SCOOP

SAR Altimetry Coastal and Open Ocean Performance

Requirements Baseline (RB)
D1.2

Sentinel 3 For Science – SAR Altimetry Studies
SEOM Study 2. Coastal Zone and Open Ocean Study
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Table of Contents

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1 Introduction

1.1 Rationale and scope of this document

This is the **Requirements Baseline** (RB) report for SCOOP and represents the deliverable D1.2 of the project.

This document aims at reviewing the requirements for altimetric products in the open ocean and coastal zone and at identifying the products that can be provided by SAR altimetry, inclusive of L1b research products (both stacked and multi-looked waveforms over homogeneous and non-homogenous targets), as well as the models necessary for the processing. Starting from previous surveys to establish user requirements for ocean and coastal altimetry carried out within the PISTACH, COASTALT, CP4O and Sea Level CCI Projects, the target is to derive an updated analysis of the main needs and characterize limitations and drawbacks of products and models already available, as well as to gather all the scientific algorithmic requirements to fulfil the assigned SCOOP study tasks.

We also define which input data classes (FBR, L1, L1B, etc.) are necessary to achieve the SCOOP study objectives, to be passed to WP2000 for extension, consolidation and data procurements.

1.2 Review of past user consultations

1.2.1 PISTACH and COASTALT consultations

During the initial phase of the PISTACH and COASTALT projects in 2007-2008, both projects carried out surveys to gather user requirements relevant to development and applications of coastal altimetry. Despite some differences (due to the different sensor focus of the two projects: PISTACH was focusing on Jason-2 and COASTALT on Envisat), the two surveys had several questions in common. The joint results were presented in Dufau et al., 2011, including a comprehensive list of requirements for coastal altimetry products. Although Dufau et al.'s main focus was coastal altimetry, some of their requirements naturally propagated to SAR altimetry, as some of the needs of coastal altimetry (specific processing and optimized correction, exploitation of high resolution along-track data) are shared by typical SAR altimetry too. We list here a selection of Dufau et al.'s (2011) requirements that are of relevance to SCOOP. Products should:

- Be provided along-track (even though a large number of respondents also asked for 2D-gridded products)
- Be provided at the maximum posting rate compatible with an acceptable signal
- Provide not only the SSH, but also anomaly and mean value, and a coastal mean dynamic topography (MDT).
- Be provided with individual corrections (HF dynamics, for example) to ease its use in synergy with 2D and 3D models. Each user would then be able to apply the best combination of correction for its study.
- Include not only sea surface height, but also significant wave height and wind speed.
- Be in netCDF format.
- Include data as close to the coast as possible, even when none of the main estimated parameters are considered reliable.
- Put in place all those improvements in corrections (including local corrections) and retracking so that accuracy and precision are optimized.

- Provide the users with an error budget and clear documentation on the characteristics and limitations of the products.
- Provide quality flags.
- Present continuity with the altimeter products provided over open ocean [this is particularly relevant to data from CryoSat-2, and translates into continuity of parameters at the boundary between SAR and LRM zones]

1.2.2 CP4O Scientific Requirements Consolidation

Within Work Package 1000 (WP 1000) of the CryoSat Plus for Oceans (CP4O) project, specific work was carried out under the lead of Starlab in order to consolidate the baseline scientific requirements for satellite altimetry. The resulting document (Clarizia et al., 2013) analysed the results from a user consultation undertaken with key institutions and merged these results with those derived from the COASTALT and PISTACH user surveys described above (1.2.1). It then used these results together with previous literature and main outcomes from recent workshops and meetings, to characterize the limitations and drawbacks of existing altimetric products, and defined a list of scientific and operational requirements under the four main scientific themes addressed by CP4O, i.e. Open Ocean; Coastal Zone; Polar Ocean and Sea Floor Bathymetry, and in terms of data format, delivery and latency.

Limitation of space precludes the inclusion of all the requirements from Clarizia et al., (2013) in this document, though it is worthwhile to note some key general recommendations;

SAR Retracking methods:

- Optimal and computationally efficient SAR altimeter waveform retracking methods need to be defined, and the quality of SAR altimeter L1B multi-looked waveforms needs to be assessed.
- Investigations on how to improve the capability of SAR altimeters (i.e. in low sea state conditions) are needed.
- Studies on the impact of other factors like swell direction and mispointing need to be addressed.
- The inter-calibration (or absolute calibration) of the different open ocean retrackers (i.e. conventional Brown retrackers, SAR retrackers, pseudo-LRM retrackers) should be addressed to guarantee continuity and consistency of results.

Surface Backscatter Coefficient and Sea State Bias: A proper derivation of Sigma-0 (σ^0) and wind speed is necessary to derive a SSB correction, and there is a need for an increase of the amount of SAR mode data, which is currently insufficient to apply the standard methods to develop SSB models (e.g. non-parametric method).

Coastal Zone Processing:

- Further studies are needed to improve the wet tropospheric correction (WTC) in coastal areas.
- Further development of retracking techniques in coastal areas is needed. Dedicated coastal retrackers might have to be developed for SAR altimetry data in the coastal zone (as for conventional coastal altimetry).
- The impact of ground-track orientation with respect to the coast should be addressed.
- Some new quality flags and auxiliary data specific to SAR/SARIn in coastal zone need to be developed (e.g. a coastal proximity parameter for SAR mode, a cross-track angle for SARIn, the land fraction in SAR footprint, the misfit etc.).
- Identification of the most crucial and urgent atmospheric corrections for SAR altimetry to improve the performances in coastal areas. Development of atmospheric corrections for Cryosat-2 data in coastal areas (e.g. as a combination of existing radiometer data and models).

Improvements in data and formats are needed: Data need to be reliable, bug-free, and products need to be upgraded more often. Data formats need to be standardized and uniform, with practical structures.

Documentation of SAR data processing: Public documentation for all stages of the SAR data processing should be provided for the benefit of the users. This should include clear information about how the SAR data are focused, stacked and retracked.

