HYDROCOASTAL

SAR/SARin Radar Altimetry for Coastal Zone and Inland Water Level

Processing Options Configuration Control Document

Sentinel-3 and Cryosat SAR/SARin Radar Altimetry for Coastal Zone and Inland Water

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1 Introduction

1.1 The HYDROCOASTAL Project

The HYDROCOASTAL project is a project funded under the ESA EO Science for Society Programme, and aims to maximise the exploitation of SAR and SARin altimeter measurements in the coastal zone and inland waters, by evaluating and implementing new approaches to process SAR and SARin data from CryoSat-2, and SAR altimeter data from Sentinel-3A and Sentinel-3B.

One of the key objectives is to link together and better understand the interactions processes between river discharge and coastal sea level. Key outputs are global coastal zone and river discharge data sets, and assessments of these products in terms of their scientific impact.

1.2 Scope of this Report

This is the Processing Options Configuration Control Document (POCCD) for HYDROCOASTAL.

To enable a meaningful comparison of results and assessment of the various algorithms, it is essential that all the partners in HYDROCOASTAL use the same full set of instrumental parameters and that the various options available for the processing are clearly defined, selected and documented. The objective of this document is to achieve that aim by listing the various processing options for a task.

The POCCD is a working document to be updated during the project.

1.3 Applicable Documents

AD-01 Sentinel-3 and CryoSat SAR/SARin Radar Altimetry for COASTAL ZONE and INLAND WATER - Statement of Work, V1.0 10/01/2019 Ref: EOP-SD-SOW-2018-089

1.4 Reference Documents

RD-01 HYDROCOASTAL Technical Proposal. V1.1 28/11/2019, SatOC and HYDROCOASTAL team.

RD-02 HYDROCOASTAL Implementation Proposal. V1.1 28/11/2019, SatOC and HYDROCOASTAL team.

RD-03 HYDROCOASTAL Management Proposal. V1.3 26/11/2019, SatOC and HYDROCOASTAL team

RD-04 HYDROCOASTAL Financial Proposal. V1.2 28/11/2019, SatOC and HYDROCOASTAL team

RD-05 HYDROCOASTAL Contractual Proposal. V 1.2 26/11/2019, SatOC and HYDROCOASTAL team

RD-06 HYDROCOASTAL Deliverable 1.3 ATBD (Algorithm Theoretical Basis Document). V1.1 08/10/2020, isardSAT and HYDROCOASTAL team.

RD-07 HYDROCOASTAL Deliverable 2.3 PSD (Product Specification Document). V1.1 08/10/2020, isardSAT and HYDROCOASTAL team.

1.5 Document Organisation

After this introductory section, section 2 provides an overview of the relevant processing stages and different approaches considered, following a similar order as in the ATBD [RD-06]. For each algorithm, eventual procedure options and parameters are introduced and described.

2 Overview of Relevant Processing Stages and Different Approaches

2.1 TO L1B, L1B(S) (isardSAT)

2.1.1 Algorithm Overview

The main processing stages of the Doppler-Delay processor (DDP) are:

1. Surface locations, Final burst datation and Window delay
2. Beam angles computation
3. Azimuth processing (Delay-Doppler processing + Stacking)
4. Geometry corrections
5. Range compression
6. Multi-looking
7. Scaling factor computation (sigma0 extraction)

L1B(S) waveform stacks are generated at stage (5), while L1B multi-looked waveforms are generated at stage (6). For details on the description and mathematical formulation of each of the processing stages please refer to the HYDROCOASTAL deliverable D1.3 ATBD, Section 3 [RD-06].

2.1.2 Additional Optional Processing Stages

The processing stages, which might potentially improve the performance and that can be optionally activated/deactivated using the processing configuration file, can be summarized as:

- Burst azimuth weighting: to reduce the side-lobes of the Doppler or beam PTR, minimizing the effect of possible land contamination being acquired by the side-lobes,
- Azimuth processing method: exact or approximate. It can be useful for areas with high topographic variability (close to coastal regions),
- Multi-looking with zeroes method: allows to consider or not the inclusion of zero-valued samples in the averaging,
- Zero-padding in across-track (range oversampling factor): allows the generation of a finer range bin step, which might be useful to properly sample the leading edge for very specular echoes.

For details on the description and mathematical formulation of each of these new processing algorithms please refer to the HYDROCOASTAL deliverable D1.3 ATBD, Section 3 [RD-06].

2.1.3 Processing Options Definition

The processing options and configuration parameters will be contained in a JSON file. Each parameter of this JSON file will have four fields:

- Name
- Value
- Units

- Description

The following table contains the processing options of the SAR chain:

Field Name	Description	Value / Range	Units
Waveforms correction (calibration)			
CAL2 application (CAL2_flag_cnf)	Carry out the application of the low-pass filter modulation or CAL2	0: deactivated 1: activated	flag
Application of CAL1 intra-burst (CAL1p2p_flag_cnf)	Application of the amplitude and phase intra-burst corrections	0: deactivated 1: activated	flag
Azimuth-related processing			
Burst azimuth windowing (azimuth_window_cnf)	Flag to indicate the window at burst level before performing the azimuth FFT	0: None 1: Hamming [DEFAULT] 2: Hanning	flag
Azimuth processing method (force_exact_method_cnf)	Value that forces the precision of the Delay-Doppler process	0: Approximate method 1: Exact method	flag
Range-related processing			
L1B-S and L1B range oversampling factor (zp_fact_range_cnf)	Number of zero-padding applied to the waveforms during the range compression process	1,2, 4, ..., 1024, ...	[ ]
Range window (range_window_cnf)	Flag to indicate the window in the range time domain level before performing the range FFT	0: None 1: Hamming [DEFAULT] 2: Hanning	flag
Geometry correction			
Window delay alignment (win_delay_ref_cnf)	Indicates which method to be used in the window delay alignment (reference window delay to perform geometry corrections)	0: Normal alignment[1] 1: Beam with maximum power 2: Closest to a given window delay defined by a reference height “elevation_ref_cnf” 3: First window delay in stack 4: Force to minimum window delay 5: Coastal operation[2]	flag
Reference height (elevation_ref_cnf)	Indicates the reference height used for the window delay used in the geometry corrections (option 2 of flag “win_delay_ref_cnf”)	Height in meters	m
Stack & multilooking related processing			

[1] Window delay associated to the surface, linked to the window delay of the burst right above the surface
[2] Align w.r.t window delay of the first beam/burst in stack tagged as land assuming the land/sea mask information provided in the FBR.

