SCOOP

SAR Altimetry Coastal and Open Ocean Performance

-Processing Options Configuration Control Document (POCCD), D1.4 -

Sentinel 3 For Science – SAR Altimetry Studies

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Change Record

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29/07/16	1.1	All		Updates following ESA review
07/03/17	1.2	2		Revised to match L1B, L2 code updates
02/08/17	1.3			Revised according to the new SAMOSA code.
04/02/19	1.4	2		Update of the Doppler stack processing section and configuration options according to the final implemented/coded L1B processing chain Inclusion of section 2.2 (with algorithms overview, optional processing and their definition) related to the L2 processor implemented by isardSAT based on SAR ocean waveform retracker developed by Ray et. 2015

Control Document

Process	Name	Date
Written by:	P.D. Cotton, E.Makhoul-Varona, F. Martin, M Naeije	31/03/16
Checked by		
Approved by:		

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Cotton, Makhoul-Varona, Martin, Naeije	SatOC, isardSAT, Starlab, TU Delft	SCOOP_ESA_D1.4_POCCD

	Signature	**Date**
For SCOOP team		
For ESA		

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1 Introduction

This is the Processing Options Configuration Control Document (POCCD) report for SCOOP and represents D1.4 of the project.

To enable a meaningful comparison of results and assessment of the various algorithms, it is essential that all the partners in SCOOP 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 in the case that new findings from SCOOP, from the community, or new results coming from the S-3 prelaunch or post-launch calibration indicate that is necessary to add new processing options or update an instrumental parameter. These changes will be made upon agreement between ESA and the SCOOP manager. The POCCD allows these updates to be properly documented and propagated to all of the consortium.

2 Overview of relevant processing stages and different approaches

2.1 Doppler stack processing

2.1.1 Algorithm's 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)

For details on the description and mathematical formulation of each of the processing stages please refer to the SCOOP deliverable D1.3 ATBD.

2.1.2 Additional optional processing stages

The new 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)
- Antenna weighting: compensation of the antenna weighting due to the different observation geometry per Doppler beam
- 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 SCOOP deliverable D1.3 ATBD.

2.1.3 Delay-Doppler processing options definition

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

- Name

- Value
- Units
- Description

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

Field Name	Description	Value	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 (hamming_window_cnf)	Flag to activate or not the Hamming window at burst level before performing the azimuth FFT	0 None 1 Hamming	Flag
Azimuth processing method (force_exact_method_cnf)	Value that forces the precision of the Delay-Doppler process	0 Approximate method 1 Exact method	
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 hamming window (window_rg_cnf)	Flag to activate or not the Hamming window in the range time domain level before performing the range FFT	0 None 1 Hamming	
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	Height in meters	

[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

Field Name	Description	Value	Unit s
	corrections (option 2 of flag "win_delay_ref_cnf")		
Stack & multilooking related processing			
Antenna weighting[3] (compensate_antenna_weighting_ cnf)	Flag to compensate for the antenna pattern	0: deactivated 1: activated	flag
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
Min look angle for beams removal (mask_look_angles_CR2_max_ch d)	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)	Flat to remove the noisy beams in the stack following the Sentinel-3 baseline[4]	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	

[3] In the implemented version of the delivered code the theoretical antenna pattern on a Gaussian approximation is considered: $\exp\left(-\ln(2)\cdot\left(\frac{\theta_{look}}{\frac{\theta_{3dB}}{2}}\right)^2\right)$; only the along-track or Doppler dimension is compensated θ_{look} is the look angle and θ_{3dB} the antenna beamwidth (in the along-track dimension);

[4] The approach is as follows: if the noise of a beam (computed in a given set of range bins before the leading) 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.: $P_n^{stack} + \beta \cdot \sigma_n^{stack}$.