Provision of full archive of SAR FBR and/or stack data in critical areas: This should allow final scientific users to derive specially tailored applications especially in critical areas, such as coastal zones, and in-land waters.

1.2.3 Sea Level CCI requirements

For completeness it is appropriate to cite the requirements for monitoring of global and regional Sea Level from the work carried out in the Sea Level Climate Change Initiative (CCI), described in Larnicol et al. (2014). The analysis consolidated the requirements coming from recent international frameworks, the Ocean Topography community, and to some extent from the Climate Modelling Group (CMUG) of the CCI as well as past user requirements surveys.

The requirements in Larnicol et al. (2014) refer to the Sea Level Essential Climate Variable (ECV) and are quantified in terms of accuracy and stability, and summarized in their table 5.1 which is reproduced below.

Variable/paramer	Requirement number	Horizontal resolution	Temporal resolution	Accuracy	Stability
Global Mean sea level	UR-SLCCI-SPC-01	Global mean	NA	2-4 mm over an orbital cycle[1]	Long term drift <0.3 mm/y Annual time scale <0.5 mm/y over 12 months
Regional sea level	UR-SLCCI-GEN-02	25-50 km	week	1 cm over a grid mesh of 50-100 km	<1 mm/y over a grid mesh of 50-100 km
Mesoscale[2]	UR-SLCCI-GEN-05	15 km	daily	0.5 cm	No strong requirements
Coastal (local)	UR-SLCCI-GEN-05	15 km	monthly	1.0 cm	Long term drift <1.0 mm/y Annual time scale <1.0 mm/y over 12 months
Global Coastal	UR-SLCCI-GEN-05	Global coastal mean	monthly	1.0 cm	Long term drift <0.4 mm/y Annual time scale <0.5 mm/y over 12 months

Table 1 – Synthesis of the sea level monitoring requirements gathered by the sea level CCI project (table 5-1 of Larnicol et al., 2014),

[1] Individual global mean sea level values are obtained by geographically averaging sea surface heights measured over the ocean during an orbital cycle (the period needed to cover the whole oceanic domain – 10 days for Topex and Jason satellites; 35 days for ERS and Envisat). To reach the stated accuracy, individual sea surface height measurements must be accurate to 1-2 cm.

[2] Requirement for smallest signal to be sampled.

The CCI requirements are a useful reference for the climate application of SAR altimetry data. They are already applicable to data from CryoSat-2 over those regions that have been in SAR mode for a number of years allowing the derivation of ECV indicators (trends plus amplitudes and phases of the periodic signals).

The CCI requirements are not yet relevant to SCOOP for Sentinel-3 (except for the 0.5 cm accuracy for the measurements of the mesoscale) but they will be relevant in the future: when long time series (of at least 1 or 2 years or more) will have been acquired by Sentinel-3 those requirements should be satisfied for this mission to contribute successfully to the monitoring of the Sea Level ECV, globally and regionally.

The essential climate variable is now at version 1.1 including data from Topex-Poseidon, GFO, Jason 1 & 2, ERS 1 & 2 and Envisat missions. Version 2.0 (release planned in late 2016) will include data from CryoSat-2 and SARAL / AltiKa. In the future, data from Jason-3 and Sentinel-3 will be included. Further information regarding SL_cci ECV products can be found in the SLCCI D4.1 Product Validation and Inter-comparison Report.

2 Requirements on input SAR Altimeter input data streams

This section is a summary of the input data detailed in the SCOOP Source Data Requirements document (Ash, 2016), and also lists the Regions of interest for the SCOOP project.

2.1 Requirements on data from CryoSat-2

The data required are **Cryosat-2 Calibrated Full Bit Rate, Baseline C**, plus any consolidated L1b and L2 SAR and RDSAR products; these include the official CryoSat-2 products, along with the Geophysical Ocean Products (to be used as a reference), and data from improved processors such as the G-POD CryoSat-2 SAR Service (SARvatore) and from previous projects such as CP4O.

Identifier	Description	Source
SCOOP-INP-1	The expected input data are CryoSat-2 SAR FBR data, consolidated available L1b and L2 SAR and RDSAR data products	SOW R-3 SOW R-11 SOW R-18

2.1.1 Regions of interest

Regions are indicated in the map below, with yellow stars indicating open ocean areas and orange stars indicating coastal areas (note the Northeast Atlantic and Agulhas regions are assigned to both):

