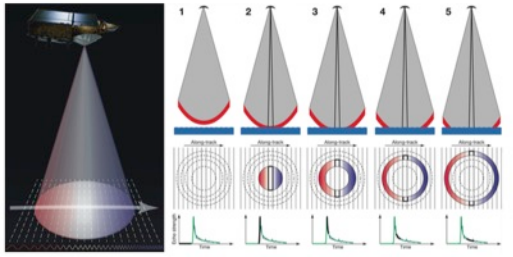
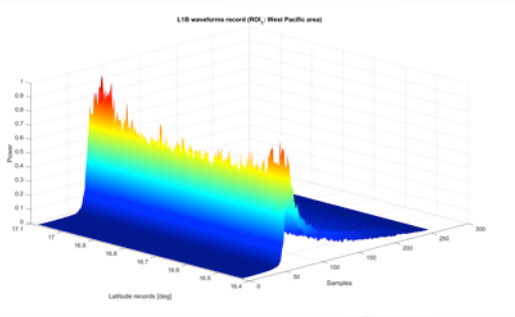




Improved Retrieval Methods for Sentinel-3 SAR Altimetry over Coastal and Open Ocean and recommendations for implementation: ESA SCOOP Project Results.

Marc Naeije, David Cotton, Thomas Moreau, Eduard Varona, Christine Gommenginger, Mathilde Cancet, Luciana Fenoglio-Marc, M Joana Fernandes, A Shaw, Pablo Garcia, Marco Restano, Américo Ambrósio, Jérôme Benveniste

d.cotton@satoc.eu

esa

seom scientific exploitation of operational missions

SATOC Satellite Oceanographic Consultants · CLS · isardSAT · National Oceanography Centre Natural Environment Research Council · NOVELTIS · Starlab Living Science · TU Delft Delft University of Technology · universitätbonn · U.PORTO Faculdade de Ciências Universidade do Porto

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 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***

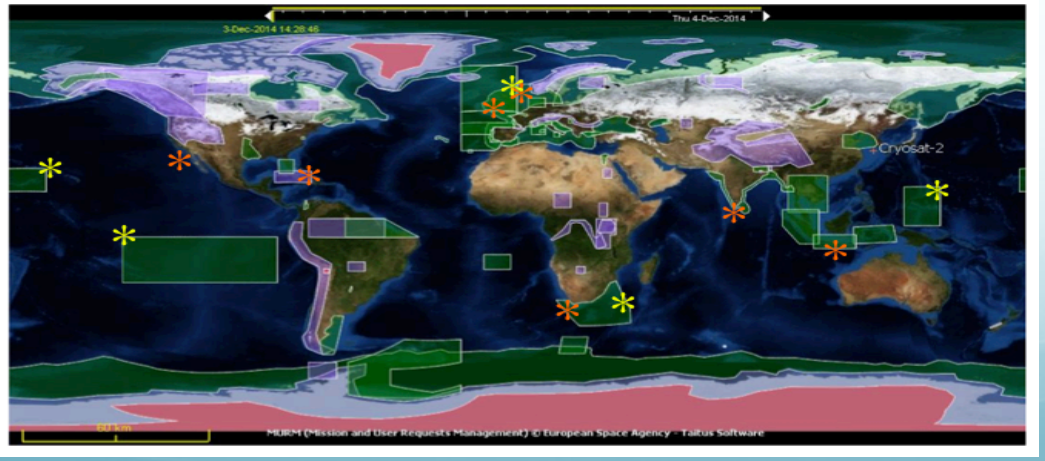


Image credit: ESA

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.