Multi-looking method (use_zeros_cnf)	Average through all the samples or just consider the non-0 samples	0: Only non-0 samples 1: All samples considered	flag
Zero beams removal (avoid_beams_mask_allzeros_cnf)	Flag to remove from the multilooking the beams whose all range bins are all set to zero	0: deactivated 1: activated	flag
Cryosat-like beams removal (mask_look_angles_CR2_cnf)	Flag to remove the outer beams in the stack based on a min and max look angle threshold ("mask_look_angles_CR2_max_chd" and "mask_look_angles_CR2_min_chd")	0: deactivated 1: activated	flag
Min look angle for beams removal (mask_look_angles_CR2_min_chd)	Minimum look angle below which the beams in a stack will not be considered (when beams removal a la CryoSat-2 is considered)	-0.6*180/π	rad
Max look angle for beams removal (mask_look_angles_CR2_max_chd)	Maximum look angle above which the beams in a stack will not be considered (when beams removal a la CryoSat-2 is considered)	+0.6*180/π	rad
Sentinel-3 like beams removal (avoid_noisy_beams_cnf)	Flag to remove the noisy beams in the stack following the Sentinel-3 baseline[3]	0: deactivated 1: activated	flag
Threshold factor noise (param_std_noise_thres_cnf)	Factor indicating the number of times the standard deviation of the noise used in the Sentinel-3 like beams removal	3	[ ]
Noise estimation window (noise_estimation_window)	Vector of two dimensions indicating the first and last range bin (non-zero padded) to be used for noise estimation	[12 16]	[ ]
Noise estimation method	String indicating the method used to estimate the statistics of the noise over the stack (considered in Sentinel-3 like beams removal)	Default: 'after_geom_corr': estimation of average and standard deviation performed after geometric corrections'before_geom_corr': estimation of average and standard deviation performed before geometric corrections	
Stack masking (apply_stack_mask_cnf)	Flag to apply a mask to the stack in order to delete undesired phenomena(including masking of the wrapped samples due to geometry corrections)	0: deactivated 1: activated	flag
Masking & Product & verbosity			
Geographical mask (mask_flag)	Flat to consider the application of a geographical mask to the input FBR;	0: deactivated 1: activated	flag

[3] The approach is as follows: if the noise of a beam (computed in a given set of range bins before the leading edge) is higher than the average of the noise (P_n^stack) plus a factor β of the standard deviation of the noise -σ_n^stack (both estimated in the same range bins but all over the stack), that beam is discarded, e.g.: P_n^stack + $\beta \cdot \sigma$_n^stack.

	the mask shall be contained in a kml file		
Generate L1B product (writing_L1B)	Flag to generate the L1B product in netcdf format	0: deactivated 1: activated	flag
Prompt figures (figures_visible_cnf)	Flag that prompts up per screen the potential figures (if any) that might be generated by processor		flag

2.2 Stack Processing and Re-Tracking Algorithms to L2

2.2.1 2-step Analytical retracker (isardSAT)

2.2.1.1 Algorithm Overview

The main steps included in this algorithm are:

1. Pre-processing (or waveform filtering),
2. Waveform modelling,
3. Fitting procedure,
4. Geophysical corrections.

The pre-processing stage can be understood as a two-step filtering process. The records are filtered using a water-land mask and then the window delay information is used to properly extract a cut of the waveform corresponding to the nadir water body return. The waveform modelling is in charge of generating the theoretical model of the multi-looked SAR waveform used within the fitting procedure in order to infer the different geophysical estimates (including the retracked range correction). The fitting procedure tries to converge to a solution that minimizes the error between both in a LSE basis by iteratively updating the stack model. Finally the corrections are applied.

2.2.1.2 Additional Optional Processing Stages

No additional optional processing stages that could be optionally activated/deactivated by the user have been implemented.

2.2.1.3 Processing Options Definition

The following table contains the processing options of the chain:

Field Name	Description	Value	Units
mission	Mission name	CS2,S3A,S3B	--

mode	SAR mode	SAR, SARin	--
L1proc	L1B processor being used.	ESA, ISD	--
use_zeros_cnf	Flag indicating whether to use or not the zeros in the multi-looking processing	true / false	--
ZP	Zero-padding value	1	--
window_type_a	Along-track or azimuth window type (flag values: Hamming, Hanning, or Boxcar)	Hamming, Hanning or Boxcar DEFAULT: Hamming	--
window_type_r	Across-track or range window type	Hamming, Hanning or Boxcar DEFAULT: Hamming	--
retracker_name	A string vector indicating the different retrackers to be used. One or more than one at a time can be active. For example [“THRESHOLD”, "ANALYTICAL" ,"OCOG"] will activate all of them and [“THRESHOLD”, "OCOG"] only the Threshold and the OCOG retrackers.	[“THRESHOLD”, "ANALYTICAL","OCOG"]	--
analytical_type_of_fitting	Type of fitting when using analytical retracker: options: SWH, MSS or 2-step	SWH, MSS, 2step	--
ref_sample_wd	Reference sample (zero-padded) for the window delay.	64	samples
mask_ROI_flag	Flag that activates filtering out those surfaces outside the kml mask. The mask should be created in “google earth” software as a single polygon and saved as a kml file.	true / false	--
mask_looks_flag	Flag that activates filtering those surfaces without a minimum number of beams in the stack	true / false	--
Neff_thres	Number of minimum number of beams per stack that a surface shall have in order not to be discarded from fitting (meant to be useful for the beginning and end of track)	true / false	--
wvfm_portion_selec	Flag to activate the portion selection of the waveform where to consider the fitting	true / false	--
wvfm_portion_selec_type	Type of waveform portion selection to	ref_height, ref_height,	--

