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

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## The SCOOP Project

SCOOP (SAR Altimetry Coastal & Open Ocean Performance) is funded under the ESA SEOM (Scientific Exploitation of Operational Missions) Programme to answer the questions:

- *What performance can we expect from Sentinel-3 SAR Altimeter (SRAL) data over the open ocean and coastal zone?*
- *Can we enhance this performance with improved processing schemes?*

### Phase 1 : Evaluating the Expected Performance of Sentinel-3 SRAL

In Phase 1 the expected performance of the Sentinel-3 SRAL altimeter was evaluated in open ocean & coastal zone studies, through the assessment of a 2-year test data set.

### Phase 2: Implementing/assessing SRAL processing enhancements

In SCOOP Phase 2, a number of possible improvements to the SAR processing algorithms were implemented and a second test data set generated. This new data set was then assessed to identify and validate any improvements in performance, in the open ocean and coastal zone.

## SCOOP SAR Mode Altimeter Test Data Sets

The SCOOP studies are based on 2-year test data sets derived from CryoSat-2 FBR data, produced for 10 regions (Figure 1).

***Test Data Set 1 – CryoSat FBR reprocessed with Sentinel-3 SRAL Baseline Configuration***

- SAR L1B, SAR L2 (using ESA GPOD facility) à la Sentinel-3 Baseline
  - CryoSat-2 FBR to L1B: Calibrations according to Baseline C
  - L1B to L2: SAMOSA 2 waveform model, Look up Table for variable Point Target Response (PTR) width as a function of SWH
- RDSAR L2 (new code by TU Delft based on RADS to be equivalent to S-3 processing)
- Wet Troposphere Correction (Enhanced *GPD+ WTC* produced by U Porto)

***Test Data Set 2 - Enhanced Processing - Modifications to TDS1***

- SAR L1B, SAR L2 (by isardSAT)
  - CryoSat-2 FBR to L1B – Inclusion of Zero padding, Hamming windowing, approximate beam forming, stack edge limits (within +/- 0.6° ), no intra-burst alignment
  - L1B to L2 – isardSAT ocean retracker (Ray et al 2015), fixed PTR setting
- RDSAR – As for TDS1 with updated (RADS) corrections, GDRE standard orbit, extra data set with MLE4 retracker

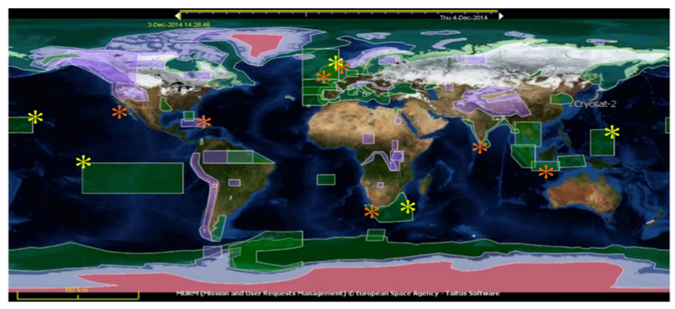


**Figure 1** Regions included in the SCOOP study, based on a CryoSat SAR mode mask figure from ESA, with yellow indicating open ocean areas and orange coastal areas (note the Northeast Atlantic and Agulhas regions are assigned to both)

*The SCOOP Test Data Sets are available on request to* ***scoop.info@esa.int***

# SCOOP Test Data Set 2 – Open Ocean Performance Assessment

## Noise Performance

Range:

- SCOOP TDS2-SAR lowest standard deviation (so highest precision), for SWH > 2m.

Significant Wave Height:

- SCOOP TDS2-SAR: 35% noise reduction with respect to TDS1 and CPP at SWH=2m.

*Hamming Windowing and Zero Padding in TDS2 SAR processing has improved performance (reduced noise and so enhanced precision) in range and especially significant wave height.*

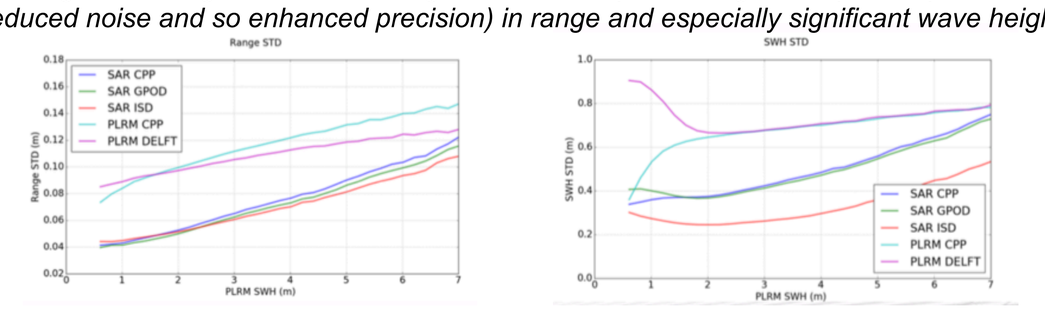


**Figure 2** Standard Deviation in Range (left), Significant Wave Height (right). SAR GPOD is TDS1-SAR, SAR ISD is TDS2-SAR, PLRM Delft is TDS1-RDSAR. CPP is Cryosat Prototype Processor – a CNES/CLS product

