Improvements to Sea Level measurements in the Coastal Zone through SAR mode altimetry: The ESA CP4O and SCOOP projects

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SAR Mode Altimetry: CryoSat-2 and Sentinel-3

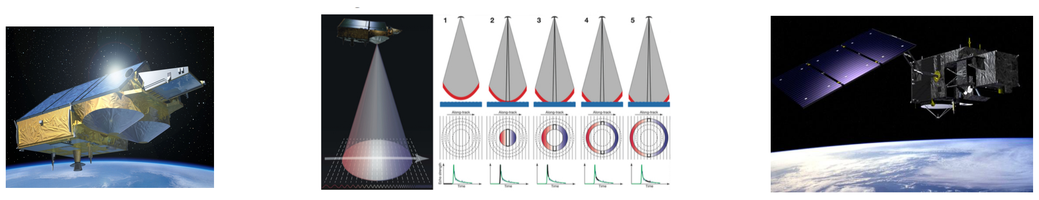


Figure 1: Left – The CryoSat-2 satellite; Centre – A schematic of Delay Doppler altimeter echo processing; Right –the Sentinel-3 Satellite

The European Space Agency (ESA) CryoSat-2 satellite, launched in 2010, was the first satellite to fly a satellite altimeter with the capability to operate in Delay Doppler, or Synthetic Aperture Radar (SAR) mode. This initial success has since been followed with the launch of the European Sentinel-3 satellite in 2016, which also operates a SAR mode altimeter, building on the heritage and experience gained in CryoSat-2.

In SAR mode (available on CryoSat-2 and Sentinel-3), the processing of the returned signal is able to take multiple looks at each patch of ocean, by taking into account the Doppler modulation of the returned signal, thus providing higher along-track resolution (~300m rather than ~7km), and a better signal to noise ratio, providing the capability to make accurate along-track measurements of sea-level close to the coastline.

CryoSat-2 (but not Sentinel-3) also operates the SARIN Mode which, by virtue of the two side-by-side antennas operating on the platform, provides information on the across track angle of arrival of the signal reflected from the surface.

Satellite Altimetry and the Coastal Zone - The CP4O and SCOOP Projects

In the "conventional" mode of operation, satellite altimeters have difficulty in making accurate measurements close to the coast, as the footprint of the altimeter at the ground is typically ~7km, and any ground within that footprint can contaminate the returned waveform, making it difficult, or impossible, to process. Thus at best one can hope to make sea level measurements within 7km of the coastline, and frequently even this is not possible. This has obvious implications when trying to validate against tide gauge data.

We present results from two ESA studies: CP4O (CryoSat Plus for Oceans) and SCOOP (SAR Altimetry Coastal & Open Ocean Performance), in which the performance of SAR altimetry in the coastal zone and open ocean are assessed, and improvements to the processing schemes are developed and tested.
The objective of CP4O was to develop and evaluate new ocean products from CryoSat data and so maximize the scientific return of CryoSat over oceans. The aim of SCOOP is to characterise the expected performance of Sentinel-3 SRAL SAR mode altimeter products, and then to develop and evaluate enhancements to the baseline processing scheme in terms of improvements to ocean measurements.

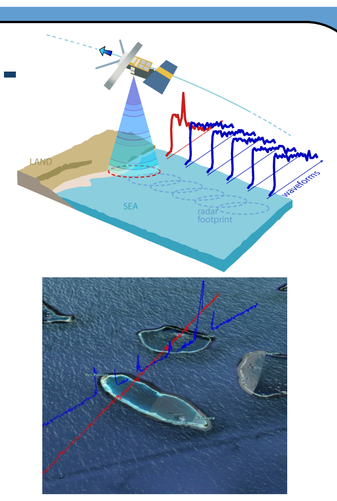


Figure 2: Top – A schematic showing the corruption on the altimeter echo at the coast. Bottom : Showing the improved tracking from CryoSat-2 SAR mode (red), over "conventional" Jason-2 altimeter data (blue) (Credit NOC)

CryoSat-2 SAR mode data in the coastal zone (CP4O)

A detailed analysis of the performance of CryoSat-2 data in the coastal zone was carried out in the CP4O Project.
It was concluded that, under favourable conditions, sea level measurements **at 2 km from the coast can** display the same level of noise as over the open ocean
Adoption of specific processing configuration (Hamming filter, Zero padding) improves the noise characteristics especially in the "last few kms"
Results from validation against tide gauges are encouraging - with fine tuning of search radius (and sometimes outlier removal) we can get **RMS < 10 cm with search radii around ~20 km**
In addition the consistency of the L2 re-tracking algorithms over the open ocean was checked, to ensure the continuity of the corrected altimetric SSH from open ocean to coast.

