SCOOP

SAR Altimetry Coastal and Open Ocean Performance

Technical Note 2– SCOOP Scientific Outcomes

Deliverable D2.7

Sentinel 3 For Science – SAR Altimetry Studies

SEOM Study 2. Coastal Zone and Open Ocean Study

ESA Contract 4000115382/15/I-BG

Project reference: SCOOP_ESA_D2.7

Issue: 1.1

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Change Record

Date	Issue	Section	Page	Comment
4 October.2019	1.0			First Issue
22 November 2019	1.1	Various	Various	Revision following ESA review

Control Document

Process	Name	Date
Written by:	P.D. Cotton, M. Cancet, L. Fenoglio-Marc, M. J. Fernandes, C. Gommenginger, T. Moreau, M. Naeije, A. Shaw	04.10.19
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1 Introduction

1.1 The SCOOP Project

SCOOP (SAR Altimetry Coastal & Open Ocean Performance) is a project funded under the ESA SEOM (Scientific Exploitation of Operational Missions) Programme Element, 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. A further objective is to develop and evaluate an improved Wet Troposphere correction for Sentinel-3.

1.2 Scope of this Report

The scope of this technical note is to summarise the scientific outcomes of the SCOOP Project.

This includes a review of the processing approaches applied to generate the two main test data sets, and some additional smaller products.

In the next two sections we summarise the main findings from the assessment of the two test data sets, achieved through cross validation against other satellite data, in situ data and other analyses.

In section 5 we present the main findings from the development and analysis of an improved wet troposphere correction.

In Section 6 we provide some technical guidance on processing and using ESA SAR altimeter products, based on our experience in SCOOP.

1.3 Document Organisation

This document is organised in six main sections,

- Section 1: A short introduction defining the scope of this report.
- Section 2: Overview of processing approaches applied in SCOOP
- Section 3: Summary of the RDSAR Product Validation Results.
- Section 4: Summary of the SAR Product Validation Results.
- Section 5: Summary of the Wet Troposphere Correction study
- Section 6: Technical guidance on processing / using ESA SAR altimeter products

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2 Overview of Processing Approaches

2.1 Introduction – Overview of the Test Data Sets

To support the objectives of the SCOOP project, two test RDSAR and SAR altimeter data sets were generated, over 10 regions of interest (Figure 1).

Both test data sets were generated from CryoSat-2 FBR data. The first was processed with algorithms equivalent to the Sentinel-3 baseline, and the second with algorithms expected to provide an improved performance. The different processing schemes are summarised below, and detailed fully in two SCOOP Algorithm Theoretical Basis Documents (ATBD), available at http://www.satoc.eu/projects/SCOOP/docs/SCOOP_D1.3_ATBD_v17.pdf and http://www.satoc.eu/projects/SCOOP/docs/SCOOP_D1.3_ATBD_L2_isardSAT_v1a.pdf

The products cover a 2 year period (2012-2013) for all regions of interest except ROI 10 (Harvest). The mode mask only switched to SAR mode for this region on 1st December 2015, so the time coverage for this region is 01/12/2015 to 31/12/2016.

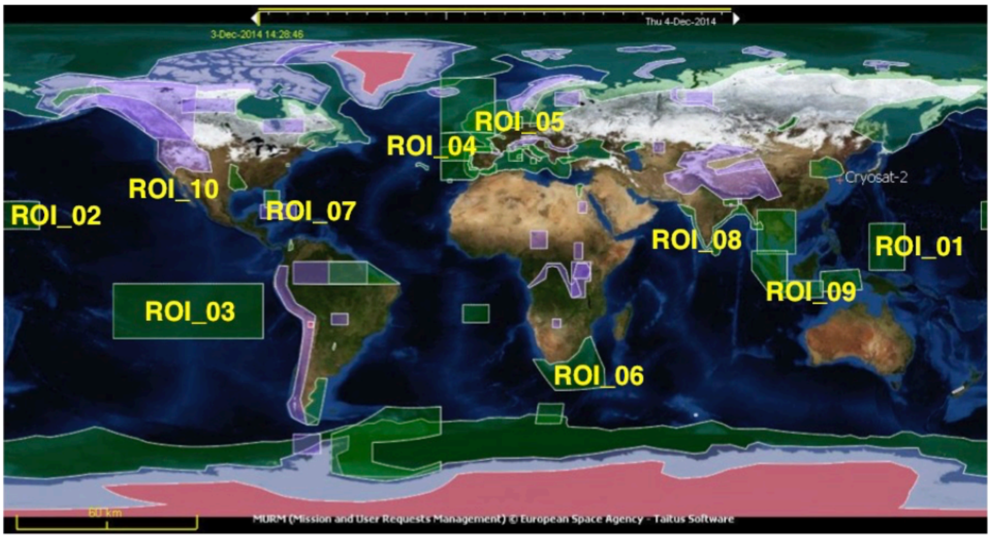

Figure 1. The CryoSat mode mask (V3.4). The 10 regions of interest for which the SCOOP Test Data was generated are indicated.

2.2 Test Data Set 1

2.2.1 Introduction

The objective of the first test data sets was to implement a processing scheme equivalent to the Sentinel-3 baseline

2.2.2 RDSAR Products

RDSAR products are products generated from SAR mode altimeter data, but processed to provide a product corresponding to the "conventional" low rate mode data product. The return echoes are not delay Doppler processed but compiled and averaged together to produce 20Hz waveforms similar to conventional LRM waveforms.

For SCOOP new code was written by TU Delft, drawing on the experience of working with the RADS software, aiming to create an RDSAR product as near equivalent as possible to the Sentinel-3 RDSAR product.

The ten processing steps to generate the LRM waveform are:

1. Gather 4 bursts of 64 echoes.
2. Adjust the FAI for each burst.
3. Align the echoes horizontally.
4. Align the echoes vertically (optional).
5. Correct echo amplitude and phase.
6. Zero-pad the echoes.
7. Perform a 1-dimensional FFT, horizontally.
8. Incoherently average the individual waveforms.
9. Apply low-pass filter correction.
10. Rescale the waveform.

The LRM waveforms were then retracked with an MLE3 retracker, so called as it applies a 3-parameter estimation to the echo waveforms, to derive estimates for the range, significant wave height and nadir radar back scatter.

Other points to note were that the Baseline-C Cal1 and Cal2 values for CryoSat were applied, and that the retrieved radar nadir backscatter ($\sigma 0$) was reduced by 3.04 dB and an additional drift of 0.27 dB /year was applied (determined during the CP4O project - refer to section 6.1.3).