Field Name	Description	Value	Units
		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; the mask shall be contained in a kml file	0: deactivated 1: activated	flag
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	0: not shown 1: prompted per screen	flag

2.2 L2 processor/ SAR ocean retracker (isardSAT)

2.2.1 Algorithm’s Overview

The main processing stages of the L2 processor are:

1. Pre-processing: A first estimation of the epoch is performed, using a simple threshold-based retracker rather than using the initial guess that can be potentially provided by the user in the configuration file.
2. Waveform modelling: this processing module is in charge of generating the theoretical model of the multi-looked SAR waveform.
3. Fitting procedure: Based on the input waveform and the modelled one, the fitting procedure tries to converge to a solution that minimizes the error between both in a LSE basis by iteratively updating the multi-looked waveform (or stack model).
4. Geophysical corrections: To obtain accurate geophysical retrievals, as in L2 products, geophysical compensations are necessary to correct the impact of any environmental-dependent effects on the altimeter measurements.

For details on the description and mathematical formulation of each of the processing stages please refer to the L2 ATBD see Makhoul2018a.

2.2.2 Optional processing stages

The different processing stages that can be optionally activated/deactivated using the processing configuration file, can be summarized as:

- Threshold-based epoch estimation: initial seed for the SAR ocean retracker is estimated based on a threshold-based retracker (percentage of the waveforms peak), this will avoid finding a local minimum during the fitting routine due to the initial guess provided in the configuration file or alternatively from a previous surface estimated epoch with a significant jump in the leading edge compared to the actual surface.
- Noise floor estimation: different options can be considered, assuming a fixed window size for all the surfaces or using an adaptive window exploiting the derivative of the multi-look waveform; but also an external input estimation noise fixed for all the surfaces can be also considered. The latter will avoid consider an erroneous estimation of the noise floor (potentially degrading the fitting itself) due to the presence of land contamination in the noise related area before the leading edge of the waveform.
- Waveform model: simplified (f_0) or complete model (f_0 & f_1) of the SAR ocean single look power waveform can be also selected
- Antenna pattern compensation: to be aligned with the L1B processing option that can compensate for the antenna modulation along-track at stack level, the L2 processor doesn't model the related term when generating the emulated stack.
- Zero-padding: to be aligned with the L1B processing option that considers zero-padding in range
- Multi-looking with zeroes method: the L2 processor can include or not the zeros in the multi-looking process of the modelled stack to be aligned with the configuration used in the L1B processor .

For details on the description and mathematical formulation of each of the processing algorithms please refer to the L2 ATBD see Makhoul2018a.

2.2.3 Processing options definition

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

- Name
- Description
- Units
- Value

The following table contains the processing options of the L2 SAR ocean retracker implemented by isardSAT:

Field name	Description	Value	Units
use_zeros_cnf	Flag indicating whether to use or not the zeros in the multi-looking processing	**True**: zeros of stack used in multilooking False: zeros of stack not used in the multilooking	Flag
ZP	Zero-padding value in range [5].	**2**	count
antenna_compensation_along	Flag to indicate that the antenna pattern weighting along-track (Doppler) has been compensated in L1B processing	True: along-track antenna not modelled in the stack **False**: along-track antenna modelled in the stack	flag
window_type_a[6]	Along-track or azimuth window type (flag values: Hamming, Hanning, Boxcar, Forced or Adaptive). Indicates which is the value assumed in the sigma of the Gaussian approximating the PTR. In the Adaptive case the PTR is updated according to SWH and based on empirical expression found by Dinardo[7]	Hamming Hanning Boxcar **Forced** Adaptive	flag
window_type_r[8]	Across-track or range window type (flag values: Hamming, Hanning, Boxcar, Forced or Adaptive). Indicates which is the value assumed in the sigma of the Gaussian approximating the PTR. In the Adaptive case the PTR is updated according to SWH and based on empirical expression found by Dinardo	Hamming Hanning Boxcar **Forced** Adaptive	flag

[5] To be aligned with the zero-padding in range.

[6] The related values of the sigma of the Gaussian approximating the PTR for the different type of options in the flag are included in the characterization file defined in SCOOP IODD, issue 1.3.