	be considered: 'ref_height': using a reference height from DEM (related to some peak + window around it); 'peak_win' using the maximum peak of waveform with a window around it (wvfm_portion_selec_l_samples, wvfm_portion_selec_r_samples); 'peak_valley' using the maximum peak selecting the samples around it based on two closest valleys surrounding the peak plus a margin defined by the wvfm_portion_selec_l_samples and wvfm_portion_selec_r_samples	peak_valley,	
wvfm_portion_selec_l_samples	left samples w.r.t to position of ref. position within window (either peak or valley)	10	--
wvfm_portion_selec_r_samples	Define the minimum prominence of the peaks to be sorted out in a multipeak scenario	0	--
peak_prominence_norm	right samples w.r.t to position of ref. position within the window (either peak or valley). Currently used only with ref_height option	0.4	--
th_retracker_percentage_peak	Percentage of the peak for threshold retracker	50	%
OCOG_retracker_percentage_pow_OCOG	Percentage of OCOG power	87	%
OCOG_retracker_n1	First zero-padded sample to be used in leading edge estimation	35	--
OCOG_retracker_n2	Last zero-padded sample to be used in leading edge estimation	128	--
OCOG_retracker_offset	Offset from epoch estimation	0	--
OCOG_retracker_param_comp_method	Flag indicating which type of method used to extract OCOG parameters: 0: square of power samples (Frappart) or 1: using the power samples (Wingham)	0, 1	--
OCOG_retracker_implementation_method	Flag indicating which OCOG approach followed: 0: Using threshold-based approach computed within n1 and n2; 1: Computing Amplitude reference within limits defined by the window centered at the COG; 2: Using epoch=offset+(COG-W/2)	0, 1, 2	--
analytical_retracker_rou	Mean squared slopes (MSS) when	1e-04	

	fitting the SWH. For open ocean typical value is 1e-02, for inland waters 1e-04		
analytical_retracker_Hs	Value of the SWH when fitting the MSS	1e-03	m
analytical_retracker_power_wfm_model	Define the model approximation of power wfm whether to compute: 'simple': Pkl=Bkl*sqrt(gl)*func_f0; 'complete': Pkl=Bkl*sqrt(gl)*(func_f0+Tkl*gl*simga_s^2*func_f1)	simple or complete	--
analytical_retracker_lut_flag	Flag to activate the usage of look up tables (LUTs)	true / false	--
analytical_retracker_pre_processing	flag to activate the pre-processing stage to generate an initial seed estimation of epoch based on a threshold retracker	true / false	--
analytical_retracker_pre_processing_percent_leading_edge	Percentage of peak detect to establish the mid-point leading edge	87	%
analytical_retracker_ini_Epoch	Initial seed for epoch (zero-padded sample). Recommended to use a value from the left	35	sample
analytical_retracker_ini_Hs	Initial seed for the SWH fitting	2	m
analytical_retracker_ini_Pu	Initial seed for the amplitude fitting Pu	1	--
analytical_retracker_ini_MSS	Initial seed for MSS fitting	87	--
analytical_retracker_two_step_fitting_COR_threshold_rou	Threshold below which the second fitting on MSS is used (in the 2-step fitting)	95	--
analytical_retracker_pre_processing_percent_leading_edge	Percentage of peak detect to establish the mid-point leading edge. Number between 50 and 90. The higher the closer to the peak. 87 usually used in for Ocean	87	--
geo_corr_application_flag	Flag to activate the application of the geophysical corrections	true / false	--
force_geocorr_surf_type	Flag true: use the same group of geophysical corrections to all the records independently of the flag of the surface type (forcing the type of surface indicated in product_type_surface); false: use the geophysical corrections depending on the flag surface type included in the L1B	true / false	--

product_type_surface	Type of surface to use the geophysical corrections forced to all surfaces within track	open_ocean, sea_ice, land_ice	--
Product_type	String to indicate whether land (LAN) or water product (WAT), to be consistent with Sentinel-3 products	LAN or WAT as in the S3 products	--
write_output	Flag to write the output product (true: write product; false: omit saving L2 product)	true / false	--
output_product_format	Flag to indicate the type of output product to be generated (nc: netcdf or mat: matlab file)	nc: netcdf or mat: matlab file	--
nc_name_surface_height	string indicating the name of nc variable of output product for surface height: ssh (sea surface height) or sh (surface height)	ssh (sea surface height) or sh (surface height)	--
plot_fits_flag	Flag to generate fitting plots of waveforms	true / false	--
plot_fits_lat_range	Range of min and max latitudes of surfaces, whose fitting is plotted	[-91,91]	Degrees North
plot_fits_downsampling	Downsampling of the surfaces to be plotted: every each number of surfaces the plot is generated and saved	50 (recommended)	--
visible_figures	Flag to indicate whether the generated plots shall be prompted or displayed	true / false	--

2.2.2 Specialised SARin (Aresys)

2.2.2.1 Algorithm Overview

The main steps included in this algorithm are:

1. Pre-processing: the waveforms plus the needed ancillary information are extracted from the L1b file and the subset of waveforms to be processed is selected (i.e. only waveforms flagged as valid and as ocean are selected).
2. Waveform modelling: the semi-analytical model is called to compute the theoretical multi-looked SARin cross-product and phase difference waveforms, as function of the ancillary information associated to the current L1b waveform.
3. Fitting procedure: by iteratively updating the output of the waveform modelling, a least-square minimization approach is used to obtain an estimate of the geophysical

parameters as the set of values that allow to reduce the distance between the L1b waveforms and the output of the waveform modelling.