At the University of Bonn an equivalent RDSAR product was developed independently in the TUDaBo processor, which is also based on the RADS heritage and includes some improvements. The steps above hold but the "amplitude and phase" and the "low-pass filter" corrections (Scagliola and Fornari, 2016) are applied to the burst as second and third step before the FAI adjustment. The L2 data is calculated by fitting a model to the measured L1B data with as fitting routine the Levenberg-Marquardt optimization algorithm based on least squares.

2.2.3 SAR Products

In the initial project plan, isardSAT was assigned the task to generate the SAR Altimeter product to L1B, and STARLAB the task to generate the L2 product from this L1B data set. However, due to staff shortages at STARLAB, and an eventual decision from STARLAB to discontinue its involvement in the SCOOP project, this approach was not continued, although some important processing issues were identified.

A decision was then made, in agreement with ESA, to generate the first SAR altimeter test data set using the ESA GPOD facility (http://gpod.eo.esa.int), using the ESA CryoSat FBR product as input and selecting the following processing options:

- CryoSat FBR to L1B – Delay Doppler Processing
    - CryoSat calibrations applied according to Baseline-C
- L1B to L2 Echo Modelling / Retracking
    - SAMOSA 2 Model
    - Application of Look Up Table for PTR width as a function of SWH

- Other selections
  - Filter Out Duplicated Products (Enabled)
  - Data Posting Rate (20Hz)
  - Hamming Weighting (no)
  - Exact Beam Forming (Approximated)
  - FFT Zero padding (no)
  - Radar Receiving Window size (128)
  - Antenna Pattern Compensation (No)
  - Dump SAR Stack data in output (No)

2.3 Test Data Set 2

2.3.1 RDSAR Products

2.3.1.1 Main Phase 2 RDSAR Test Data Set

The main processing chain remained the same for the RDSAR Test Data Set 2. The most recent corrections and models were applied, and the orbits updated to the GDRE standard (more information is available in the RADS4 manual (https://github.com/remkos/rads).

2.3.1.2 RDSAR MLE4 Test Data Set

Questions were identified during the SCOOP project as to the accuracy and stability of the attitude information in the CryoSat-2 FBR product. As the attitude information is input into the MLE3 retracking algorithm, this could result in errors in the retrieved geophysical parameters. An MLE4 retracker does not input attitude information, but rather estimates attitude along with the other retrieved parameters (range, significant wave height, and radar backscatter).

Smith and Scharoo (2011) have identified that, if accurate attitude information is available, MLE3 is preferred because in the Southern Oceans (with larger SWH), larger errors in the 20hz-to-1hz estimates occur for MLE4 (higher $sigma_{SSH}$ so higher range noise), because MLE4 allows large sea states to “leak” error into the off-nadir angle estimate. However, others (for instance at CLS and CNES) have preferred MLE4 retrackers, to avoid the dependency on accurate attitude information. Drawbacks of the MLE4 are known, mainly impacting the sigma0 estimation over non-ocean waveforms (rain cells and sigma0 blooms). Despite these drawbacks, MLE4 performs better than MLE3 for range and SWH estimates, in these atypical regions and more globally over all ocean [Thibaut et al., 2010].

Therefore, because of the uncertainties in the attitude information in the CryoSat products (Scagliola et al, 2018), a small data set using an MLE4 retracker was generated for SCOOP, covering the North Sea Region of Interest.

For the TuDaBo processing scheme, the L2 data is calculated by fitting a model to the measured L1B data with as fitting routine the Levenberg-Marquardt optimization algorithm based on least squares. The implemented retrackers in the TUDaBo-RDSAR are BMLE3 (Amarouche et al., 2004), SINC2 (Buchhaupt et al., 2018) and TALES (Dinardo et al., 2018).

2.3.2 SAR Products

2.3.2.1 Main Phase 2 SAR Test Data Set

isardSAT applied an end to end processing chain to generate the 2nd Test Data Set SAR altimeter product, which included both delay Doppler processing from FBR to Level 1B, and re-tracking from L1B to L2.

Starting from a processing chain intended to be equivalent to the Sentinel-3 baseline (and also the first Test Data Set), some modifications were applied and tested to investigate the impact on the geophysical parameters derived in the L2 product. Based on this testing the following specification for the processing of the 2nd Test Data Set (SAR product) was agreed:

- FBR - L1B Processing
    - Zero-padding (factor 2) in range
    - Intra-burst windowing (Hamming)
    - Approximate beamforming (azimuth processing)
    - Cut stack edges (restrict to looks $-0.6° < \theta_{look} < 0.6°$)
    - No intra-burst alignment
- L1B to L2 processing:
    - In-house isardSAT implementation of SAR ocean retracker (*Ray et al. 2015*)
    - Adapted to L1B processing modifications (consistency L1B-L2)
    - Fixed PTR setting (not SWH dependent), based on S3 IPF (azimuth PTR coefficient = 0.3831; range PTR coefficient = 0.513)
    - $\sigma0$ bias applied

2.3.2.2 “Experimental” Coastal Data Set

The default SAR altimeter “SARVATORE” processing on GPOD takes the window delay that minimises “altitude – (window delay*c/2)” as the reference point for the retracking. However, for tracks coming off the land and for products close to the coast this approach does not position the window correctly. Therefore, a new isardSAT scheme was implemented that instead takes the first window delay of the first full ocean return as the reference, thus waveforms are aligned with respect to the first burst or look in the stack marked as ocean and not lost. This ocean decision is based on the rough ocean/land mask from the FBR at burst level.

Applying this approach, a reduced data set was generated for the following regions

- North East Atlantic
- North Sea
- Agulhas
- Harvest
- North Indian Coast
- Indonesia
- Harvest

A coastal mask was applied to the North East Atlantic, North Sea and Agulhas data sets for L2 processing to reduce the computational load.

This data set was produced for internal assessment and validation, but because the analysis did not show an improvement on the existing SAR Mode Test data set (indeed performance was worse in some regions), it has not been made more widely available.

The processing of this data set is described in Makhoul (2018)

2.3.2.3 isardSAT Coastal Processing Study over Cuba

In addition, isardSAT carried out a study to develop a test another coastal processing approach, building on a study carried out under a CCN to the CP4O Project (Garcia et al., 2018). The principle is that close to the coast, land contamination of the return echo can lead the processing software to re-track from a false leading edge. This causes jumps in the retrieved range and hence in sea surface height. The isardSAT solution developed for this study (reported at the SCOOP Acceptance Review) uses the MSS2 mean sea surface field in the product (MSS DTU15) to fix the initial position of the retracking point, and limits the waveform to a number of range bins around this point. Initial studies by isardSAT on a data set around Cuba found an improvement in the stability of the SSH solution of around 50%.