[7] Please refer to Eq. 5.4-36 in the SCOOP ATBD.

[8] The related values of the sigma of the Gaussian approximating the PTR for the different type of options in the flag are included in the characterization file defined in SCOOP IODD, issue 1.3.

Field name	Description	Value	Units
retracker_name	A string vector indicating the different retrackers to be used: current option in SCOOP is only 'ANALYTICAL'	ANALYTICAL[9]	Flag
analytical_type_of_fitting	Type of fitting when using analytical retracker: current option in SCOOP is SWH	SWH[10]	Flag
ref_sample_wd	Reference sample (zero-padded) for the window delay[11]	128	Count
mask_ROI_flag	Flag that activates filtering out those surfaces outside the kml mask	True: filter only surfaces within the defined mask[12] **False**: all the surfaces in the input L1B are considered	flag
mask_looks_flag	Flag that activates filtering those surfaces without a minimum number of beams in the stack	True: filter out those surfaces whose contributing number of beams or looks to multi-looked waveform is below a given threshold **False**: no surface is filtered out depending on the number of its contributing beams or looks	flag
Neff_thres	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)	256	count

[9] Analytical refers to the physical-based SAR ocean retracker implemented by isardSAT and based on the model proposed by Ray et a. 2015.

[10] The SAR ocean retracker implemented for SCOOP considers the SWH as a fitting parameter fixing the mean-squared slopes parameter.

[11] It refers to the reference sample position for the window-delay or equivalently the on-board tracker (for CryoSat-2 data is half of the window which would be 64, but in case of zero-padding of 2 as the SCOOP processing baseline this number is 128).

[12] A kml file with a polygon defining the mask can be ingested in the processor.

Field name	Description	Value	Units
wvfm_discard_samples	Flag to discard some samples at begining and/or end of waveform	True **False**	Flag
wvfm_discard_samples_begin	Number of zero-padded samples at the beginning of waveform to be discarded	**10**	count
wvfm_discard_samples_end	Number of zero-padded samples at the end of waveform to be discarded	**10**	count
analytical_retracker_Thn_flag	Flag to account for ThN estimation	**True** False	Flag
analytical_retracker_Thn_estimation_method	Flag to indicate the type of noise estimation method being used ('external': using an external-input cnf value analytical_retracker_external_Thn_value; 'fixed_window': using a set of range bins in a given window to estimate the noise using the first sample analytical_retracker_Thn_w_first and window width analytical_retracker_Thn_w_width; 'adaptive': use an adaptive window computed based on the derivative of the waveform and a given threshold analytical_retracker_Thn_threshold_noise, which is accordingly increased by a factor analytical_retracker_factor_increase_noise_iter with a given maximum number of iterations max_iter_noise)	**external** fixed_window adaptive	Flag
analytical_retracker_external_Thn_value	External value of the noise level	**0.00245**[13]	norm
analytical_retracker_Thn_w_first	Gate number to start Thermal noise windowing; this is a zero-padded subscript indice thus must be > 0	**12**	Flag

[13] A normalized value between 0 and 1 (1 maximum of the normalized multilook power waveform). It can be estimated from a set of normalized open ocean-like waveforms .

Field name	Description	Value	Units
analytical_retracker_Thn_w_width	Thermal noise window width in zero-padded range bins	**20**	Flag
analytical_retracker_threshold_noise	threshold used to estimate the samples used in the adaptive noise window estimation based on the derivative of the window	**1e-3**	norm
analytical_retracker_factor_increase_noise_iter	factor to multiply the threshold of noise per iteration	**1.5**	count
analytical_retracker_max_iter_noise	Maximum number of iterations for adaptive noise estimation	**100**	Count
analytical_retracker_rou	Mean squared slopes (MSS) when fitting the SWH, models the surface radiation pattern alpha_sigma=1/(H_orb^2*MSS): a value of -1 indicates that no specific radiation pattern is considered in the model alpha_sigma=0. For open ocean typical value is 1e-02 for waters 1e-04	**-1:** Indicates that the alpha_sigma term is 0, and so a perfect isotropic radiation pattern is assumed	
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*sigma_s^2*func_f1)	simple **complete**	flag
analytical_retracker_lut_flag	Flag to activate the usage of look up tables (LUTs) for func_f0 and func_f1	**true** false	flag
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	flag
analytical_retracker_pre_processing_percent_leading_edge	Percentage of peak detect to establish the mid-point leading edge	**87**	count