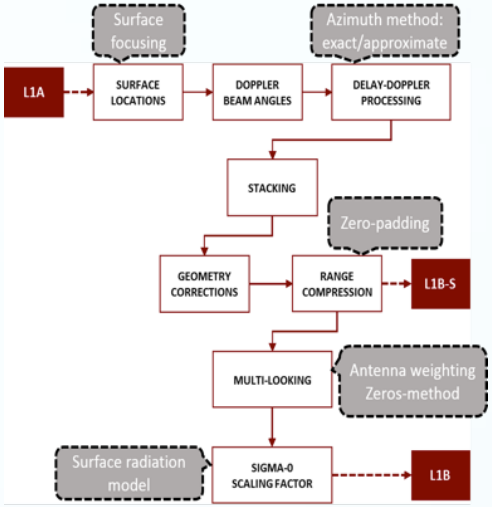


Image credits isardSAT

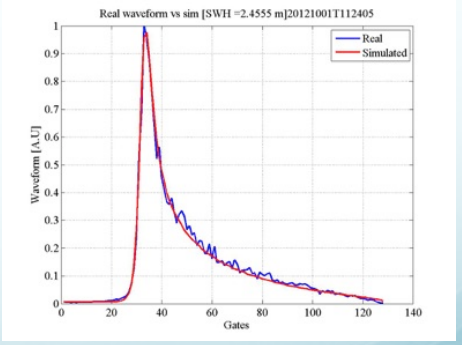


Image credits Starlab

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

Analysis of SAR Product – Open Ocean

Analysis of SAR Products

TDS2 - Zero–Padding and Hamming Window

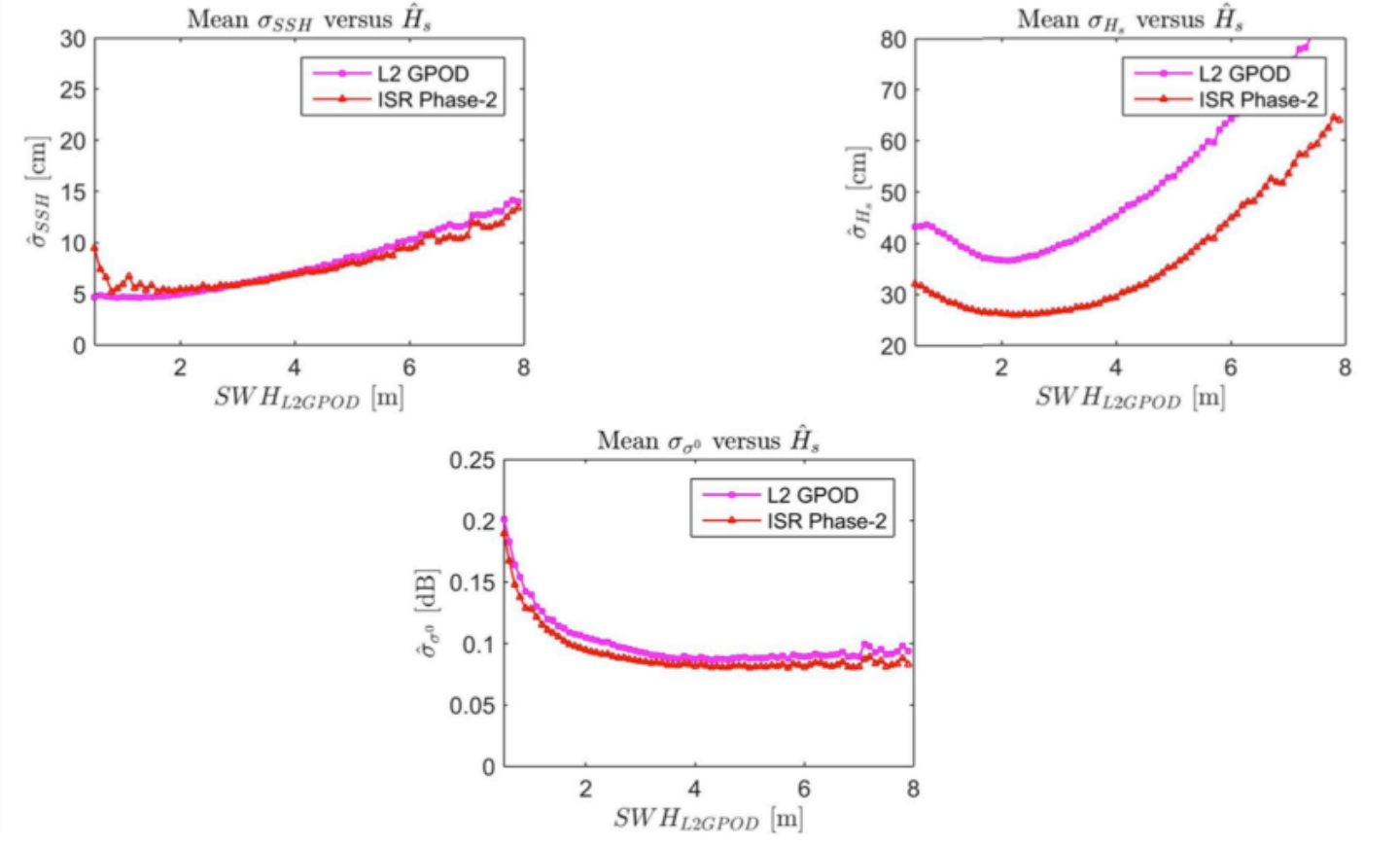
- Zero–Padding and Hamming Windowing reduces noise in SSH and SWH (more significantly for SWH ~ 35%)
- Still significant SWH bias, due to fixed PTR width correction. Calibration needed.
- Radial Velocity dependence resolved, removed intra-burst alignment
- SAR SSH bias a function of SWH -> Need a SAR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

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



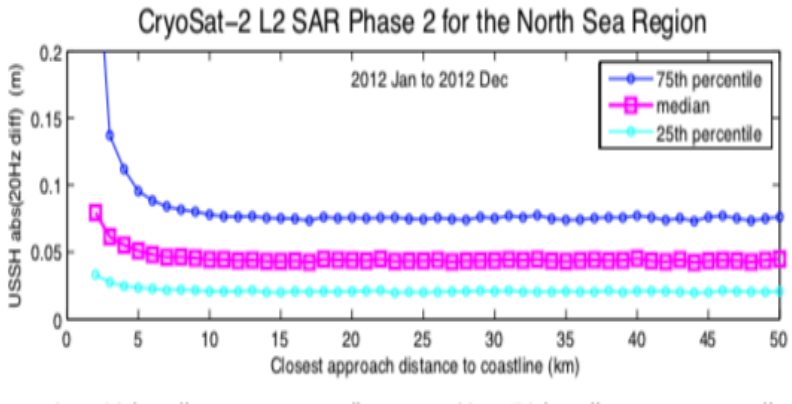
- SSH: TDS2 noisier than TDS1 at low SWH, but better performing at high SWH
- SWH: TDS2 improved on TDS1 for all SWH (10cm lower std)
- σ0: TDS2 slightly lower noise than TDS1 for all SWH.