The processing of this data set is described in Garcia (2018)

The conclusions of this study were:

- A solution for improving the Coastal Ocean SSH has been adapted from the CP4O project, based on the Mean Sea Surface (MSS2 L2 variable) is used instead of a smoothed window delay (as was used for the CP4O CCN solution).
- Data from Sentinel-3B cycles 11-12 was used (Closed Loop tracking mode).
- The Area of Interest was the Cuba archipelago, which is an area with a complex coastal topography.
- The results of the study show an improvement in the stability (along track SSH differences) of around 50%, reducing the impact of the coastal echoes contamination in the final geophysical retrieval.
- Future studies could be developed to further adapt the retracker for SWH and wind retrieval.

2.3.2.4 CLS Single Echo Processing Study

A study by CLS investigated the potential usefulness and relevance of the individual Doppler beam re-tracker in retrieving oceanic geophysical parameters from non-averaged Cryosat-2 SIRAL altimeter data. Contrary to the traditional delay/Doppler processing approach that computes the altimetric parameters from averaged waveforms, the proposed methodology first makes estimates of the sea surface height and sea state for each look bin of a stack then sums them, thus giving equal weight in the noise level reduction and an expected improvement of the parameter precision. The results were compared with the outputs of the CPP v14 products obtained with the CNES processing prototype developed by CNES.

Analysis of a test data set produced in this way demonstrated a significant noise reduction in range and SWH, better than what is obtained in unfocused SAR altimetry. However this study did not support clear conclusions on the accuracy of estimates due to the use of inaccurate SAR backscattered waveform model (from the CPP prototype) for retracking individual Doppler beams. If approximations made in developing the SAR CPP echo models were of low importance for processing multi-looked power waveforms, they now appear critical to fit model with individual beam data. This effect mostly impacts the parameter estimation of the outer beams and the accuracy of the mean parameters. It should be noted that the SAMOSA model also uses approximation (Gaussian PTR) that would prevent to converge to the exact solution. A more realistic SAR multi-look altimeter model as the one developed in CNES Sentinel-3 processing prototype (S3PP) should lead to much better performance. Further work is needed to fully validate the method, based on the use of the S3PP SAR altimeter model.

Secondly, due to the high computational burden required for estimating mean parameters of each 20-Hz sample, the number of study cases has been limited to a few examples. A trade-off has to be found between the computational cost and the accuracy to enable the method to be used on a larger amount of data.

The individual Doppler beam processing is of potential interest for a wide range of applications (in ocean and coastal regions as well as sea ice and inland water areas). It may also be used to reveal potential inaccuracies in the multi-look altimeter observation model to fit SAR altimeter data. Other sources of improvement in SAR processing (accounting for the range walk, including the vertical orbital wave velocity in the model) could also be assessed through this method to see whether their contribution may improve the consistency between data and backscattered waveform models, enhancing the accuracy of the estimates.

The full results are provided in a SCOOP Technical Note (Moreau et al, 2019).

3 RDSAR Product Validation Results

3.1 Introduction

Full details of the Product Validation analyses are provided in the SCOOP Product Validation Report (Cotton et al, 2019). We summarise the main results here and highlight the issues that these findings raise.

3.2 Main RDSAR Product Validation Results

SCOOP RDSAR Phase 1 Test Data Set V Phase 2 test Data Set

- The RDSAR TDS1 and RDSAR TDS2 (MLE3 processing) give similar results in terms of SSH performance (accuracy and precision).
- The SSHA (anomaly) parameter in the RDSAR TDS1 shows an unexpected loss of data close to the coasts, which is corrected in RDSAR TDS2.

SCOOP RDSAR Phase 2 Test Data Set

- RDSAR TDS2 demonstrated an improved noise performance when compared to the CNES CPP PLRM, but higher correlated errors degrading the SLA content at scales below 100km.
- RDSAR TDS2 SWH exhibit significant biases, believed to be a consequence of a lack of (SWH dependent) correction for the PTR width.
- Sigma0 shows a bias of 0.2 dB, dependant on SWH, and possibly correlated with mispointing angle.
- Comparison of the RDSAR TDS2 and the CNES CPP PLRM showed differences below 2cm in Sea Level Anomaly
- Residual errors were believed to be correlated to mispointing. The RDSAR processing uses attitude measurements from the products as inputs to the processing, but are estimated in the CNESS CPP PLRM product through its MLE4 re-tracker
- The RDSAR TDS1 product showed a greater data loss at the coast than the TUDaBo RDSAR product[1]. This was partly attributed to the better performance of the coastal "TALES" re-tracker in the TUDaBo product compared to the MLE re-tracker applied to the SCOOP RDSAR product. Therefore, in coastal regions a dedicated coastal re-tracker, such as TALES, is recommended. It is noticed that the data loss near coast is large, a threshold is set to sea level values and strangely many of the data have exactly that value, which mean that those data are not usable.
- The along-track noise of the RDSAR data is globally 50% higher than the noise of the SAR datasets.

SCOOP MLE4 RDSAR Phase 2 Test Data Set

- U Bonn found that the phase 2 MLE4 RDSAR SSH retrievals were generally noisier than for the MLE3 dataset and a slight loss of data in the first 10 km offshore. However, the

[1] Refers to an RDSAR product produced jointly by the Technical University of Darmstadt and University of Bonn. Fenoglio-Marc et al., (2017)

comparison with the in situ significant wave heights at Harvest carried out by Noveltis showed an improvement with the MLE4 dataset, compared to the MLE3 dataset.

3.3 Issues Identified

- Further validation of RDSAR is recommended under a wider range of mis-pointing angles and radial velocities. There seems to be a problem with the CryoSat attitude information. It is understood the new Baseline-D Cryosat-2 product will include corrected attitude information. It is recommended to investigate if this new product successfully addresses this problem.
- A (SWH dependent) correction for the PTR width should be included in the RDSAR processing. The TUDaBo SINCS waveform model does not make a PTR approximation.
- Further work is needed to better understand and correct the long wavelength errors (e.g. due to swell) in the RDSAR product. These issues need to be addressed to ensure better continuity with conventional altimetry missions, and ultimately make this processing of interest for the Sentinel-3 mission.
- Coastal re-trackers (e.g. ALES, TALES) should be applied for coastal data sets as they have been clearly shown to improve performance.
- Further tests on the performance of an MLE4 re-tracker on the RDSAR product and the impact for the climate record should be carried out.

4 SAR Product Validation Results

4.1 Introduction

Full details of the Product Validation analyses are provided in the SCOOP Product Validation Report (Cotton et al, 2019). We summarise the main results here and highlight the issues that these findings raise.