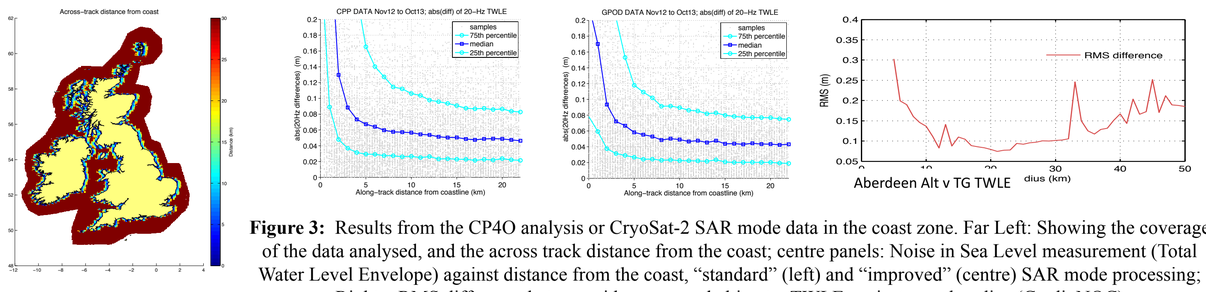


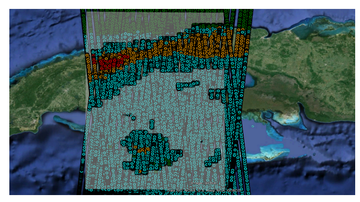
Figure 3: Results from the CP4O analysis or CryoSat-2 SAR mode data in the coast zone. Far Left: Showing the coverage of the data analysed, and the across track distance from the coast; centre panels: Noise in Sea Level measurement (Total Water Level Envelope) against distance from the coast, "standard" (left) and "improved" (centre) SAR mode processing; Right – RMS difference between tide gauge and altimeter TWLE against search radius (Credit NOC)

SIRAL Coastal Processing (CP4O)

As part of CP4O an improved coastal processing scheme was developed and tested for SARIN mode data over the Cuban Coast

The approach developed analysed **window delay, and** fitted a **smoothed model** to avoid jumps. This was used to **identify the ocean surface tracking point**, **truncate waveform** and re-track. This approach can also be used in SAR mode and LRM data.

Analysis of one full year of data demonstrated isardSAT retrievals were much less noisy than ESA standard product, giving a 60% improvement in performance in terms of reduction of SSH Standard Deviation



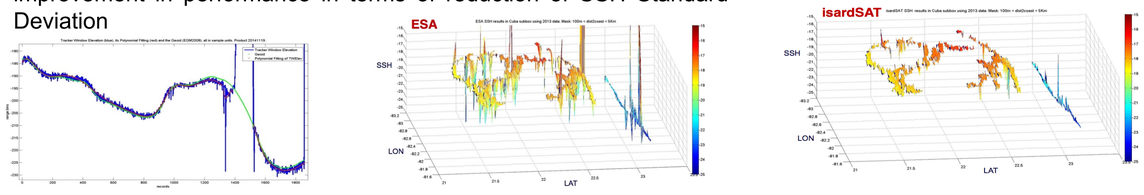


Figure 4: Top right: Showing the coverage of the data analysed (Western Cuba); Left: Fitting a smoothed model (red) to the tracker window delay(red). The geoid is in green; Centre and Right: Retrieved Sea Surface Height (SSH) in the standard ESA product (Centre) and as processed by isardSAT (Right). The significant reduction of noise achieved is clearly evident (Credit isardSAT)