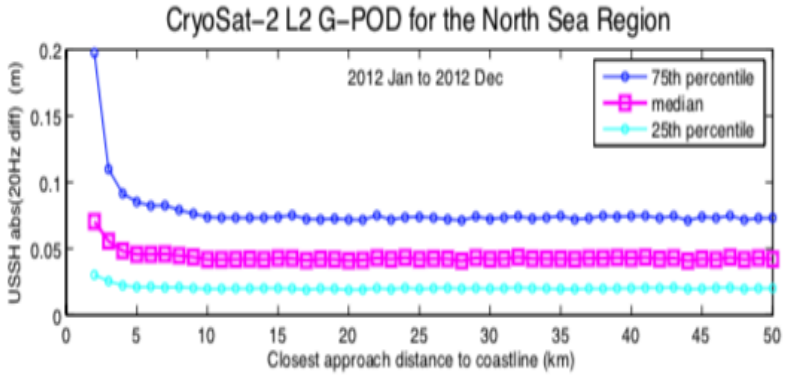
SCOOP Data Sets – Performance Analyses

Coastal Zone

SAR Product

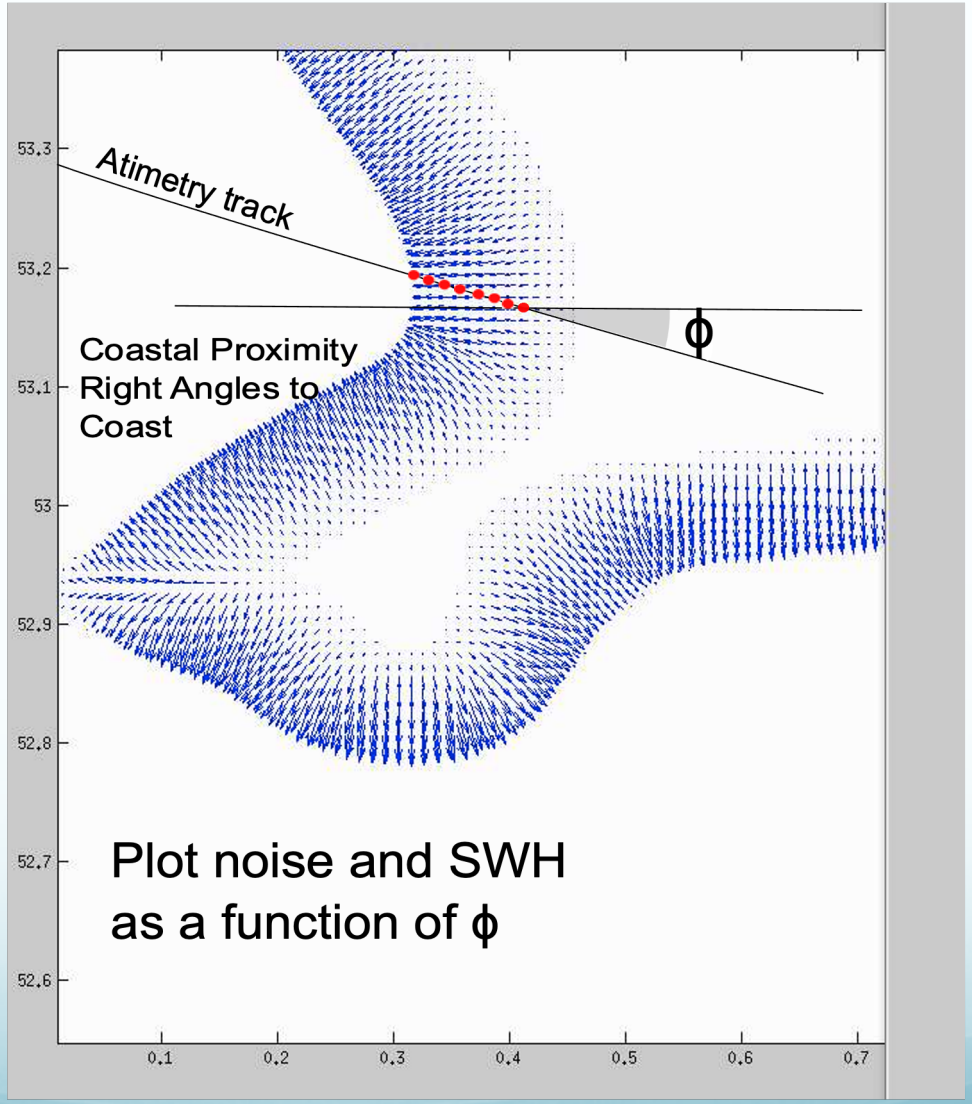
TDS 2 Coastal Performance (by SKYMAT)