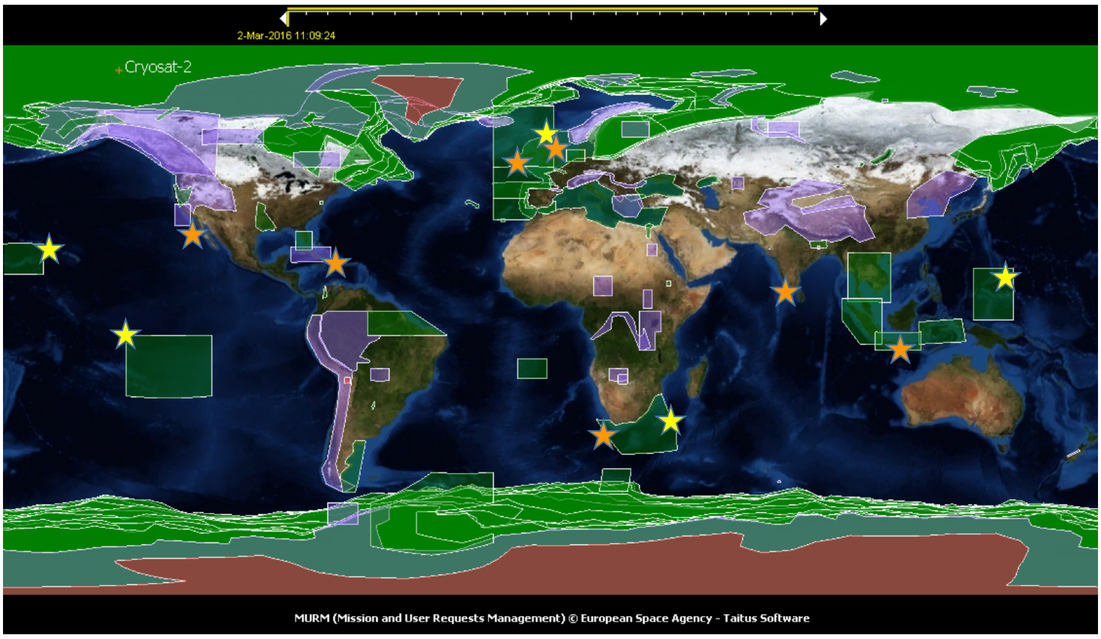


Figure 1 – CryoSat-2 mode mask v3.8, with the SAR mode areas selected as Regions of Interest (RoIs) in SCOOP marked with a star. Yellow stars indicate open ocean RoIs, orange stars indicate coastal RoIs

Regions of interest are summarised in the following table, including SAR mode mask names and project partner(s) who has requested the region:

Project label	Mask name(s)	Location	Requested by
ROI_01	CP4O_002	West Pacific	isardSAT
ROI_02	CP4O_003	Central Pacific	isardSAT
ROI_03	SAR_Pico_00	East Pacific	CLS
ROI_04	AN6524_1, AN6524_5, AN6524_6	Northeast Atlantic	CLS, NOC, Starlab
ROI_05	AN6524_4	North Sea	UBonn
ROI_06	Agulhas	Agulhas	CLS
ROI_07	CP4O_01	Cuba	isardSAT

ROI_08	**ESurge_1**	**North Indian Coast**	**NOC, UBonn**
ROI_09	**AN6531_4**	**Indonesia**	**NOC**
ROI_10	**Harvest**	**California**	**Noveltis**

Table 2 – Region of interest for SCOOP

The precise coordinates of the geographical boxes for each ROI are given in the Source Data Requirements (Ash 2016).

2.2 Requirements for data from Sentinel-3

2.2.1 Data from Sentinel-3 simulator

In the SCOOP SoW it was suggested that SAR investigations would also be based on Sentinel-3 simulated test data set (L1b) generated by SPS, as at the time of writing the proposal the launch of Sentinel-3 was one year away. As the start of the actual contract has been delayed and the satellite is now operative, it seems appropriate to use real Sentinel-3 data instead of the simulated data so **we suggest to de-scope the use of simulated S-3 data in favour of real data.**

It is recommended that a selection from the Test Data Set generated from Cryosat FBR data, processed “à la Sentinel-3, is compared to “real” Sentinel-3 data, in order to identify any key differences between the two data sets

2.2.2 Sentinel-3 data

The data required are Sentinel-3 L1A (complex echoes that have been sorted, calibrated and with geolocation information), in substitution of data from the Sentinel-3 simulator.

Identifier	Description	Source
SCOOP-INP-2	The expected input data are Sentinel-3 L1A data (complex echoes that have been sorted, calibrated and with geolocation information), in substitution of data from the Sentinel-3 simulator	SOW R-3 SOW R-12 SOW R-19

3 Requirements on Processing Algorithms

3.1 Delay-Doppler Processing (L1A-L1B)

3.1.1 Scientific Justification for SCOOP objectives

Taking into account the user requirements defined in §1.2 and the objectives of this Sentinel-3 study specified in the ESA Statement of Work for this project (ESA, 2014) dedicated Delay-Doppler processing (DDP) needs to be implemented and validated. This requires a specific processing scheme for coastal altimetry since there is no ad-hoc processor for Sentinel-3; while for Open Ocean, the existing processing baselines can be further improved/updated with innovative methods that could lead to a better performance. This is in line with the main objective of this SEOM study, such that an improved retrieval of the SSH, SWH and U10 over the open ocean and especially in the coastal regions is achieved with Sentinel-3 baseline.

In this sense, and to fulfil the scientific objectives of the Sentinel-3 study-2, which are to characterise the expected performance of Sentinel-3 SRAL SAR mode altimeter products over the open ocean and coastal zone, and then to develop and evaluate enhancements to the processing baseline, a set of requirements at DDP level have been established in the SOW and need to be consolidated in the framework of the SCOOP project. A detailed compilation of the SOW requirements related to the DDP can be found in section 3.1.2.1

In order to conform to the main objective of this SEOM study, and for this first level of data processing, the DDP shall be optimised to the specific surface characteristics (Open Ocean/coastal zones). A number of improvements have been identified that can be beneficial for the particular characteristics of open ocean and especially for the challenging coastal scenario. These algorithmic upgrades are defined in section 3.1.2.2. Most of these improvements can be incorporated in the delay Doppler processing thanks to the change of the reference from the satellite to the surface, so that the algorithms and corrections are computed and applied from the surface point of view. Most of the improvements/options have already been specified, implemented and verified in the Sentinel-6 Poseidon-4 Ground Prototype Processor, developed by isardSAT under an ESA/ESTEC contract.

On top of the overall increased performance achievable by the new algorithms described in section 3.1.2.2 the new DDP will allow:

• focusing the beams to particular points such that an improved surface sampling in coastal regions is obtained (getting closer to the coast).

• cleaning the beams with no useful information such as ambiguities, contamination, aliasing, etc.

The SCOOP Algorithm Theoretical Basis Document (ATBD) will describe the processing that is implemented (Cotton et al, 2016).

3.1.2 Requirements

- To validate the expected state-of-the-art performance of Sentinel-3, exploiting the current Sentinel-3 DDP baseline, simulated Sentinel-3 data both over Open Ocean and coastal regions will be used. This is in line with the SOW requirements (SCOOP-ALG-DDP-1, SCOOP-ALG-DDP-4, SCOOP-ALG-DDP-5, SCOOP-ALG-DDP-8 and SCOOP-ALG-DDP-9)
- Assess data quality and retrieval performance for innovative/upgraded techniques using both CryoSat-2 SAR FBR products and possibly simulated data. This is in line with the SOW requirements , (SCOOP-

ALG-DDP-2, SCOOP-ALG-DDP-3, SCOOP-ALG-DDP-4, SCOOP-ALG-DDP-6, SCOOP-ALG-DDP-7, SCOOP-ALG-DDP-8, SCOOP-ALG-DDP-9 and SCOOP-ALG-DDP-10) and with the new requirement SCOOP-ALG-DDP-11.