2.2.2.2 Additional Optional Processing Stages

No additional optional processing stages that could be optionally activated/deactivated by the user have been implemented.

2.2.2.3 Processing Options Definition

The following table contains the processing options of the chain:

Field Name	Description	Value	Units
retracking_mode	Define the retracking mode 1) retrack power waveform 2) retrack cross product waveform 3) retrack cross product and phase difference in sequence 4) retrack jointly cross product and phase difference with weights	power (P), cross product (XP), cross product and phase difference (XPPD) or cross product and phase difference weighted (XPPDweighted)	None
objective_function	Define the objective function used for minimization: 1) Weighted approach 2) phase difference with SWH_0 from cross product fit	of_weighted, of_fix_swh	None
phase_difference_mode	select processing approach for phase difference waveform (scale between 0-1, unwrap or unwrap-smooth-rewrap	scale, unwrap, unwrap-smooth-rewrap	None
phase_difference_weight	weight assigned to the phase difference waveform in the objective function	[0,1]	Unitless
cross_product_weight	weight assigned to the cross product waveform in the objective function	[0,1]	Unitless
min_coherence	Threshold value for the coherence used to define fitting mask	[0,1]	Unitless
apply_slope_correction	Add across-track surface slope to antenna bench roll angle	false/true	None

retrack_from_bin_delta	bins before retracking gate defining the begin of the fitting mask	[0,1024]	Unitless
retrack_until_bin_delta	bins after retracking gate defining the end of the fitting mask	[0,1024]	Unitless

2.2.3 MWaPP (DTU Space)

2.2.3.1 Algorithm Overview

The main stages included in this algorithm are:

1. Finding the waveforms that occur over an inland water body. This is done using the Global Surface Water Explorer land/water mask.
2. Then all waveform bins in the chosen waveforms are referenced to the same heights using interpolation and a mean of all the waveforms is found.
3. For the mean waveform, the first peak higher than 20% of the maximum power is identified.
4. For every original waveform, the peak closest to the one identified in step 3. is found.
5. The subwaveform around the peak found in step 4 is retracted using an ocog-retracker with a threshold of 80%.

2.2.3.2 Additional Optional Processing Stages

Currently, none.

2.2.3.3 Processing Options Definition

Currently, none.

2.2.4 ICC-ER Empirical Retracker (ATK)

2.2.4.1 Algorithm Overview

The main steps included in the algorithm of the “Isolate, Cleanse, Classify - Empirical Retracker” are:

1. For each Doppler beam of the Stack (current record):
    a. **Isolate** the M major peaks, in a valley-to-valley definition of the peaks that account for local noise. This is reached in three major steps:
        - all ‘raw’ peaks and valleys are detected: each peak is naturally delimited by a fore and an aft valley,

- all peaks are sorted in descending order with two options for the sorting method: sorting_method: {'peakvalue', 'v2p+p2v'} which is either the peak value or the sum of the two amplitudes around the peak (from fore valley to peak and from peak to aft valley),
- the vicinity of each of the M highest peaks ($1 < m \leq M$) is iteratively browsed, ratingfirst in the fore direction and then in the aft direction, in order to expand the peak's limits (the fore and aft valleys) by progressively integrating the small peaks ('noise') that are beyond these limits. The process ends in one direction as soon as a large enough peak is found in that direction. At each iteration the "browsed peak" with index m_B shall pass a "noise" test that involves a Noise-to-Peak ratio K_{NP} that is applied to the highest peak (m=1) to define an absolute acceptable noise threshold.

b. **Cleanse** the Stack by removing the peaks that are poping up at some beams and are absent at most others. Rather than producing a unique "clean" waveform this step produces up to M "clean" pseudo-waveforms (PWF) in SARINM and up to one PWF in SARM. Let's describe the SARINM case which is the most generic one. In order to build the pseudo-waveforms associated to the m-th peak, we build a new Stack by simply masking the initial Stack and keeping the samples that are within the valley-to-valley limits of this peak at all beams; the rest of the Stack is set to *NaN*. At any range gate, whenever a peak is not "seen" in more than a given ratio of Contributing Beams, K_{CB}, then it is ignored and the whole range gate line is set to *NaN*. At the end of the process the most powerful contiguous block of range gates is the selected extent for the m-th peak (cumsum test). All other range gates of the Stack are set to *NaN*. If the peak extent does not reach a minimum size of l_{PEmin} range gates then the peak is discarded, otherwise the PWF corresponding to the m-th peak is obtained through multi-looking. We denote M_{PWF} the number of output PWF e.g. the number of peaks among M that have passed this step. In SARM we select the first PWF e.g. the one that has its non *NaN* values starting at the lowest range gate index.

2. Process all PWF of all records as follows:

a. **Classify** the pseudo-waveform. There are two different versions of the classifier:

- SARM classifier: a simple Pulse Peakiness (PP) test is performed on the PWF with two possible classes: {Water, Non Water} and a single PP threshold KPP,
- SARINM classifier: WIP.

b. **Retrack** the selected peak(s). The retracked point is located at $K_R \in]0,1[$ of the highest peak's value on the leading edge side of the PWF (same threshold as the one used with ICE1 for SARM CS2 WF). The value of K_R depends on the *mission_id* ∈ {'cryosat2', 'sentinel3a', 'sentinel3b'} and the *altimeter_mode* ∈ {'LRM', 'SARM', 'SARINM'}. A linear interpolation is used to provide the epoch value as a floating point number of bins.

2.2.4.2 Additional Optional Processing Stages

There are no additional optional processing stages.