4.2 SAR Products

4.2.1 Open Ocean

Sea Surface Height / Sea Level Anomaly

- The global scale analysis over the two sets of regions shows consistency between the SSH in SAR TDS1 and SAR TDS 2.
- No dependency on the radial velocity was found on the SSH differences between SAR TDS1 and SAR TDS 2. SSH from initial versions of the product were found to exhibit such a dependency.
- Very similar noise performance is obtained for both SAR TDS1 and SAR TDS 2, with a slight improvement in SAR TDS2 at higher SWH that can be related to the intra-burst Hamming application.
- No improvement in the detection of small-scale oceanic structures was observed between SAR TDS1 and SAR TDS 2, since neither the sea level noise level nor the long ocean wave correlated errors have been reduced. In fact the sea level spectrum has slightly more energy for scales from 2 to 10 km due to an overlap between consecutive measurements (resulting from the application of the Hamming function).
- The SAR altimeter Test Data Set 2 shows an improvement on the content of the LRM datasets for wavelengths below 100 km.

Significant Wave Height

- SAR TDS 2 provides a much-enhanced measurement precision of SWH on SAR TDS1, with a reduction in noise of around 10cm throughout the SWH dynamic range (1-8m). Part of this improvement is believed to be related to the combined setting of intra-burst Hamming and zero-padding, and part to the better stability of the re-tracker, associated to the way that the SWH initial seeding is implemented (based on a sliding window of previous estimates)
- However, a significant bias was seen in SAR TDS 2 SWH, especially at low SWH. This was believed to be related to the PTR setting: SAR TDS1 used a variable PTR empirically tuned for the re-tracker implementation in GPOD (LUT), while SAR TDS2 used the isardSAT in-house re-tracker with a fixed PTR setting. In-situ measurements should be used to fine tune and calibrate the PTR settings.

Sigma0 (Nadir Surface Radar Backscatter):

- Global scale analysis over the two sets of regions shows consistency between the Sigma0 of SAR TDS1 and SAR TDS 2, where a small dependency (below 0.1 dB) as a function of radial velocity is observed on the Pacific regions. This can be linked specifically to some related orbit height dependency

- Similar noise performance is obtained for both data sets SAR TDS1 and SAR TDS 2, with a slight improvement for SAR TDS 2.

Sea state impact on the SAR sea surface height estimates:

- The investigation of the SAR SSH absolute bias estimates against the in situ SWH measurements at Harvest shows the clear dependency of the bias variability with the significant wave heights.

4.2.2 Coastal Zone

Sea Surface Height / Sea Level Anomaly

- A general improvement was noticed from SAR TDS 1 to SAR TDS 2, with lower noise and variability in SAR TDS 2 (except in the first kilometre offshore) and more data retrieved whatever the distance to the coast.
- For Sea Level Anomaly, the SAR mode performs better than RDSAR, in terms of lower noise, and better agreement with reference data sets (models and tide gauge data)
- From the studies carried out by U Bonn, and through comparisons against a SAR product generated on GPOD by U Bonn using the SAMOSA+ re-tracker (Dinardo et al., 2018), the SAMOSA+ re-tracker has been shown to provide better performance (in terms of lower noise in Sea Level Anomaly) at the coast than SAMOSA2.

Significant Wave Height

- A bias in the SWH measurements was observed between the SAR TDS1 and SAR TDS 2, for SWH less than 1.6 m.

Coastal Proximity

- In terms of the noise of Uncorrected Sea Surface Height (USSH) on approaching the coast, the performance of the SAR TDS1 and SAR TDS 2 was similar, with a median value of "noise" (measured as the differences between successive values of USSH) of less than 5cm to within 3km of the coast. A filter only allowing data with a waveform misfit value of less than 3 was applied. No dependence of USSH performance on Significant Wave Height (SWH) was found.

Angle of Arrival

- An investigation into any dependency on performance with the angle of arrival with respect to the coastline found no dependence of noise in SSH on angle of arrival, but did find a greater loss of data for measurements along tracks arriving at angles of 30° or less with respect to the coastline. This indicated that the data filtering was removing noisy or contaminated waveforms.

Data Filtering

- The SKYMAT /SatOC study found that the application of the misfit < 3 filter significantly reduces the data available within 10km of the coast, but improved the noise performance, by excluding contaminated waveforms.
- Noveltis applied a filter on waveform misfit < 4, and a Pearson Correlation > 95%. The Pearson correlation parameter was only available in SAR TDS2. They found the selection based on misfit < 4 to be stricter, but suggested the optimum values of this threshold could vary dependent on region.

isardSAT Coastal Data Set

- None of the studies found any improvement in the “experimental” coastal data set when compared to the SAR TDS 2. In fact a degraded performance was found at Harvest (SCOOP Product Validation Report, Section 6.2.2).

4.2.3 Issues Identified

- On the basis of the assessment results, showing substantial reduction of SWH noise and almost matching SLA performance (with CNES CPP), the use of the innovative SARM processing (Zero padding factor 2 and Hamming window) for Sentinel-3 mission is recommended to improve ocean altimetry products for end-users.
- Application of the Hamming windowing appears to increase the bias in SWH at low wave heights
- In situ measurements should be used to fine tune and calibrate the PTR settings within the (isardSAT) SAR mode processing.
- Further analyses should be performed on a global scale (using Sentinel-3 data) to confirm results over a wider range of conditions. Such analyses should pay close attention to any sea level changes in the spectrum.
- The increase in the SSH bias variability for large wave conditions highlights the fact that an appropriate SSB correction dedicated to the SAR SSH is needed to compute accurate SSH.
- Further investigations are required to understand why performance degradations were observed in the “experimental coastal” data set prepared by isardSAT.
- Further studies should be carried out into the development of coastal re-trackers for SAR mode echoes.

5 Wet Troposphere Correction Study

5.1 Introduction and Wet Troposphere Correction (WTC) Product Overview

Sentinel-3 carries a 2-band MicroWave Radiometer (MWR), similar to that of Envisat. Therefore, it is expected that S3A MWR-derived WTC will exhibit similar performance and problems to those of Envisat, particularly in coastal and polar regions (Fernandes et al., 2015). CryoSat-2, designed as a mission for observing the cryosphere, does not possess an on-board MWR, relying on the WTC derived from the ECMWF model.

The GPD+ algorithm has been developed with the purpose of determining improved WTC for these two types of missions using data combination of all available observations and best atmospheric models (Fernandes and Lázaro, 2016). While in case of missions such as Sentinel-3, GPD+ preserves the valid MWR observations over open-ocean, only estimating new values in regions of invalid MWR-derived WTC, in the case of CryoSat-2 estimates are obtained for all along-track points. In the absence of observations, the value of the first guess computed from the ECMWF operational model are adopted. In both cases, the final WTC are continuous, valid over all surface types. The data combination is performed by objective analysis, taking into account the variability of the WTC field and the accuracy of the observations.