## Sea Level Anomaly Spectra

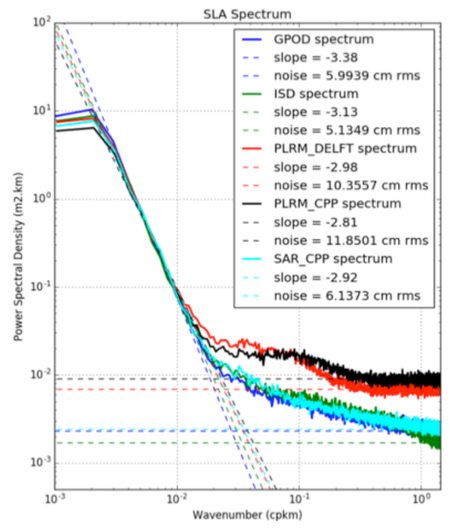


**Figure 3** Sea Level Anomaly Spectrum for SAR TDS1 (GPOD), SAR TDS2 (ISD), RDSAR TDS1 (PLRM_DELFT). CPP is Cryosat Prototype Processor – a CNES/CLS product

### Comparison of SLA Spectra

- Same behaviour for all products on large scales ( > 100km)
- Short wavelength correlated errors affects RDSAR products 7-50km (”spectral bump”)
- Swell induced effects (red noise spectrum) at sub- mesoscales ( < 30km) for SAR products
- Large noise reduction in High Frequency content < 90 km achieved by SAR mode, leads to better observability of small scale ocean signals
- Difficult to separate between performance of different SAR processing schemes (TDS1, TDS2, CPP). So no evidence of improved performance in terms of ability to resolve small length scales

# SCOOP Test Data Set 2 – Coastal Zone Performance Assessment

## Coastal Performance v distance from Coast

Assessment of the ”noise” performance in retrieved Uncorrected Sea Surface Height (USSH) against the distance from the coast.

“Noise” is calculated as the absolute difference between successive 20Hz values of USSH.

Data filtered through goodness of fit to model waveform.

Very similar performance in both Test Data Sets. TDS1 (left) and TDS2 (right), show noise of less than 5cm to within 4km of the coast (and < 10cm at 2km).

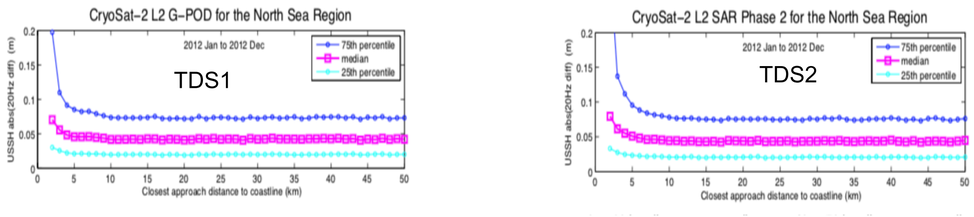


**Figure 4** Along-track noise at 20Hz of uncorrected Sea Surface Height. Left TDS2-SAR, Right TDS1-SAR

## Coastal Performance: Angle of Arrival

Investigated if the ”angle of arrival” of the satellite track at the coast impacts on performance.

The effective footprint of the SAR product is a thin slice, 250m along track and up to 7km across track, so an altimeter track arriving at a coast at an oblique angle may be expected to “see” the coastline further away than one arriving at right angles.

In fact, because of effective data filtering, which excludes noisy results from poorly defined waveforms, there is no increase in noise / loss of precision in retrieved data. Instead there is a greater loss in the number of retrieved valid data points




**Figure 5** Performance according to Angle of Arrival. (Left Panel) explanation of geometry – satellite track with respect to coastline orientation. (Top Panels) USSH “Noise” against Angle of Arrival (AoA), (Bottom Panels) % of data lost against distance to the coast and AoA

## SCOOP Recommendations

**SAR Mode Processing**

- Recommend modifications to the Sentinel-3 SAR mode processing (Zero-padding and Hamming window) to improve ocean altimetry products.
- A SAR dedicated Sea State Bias correction is needed for accurate Sea Surface Height.
- Further development and testing of coastal re-trackers for SAR mode is recommended.
- Continue development and evaluation of other processing approaches:
  - 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**

## SCOOP Outputs

The outputs of the SCOOP project include:

- **Scientific Review**
- **Test Data Sets**: SAR products, RDSAR products and Wet Troposphere Corrections.
- Descriptions of the processing schemes, in “**Algorithm Theoretical Basis Documents**”.
- **Product Validation Report** – A detailed full description of the assessments of all Test Data Sets.
- **Scientific Outcomes Technical Note**: Processing approaches, summary of validation results, technical guidance on processing.
- **Scientific Road Map** including recommendations for further developments, implementations and research for Sentinel-3 SRAL SAR data.
- Further **Technical Notes**: Study for **Swell and Sea State Bias**; **Exploitation of Single Look Echoes**.
- There is an ongoing final study by NOC into improving L1B stack processing at the coast

All will soon be available from the project web site ***www.satoc.eu/projects/SCOOP***

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