://www.satoc.eu/projects/SCOOP/

Swell Impact on SAR mode (CLS)

Image credits CLS

Simulated Doppler echo :





- According to theory expect long period swell, aligned to the sub-satellite track to cause waveform artefacts and errors in processing
- Evidence of increased noise in SSH and SWH, and bias in retrieved SWH, associated with higher SWH, and longer wave periods
- Need larger global study, with co-located measured wave spectrum and wave models
- Can modified processing reduce impact? Would auxiliary wave data be needed
- Need SAR mode SSB correction.

Analysis of RDSAR Product

SSH / SLA
Residual differences between CPP and SCOOP TDS (1 and 2) believed to be correlated to mis-pointing. The SCOOP RDSAR Phase 2 data set demonstrated an improved noise performance, but higher correlated errors degrading the SLA content at scales below 100km.

SWH:
Bias in SWH due to fixed width PTR correction. SWH dependant correction needed

σ0: SWH dependent bias – related to mispointing?

MLE4 retracker: Should address mispointing problem?

Problem with loss of data at the coast -> Coastal retracker recommended (e.g. ALES family..)

Analysis of SAR Product

Analysis of SAR Products

TDS2 - Zero–Padding and Hamming Window

- Zero–Padding and Hamming Windowing reduces noise in SSH and SWH (more significantly for SWH ~ 35%)
- Still significant SWH bias, due to fixed PTR width correction. Calibration needed.
- Radial Velocity dependence resolved, removed intra-burst alignment
- SAR SSH bias a function of SWH -> Need a SAR mode SSB correction.
- Slight improvement in $\sigma 0$ performance for TDS2

The SAMOSA+ retracker shows better performance (in terms of lower noise) at the coast than SAMOSA2.

Wet Troposphere Correction – U Porto

- GPD+ significantly improves the accuracy of the Cryosat-2 SSH and SLA.
- GPD+ WTC would give added value to Sentinel-3A products, current composite correction not suitable for use