2.2.4.3 Processing Options Definition

The following table contains the processing options of the chain:

Field Name	Description	Value	Units
	Isolate (Stage 1a)		
max_num_peaks	The maximum number of major peaks (M) to be isolated and expanded (may be > 1, even in SARM as it controls some intermediate steps of the algorithm).	[1, floor(I/2)] where I is the num. of range gates in the input Stack or WF.	us
sorting_method	peak sorting method (see the algorithm description)	{'peakvalue', 'v2p+p2v'}	str
max_noise_to_peak_ratio	K_{NP}	]0,1[	fl
	Cleanse (Stage 1b)		
altimeter_mode	self describing	any value in {'LRM', 'SARM', 'SARINM'}	str
min_contrib_beams_ratio	K_{CB}	]0,1[	fl
min_peak_extent_rg	I_{PEmin}	[3,I] where I is the num. of range gates in the input Stack or WF.	uc
	Classify (Stage 2a)		
thresh_pp	K_{PP}	]0,1]	fl
	Retrack (Stage 2b)		
mission_id	self describing	any value in {'cryosat2', 'sentinel3a', 'sentinel3b'}	str
altimeter_mode	self describing	any value in {'LRM', 'SARM', 'SARINM'}	str
thresh_rtk	depends on both the mission_id and the altimeter_mode. The values are stored in a python dict of dict: thresh_rtk[mission_id][altimeter_mode]	]0,1[	fl

2.2.5 STARS Type (U Bonn)

2.2.5.1 Algorithm Overview

The Spatio-Temporal Altimeter Retracker for SAR altimetry (STARS) is an enhancement of the STAR retracker originally developed for low resolution mode and uses the functional waveform model Signal model Involving Numerical Convolution for SAR (SINCS) to retrack the Delay Doppler.

The main processing stages of STARS are:

1. partitioning the waveform into individual sub-waveforms
    a. generating dictionary elements
    b. constructing the conditional random field (CRF)
    c. selecting sub-waveforms based on the CRF-solution
2. retracking all individual sub-waveforms using SINCS
3. selecting final estimates for each 20 Hz position
    a. pre-processing of the point-cloud
    b. applying Density-Based Clustering of Applications with Noise (DBSCAN) and Random Sample Consensus) for line detection within point-cloud (RANSAC)
    c. selecting final estimates

For details on the description and mathematical formulation of each of the processing stages, please refer to the HYDROCOASTAL deliverable D1.3 ATBD, Section 8 [RD-06].

2.2.5.2 Additional Optional Processing Stages

There are no additional optional processing stages.

2.2.5.3 Processing Options Definition

There are no processing options.

2.2.6 ALES+ for SAR (TUM)

2.2.6.1 Algorithm Overview

ALES+ SAR is based on an empirical application of the Brown-Hayne functional form that models the radar returns from the ocean to the satellite. It needs as input the multi-looked waveform produced at any L1B of choice.

The main processing stages of the ALES+ SAR retracker are:

1. Leading Edge Detection

2. Choice of Trailing Edge Slope
3. Subwaveform Retracking
4. Sea State Bias Correction

For details on the description and mathematical formulation of each of the processing stages, please refer to the HYDROCOASTAL deliverable D1.3 ATBD, Section 9 [RD-06].

2.2.6.2 Additional Optional Processing Stages

None

2.2.6.3 Processing Options Definition

None

2.2.7 Specialised COastal OPerator for SAR - SCOOP-SAR (NOC)

2.2.7.1 Algorithm Overview

SCOOP-SAR is a prototype coastal SAR waveform retracker developed by NOC in the ESA SCOOP project to retrieve more and better SAR altimeter data very close to land for the Cryosat-2 mission.

SCOOP-SAR operates on L1B(S) stack data, with input from L2 output, and uses an adaptive data-based approach for stack and waveform subsetting.

The algorithm has so far been tested only on a small number of Cryosat-2 L1B(S) products.

For details on the description and mathematical formulation of each of the processing stages please refer to the HYDROCOASTAL deliverable D1.3 ATBD, Section 10 [RD-06].

2.2.7.2 Additional Optional Processing Stages

None

2.2.7.3 Processing Options Definition

None

2.3 L2 to L3 (River Level Time Series)

There are two L3 methods described in this chapter:

- L3 river/lake level method, developed by DTU,
- L3 river level method, developed by AHL.

2.3.1 L3 River/Lake Level (DTU)

2.3.1.1 Algorithm Overview

The DTU level 3 water level time series product is contracted via a state-space time series model. The process part is a simple random walk. The error distribution in the observation part is a mixture between a Cauchy and a Normal distribution limiting the effect of erroneous measurements. The main steps in the processing is outlined below.

- Data extraction using a water mask
- Crude outlier identification
- Preparation of data input format
- Estimation of Water level time series
- Constructing output file

For details the algorithm is specified in HYDROCOASTAL deliverable D1.3 ATBD, Section 6 [RD-06] and the data output format is specified in HYDROCOSTAL deliverable D2.3 PSD, Section 4 [RD-07].

2.3.1.2 Additional Optional Processing Stages

Currently, none

2.3.1.3 Processing Options Definition

Currently, none

2.3.2 L3 River Level (AHL)

2.3.2.1 Algorithm Overview

The AHL L3 Processor allows the generation of L3 data of river water level, from L2 retracked data, in the form of:

- **time series** of river water levels **for repeat orbit satellites**, overflying regularly the same locations over inland waters and eligible to the concept of Virtual Stations (VS).
- **space-time series** of river water levels **for non-repeat orbit satellites**, not overflying regularly the same locations over inland waters, but regularly the same waterbody/region in different locations, not eligible to the concept of Virtual Stations (VS).

For each retracker, the L3 data contain one and only one Water Level (WL) measurement per overflight of the satellite over the waterbody (cf. OPO Reduction). The algorithm has been designed to scale fluently from the processing of the TDS up to the GVP (i.e., global scale).

2.3.2.2 Additional Optional Processing Stages

Currently, none.