Compared with previous GPD versions, GPD+ has the following main characteristics (Fernandes and Lázaro, 2016):

- Improved detection of valid/invalid MWR observations, of relevance for all missions except CS2;
- External data sets include scanning imaging MWR (SI-MWR) and GNSS-derived path delays;
- All radiometer data sets have been calibrated with respect to the Special Sensor Microwave Imager (SSM/I) and the Special Sensor Microwave Imager Sounder (SSM/IS) set of sensors, due to their stability and independent calibration.

5.2 WTC Product Assessment Results

CLS and the University of Porto carried out an assessment of the GPD+ WTC generated for CryoSat within the SCOOP project. Both noted the limited geographical coverage of the regions of interest and observed that a data set with global coverage would be preferred to give a comprehensive analysis.

- CLS found that the GPD+ approach leads to a significant improvement in the accuracy of the Cryosat-2 SSH and SLA.
- The GPD+ WTC reduces the sea level anomaly variance with respect to the ECMWF operational model correction from both along-track analysis and cross-overs by ~2 cm^2 (particularly effective in low latitude areas).
- Along track discontinuities of a few mm height were observed, without however adverse impact on the SLA accuracy. In case of occurrence of higher discontinuities, a strategy to better handle such discontinuities should be envisaged.

- U Porto's analysis found that when compared to the ECMWF operational model, GPD+ leads to SLA variance reduction at crossovers and in particular near the coast for most of the SCOOP regions of interest.
- Other diagnostics such as WTC differences with respect to J2 and with respect to GNSS confirm that overall GPD+ is closer to these accurate WTC datasets and therefore offers an improved correction in comparison with the ECMWF model. The comparison with GNSS also shows no evidence of land contamination in the GPD+ WTC.
- The short dimension of some of the selected ROI made difficult the assessment of the correction in some regions, e.g. in Harvest and Indonesia. Previous studies had shown that the WTC errors in the Indonesia region are particularly large, even exceeded by the ocean tide errors (Handoko et al, 2017, Legeais at al., 2018), and should be subject of a dedicated study.

U Porto also generated a GPD+ WTC for Sentinel-3 and analysed its performance (Fernandes and Lázaro, 2018). Two versions of the corrections have been generated: GPD1, "a la Cryosat" , using only third party data; GPD2, the "usual" GPD+ WTC, using all available data sources, including valid observations from S3A on-board MWR. Their main findings were:

- The comparisons of the S3A MWR with other MWR (GMI and J3) indicate good overall agreement between all sensors.
- A stable temporal evolution of the S3A MWR-derived WTC is observed. A strong periodic signal is found in the differences with respect to GMI due to the orbit configurations of the respective spacecrafts.
- Strong ice and land contaminations are observed in the S3A MWR observations, in line with the expected behaviour of a dual-frequency MWR. This makes the establishment of validation criteria for the MWR observations difficult, but unavoidable and indispensable, particularly at the high latitudes.
- Comparison with GNSS shows land contamination in the S3A MWR up to 20-25 km from the coast. The same is not observed in any of the analysed GPD+ WTC.
- The GPD2 WTC (includes S3A MWR) shows a small reduction in SLA variance at crossovers with respect to GPD1 (no S3A MWR), however this reduction in SLA variance is not observed when analysing along-track variance differences. The later result was not previously expected and has not been observed before for any of the analysed missions, thus indicating that the S3A MWR-derived WTC can still be improved.

5.3 WTC Recommendations

- An assessment of the GPD+ performance over polar regions was not possible due to the limited geographical coverage of the test data set.
- Due to its unique characteristics, the Indonesia region should be subject of a dedicated study, improving both the WTC and the ocean tide model in this region.
- The GPD+ correction clearly outperforms the ECMWF operational model-derived correction in both open ocean and coastal areas. This improved solution is of particular interest for altimetry missions which do not possess on-board microwave radiometer. For the Sentinel-3 mission embarking an MWR sensor, such a solution is of interest whenever MWR measurements are considered invalid, but could also be used as independent data for assessing the on-board MWR derived WTC (using a version of the correction solely based on third party data).
- Along track discontinuities of a few mm height were observed, without however adverse impact on the SLA accuracy. In case of occurrence of higher discontinuities, a strategy to better handle such discontinuities should be envisaged.

- The composite correction present in the products is not suitable for use. The average percentage of points with invalid Composite WTC is 23%.
- The GPD+ WTC would be an added value for Sentinel-3A products.

6 Technical Guidance on Processing / Using ESA SAR Altimeter Products

6.1 RDSAR Products

6.1.1 Introduction

The following observations and recommendations apply to the processing of Cryosat FBR (Baseline C) data into an RDSAR product, and to the use of the SCOOP RDSAR Test Data Set.

6.1.2 Quality Checks

General Recommendation

SCOOP RDSAR files are netcdf files and can be easily read with standard opensource and commercial software. For a detailed description of the ingredients of the SCOOP RDSAR product, which corrections to be used and which data quality flags are available, the reader is referred to the RADS data manual (https://github.com/remkos/rads).For general application it is recommended to apply the following edit criteria for outlier detection (these are the standard values used in RADS to clean the data and prepare them for comparison):

- Sea level anomaly: -3 < sla [m] < 3
- Orbital altitude rate: -40 < alt_rate [m/s] < 40
- Ku-band range corr. for instr. effects: 700,000 < range_ku [m] < 800,000
- Dry tropospheric correction -2.4 < dry_tropo [m] < -2.2
- Wet tropospheric correction -0.6 < wet_tropo [m] < 0.0
- Ionospheric correction -0.4 < iono [m] < 0.04
- Inverse barometer -1 < inv_bar [m] < 1
- Solid Earth tide -1 < tide_solid [m] < 1
- Ocean tide -5 < tide_ocean [m] < 5
- Ocean load tide -0.5 < tide_load [m] < 0.5
- Pole tide -0.1 < tide_pole [m] < 0.1
- Sea state bias -1 < ssb [m] < 1
- Ku-band significant wave height -0.5 < swh [m] < 8
- Ku-band backscatter coefficient 6 < sig0_ku [dB] < 27
- Ku-band automatic gain control 0 < agc_ku [dB] < 70
- Altimeter wind speed -1 < wind_speed_alt [m/s] < 30
- Standard deviation of Ku-band range 0 < range_rms_ku [m] < 0.18
- Ku-band peakiness 1.1 < peakiness_ku [-] < 1.6
- Flag word between 32 (lower limit) and 0 (upper limit): for explanation see RADS data manual
- Standard deviation of Ku-band swh 0 < swh_rms_ku [m] < 2.1
- Standard deviation of Ku-band backscatter coefficient 0 < sigm0_rms_ku < 1

U Bonn Checks

The quality check performed by Uni Bonn for the validation consists in screening based on flags and on thresholds. A first screening of the altimeter data consists of rejecting data over land and inland waters. Secondly, we apply thresholds to SSH and SWH eliminating SSH data with departure from the mean sea surface (MSS) larger than 15 meters and SWH in the range between -1.5 meters and 15 meters. Thirdly, different outlier detection rules are applied to the sea level anomaly (SLA) and SWH parameters. For SLA in a coastal zone, which has approximately a normal distribution, a 3-sigma criterium is applied. For coastal SWH , which is not normally distributed, the measurements are filtered using the misfit between the model and data waveforms, if the misfit is provided in the data.