3.1.2.1 Scientific requirements

Identifier	Description	Source
SCOOP-ALG-DDP-1	Characterize the expected Sentinel-3 performance on the open ocean for the Sentinel-3 processing baseline	SOW R-9
SCOOP-ALG-DDP-2	Investigation of improved/upgrade processing methods to obtain better performances for Sentinel-3 (w.r.t R-9) over open ocean	SOW R-10
SCOOP-ALG-DDP-3	SAR and RDSAR datasets built from CryoSat-2 SAR FBR products, but also including the possibility to obtain consolidated end products from the G-POD CryoSat-2 service	SOW R-11
SCOOP-ALG-DDP-4	Use available simulated Sentinel-3 test data sets or require additional simulated data sets over the open ocean	SOW R-12
SCOOP-ALG-DDP-5	Characterize expected Sentinel-3 performance in coastal zones for the Sentinel-3 processing baseline	SOW R-16
SCOOP-ALG-DDP-6	Investigation of improved/upgraded processing methods to obtain better performances for Sentinel-3 (w.r.t R-16) over coastal regions	SOW R-17
SCOOP-ALG-DDP-7	SAR and RDSAR datasets built from CryoSat-2 SAR FBR products, but possible to ask for consolidated end products from G-POD CryoSat-2 service	SOW R-18
SCOOP-ALG-DDP-8	Use available simulated Sentinel-3 test data set or require additional over coastal regions	SOW R-19
SCOOP-ALG-DDP-9	Supporting activity on land proximity and ground-track orientation influence on SAR data quality in coastal zones	SOW R-20
SCOOP-ALG-DDP-10	Supporting activity on SAR Stack data analysis and exploitation: land contamination/spurious/ambiguity masking and separation between diffusive or specular coastal waters scattering	SOW R-21
SCOOP-ALG-DDP-11	The DDP shall be able to automatically select the type of algorithm to be implemented both when generating the different surfaces and in the azimuth processing depending on the surface	NEW

	characteristics in order to optimize the related performance as per SOW R-10 and SOW R-17

3.1.2.2 Methodological requirements

In this project the DDP new capabilities that may result in improvements to both Open Ocean and coastal altimetric data will be implemented (in line with requirements SCOOP-ALG-DDP-2 and SCOOP-ALG-DDP-6). The complete list will be described and specified for each particular site that will be processed.

In the following sections the list of improvements is presented. It should be noted that most of the improvements/options listed below are already specified, implemented and verified in the Sentinel-6 Poseidon-4 Ground Prototype Processor, developed by isardSAT under an ESTEC/ESA contract.

3.1.2.2.1 Burst azimuth windowing

Before performing the azimuth FFT, the 64 pulses within a burst can be weighted. Weights can be provided in an input file, hence any weighting can be used (Boxcar, Hamming, Hanning, etc., or defined by the user). Such weighting can be used to minimize the impact of side-lobe effects in the Doppler/azimuth PTR, at the expense of a degraded along-track resolution. This weighting might be useful when operating close to the coast as high reflectivity land scattering can contaminate the signal of interest.

3.1.2.2.2 Surface focusing

The surface locations can be moved (that is, the beams steered to a different place) by the user along the ground track of the satellite, if there is special interest in focusing the beams to a particular target such as in coastal zones (coastal edges, island transitions among others), transponders, rivers, lakes, etc. Such processing option can be also exploited for the co-location of SAR data with RDSAR or LRM data. This potential method is in line with the requirement SCOOP-ALG-DDP-9.

Figure 3-1 depicts the different options over an exemplary coastal region to show its potentiality. The top plot shows the surface locations of a ground track over a coastal region, in yellow triangles.

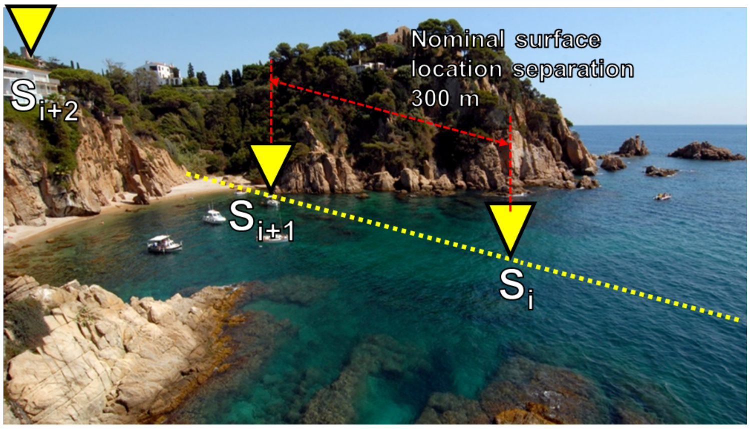
When steering the beams, the user can decide which option to choose among the available ones (by configuration). The options are:

Move (or add) only one single location (red triangle), and leave all the rest (all other locations) where they were. This is depicted in

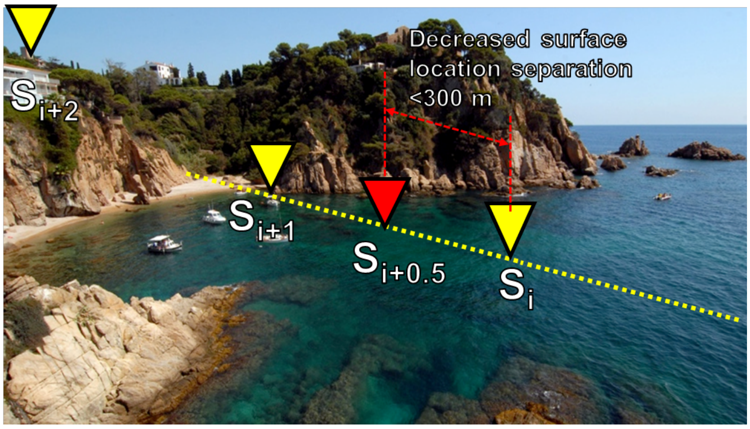
1. Figure 3-1 middle plot.