2.3.2.3 Processing Options Definition

The processing options and configuration parameters will be contained in a JSON file. Each parameter of this JSON file will have four fields:

- Name
- Value
- Units
- Description

The following table contains the processing options of the L3 River Processor:

Field Name	**Description**	**Value**	**Units**
L2WM to L3 stage			
flag_water_mask_dataset	Defines the water mask dataset in use.	1: SWBD 2: GSW	none
flag_process_as_repeat_orbit	When set to true, process data as repeat orbit data. Process data as non-repeat orbit data otherwise.	True or False	none

2.4 L3 to L4 (River Discharge)

There are four L4 methods described in this chapter:

1. Rating Curves method, developed by NUIM.
2. Bjerklie equation method, developed by NUIM.
3. Manning approach method, developed by NUIM.
4. Merging method, developed by CNR.

2.4.1 Rating Curves method (NUIM)

2.4.1.1 Algorithm Overview

The algorithm is based on the establishing of the empirical relation between L3 water level (H) and in situ river discharge (Q) simultaneously measured at nearest gauging station. The processing steps include:

1. L3 water level time series separation by hydrological phases (flood rise, flood recession, low level period, ice presence etc) to account for potential hysteresis between the rising and falling flood limbs and the ice effect (if relevant).
2. Fitting H-Q equations (unique or specific for each hydrological phase) by least-square minimization approach.

2.4.1.2 Additional Optional Processing Stages

1. Use of unique or phase specific rating curves

2.4.1.3 Processing Options Definition

The following table contains the processing options of the chain:

Field Name	Description	Value	Units
flagNbRC	Number of the rating curves to apply	[1,2,3]	none
q_insitu	Vector of in situ discharge	[0-400000]	m^3/s
time_insitu	Matrix of the time corresponding to q_insitu: [YYY, MM, DD]	[0-2030]	none

2.4.2 Bjerklie equation method (NUIM)

2.4.2.1 Algorithm Overview

The algorithm is based on the use of the empirical formula relating the river discharge (Q) to the river depth (D) corrected on L3 water level (H), the L4 water slope and the river width (B). The processing steps include:

1. Updating the look up table with the river depth (D0) at minimal H taken from auxiliary databases.
2. River depth correction for water level changes
3. Fitting the B-H equation by least-square minimization approach.
4. River width estimation using B-H equation.

2.4.2.2 Additional Optional Processing Stages

1. Calibration of the D0 using simultaneous in situ discharge

2.4.2.3 Processing Options Definition

The following table contains the processing options of the chain:

Field Name	Description	Value	Units
flag D0	Activation of calibration of the D0 if Q_{insitu} is available	[0, 1]	none
q_insitu	Vector of in situ discharge	[0-400000]	m^3/s
time_insitu	Matrix of the time corresponding to q_insitu: [YYY, MM, DD]	[0-2030]	none

2.4.3 Manning approach method (NUIM)

2.4.3.1 Algorithm Overview

The algorithm is based on the use of the Manning equation for estimation of the mean water velocity (V). This algorithm uses the water slope variable derived from the L3 altimetric water level spatio-temporal model. The discharge is calculated as the product of the velocity and river cross-section area (A). The main algorithm is applied to the bankfull flow.

1. Ice period flagging if relevant [flagIce==1 is ice presence]
2. Updating the look up table with the river depth (D0) at minimal H taken from auxiliary databases.
3. River depth (D) correction for water level changes
4. Fitting the B-H equation by least-square minimization approach.
5. River width estimation using B-H equation.
6. Flow contributing cross-section water area estimation
7. Calibration of the friction coefficient (n)

2.4.3.2 Additional Optional Processing Stages

1. Floodplain segregation and parameterization routine
2. Additional channels flow routine

2.4.3.3 Processing Options Definition

The following table contains the processing options of the chain:

Field Name	Description	Value	Units
flagD0	Activation of simultaneous calibration of the n and D0	[0, 1]	none
q_insitu	Vector of in situ discharge	[0-400000]	m^3/s
time_insitu	Matrix of the time corresponding to q_insitu: [YYY, MM, DD]	[0-2030]	none
flagFloodplain	Activation of the FloodPlain routine	[0, 1]	none
floodPlainWidth	Dynamic vector of the floodplain width corresponding to L3 water level	[0-30000]	m
floodPlainH0	Altimetric water level for the start of the floodplain inundation	[-10 - 1000]*	m

floodPlainFriction	The constant of the Manning friction coefficient for the floodplain, depending on vegetation type (from USGS lookup tables)	[0.03-0.13]	none
flagOtherChannels	Activation of the 2nd and 3d channel routine	[0, 1, 2]	none
otherChannelsWidth	Dynamic vector of the secondary channel width corresponding to L3 water level	[0-1000]	m
otherChannelsD0	Channel depth at minimal water level	[0-20]	m
otherChannelsFriction	Constant of the Manning friction coefficient (can be the same as for bankfull discharge)	[0.018-0.040]	none

* this range is not adapted for high altitude sites

2.4.4 Merging method (CNR-IRPI)

2.4.4.1 Algorithm Overview

The algorithm is based on the use of both altimetry derived water level, H, and reflectance ratio C/M extracted for the selected gauging station. The processing steps include:

1. Extraction of a box centered in the virtual station (or gauged station) for each cloud free imagery in the near infrared band of multispectral images.
2. Calibration of the location of pixel C, in a dry area and M, close to the river, and calculation of C/M reflectance ratio.
3. Calibration of the three parameters of the merging method that uses the reflectance ratio C/M and the altimetry water level time series.
4. Estimation of river discharge through the application of the merging method.

2.4.4.2 Additional Optional Processing Stages

1. The reflectance ratio product can be extracted by considering the original resolution of the images or the resampling at 3x3 pixels.
2. The multispectral images used to extract the reflectance ratio can be derived by different sensors: MODIS or OLCI or Landsat.