CLS Checks

For the Open Ocean study, CLS applied the following quality checks to identify valid data in the RDSAR product are:

- measurements from high latitudes were removed to avoid sea ice coverage,
- only data more than 100 km from the shoreline (and the points with a bathymetry lower than -1000 m) were selected to avoid the increased errors in the coastal zone, and
- data points for which the SLA value departs from the reference level beyond 1 m were filtered out. This selection is severe but ensure to eliminate all outliers (that may be related to some spurious observations caused by sea ice, rain, blooms) and to reduce the effect of oceanic variability.

6.1.3 Calibrations, Parameter Bias Adjustments, and Geophysical Corrections

Cal1, Cal2

The baseline-C calibration correction values Cal1 and Cal2 as defined in the “CryoSat Characterization for FBR users” document by Aresys (see reference list) are already applied during the level 1A to level 1B RDSAR processing (the software reads these values from an auxiliary input file).

Sigma0

Concerning the estimated backscatter coefficient, sigma0, and this was already established during the CP4O project, occasional jumps lead to a trend over time; for PLRM -3.04 dB + 0.27 dB/year system bias/trend is added to the data (starting 1 May 2011). This particular trend and bias followed from comparing the backscatter with actual wind values over time (Thales and RADS analyses, Dec. 2013). In other words, the backscatter is calibrated by applying this value. This is an external fix, related to chosen re-tracker and should be applied separately when regarding the SCOOP RDSAR product (if not already in so-called RADS format, otherwise it already has been applied).

Orbit

Use of GDRE standard orbits is recommended (referred to as alt_gdre in the netcdf file).

Other Geophysical Corrections

The following geophysical corrections are recommended (but the end-user may of course choose, alternatives are given in the data files);

- For tide_ocean: tide_ocean_got48, which is the ocean tide variation GOT4.8 model including long-period equilibrium tides
- For tide_load: tide_load_got48, which is the load tide variation GOT4.8 that has to be added to the ocean tide (to complement solid earth tide and pole tide)
- For mss: mss_cnescls11, which is the CNES-CLS11 mean sea surface height model to reduce sea heights to sea level anomalies

6.1.4 Issues arising from the RDSAR Processing development

Mispointing

- There are known to be some problems with the attitude information that is present in the Cryosat Baseline-C product (Scagliola et al, 2018)
- It is understood the new Baseline-D product has corrected these problems. Further investigations are recommended to confirm this.

Re-trackers

- Smith and Scharroo (private communication) recommend the use of MLE3 for large wave height regimes, but this relies on accurate attitude information.
- CNES recommends the use of an MLE4 re-tracker, to avoid possible errors associated with incorrect attitude information, and to provide continuity with other data sets. An extra test run was employed to two of the ROIs and already showed that MLE4 provides a much better shaped SLA power density spectrum and improved SWH estimates, though the noise for the MLE4 result was slightly higher than for the ML3 (9.5 cm vs 9.2 cm).
- The PLRM waveform retracking should also address the effects of the pulse-to-pulse correlation within bursts, that leads to varying statistical properties over the waveform bins and furtherly estimate biases
- Coastal retrackers (e.g. ALES Passaro et (2014), TALES and STAR (Fenoglio et al, 2019a; Roscher et al, 2017; Fenoglio et al., 2019b) are recommended for coastal applications. However, there is an open issue on how to provide continuity with offshore data. Comparison of the RDSAR Delft Processing with TUDaBo (Fenoglio and Buchhaupt, 2019) shows comparable performance of TU Delft RDSAR MLE3 and TUDaBo MLE3 and better performance of TALES and STAR in coastal zone. Also, the ALES re-tracker type approach relies on a truncated waveform, limited to waveform bins around the leading edge and peak. MLE4 requires information from the waveform tail, and so could not be used in this approach.

PTR width

- It was established that the use of a fixed width PTR correction results in errors in the estimation of Significant Wave Height, particularly for low wave heights, and also introduced a bias in the SWH of approx.. 10 cm. Thus, a variable SWH dependent correction (as provided in a dedicated Look Up Table) is recommended.

6.2 SAR Products

6.2.1 Quality Checks

SCOOP partners applied their own additional filters / quality checks, as follows:

Noveltis

Noveltis noted that several parameters and flags are available, depending on the products:

- Phase 1 SAR products:
  - Misfit parameter (*Misfit_20Hz*) ;
- Phase 2 SAR products:
  - Misfit parameter (*Misfit_analytical_SWH_MSSfixed_20_ku*) ;

- Pearson correlation parameter (*Pearson_corr_analytical_SWH_MSSfixed_20_ku*);
- Validity flag (*Flag_validity_L1B_wvfm_20_ku*).

The validity flag, only available in the Phase 2 dataset, indicates whether the L1B waveform is valid or not to be used in the retracking process. In the case of the Harvest region, when considering the first 6 months of the dataset (79 files, from mid-December 2015 to mid-May 2016), only two points over the ocean are flagged because of this validity flag.

The misfit and the Pearson correlation parameters both quantify the fitting between the retracking model and the waveforms. Both datasets contain the misfit parameter but the Pearson correlation parameter, for which the recommendation is to filter out the data with correlation lower than 95%, is only available in the Phase 2 dataset.

As a consequence, Noveltis based their selection of data on the misfit parameter value in order to compute the statistics in similar conditions for both datasets. Results showed that most of the outliers in the Phase 2 SAR USSH and SWH data are filtered out when considering misfit values lower than 4. With this misfit threshold of 4, 97% of data are used. It should be noticed that the optimal value of the misfit threshold may vary depending on the region. Also, in the Harvest region, the selection based on misfit values lower than 4 is stricter than the selection based on Pearson correlations higher than 95%.

CLS

For the Open Ocean study, CLS applied the following quality checks to the SCOOP SAR products

- measurements from high latitudes were removed to avoid sea ice coverage,
- only data more than 100 km from the shoreline (and the points with a bathymetry lower than -1000 m) were selected to avoid the increased errors in the coastal zone, and
- data points for which the SLA value departs from the reference level beyond 1 m were filtered out. This selection is severe but ensure to eliminate all outliers (that may be related to some spurious observations caused by sea ice, rain, blooms) and to reduce the effect of oceanic variability.