Move from one particular surface location (red triangle), all the locations coming after that selected (orange triangles) equally spaced. This is depicted in

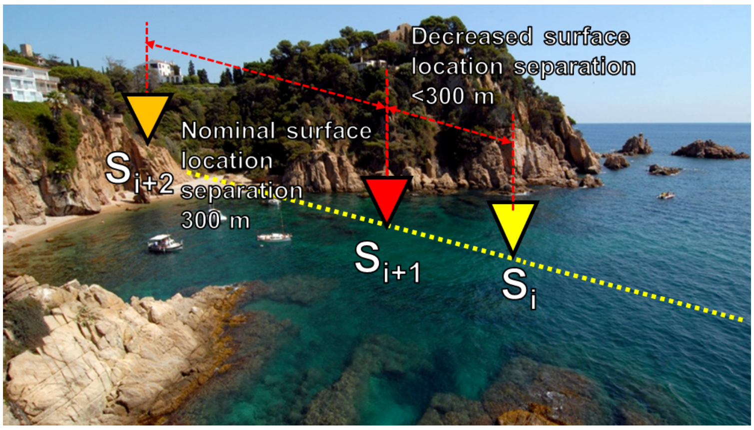
2. Figure 3-1 bottom plot.
3. Move N locations, steering them all to the ocean. The user should know that the locations steered to the ocean will not meet the minimum Doppler angle resolution, therefore some correlation will be present in the data from those locations.



With this scenario, echoes would be masked by land contamination, as the surface locations are very close to the shore



Add a new surface location in order to get less contaminated echoes



Move a specific surface to a given location as well the subsequent to keep spacing

Figure 3-1 Surface locations in a nominal case (top), and when the surface is forced (centre and bottom) to middle position. Different options can be configured: a) creating an extra surface (central plot) or b) moving the surfaces in order to match the desired location (bottom plot).

3.1.2.2.3 Azimuth processing method

Doppler beams can be generated in two different ways depending on the variability of the surface. With this flag, it is possible to choose whether the approximate or the exact method is used.

With the **approximate method**, the beams are correctly focused for low variability surfaces. One azimuth FFT for each burst is needed in order to steer all the beams. Figure 3-2 shows the beams after the approximate azimuth processing of one burst. After the central beam is steered to the surface location "b", the other beams are equally distributed to the other surface locations.

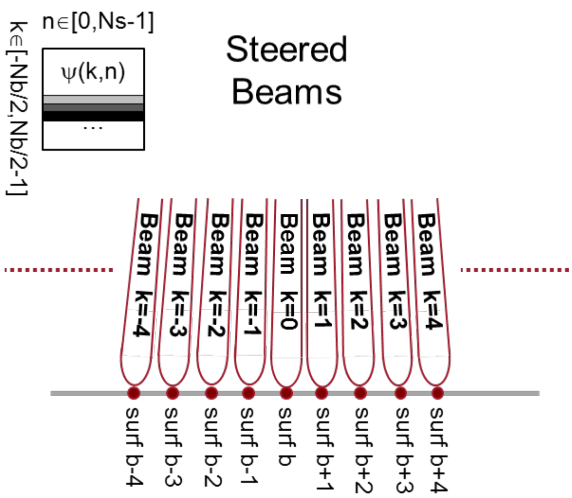


Figure 3-2 Geometry of the approximate beam-forming method.

In high variability surfaces, the approximate method can produce unevenly spaced projections on the ground. In the **Exact method**, 64 azimuth FFTs are performed for each burst and a different phase shift to each beam in order to steer them properly to the surface location. The exact approach results particularly interesting for areas with high dynamic topography variation as it can be the case of some coastal regions.

This potential method is in line with the requirement SCOOP-ALG-DDP-9.

3.1.2.2.4 Stack masking

The range and azimuth bins of the Doppler beams with no useful information such as Doppler ambiguities, land contamination, aliasing, etc., can be removed in order to have cleaner stacks. Such masking might be crucial when operating in challenging coastal regions, where land contamination can be a major impairment.

This potential method is in line with the requirement SCOOP-ALG-DDP-10.

These different options are classified as a function of the dimension they are applied to: the azimuth (or along-track) direction (i.e. the selection of a given number of central beams) and the range direction (e.g., removing contaminated samples as shown in Figure 3-3)

However, these corrections may be applied in both directions at the same time. Examples of this are land contamination removal or Doppler ambiguities removal. In the case of Sentinel-3 the impact of the ambiguities is really low since they are basically modulated through the secondary lobes of the antenna pattern in along-track. From SAR imaging theory is known that the signal in the azimuth dimension or along-track is a discretized signal, sampled at PRF and it is not effectively band-limited since the Doppler spectrum is mainly modulated by the antenna pattern (the 3dB beamwidth limits the effective Doppler bandwidth being observed). Then, depending on the PRF settings and for the considered Doppler bandwidth the Doppler ambiguities might enter through the antenna main lobe and so fold back in the fundamental Doppler band (-PRF/2 to PRF/2) or not. In the case of Sentinel-3, having an equivalent Doppler bandwidth limited by the antenna pattern around 15 KHz ($BW = \frac{2}{\lambda} \cdot v_{sat} \cdot \theta_{3dB}$) and a PRF of 17.82 KHz, the Doppler-related ambiguities end up outside the main lobe of the antenna and are down-weighted. All the beams containing residual Doppler ambiguities can still be removed, but there is an option to delete only the range samples affected by these contaminations or ambiguities for each beam of the stack.