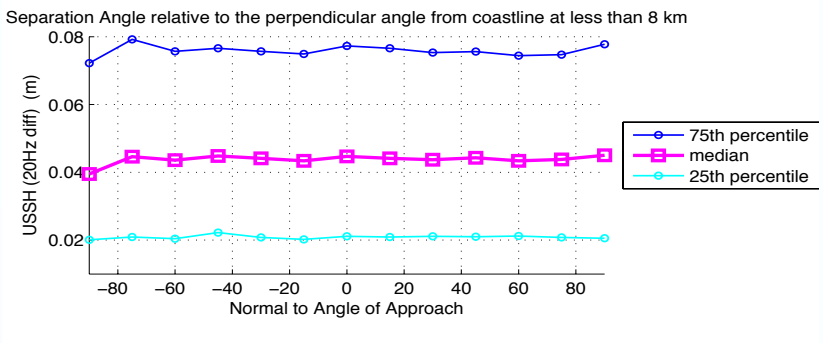


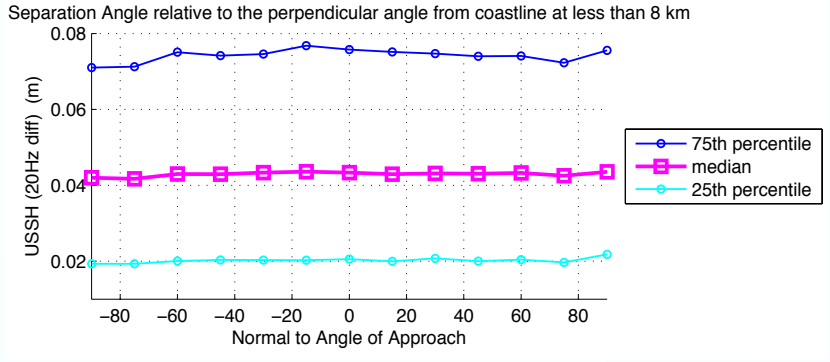
- Data filtered using waveform misfit < + 3
- Performance in terms of “noise” in SSH very similar between two test data sets.

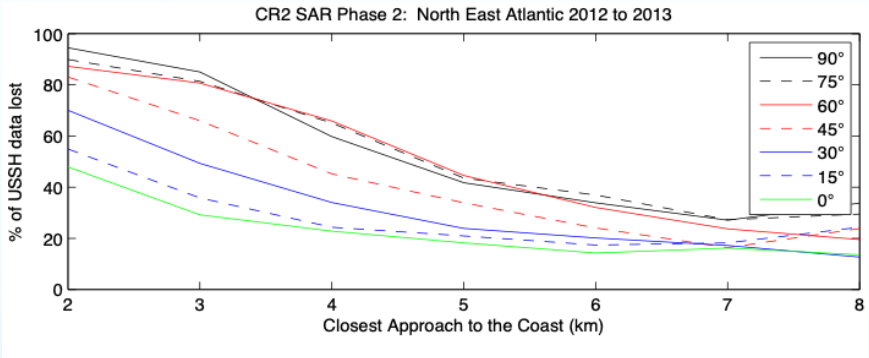
SCOOP SAR TDS2 Coastal Performance – Angle of Arrival