2.4.4.3 Processing Options Definition

The following table contains the processing options of the chain:

Field Name	Description	Value	Units
flagSensor	Multispectral sensor used to derive reflectance ratio	MODIS, OLCI, Landsat-8	none
flagPx	Resampling of the multispectral images: single (1x1) or multiple (3x3) pixel	[1,3]	none
q_insitu	Vector of in situ discharge	[0-400000]	m^3/s
time_insitu	Matrix of the time corresponding to q_insitu: [YYY, MM, DD]	[0-2030]	none

3 Tables of Instrument Parameters

3.1 Cryosat-2 Parameter Table

INSTRUMENT PARAMETERS	
Ku band frequency	13.575 GHz
Rx bandwidth	320 MHz
Rx pulse width	44.8 μs
Chirp slope sign	negative
SAR pulse repetition frequency	18181.818 Hz
Frequency sweep rate (chirp scaling factor)	350 MHz/49μs or 320Mz/44.8μs
Number of samples per pulse	128
Number of pulses in a BURST	64
Burst length	$64/PRF_{SAR}$
Burst repetition interval	0.011693825 s
PTR 3dB width	2.801e-9 s
ANTENNA PARAMETERS	
Antenna 3dB aperture used to compute the doppler model	2D elliptic sinc function: teta3dB_X = 1.095 deg teta3dB_Y = 1.22 deg
Antenna gain at boresight	42.6 dB

3.2 Sentinel-3 Parameter Table

INSTRUMENT PARAMETERS	
Ku band frequency	13.575 GHz
Rx bandwidth	320 MHz
Rx pulse width	44.8 µs
Chirp slope sign	negative
SAR pulse repetition frequency	17825.311 kHz
Frequency sweep rate (chirp scaling factor)	320MHz / 44.8µs
Number of samples per pulse	128
Number of pulses in a BURST	65 (64 Ku + 1C)
Burst length	0.814967936 s (considering the 64 Ku pulses)
Burst repetition interval	0.012733874 s
PTR 3dB width	2.819e-09 s
ANTENNA PARAMETERS	
Antenna 3dB aperture used to compute the doppler model	2D circular sinc function: teta3dB_X = 1.35 deg teta3dB_Y = 1.35 deg
Antenna gain at boresight	41.9 dB

4 List of Acronyms

ACE2 Altimeter Corrected Elevations (vers. 2)
AD Applicable Documents
AGC Automatic Gain Control
AH Alti-Hydro
AHP Alti-Hydro Product(s)
AI Action Item
AIM Action Item Management (tool)
AltiKa Altimeter in Ka band and bi-frequency radiometer instrument
AMSR-E Advanced Microwave Scanning Radiometer-Earth Observing System
ANA Agência Nacional de Águas (National Water Agency, Brazil)
AoA Angle of arrival
API Application Programming Interface
AR Acceptance Review
ASAP As Soon As Possible
ASCII American Standard Code for Information Interchange
ATBD Algorithm Technical Basis Document
ATK Along-Track S.A.S.
AVISO Archivage, Validation et Interprétation des données des Satellites Océanographiques
BIPR Background Intellectual Property Right
CASH Contribution de l'Altimetrie Spatiale à l'Hydrologie (Contribution of Space Altimetry to Hydrology)
CCN Contract Change Notice
CFI Customer Furnished Item
CLASS NOAA/Comprehensive Large Array-Data Stewardship System
CoG Centre of Gravity
CPP CryoSat-2 Processing Prototype (CNES)
CRF Conditional Random Field
CryoSat-2 Altimetry satellite for the measurement of the polar ice caps and the ice thickness
CRISTAL Copernicus polaR Ice and Snow Topography ALtimeter
CRUCIAL CRyosat-2 sUCcess over Inland wAter and Land
CSV Comma Separated Values
CTOH Centre de Topographie des Océans et de l'Hydrosphère (Centre of Topography of the Oceans and the Hydrosphere)
DAO Data Access Object
DARD Data Access Requirement Document
DBSCAN Density-Based Clustering of Applications with Noise
DDM Delay-Doppler Map
DDP Delay-Doppler Processor
DEM Digital Elevation Model
DGC Doppler Ground Cell
DPM Detailed Processing Model
DPP Data Procurement Plan
DTC Dry Tropospheric Correction
DTU Danmarks Tekniske Universitet (Technical University of Denmark)
DVT Data Validation Table
ECMWF European Centre for Medium-Range Weather Forecasts
ECSS European Cooperation for Space Standardisation
EGM Earth Gravitational Model
ENVISAT ENVIronment SATellite
EO Earth Observation
EOEP Earth Observation Enveloppe Programme
EOLi Earth Observation Link
EOLi-SA EOLi-Stand Alone
EPN EUREF Permanent Network
ERA ECMWF ReAnalysis
ESA European Space Agency
EUREF IAG Reference Frame Sub-Commission for Europe
FBR Full Bit Rate
FFT Fast Fourier Transform
FR Final Review
FTP File Transfer Protocol
FCUP (from portuguese) *"Faculdade de Ciências da Universidade"*, Science faculty of the University of Porto
GDAL Geospatial Data Abstraction Library
GDR, [I-,S-] Geophysical Data Record, [Interim-, Scientific-]
GFZ Deutsche GeoForschungsZentrum (German Research Centre for Geosciences)
GNSS Global Navigation Satellite System
GOCE Gravity field and steady-state Ocean Circulation Explorer