All these options are integrated together in one single mask for each stack. This mask can be built by defining the range bins of the Doppler beams to be avoided, either theoretically or by means of an array or a predefined file.

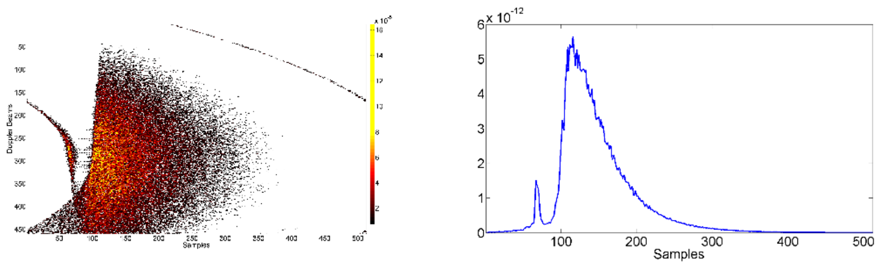


Figure 3-3 Example of Stack data (left) and corresponding L1b waveform (right) of simulated data with land contamination.

This way of cleaning the stack has already been proven to be very powerful with Sentinel-6 simulated data, significantly improving the performance. isardSAT has also used this method to clean stacks of CryoSat data in difficult geometric circumstances like coastal areas or lakes.

3.1.2.2.5 Antenna weighting

The antenna pattern is commonly being accounted for in the retracking models. However, compensating for the antenna pattern on the waveform itself has several advantages. Historically the retrackers have been analytical, implying the assumption of a Gaussian antenna pattern (e.g. Amarouche et al, 2004 for LR and Ray et al. 2015 for HR ocean retrackers). The compensation for the antenna pattern in the Level 1B waveform allows the use of a real pattern with no need for assumptions or approximations.

The **major advantage** however, is not in the compensation of the Level 1B waveform, but **at stack level: for each Doppler beam of the stack according to the pointing angle of each beam.**

This potential method is in line with the requirement SCOOP-ALG-DDP-10.

3.1.2.2.6 Multi-looking zeros method

After compensating for the geometry corrections, some samples may have suffered a wrap within the window and thus they have been set to 0. Apart from that, some other samples may have been forced to zero using the mask described above in 3.1.2.2.4.

When multi-looking the stack, all the range samples of all beams are commonly used, even the ones that have been forced to zero. Accounting for these zeros reduces the mean power on those samples, causing a waveform distortion.

With this option we can choose to sum the zeros or not. It must be noted that CryoSat baseline A, B and C do account for the zeros in the ground processing.

This potential method is in line with the requirement SCOOP-ALG-DDP-10.

3.1.2.2.7 L1B-S and L1B range oversampling factor

Due to data rate volume limitations, the range compression FFT is normally performed with a zero-padding factor of 1, or maximum 2. An FFT with a zero-padding factor is theoretically the best possible interpolation, because it uses the phase information, as it is performed with the video signals before the waveform power computation.

Zero-padding may provide improved retrievals because more samples are available for the geophysical fitting of the model. This means that the leading edge can be properly sampled, this is especially interesting for very specular returns (with low SWH) and that more samples can be available to perform a better estimation of the noise floor to be included in the retracking model.

This option gives the possibility to perform the range compression FFT with any zero-padding factor which is a power of 2, either at stack level (L1B-S) or at Level 1B level.

3.1.2.2.8 Sigma-0 computation at stack level

Historically, and up to now, Sigma-0 is computed from the Level 1B waveform in two steps:

- Retracking the waveform to retrieve Pu (or Amplitude)
- Applying a so-called Sigma-0 scaling factor derived from the radar equation and that contains all the factors, instrumental and geometrical, to be applied to Pu to retrieve Sigma-0.

Currently in all altimetry DDPs, the information on the Sigma-0 scaling factor provided at Level 1B is the one that is applied to the Level 1B waveforms. This simple method needs and has been revised in the Delay-Doppler processing (or SAR altimetry).

isardSAT has developed an in-house dedicated method to calculate the Sigma-0 scaling factor needed for the computation of the final Sigma-0 after retracking, that is based on the knowledge of the stack (L1B-S) data. This is particularly interesting over topography changing surfaces that may be found in coastal zones.

This potential method is in line with the requirement SCOOP-ALG-DDP-10

3.1.2.3 Implementation requirements

SCOOP-ALG-DDP-12	Select, apply and enforce a well-known coding standard (in line with SCOOP`-ALG-DDP-18)	SOW R-26
SCOOP-ALG-DDP-13	Early visibility on all developed scientific source codes to the ESA Technical Officer	SOW R-27
SCOOP-ALG-DDP-14	The selected algorithm/method shall be described in detail in the corresponding	SOW R-28

	section of the ATBD document	
SCOOP-ALG-DDP-15	Implementation of the processing algorithms defined in ATBD (as an evolutionary prototype)	SOW MR-12
SCOOP-ALG-DDP-16	Set up and operate an SPMT to trace the software anomalies/issues	SOW MR-19
SCOOP-ALG-DDP-17	Update the ATBD with the findings from the project	SOW MR-24
SCOOP-ALG-DDP-18	EO Science team should implement the scientific algorithms using evolutionary prototyping	SOW MR-44
SCOOP-ALG-DDP-19	Prototype software developed in well-known coding and software management	SOW R-80
SCOOP-ALG-DDP-20	Prototype software delivered in source code and executable formats with compilation and installation instructions + manual user	SOW R-81
SCOOP-ALG-DDP-21	Software package delivered on electronic storage media as per ESA requirement	SOW R-82
SCOOP-ALG-DDP-22	The DDP should be able to ingest both CryoSat-2 C-FBR and Sentinel-3 L1A data formats	NEW
SCOOP-ALG-DDP-23	The DDP should be implemented in a flexible and transparent way to the user such that the different processing baselines can be easily configurable	NEW

3.1.3 Evaluation of delay-Doppler Processor

The evaluation of the stack characteristics is a key step to evaluate the performance of a DDP. These characteristics can be statistical, such as the mean, standard deviation, kurtosis and skewness of the Gaussian that fits the power profile of the stack, as well as numerical, like the alignment of the stack and its possible slope.