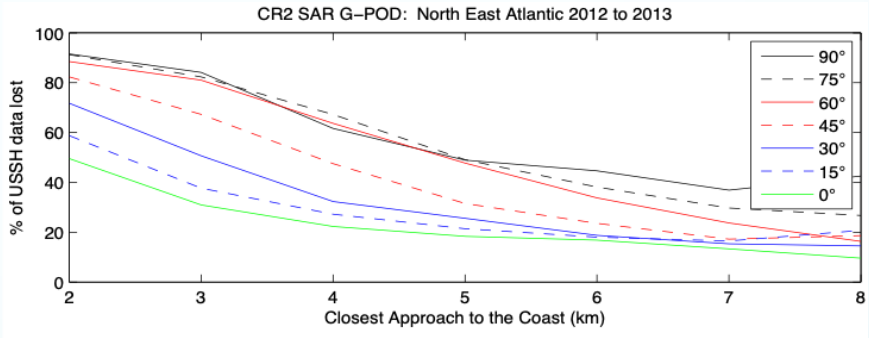


SCOOP SAR TDS2 Coastal Performance – Angle of Arrival



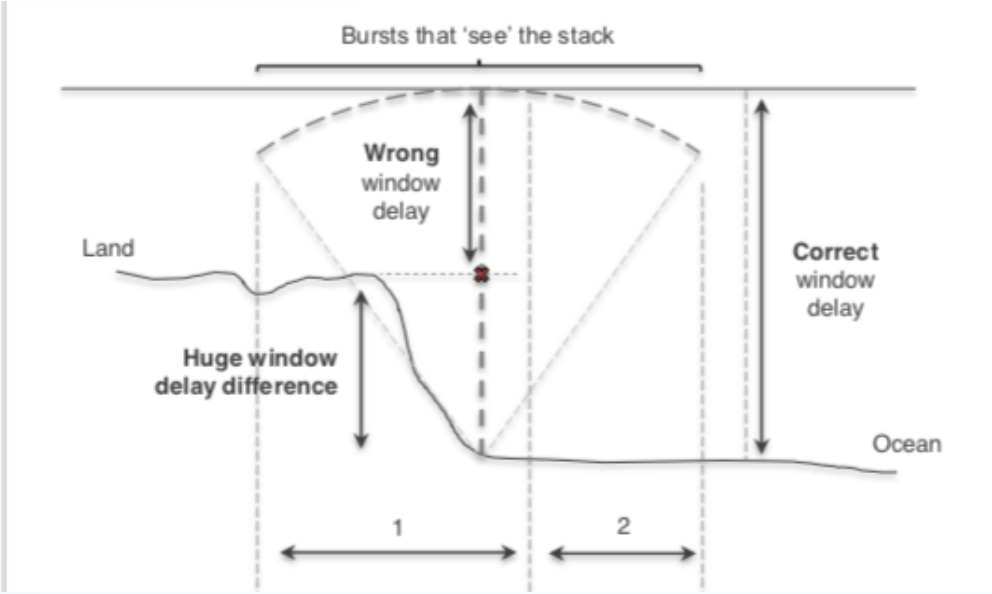




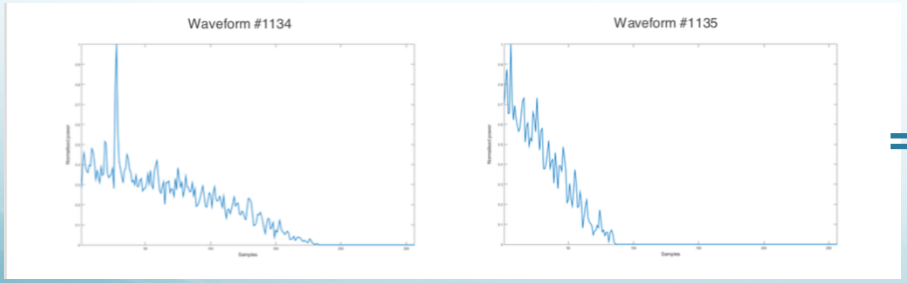


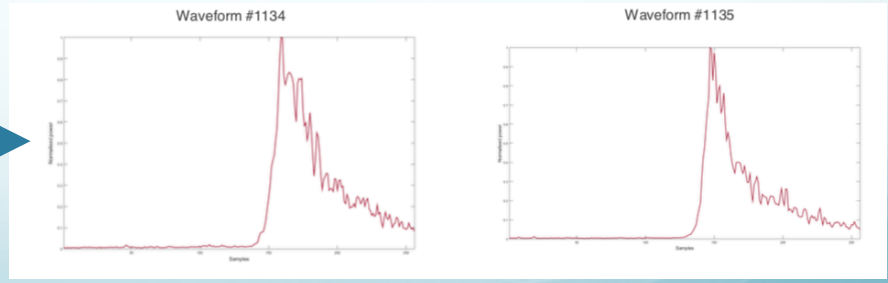
- No dependence of SSH “noise” on angle of arrival
- Much greater loss for oblique angles of arrival (> 80% lost AoA > 45°)
- Data filtering doing its job
- No significant differences between TDS1 and TDS2
- Can coastal processing, e.g. waveform stack selection, retrieve more data?

isardSAT Coastal Data Set



- For tracks coming off the coast, with step in window delay, waveforms "lost" because previous window delay used as reference for the tracker
- Use window delay from first "ocean" return (based on rough ocean/land mask
- Waveforms from "zone 2" aligned with first burst or look in the stack marked as ocean, and data can be retrieved.



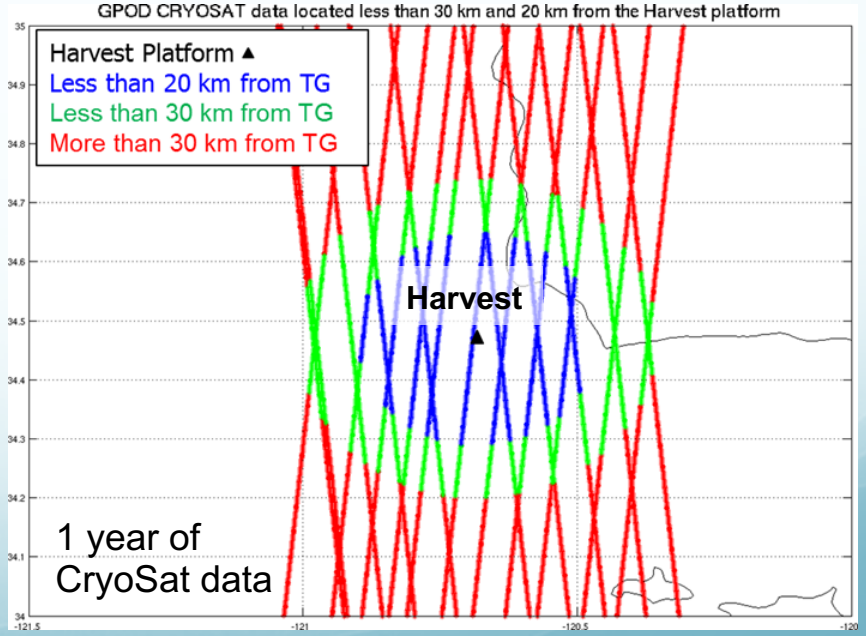


- L2 "coastal" data set produced with this approach for NE Atlantic, N Sea, Agulhas