Field name	Description	Value	Units
analytical_retracker_ini_Epoch	Initial seed for epoch (zero-padded sample)	**35**	count
analytical_retracker_ini_Hs	Initial seed for the SWH fitting	**2**	m
analytical_retracker_ini_Pu	Initial seed for the amplitude fitting Pu	**1**	
fitting_fun_type	Flag indicating the type of fitting routine to be used: 'flag': Using the lsqcurvfit function; 'fmin': using the fmin search algorithm	**lsq** fmin	flag
lsq_algorithm	Flag indicating the type of specific minimization algorithm: 'levenberg-marquardt' or 'trust-region-reflective'	levenberg-marquardt **trust-region-reflective**	
fitting_options_lb	Lower bounds in the fitting for the fitted parameters. levenberg-marquardt doesn't accept lower conditions shall be indicated as null	**[0,0,0]**[14]	[count,m,norm]
geo_corr_application_flag	Flag to activate the application of the geophysical corrections	**true** false	flag
atm_att_correction_flag	Flag to activate the atmospheric attenuation correction on sigma0[15]	**true** false	Flag
write_output	Flag to write the output product (true: write product; false: omit saving L2 product)	**True** false	Flag
plot_fits_flag	Flag to generate fitting plots of waveforms	true **false**	Flag

[14] First value refers to the epoch (in range bins), second to the SWH and third one to the normalized power.

[15] It requires to provide in the call to the processor the path containing all the nectdf maps including the atmospheric corrections for sigma0.

Field name	Description	Value	Units
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**	count
visible_figures	Flag to indicate whether the generated plots shall be prompted or displayed while executing	true **false**	flag

2.3 Echo Modelling / retracking

2.3.1 Algorithm Overview

The main processing stages of the Echo modelling / retracking are:

1. Selection of the configuration parameters.
2. Definition of the main constants.
3. Definition of the starting values for the retracker.
4. Read L1B data.
5. Computation of Doppler Beams.
6. Normalization of the Waveform.
7. Computation of the Noise.
8. Fitting the SAR Waveform.
    a. Set up a priori parameters.
    b. Simulation of the SAR Waveform.
        i. Definition and computation of main constants.
        ii. Computation of α_p as a function of SWH.
        iii. Computation of the basis functions.
        iv. Anti-Aliasing Filter.
        v. Waveform Computation.
    c. Execution of the Fitting.
    d. Results storage.

2.3.2 Additional optional processing stages

The main improvements and additional processing stages included in the echo modelling and retracking are,

- Appropriate handling of the energy distribution over the different echoes of the delay-Doppler stack.

- Constant values of the PTR Gaussian approximations width, based on the S3 IPF. Those constant values are,
  - Azimuth PTR Gaussian approximation coefficient = 0.3831
  - Range PTR Gaussian approximation coefficient = 0.513
- Complete implementation of SAMOSA-2 model (SAMOSA-3 Waveform model is a truncated version of the SAMOSA-2 waveform model).
- Thermal noise estimation, based on an empirical approach considering the range gates located before the waveform leading edge, and accounting for the leading edge position variability as a function of the SWH.