SCOOP Coastal Zone Study

The SCOOP project is running from 2015-2018. Within SCOOP there is a specific coastal zone study with the following aims:

- Characterise the expected performance of Sentinel-3 SRAL data in the coastal zone, including a specific regional study in the German Bight and a study of the impact of swell on the US West Coast .
- Develop, test and implement modifications to the processing of the L1B-S product (e.g. zero-padding, burst weighting window, higher posting rate).
- Evaluate the performance of products generated by this modified processing chain and make recommendations with regard to future implementation.
- Develop techniques to identify and discriminate against the impact of land contamination on the nadir ocean echo.
- Develop, test and implement coastal re-trackers for Sentinel-3 SAR and RDSAR data
- Investigate how the orientation of the ground track with respect to the coastline, and the proximity of the land, affect performance.

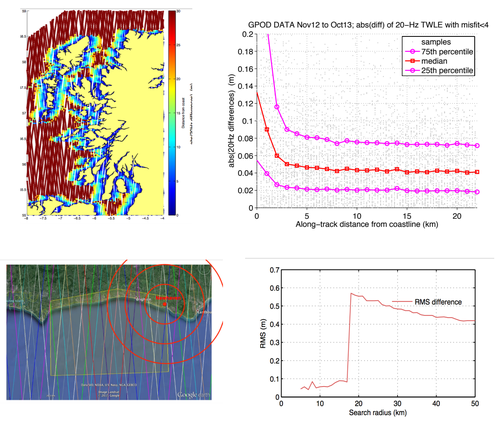


Figure 5: Approaches in the Coastal Ocean study to characterize performance in precision in Sea Level (Total Water Level Envelope – TWLE) retrieval close to the coast (top), and (bottom) comparison of satellite retrieved TWLE against Tide Gauge Data (Credit NOC)

SCOOP Regional Studies

Two regional studies are being carried out in SCOOP to assess the performance of the "standard" and improved products, in the German Bight, and off the Western Coast of the USA (California). The California study will in particular investigate the impact of swell, the German Bight study will compare against in situ data and models.

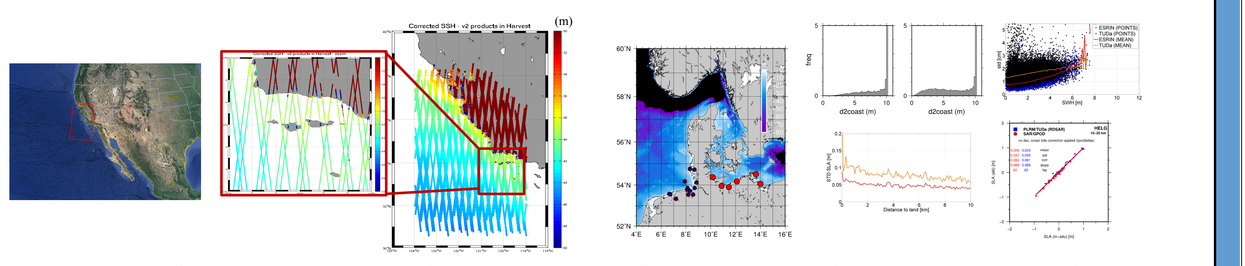


Figure 6: The SCOOP regional coastal studies. Far left – The region for the W USA coast study, centre left – some early analyses of SAR mode altimeter products. Centre Right - the region for the German Bight study. Far Right – some of the metrics that will be used (Credit Noveltis and U Bonn)

Wet Troposphere Modelling

Altimeter data processing has to include corrections for various geophysical factors that affect the accuracy of the retrieved products. One of the key corrections is the Wet Troposhere Corrections. SCOOP will produce an enhanced wet tropospheric correction (WTC) for Sentinel-3, over the open and coastal ocean.

The algorithms are based on the GNSS-derived Path Delay Plus (GPD+) methodology developed by U Porto in the scope of previous ESA projects (COASTALT, CP4O and SL_cci).

Figure 7 illustrates the performance of the GPD+ WTC for Envisat. Since Sentinel-3 possesses a two-channel on-board MWR, similar to Envisat, it is expected that both radiometers and the corresponding GPD+ WTC have similar performances in the open ocean but significantly better over the coast.