Noveltis – Harvest

- Evaluation of the SCOOP products at the Harvest calibration site
  - CryoSat-2 SAR zone specifically designed for the SCOOP project: data since Dec. 2015
    - **SAR datasets**
      - Phase 1 from GPOD
      - Phase 2 from IsardSAT
      - Experimental coastal dataset from IsardSAT (Phase 2)
    - **RDSAR datasets**
      - Phase 1 MLE3
      - Phase 2 MLE3 and MLE4

→ 6 months (Dec. 2015 – May 2016) or 1 year (Dec. 2015 – Dec. 2016) of data, depending on the dataset

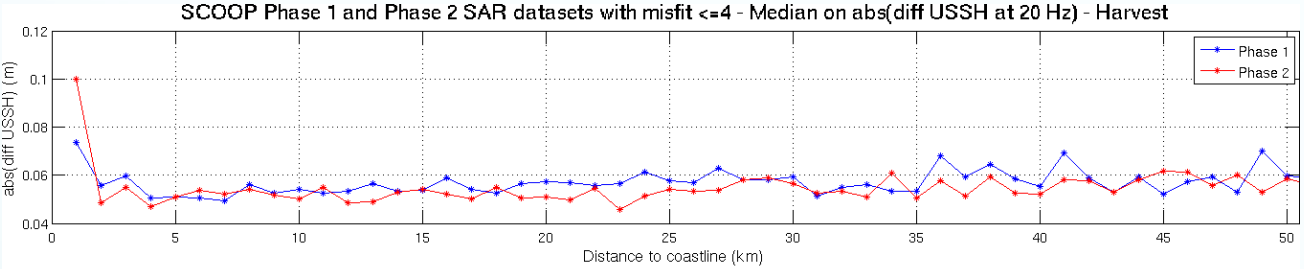


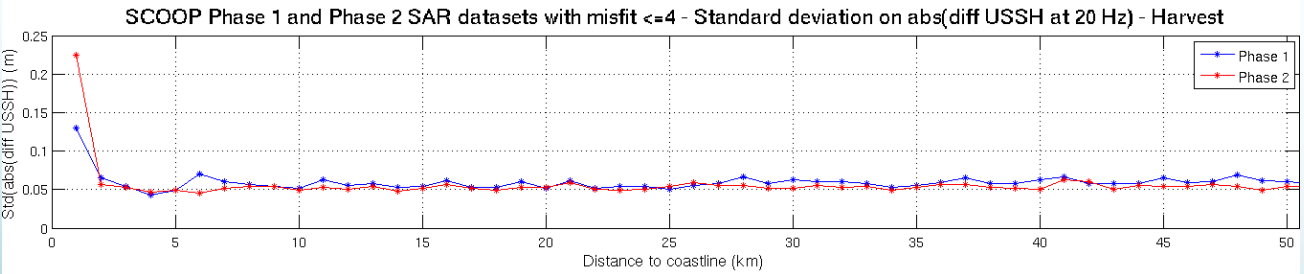
Noveltis – Harvest

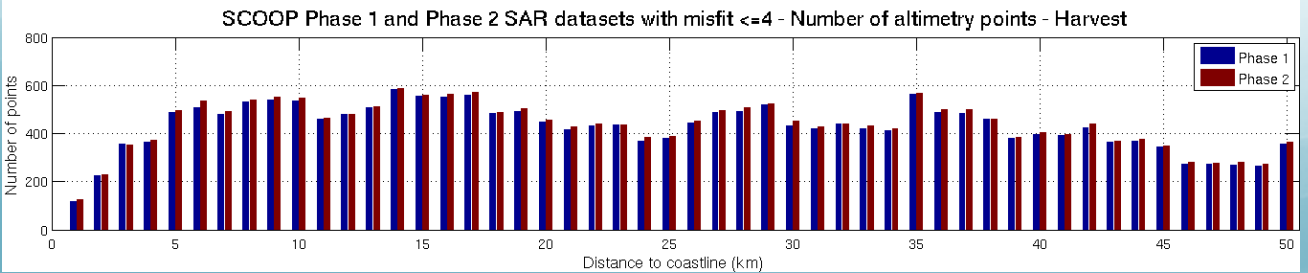
- Evaluation of the SAR datasets (Phase 1 and Phase 2)
  - **Analysis of the USSH variability as a function of the distance to the coast**

→ USSH = altitude – range (at 20 Hz) / misfit ≤ 4

→ Analysis on 6 months of data (12/2015 – 05/2016)







→ Strong reduction in the number of coastal points due to editing on misfit value, for both datasets