3.2 L1 to L2 algorithm and models

3.2.1 Processing 'a-la-CryoSat-2, Baseline C'

Research carried out in the SAMOSA and CP4O projects has resulted in a number of improvements to the L2 algorithms for SAR altimetry. Therefore it is sensible, as explicitly required by the SoW, to base the retracking of the SAR waveforms on the SAMOSA waveform model (as described in Ray et al., 2015) with the retracker configuration agreed in the frame of the CP4O project following the processing choices described in 3.1.2.2 (one particular aspect is that those beams with all-zero samples are not included in the multi-look averaging). The relatively new baseline-C calibration of the sigma0 should be adopted. We call the combination of these L1A to L1B and the to L2 processing options processing ‘a-la-CryoSat-2, Baseline C’; this should ensure the best quality of the output. The resulting data set is designed to be exactly equivalent to the current Cryosat-2 Baseline C data set, and in summary the processing entails:

- Zero padding is applied prior to FFT (so waveforms have 256 range bins);
- Hamming windowing is applied;
- Samples set to zero due to wrapping effects (geometry corrections) are not considered in the multilooking;
- The new CryoSat-2 calibrations are applied (baseline-C);
- A Look-Up Table (LUT) is applied for the selection of a variable width alpha_p of the Point Target Response (PTR) as a function of SWH.

Identifier	Description	Source
SCOOP-ALG-L2-1	Improved L2 data for the SCOOP investigation will be processed with the improvements described in the CP4O processor configuration	SOW R-10 SOW R-17

3.2.2 Processing ‘a-la-Sentinel-3’

For reference and comparison, it is prescribed in the SoW that the data should also be processed with the current baseline configuration for Sentinel-3 (which is optimized for open sea studies). We call this processing “a-la-Sentinel-3”.

This is designed to be as close to S3 processing as we can get, so in summary it entails:

- no zero padding,
- no hamming windowing
- Cryosat calibrations applied are according to the procedure for Baseline-C (Calibration values are reported in the document “CryoSat characterisation for FBR users” available at: https://wiki.services.eoportal.org/tiki-index.php?page=CryoSat+Technical+Notes)
- The stack masking designed for Sentinel-6 has been applied. This is equivalent to the approach implemented in Sentinel-3, where the geometry corrections are separated in fine and coarse shifts. The stack masking implies the creation of “all-zero” or “empty” samples beams at the edges of the Doppler stack. Such beams are excluded, i.e. not counted when it comes to multi-looked averaging, in both CryoSat-2 and Sentinel-3 processing configurations[1].

[1] The exclusion of all-zero beams was indicated by ESA according to what reported in Table 1 of Annex 2 of the SoW. In brief, a stack thresholding is applied in both S3 and CS2 baselines to discard the most outer or noisy looks. ESA also provided a “soft” reference value of 212 useful looks to be included in the multi-looking processing and the guidelines to implement a noise threshold (as detailed in the S3 DPM) to further discards noisy beams. The “soft” reference value has been roughly verified during preliminary evaluations indicating that all available information (from documents and S3 processing experts) have been correctly included

A future version of the data should evaluate the specific impact of excluding form the averaging the zero samples in the useful beams, as coded in requirement SCOOP-ALG-L2-3 below.

Identifier	Description	Source
SCOOP-ALG-L2-2	Reference L2 data for the SCOOP investigation will be processed with the baseline Sentinel-3 Delay-Doppler processing configuration. A secondary supporting activity will be run on Swell fields influence on SAR data quality (range, wave and wind) by reviewing the outcome of an EUMETSAT report making recommendations and carrying out further investigations as necessary	SOW R-9 SOW R-13 SOW R-15 SOW-R-16
SCOOP-ALG-L2-3	Data for the SCOOP investigation will also be processed with the baseline Sentinel-3 Delay-Doppler processing configuration but excluding the zero-power samples in the multi-looking	NEW

3.2.3 Specific retracking for the Coastal Zone

Further retracking schemes (for instance, sub-waveform retrackers) will be tested to see whether they bring benefits, especially in the coastal zone.

Identifier	Description	Source
SCOOP-ALG-L2-3	Several coastal retracker classes are required in order to retrack SAR L1b data in coastal zone.	SOW R-22

4 Selection of data

4.1 Selection for the Open Ocean

The key test areas for the open ocean (see Table 2 and Ash, 2016) are ROI_01 (West Pacific), ROI_02 (Central Pacific), ROI_03 (East Pacific), ROI_04 (Northeast Atlantic), and ROI_06 (Agulhas).

4.2 Selection for the Coastal zone

The key test areas for the coastal zone (see Table 2 and Ash, 2016) are ROI_04 (Northeast Atlantic), ROI_05 (North Sea), ROI_06 (Agulhas), ROI_07 (Cuba), ROI_08 (North Indian Coast), ROI_09 (Indonesia), and ROI_10 (California).

An additional requirement is for a high-resolution coastal mask. The recommendation is for the latest version of the full-resolution GSHHS database (Wessel and Smith, 1996, and regularly updated since then)

Identifier	Description	Source
SCOOP-AUX-1	A high resolution land/water mask is required	SOW R-3

4.3 Selection of Wet Troposphere products

The best possible wet tropospheric correction is needed, in particular for the investigations in the coastal zone but also for the open ocean given that CryoSat-2 does not have a microwave radiometer on-board. As detailed in the State-of-the art document (Cipollini et al., 2016) this correction is the GPD+ developed by University of Porto, based on the combined usage of third-party data (imaging radiometer, GNSS data, meteo-office models, etc.) and is itself an evolution of the GPD (Fernandes et al., 2015).