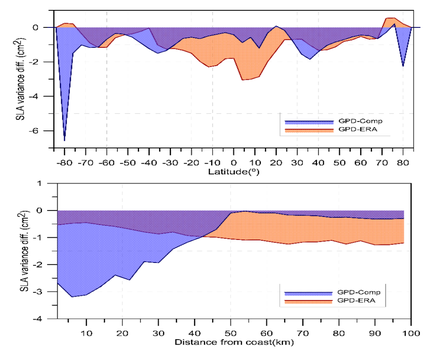


Figure 7: Variance difference between GPD+ and AVISO composite WTC (blue) and with the ERA Interim model (orange), function of latitude (top) and distance from coast (bottom) (Credit U Porto)

SCOOP SAR Mode Altimeter Test Data Sets

The SCOOP studies are based on a 2-year test data set derived from CryoSat-2 FBR data, with Sentinel-3 SRAL equivalent processing, produced for 10 regions across the global oceans (Figure 8).

In **phase 1,** processing equivalent to that in the Sentinel-3 baseline was applied to the CryoSat FBR data, summarised below:

Delay Doppler Processing (to L1B)
- No zero padding, no hamming windowing. CryoSat calibrations applied according to Baseline-C
- Stack masking designed for Sentinel-6 applied. Equivalent to Sentinel-3 approach.

Echo Modelling / Re-Tracking (to L2)
- Application of a Look-Up Table (LUT) for variable Point Target Response (PTR) width as a function of SWH.
- Implementation of SAMOSA-2 Waveform model. Improved thermal noise estimation.

In **phase 2**, modified processing schemes will be applied to the same source data. Options that will be investigated include:
Delay Doppler Processing (to L1B): Zero padding, hamming (and other) windowing, Stack Masking, Surface focussing, New approaches to stack processing

Echo Modelling / Re-Tracking (to L2): Coastal re-trackers (ALES approach, L1B stack geo-referencing), Stack data exploitation

The Phase-1 Test Data Set is available on request to ***scoop.info@esa.int***

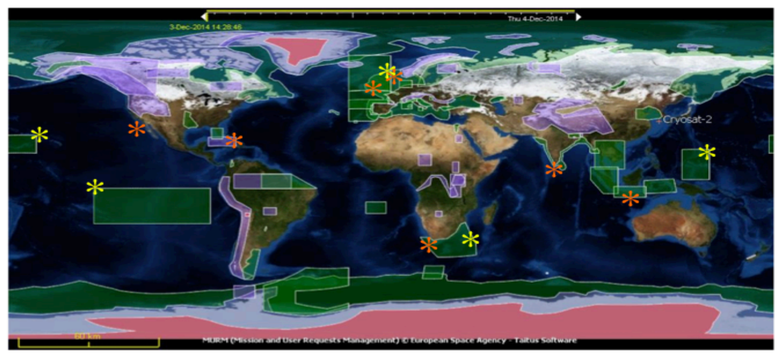


Figure 8: Regions included in the SCOOP study, based on a CryoSat SAR mode mask figure from ESA, with yellow indicating open ocean areas and orange coastal areas (note the Northeast Atlantic and Agulhas regions are assigned to both)

SCOOP Project Outcomes

The outcomes of the SCOOP project will include:
- Characterisation of the expected performance of Sentinel-3 SRAL SAR mode altimeter products, in the coastal zone and open-ocean.
- An evaluation & clear description of enhancements to the Sentinel-3 SRAL processing in terms of improved measurements over the open ocean and in the coastal zone.
- The provision of clear technical information of Sentinel-3 SRAL SAR products and their processing, supporting correct interpretation and application by the user community
- A Scientific Road Map including recommendations for further developments, implementations and research for Sentinel-3 SRAL SAR data

Acknowledgements

The work described in this presentation was supported by ESA through the STSE and SEOM programmes. We also acknowledge the support of CNES who provided the CNES-CPP CryoSat Products used in these studies. CNES-CPP products were developed by CNES and CLS in the frame of the "Sentinel-3 SRAL SAR mode performance assessment" study.

www.satoc.eu/projects/CP4O **www.satoc.eu/projects/SCOOP**