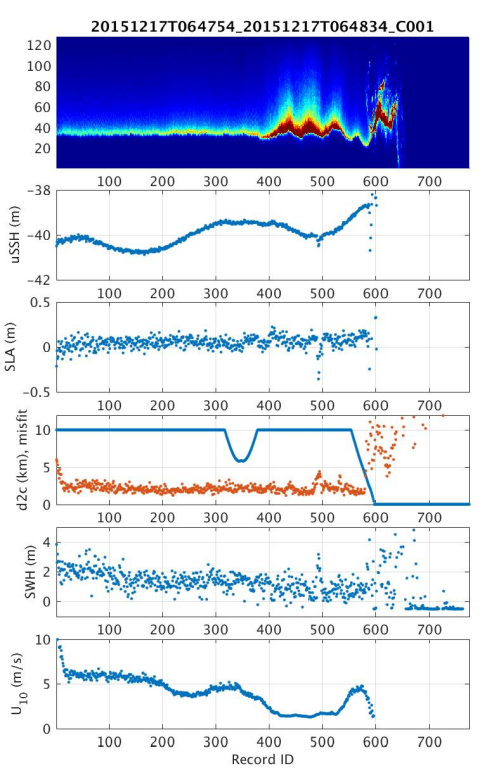
→ Slight reduction of the noise and variability with the Phase 2 dataset, except in the first kilometer

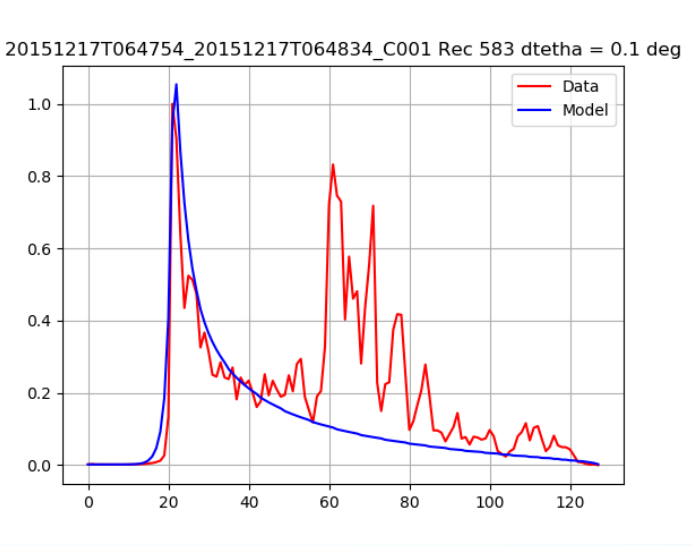
→ More data retrieved with Phase 2 dataset, whatever the distance to the coast

Noveltis – Harvest

- Conclusions and recommendations
  - SAR datasets
    - **A general improvement is noticeable from Phase 1 to Phase 2**, with lower noise and variability in the Phase 2 dataset (except in the first kilometre offshore) and more data retrieved whatever the distance to the coast.
    - **An appropriate SSB correction dedicated to the SAR SSH is needed** in the products to compute accurate SSH.
    - **Further investigations are required regarding the experimental "SAR coastal" processing** proposed by IsardSAT, given the degradation observed in the data at Harvest.
  - RDSAR datasets
    - The **MLE4 RDSAR processing shows some improvement regarding the SWH**, compared to MLE3.
    - However, **the MLE4 SSH retrievals are noisier**, with an additional slight loss of data at the coast, which needs further analyses.
  - In general, assessing the SAR/RDSAR products through local comparisons with in situ data enables to better understand the good or bad performance observed in the analyses at larger scales.

SCOOP SAR TDS2 Coastal Processing (NOC)