Identifier	Description	Source
SCOOP-AUX-2	An improved wet tropospheric correction is needed, based on the combined usage of third-party data .	SOW R-17

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6 List of Acronyms

AC/DC	Amplitude Compensation and Dilation Compensation
ALES	Adaptive Leading-Edge Subwaveform (a retracking algorithm)
ATBD	Algorithm Theoretical Baseline Documents
AVISO	Archiving, Validation and Interpretation of Satellite Oceanographic data
CAW	Coastal Altimetry Workshop
CCI	Climate Change Initiative
CCN	Contract Change Notice
C-FBR	Calibrated Full Bit Rate
CLS	Collecte Localisation Satellites
CNES	Centre Nationale d'Etudes Spatiales
COASTALT	ESA Project on Coastal Altimetry
CP4O	CryoSat Plus for Oceans
CPP	CryoSat Processing Prototype (CNES Processor for CryoSat)
CryoSat	ESA altimeter mission for polar ice investigations
CryoSat-2	ESA research satellite for the CryoSat mission, which was launched on 8 April 2010
DAC	Dynamic Atmospheric Correction
DComb	Data Combination
DDM	Delay-Doppler Map
DDP	Delay-Doppler Processor
DPM	Detailed Processing Model
ECV	Essential Climate Variable
EGU	European Geophysical Union
ECMWF	European Centre for Medium Range Weather Forecasting
EO	Earth Observation
Envisat	ESA Environmental Satellite
ERA	ECMWF Reanalysis
ERS-1, ERS-2	ESA Remote Sensing satellites
ESA	European Space Agency
ESRIN	ESA's European Space Research Institute
ESTEC	ESA's European Space Research and Technology Centre
eSurge	ESA project: Satellite data for the Storm Surge Community
EUMETSAT	EUropean Organisation for the Exploitation of METeorological SATellites
FBR	Full Bit Rate

FFT	Fast Fourier Transform
GIM	Global Ionosphere Maps
Globwave	ESA Project to produce and disseminate satellite wave data
GNSS	Global Navigation Satellite Systems
GPD	GNSS-derived Path Delay
G-POD	Grid-Processing On Demand (ESA on-demand processing service)
GPP	Ground Processor Prototype
GSHHS	Global Self-consistent, Hierarchical, High-resolution Geography Database; a high-resolution shoreline data set in the public domain.
HF	High Frequency
HR	High Resolution
IGARSS	International Geoscience and Remote Sensing Symposium
IODD	Input Output Definition Document
isardSAT	SCOOP project partner (company based in Spain, UK and Poland)
ITT	Invitation to Tender
Jason-1, Jason-2	Radar Altimeter Satellites
Jason-CS, Sentinel-6	Joint US/European Radar Altimeter Satellite mission. CS stands for Continuity of Service.
L1, L1a, L1b	(data) Level 1/1a/1b
L2	(data) Level 2
LOTUS	Preparing Land and Ocean Take Up from Sentinel-3 (EU Project)
LR	Low Resolution
LRM	Low Resolution Mode
LSE	Least Squares Estimation
LUT	Look Up Table
MDT	Mean Dynamic Topography
MLE	Maximum Likelihood Estimation
MOG2D	Modèle 2D d'Ondes de Gravité, a barotropic oceanic model
MSE	Mean Square Error
MSS	Mean Sea Surface
MWR	MicroWave Radiometer
MyOcean	GMES project to provide operational ocean products
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NOC	National Oceanography Centre
NOVELTIS	SCOOP Partner (Company based in France)
OA	Objective Analysis
OSTST	Ocean Surface Topography Science Team

PDS	Power Distribution in the Stack
PI	Principal Investigator
PISTACH	CNES supported project to develop Coastal Altimetry Products
PLRM	Pseudo-LRM mode
POCCD	Processing Options Configuration Control Document
PSD	Product Specification Document
PTR	Point Target Response
PVP	Product Validation Plan
PVR	Product Validation Report
RADS	Radar Altimeter Data System maintained by TU Delft.
RB	Requirements Baseline
RDSAR	Reduced resolution SAR mode data to pseudo LRM
REAPER	ESA Project to Reprocess ERS-1 and ERS-2 data
ROI	Region of Interest
SAMOSA	SAR Altimetry MOde Studies and Applications
SAR	Synthetic Aperture Radar
SARAL / AltiKa	Joint Indian / French Satellite Ka frequency altimeter mission and instrument
SARIN	SAR interferometric mode
SARM	SAR Mode
SARvatore	SAR Versatile Altimetric Toolkit for Ocean Research & Exploitation
SCOOP	SAR Altimetry Coastal and Open Ocean Performance
SEOM	Scientific Exploitation of Operational Missions
SatOC	Satellite Oceanographic Consultants
Sentinel-3	ESA Remote sensing mission in the Copernicus programme
Sigma0	Radar Backscatter at nadir
SIRAL	SAR interferometric Radar Altimeter on CryoSat-2
SLA	Sea Level Anomaly
SLCCI	Sea Level Climate Change Initiative
SOW	Statement of Work
SPMT	Software Programme Management Tool
SPS	(Sentinel-3) System Performance Simulator
SRAL	Synthetic Aperture Radar Altimeter on Sentinel-3
SSB	Sea State Bias
SSH	Sea Surface Height
SSM/I	Special Sensor Microwave / Imager
SSMIS	Special Sensor Microwave Imager / Sounder
STARLAB	SCOOP partner (company based in UK and Spain)

STSE	Support to Science Element
SVD	Single Value Decomposition
SWH	Significant Wave Height
TCWV	Total Column Water Vapour
TDS	Test Data Set
TECU	Total Electron Content Unit
TN	Technical Note
TOPEX	French / US Radar Altimeter Satellite
TUDelft	Delft University of Technology
TWLE	Total Water Level Envelope
UBonn	University of Bonn (SCOOP partner)
UCL	University College London
WP	Work Package
WTC	Wet Troposphere Correction

(end of document)