U Bonn

U Bonn applied the following quality checks to the SCOOP SAR products

As for RDSAR, the quality check performed by Uni Bonn for the validation consists in screening based on flags and on thresholds. Altimeter data are rejected over land and inland waters. Secondly, we apply thresholds to SSH and SWH eliminating SSH data with departure from the mean sea surface (MSS) larger than 15 meters and SWH in the range between -1.5 meters and 15 meters. Thirdly, outlier detection rules are applied to the sea level anomaly (SLA) and SWH parameters. For SLA in coastal zone a 3-sigma criterium is applied. For coastal SWH the measurements are filtered using the misfit between the model and data waveforms if the misfit was available, otherwise a 3-sigma criterium is applied. For SAR data with misfit higher of 3 were excluded.

SKYMAT/ SatOC

SKYMAT/SatOC applied the following quality checks to the SCOOP SAR products

- Data with a misfit >= 3 were excluded
- A land mask was applied to the SAR data using the GMT (The Generic Mapping Tools, Version 5.2.1) software.

6.2.2 Corrections Applied

It is appropriate to apply different corrections according to the application of the data, or the analysis that is being carried out. We provide the following guidelines

CLS

For the sake of consistency, only uncorrected SLA were considered. Comparing uncorrected (and near-collocated) SLA data from different processing approaches enabled to assess the quality of the altimeter derived parameters, without uncertainty related to possible discrepancies between geophysical corrections used in different data sets that would cast doubt on the results.

Noveltis

For the estimation of the noise and variability of the various datasets, Noveltis used the Uncorrected Sea Surface Height observations (altitude – range), without any correction applied.

For the comparison with the in situ Sea Surface Height (SSH) observations in Harvest, the corrections available in the SCOOP products (ionosphere, wet and dry troposphere, solid, polar and loading tides) were used to compute the altimetry Sea Surface Heights. Near the Harvest calibration site, the differences between the wet tropospheric correction available in the products and the GPD wet tropospheric correction provided by the University of Porto are in the order of a few millimeters.

The ocean dynamics (tides and effects of the wind and atmospheric pressure) is quite large in the Harvest region and can reach several meters. As the offshore altimetry data and the tide gauge data may not contain the same ocean dynamics signals, it is necessary to remove these signals from both measurements before performing the comparison in order to reduce the variability if the bias estimates. To apply the same corrections to both datasets (in situ and satellite), Noveltis used the following models:

- Ocean tides: FES2014 (in-house prediction) ;
- Atmospheric correction: TUGO-m simulation provided by LEGOS.

Finally, given the very large waves that can occur in Harvest, the in situ SSH data in Harvest are corrected by JPL with a Sea State Bias (SSB) estimate based on the wave heights measured on site. Because no SSB correction is available in the SCOOP altimetry products, an approximation of this correction for the altimetry SSH was computed by Noveltis, considering 3.5% of the SWH estimated by the SCOOP retracking process at the altimetry points.

U Bonn

For the estimation of the noise of the various datasets, Uni Bonn used the uncorrected Sea Surface Height observations (altitude – range), without any correction applied. The same was done in the analysis of the along track geophysical parameters.

For the comparison between the altimeter Sea Surface Height (SSH) with the in-situ measurements and with the model heights or with SSHs from other satellite missions, the corrections used are mainly those contained in the GPOD SARvatore Level 2 netcdf files. This for ionosphere, wet and dry troposphere, solid, polar and load tide, DAC and ocean tide. The Sea state bias is not available in SARvatore GPOD and we use a SSB equal to 4.7 % of the SWH.

SKYMAT/SatOC

SKYMAT/SatOC did not use corrections as such, for their analysis they used Uncorrected Sea Surface Height (USSH) observations, that is, Altitude minus Range. The Significance Wave Height (SWH) was derived from the retrackers.

6.2.3 Issues Arising from SAR processor development

isardSAT identified a number of important issues whilst developing, implementing and testing the SAR processor. Refer to Makhoul (2019) for information about the SAR L2 processing.

Matching of L1B and L2 processing

During the first phase of the project, when isardSAT were initially implementing the processing to L1B, and STARLAB the processing to L2, some difficulties were found in integrating the processing chains for the two stages. This was found to be due to inconsistent approaches in the referencing to the look angle and in the masking in the L1B Stack. For any stack which is not centered around zero look angle, or is not symmetrical, the correct referencing is critical in the parameters

- look angle (look_angle_start/stop_l1b_echo_sar_ku)
- masking (stack_mask_range_bin_l1b_echo_sar_ku) – this contains potential masks, and the masking of wrapped samples due to geometry corrections

Radial Velocity dependency – Intra Burst alignment

- Initial products were found to exhibit a significant SSH radial velocity dependent error, after investigating an number of potential sources of the error, the problem was found to be related to the way that the 20Hz Window delay was compensated (S Dinardo Pers.comm).

Exact /Approximate Beam Forming

- isardSAT investigated the impact of applying an approximate approach to beam forming, as opposed to an exact approach, for a limited data set over the Harvest region. The benefit of the approximate approach is that it is computationally more efficient and so takes less processing time
- Exact beamforming provides very similar performances to approximate approach (lower computational burden)

Multi-looked zeroes Method

- isardSAT investigated the impact of applying a “multi-looked zeros” method”, for a limited data set over the Harvest region.
- Multi-looking zeros-method does not impair performance as re-tracker model is aligned with such L1B processing

Cutting the edges of the waveform stack

- isardSAT investigated the impact of limiting the width of the L1B stack to ±0.6° about the centre, for a limited data set over the Harvest region
- No differences could be seen in the retrieved parameters (SSH, SWH and Sigma0).
- Thus, it was concluded the contributions from the edges of the stack was not significant and cutting the stack at the edges (±0,6° for FBR CS-2) does not have an impact on performance.

Zero-Padding in Range

- isardSAT investigated the impact of applying zero-padding factor 2 in range for a limited data set over the Harvest region.
- It was noted that the inclusion of zero-padding improved the re-tracker fitting, especially for small SWH, where the leading edge of the waveform is sharper.

- Reduced noise (Compared to the GPOD baseline) was found for SSH and SWH for SWH 1-3 m. The improvement was especially marked in SWH where noise was reduced by 35% (at SWH = 2m)

Intra-burst Hamming Window

- isardSAT investigated the impact of applying intra-burst Hamming windowing for a limited data set over the Harvest region
- Analysis of the stack showed that without Hamming windowing, the stack included contamination of the along-track sidelobes in the “noise floor” region. Applying the Hamming window removed this “contamination”, and resulted in reduced noise in retrieved SSH and SWH for SWH > 3m.