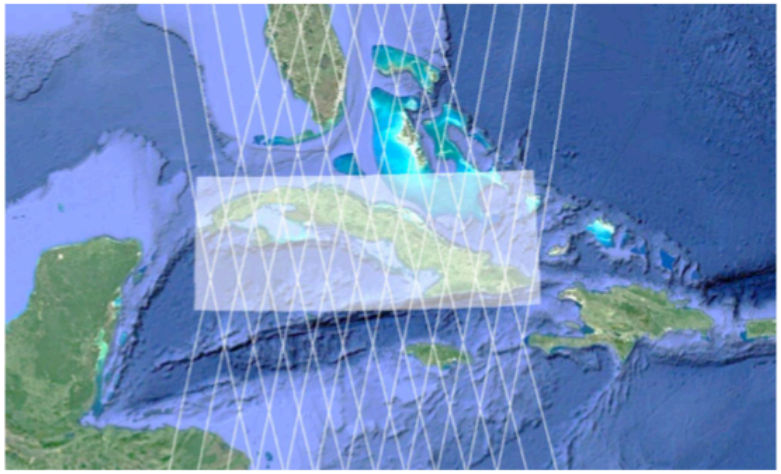




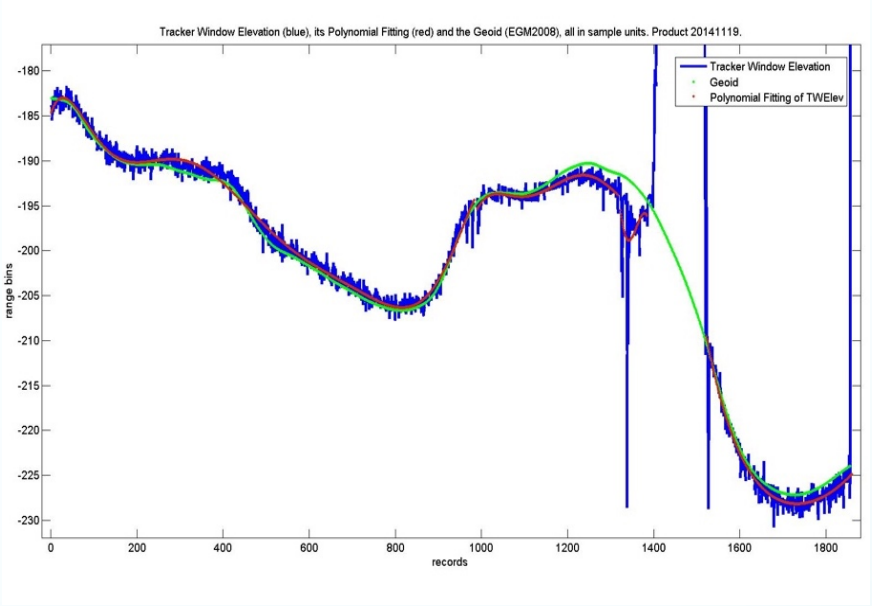
Fit SAMOSA2 model with reduced stack +/- 0.1°

- 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 ?

isardSAT Cuba study



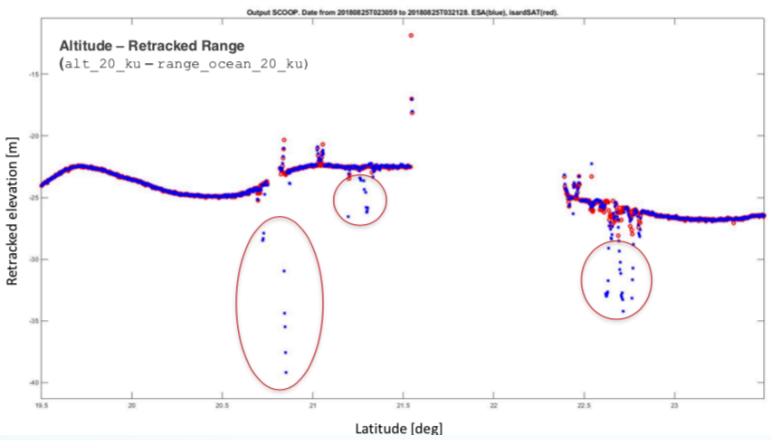
Area of interest and selected tracks



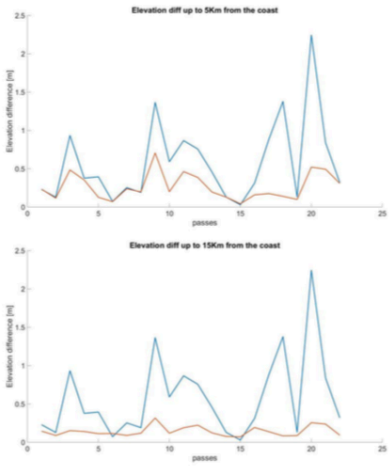
- Sentinel 3b “closed loop” data: 2018/08/10 to 2018/09/05
- Previous approach (CP4O) fitted smoothed window delay, then detected jumps through big excursions from this curve
- New approach used MSS2 variable (MSS DTU 15) to detect jumps
- LEP located in the ”expected” location, and number of range bins around LEP extracted to create sub-waveform and retracked

isardSAT Cuba Study results

Figure showing one track with ESA (blue) and isardSAT (red) Retracked Elevation.



Averaging all records within a stripe along the coast.



Improvement (isardSAT/ESA):

- 5 km: 54.57%
- 10 km: 50.49%
- 15 km: 48.15%

Reduction in impact of contamination results in 50% improvement in “stability” of retrieved SSH (calculated from the Standard Deviation in SSH)

Roadmap 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-3 products

See SCOOP Scientific Roadmap for full recommendations

HYDROCOASTAL

- ESA funded project to maximise exploitation of SAR and SARin altimeter measurements in the coastal zone and inland waters, by evaluating and implementing new approaches to process SAR and SARin data from CryoSat-2, and SAR altimeter data from Sentinel-3A and Sentinel-3B.

- New SAR and SARin processing algorithms for the coastal zone and inland waters will be developed and implemented and evaluated through an initial Test Data Set for selected regions.

- From the results of this evaluation a processing scheme will be implemented to generate global coastal zone and river discharge data sets. Case studies will assess these products in terms of their scientific impacts.

- All the produced data sets will be available on request to external researchers, and full descriptions of the processing algorithms will be provided

- Project runs Feb 2020 – Feb 2022

https://www.satoc.eu/projects/hydrocoastal/

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