2.3.3 Echo modelling/retracking processing options definition

The main configuration parameters with its default values are,

Name	Description	Value
L1B Info	Version of the L1b data provided	-
Geodetic parameters	Semi-major (a) and semi-minor axis of the Earth in the WGS84 model	a = 6378137 b =6356752.3142 flattening coefficient = 0.003352810664747
$\boldsymbol{f_c}$	Central frequency	13.575 GHz
BW	Receiver Bandwidth	320 MHz
$\boldsymbol{\tau_p}$	Pulse length	44.8 µs
$\boldsymbol{\tau_u}$	Useful Pulse Length	44.8 µs
PRF	Pulse Repetition Frequency of SAR mode	18181.818 Hz
$\boldsymbol{N_b}$	Number of beams	64
~~$\boldsymbol{N_l}$~~[16]	~~Number of looks~~	~~212~~
$\boldsymbol{N_p}$	Number of pulses	64
$\boldsymbol{\theta_{pitch}}$	Pitch bias	0°
$\boldsymbol{\theta_{roll}}$	Roll Bias	0°
$\boldsymbol{\theta_x}$	Full along-track width of the half power	1.095°
$\boldsymbol{\theta_y}$	Across-track width of the half power	1.22°

Below are listed the main re-tracking options available in the re-tracker,

[16] N_l – Number of looks has been removed as a configuration parameter as it is now taken from L1B input file

Name	Description	Value
Starting Position	Starting waveform position for the re-tracking	0
Processing Step	Waveforms steps for the re-tracking	1
Doppler Centre	Flag indicating where the centre of the Doppler range will be set.	0: Centre is at the antenna centre. 1: Centre is at the doppler zero.
FFT Window type	Window type in the Waveform model	0: Hamming. 1: Boxcar.
LUT flag	Flag indicating if a LUT is used for computing the basis functions	0: don't use LUT. 1: use LUT. 2: don't use LUT and don't use f1*. 3: use LUT and don't use f1. 5: use LUT provided by ESA, generated from a linear combination of Bessel functions.
Coherence length	Surface coherence length (only used in sea slope pdf) $$\sigma_{slopes} = \frac{\sqrt{2}\sigma_s}{L_c}$$ Where L_c is the ocean correlation length, and σ_{slopes} refers to the seas surface slopes.	0
Flag surface slope	Flag to compute the slope of the sea surface due to elliptical earth.	0
Pu_0	Initial value of Pu used in the retracker	0.2 (current value used, however is important to consider that this value can be adapted).
Pu_limits	Limits in the Pu estimation	[0.01, 5]

Pu_step	Step in the Pu estimation	0.1
Sigma_z_0	Initial value of sigma_z used in the retracker	1 (current value used, however is important to consider that this value can be adapted).
Sgma_z_limits	Limits in the sigma_z estimation	[-0.1 10]
Sigma_z_step	Step in the Sigma_z estimation	0.5
Lag_0	Initial value of the lag (epoch) used in the retracker	30 (current value used, however is important to consider that this value can be adapted).
Lag_limits	Limits in the lag estimation	[0 50]
Lag_step	Step in the Lag estimatuon	0.2
Normalize_waveform	Flag to indicate if the waveforms should be normalize or not.	0.- No. 1-. Yes.
Min_estimation_lag	Flag to limit the window used for the fitting. In this case the first 12 first are not accounted	12
Max_estimation_lag	Flag to limit the window used for the fitting. In this case the last 12 lags are not accounted	12

*In the SAMOSA retracker, the waveforms are written as a function of basis functions, where f1 relates to the first order function term.

According to Ray et al 2012, the basis functions can be defined as,

$$f_n(\xi) = \int_0^\infty e^{-\frac{1}{2}(\xi-u^2)^2}(\xi-u^2)^n du, \tag{1}$$

If the argument $\xi \gg 1$ the integral in Eq.1 can be evaluated approximately. Letting $x = \xi - u^2$, and $du = -\frac{dx}{2\sqrt{\xi - x}}$, and assuming that the integral is only signnnificant for values of x near zero, the limits of the integral can be extended to +∞ without altering the integral significantly. Then keeping the lowest order nonzero term, the basis functions can be expressed as,

$$f_0(\xi) = \sqrt{\frac{\pi}{2\xi}}, \quad (2)$$

$$f_1(\xi) = \sqrt{\frac{\pi}{2\xi}}\frac{1}{2\xi}, \quad (3)$$

$$f_2(\xi) = \sqrt{\frac{\pi}{2\xi}}, \quad (4)$$

$$f_3(\xi) = \sqrt{\frac{\pi}{2\xi}}\frac{3}{2\xi}, \quad (5)$$

$$f_4(\xi) = \sqrt{\frac{\pi}{2\xi}}3, \quad (6)$$

In order to speed up the process, the computation of the f_n can be done by means of Lookup tables (LUTs).