GPD GNSS-derived Path Delay
G-POD Grid Processing on Demand
GPT2 Global Pressure and Temperature model (vers. 2)
GPP Ground Processing Processor
GPS Global Positioning System
GRACE Gravity Recovery And Climate Experiment
GRDC Global Runoff Data Centre
GRGS Groupe de Recherche de Géodésie Spatiale (Space Geodesy Research Group)
GRLM Global Reservoir and Lake Monitor
GTN-L Global Terrestrial Network - Lakes
GVP Globally Validated Products
HDF-EOS Hierarchical Data Format - Earth Observing System
HGT A SRTM file format
HWS High Water Stage
HYCOS Hycos Hydraulics & Control Systems
HYPE Hydrological Predictions for the Environment model
IAG International Association of Geodesy
IDAN Intensity-Driven Adaptive-Neighbourhood
IE Individual Echoes
IGS International GNSS (Global Navigation Satellite Systems) Service
IM Internal Meeting (e.g. not with the client)
IODD Input Output Data Document
IPF Integrated Processing Facility
ISD isardSAT
ITRF International Terrestrial Reference Frame
IRF Impulse Response Function
Jason-1 Altimetry satellite, T/P follow-on
Jason-2 Altimetry satellite, also known as the « Ocean Surface Topography Mission » (OSTM), Jason-1 follow-on
Jason-3 Altimetry satellite, Jason-2 follow-on
Jason-CS Jason Continuity of Service
KML Keyhole Markup Language
KO Kick Off
L1A Level-1A
L1B Level-1B
L1B-S, L1BS Level-1B-S (aka, Stack data)
L2 Level-2
L3 Level-3
L4 Level-4
LAGEOS Laser Geodynamics Satellite
LEGOS (french acr.) Laboratoire d'Études en Géophysique et Océanographie Spatiale (Laboratory for Studies in Geophysics and Spatial Oceanography)
LOTUS Preparing Land and Ocean Take Up from Sentinel-3
LPS Living Planet Symposium
LRM Low Resolution Mode
LSE Least Square Estimator
LWL Lake Water Level
LWS Low Water Stage
MARS Meteorological Archival and Retrieval System
MDL Minimum Description Length
MMSE Minimum Mean Square Error
MNDWI Modification of Normalised Difference Water Index
MoM Minutes of Meeting
MPC Mission Performance Centre
MRC Mekong River Commission
MTR Mid Term Review
MSS Mean Square Slope
MSS Mean Sea Surface
MWR Microwave Radiometer
NAVATT Navigation and Attitude
NDVI Normalised Difference Vegetation Index
NDWI Normalised Difference Water Index
netCDF Network Common Data Form
NOAA National Oceanic and Atmospheric Administration
NR New Requirement (w.r.t. the SoW)
NRT Near Real-Time
NWM Numerical Weather Model
OCOG Offset Centre of Gravity
OPO One Per Overflight
OSTM Ocean Surface Topography Mission (also known as Jason-2), is also the name of the satellites series T/P, Jason-1, Jason-2 and Jason-3
OVS Orbit State Vector
PDF Probability Density Function
PEACHI Prototype for Expertise on AltiKa for Coastal, Hydrology and Ice
PEPS Sentinel Product Exploitation Platform (CNES)
PISTACH (french acr.) Prototype Innovant de Système de Traitement pour les Applications Cotières et l'Hydrologie
PMP Project Management Plan
POCCD Processing Options Configuration Control Document

PR	Progress Report
PRF	Pulse Repetition Frequency
PSD	Product Specification Document
PTR	Point Target Response
PVP	Product Validation Plan
PVR	Product Validation Report
PVS	Pseudo Virtual Station(s)
PWF	Pseudo Waveform
RADS	Radar Altimeter Database System
RANSAC	Random Sample Consensus
RB	Requirements Baseline (document)
RCMC	Range Cell Migration Curve
RCS	Radar Cross Section
RD	Reference Document
RDSAR	Reduced SAR (also known as Pseudo-LRM)
RF	Random Forest
RGB	Red, Green, Blue
RID	Review Item Discrepancy
RIP	Range Integrated Power (of the MLD) sometimes referred as Angular Power Response (APR)
RMS	Root Mean Square
ROI	(geographical) Region(s) Of Interest
RP	Report Period (a month that is being reported into a Progress Report)
RSS	Remote Sensing Systems
RWD	River Water Discharge
RWL	River Water Level
SAMOSA	SAR Altimetry MOde Studies and Applications
SARAL	In Indian "simple", in english "SAtellite for ARgos and AltiKa.
SARIn	SAR Interferometric (CryoSat-2/SIRAL mode)
SAR	Synthetic Aperture Radar
SARvatore	SAR Versatile Altimetric Toolkit for Ocean Research & Exploitation
SCOOP	SAR Altimetry Coastal & Open Ocean Performance
SDP	Software Development Plan
SEOM	Scientific Exploitation of Operational Missions
SHAPE	Sentinel-3 Hydrologic Altimetry PrototypE
SI-MWR	Scanning Imaging MWR
SME	Small and Medium-sized Enterprise
SMHI	Swedish Meteorological and Hydrological Institute
SNAP	SeNtinel Application Platform
SOA	State Of the Art
SOW	Statement Of Work
SPR	Software Problem Reporting
SPS	Sentinel-3 Surface Topography Mission System Performance Simulator
SRAL	SAR Radar Altimeter
SRTM	Shuttle Radar Topography Mission
SSB	Sea State Bias
SSMI/IS	Special Sensor Microwave Imager (SSM/I) Sounder
SSO	Single Sign-On
Stack	Matrix of stacked Doppler beams
STD	Standard Deviation
STM	Sentinel-3 Surface Topography Mission
SUM	Software User Manual
SWBD	SRTM Water Body Data
SWH	Significant Wave Height
TAI	Temps Atomique International (International Atomic Time)
TBC	To Be Confirmed
TBD	To Be Done
TCWV	Total Column Water Vapour
TDS	Test Data Set
TMI	Tropical Rainfall Measuring Mission (TRMM) Microwave Imager
TN	Technical Note
T/P	Topex/Poseidon (altimetry satellite)
TR	Technical Risk
UNESCO	United Nations Educational, Scientific and Cultural Organization
URL	Uniform Resource Locator
USGS	United States Geological Survey
USO	Ultra Stable Oscillator
UTC	Coordinated Universal Time
UWM	Updated Water Mask
VS	Virtual Station(s)
VH	Vertical-Horizontal polarisation
VV	Vertical-Vertical polarisation
WBS	Work Breakdown Structure
WF	Waveform
WFR	Water Fraction Ratio
WMO	World Meteorological Organization
WP	Work Package(s)
w.r.t.	with respect to

WTC	Wet Tropospheric Correction
XML	eXtensible Markup Language
ZP	Zero Padding