Attitude Parameters

- Differences were observed in pitch and roll information found in CryoSat-2 GPOD data and those from the ESA IPF (Baseline C) processor. SD (pers comm) advised that GPOD applied (and included in the product) attitude parameters that were retrieved from the ESA L1B product, but reverted to Baseline B equivalent parameters, and then applying a static bias correction as proposed by R Scharroo and also applied in RADS.
- During the SCOOP project, inaccuracies were identified in the attitude parameters in ESA CryoSat baseline-C products (Scagliola et al, 2018). This was believed to result in errors in processing which used these attitude parameters as inputs to (MLE3) re-tracking. It is now understood these errors will be corrected in soon to be issued Baseline-D products (ref MRest email)
- different definitions on how this angular information is exploited in the L2 processor, i.e., projection of pitch and roll on the ground (y_p and x_p, respectively) needs to be further clarified and homogenized between the different implemented retracking chains. isardSAT’s consideration is y_p=-1.0*theta_pitch*H_orb and x_p=theta_roll*H_orb, i.e., the pitch sign is reversed since according to the definition in the PHB (product handbook), a positive pitch means nose down and so a negative value of y_p w.r.t normal case

PTR Width

- The application of a fixed PTR width was observed (in all analyses) to result in significant errors in SWH at low wave heights. It is clear therefore that a variable (SWH dependent) PTR width is needed. This could be derived through calibration against other data sets (including in-situ data).

6.2.4 Coastal Processing

Some approaches to coastal processing for SAR products have been investigated as part of the SCOOP project. Investigations by NOC in processing to L1b (Stack selection) and to L2 (retracking) are ongoing and will be reported in an update to this report.

The “Experimental” coastal data set produced by isardSAT, using the first ocean window delay after the track leaves land as the tracking reference, was not found to improve performance.

A second approach, building from work in a CCN to CP4O, used the mean surface from the product (DTU15) as reference for window delay demonstrated promising results for Cuba. Therefore it is recommended that this approach is used to generate a data set for other regions, and assessed,

Coastal SAR echo re-trackers have been developed (e.g. SAMOSA+ Dinardo et al., 2018) and improved performance has been demonstrated (SCOOP Product Validation Report Section 5.2.1). We recommend continued development and assessment of such approaches.

The TUDaBo processor considers coastal processing for RDSAR and includes options to be selected and tested in different regions (Fenoglio and Buchhaupt, 2017). The unfocused SAR part of TUDaBo does not yet have a dedicated coastal retracker, while the processing options are comparable to those of the SCOOP SAR validated datasets (Fenoglio and Buchhaupt, 2019).

7 List of Acronyms

ALES	Adaptive Leading Edge Subwaveform retracker
AMR	Advanced Microwave Radiometer
AVISO	Altimetry information website (https://www.aviso.altimetry.fr/en/home.html)
BSH	German Federal Maritime and Hydrographic Agency
CCI	Climate Change Initiative (ESA programme)
CLS	Collecte Localisation Satellite
CNES	Centre National d'Études Spatiales
CORSSH	Corrected Sea Surface Height
CP4O	CryoSat Plus For Ocean
CPP	CNES CryoSat-2 Prototype Processing
CS-2	CryoSat-2
CSCM	Cold Sky Calibration Manoeuvres
DComb	Data Combination – U Porto technique for generating Wet Troposphere Correction
DPM	Detailed Processing Model
DTU	Technical University of Denmark
ECMWF	European Centre for Medium-Range Weather Forecasts
ERA	ECMWF ReAnalysis Model
ESA	European Space Agency
FAI	"Fine Altitude Instruction" (Fine Range correction)
FBR	"Full Bit Rate" CryoSat-2 product which includes multi-looked echoes at 20Hz
FTDS	First Test Data Set
GMI	Global Precipitation Measurement Microwave Imager
GNSS	Global Navigation Satellite System
GPD	GNSS derived Path Delay
GPOD	Grid Processing On Demand (https://gpod.eo.esa.int)
GPM	Global Precipitation Measurement
HAMM	Hamming Window
HS, HS0, HS1, HS2, HS3	Significant wave height of different components of the wave spectrum

IFREMER	Institut Francais de recherché pour L'Exploitation de la mer
IPF	Instrument Processing Facility
IOWAGA	Integrated Ocean Waves for Geophysical and Other Application: 3 year programme
J2	Jason-2: Radar Altimeter satellite mission, part of the JASON series
LRM	Low Rate Mode.
LUT	Look Up Table
MLE	Maximum Likelihood Estimator
MSS	Mean Sea Surface
MWR	Microwave Radiometer
NOC	National Oceanography Centre
NTC	Non Time Critical
PDGS	Payload Data Ground Segment
PLRM	Pseudo Low Resolution Mode
PVP	Product Validation Plan
PVR	Product Validation Report
PTR	Point Target Response
RADS	Radar Altimeter Database System (provided and managed by TU Delft)
RDSAR	ReDuced SAR processing. Processing to produce LRM equivalent product from SAR mode altimeter data.
RMS	Root Mean Square
ROI	Region(s) of Interest
RSS	Remote Sensing Systems
SAMOSA	Theoretically derived, physically based, SAR altimeter Echo Waveform model.
SAR(M)	Synthetic Aperture Radar (Mode)
SCOOP	SAR Altimetry Coastal and Open Ocean Performance
SEOM	Scientific Exploitation of Operational Missions (element of ESA Earth Observation Envelope Programme 4)
Sigma0, $\sigma 0$	Surface radar backscatter at nadir incidence
SI-MWR	Scanning Imaging Microwave Radiometers
SLA	Sea Level Anomaly
SL-CCI	Sea Level – Climate Change Initiative
SNR	Signal to Noise Ratio

SoW	Statement of Work
SSH	Sea Surface Height
SSM/I(S)	Special Sensor Microwave Imager (Sounder)
Std (STDD)	Standard Deviation
SWH	Significant Wave Height
S3	Sentinel-3
S3 GPP	Sentinel-3 Ground Prototype Processor
TALES	TU-Darmstadt Adaptive Leading Edge Sub-waveform retracker
TCWV	Total Column Water Vapour
TDS	Test Data Set
TUDaBo	TU-Darmstadt Bonn RDSAR/SAR processing
USSH	Uncorrected Sea Surface Height (i.e. altitude minus range)
WPD	Wet Path Delay
WTC	Wet Troposphere Correction
ZHD	Zenith Hydrostatic Delay
ZWD	Zenith Wet Delay
ZTD	Zenith Total Delay
ZP2	Zero Padding in Range 2

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