The waveform in the SAMOSA retracker is computed as,

$$\mathrm{W} = \mathrm{amp}(\mathrm{t_o} + \mathrm{t_1}), \quad (7)$$

Where amp is computed as a function of the scaling parameter(g), and the antenna gain (Go), and to and t1 as a function of the skew and the basis functions, as

$$\mathrm{t_o} = \mathrm{f_o} + \left(\frac{\mathrm{skew}}{2}\right) * \mathrm{g_s}^3 * \mathrm{f_1} - \left(\frac{\mathrm{skew}}{6}\right) * \mathrm{g_s}^3 * \mathrm{f_3} \quad (8)$$

$$\mathrm{t_1} = -\left(\frac{\sigma_z}{\mathrm{L_g}}\right) * \mathrm{T_{ky}} * (\left(\frac{\mathrm{skew}}{2}\right) * (1 - \mathrm{g_s^2}) * \mathrm{g_s^2} * \mathrm{f_0} - \mathrm{g_s} * \mathrm{f_1} + \left(\frac{\mathrm{skew}}{2}\right) * (1 - 2 * \mathrm{g_s^2}) * \mathrm{g_s^2} * \mathrm{f_2} + \left(\frac{\mathrm{skew}}{6}\right) * \mathrm{g_s^4} * \mathrm{f_4}) \quad (9)$$

More details about the computation of to and t1, can be found in the ATBD document section 5.4.2.4.2.

** In an earlier version of this document, an option was available to select the doppler step (i.e. distance between Doppler bins) in order to increase the speed up processing. This option is now not available, since we are building the full stack (based on the stack mask information provided in the L1b files).

The table below shows the main configuration parameters used for the waveform fitting.

Name	Description	Value
Sigma_z limits	Limits for the sigma_z estimation	[-0,1 10] (this values can be modified)
Sigma_z Step	Step between values of the sigma_z	0.5 (this values can be modified)
Lah limits	Limits for the epoch estimation	[0 128] (this values can be modified)
Lag Step	Step between values of the epoch	0.2 (this values can be modified)
Pu limits	Limits for the Pu estimation	[0.01 0.5] (this values can be modified)
Pu Step	Step between values of the Pu	0.1 (this values can be modified)

2.4 RDSAR Processing

2.4.1 Algorithm Overview

The main processing stages of RDSAR processing are, starting with the L1A FBR product:

1. Gather 4 bursts of 64 echoes.
2. Adjust the fine range word (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 the low-pass filter correction.
10. Rescale the waveform.

2.4.2 Additional optional processing stages

No additional optional processing stages are currently envisioned within the scope of the SCOOP project. RDSAR data are to be generated to evaluate the expected performance of Sentinel-3 RDSAR products, and to compare against the various options of Delay-Doppler processing and Echo modelling.

2.4.3 RDSAR processing options definition

Below are listed the main re-tracking options available in RDSAR processing.

Name / Description	Value
Gather 4 bursts of 64 echoes	No processing Options
Adjust the FAI for each burst	No processing Options
Align the echoes horizontally	No processing Options
Align the echoes vertically	Selectable option on/off
Correct echo amplitude and phase	Retrieved from IPFDB file: CS_OPER_AUX_IPFDBA_20101111T101900_99999999T999999_0002.EEF
Zero pad the echoes	No processing Options
Perform a 1-dimensional FFT, horizontally	No processing Options
Incoherently average the individual waveforms	No processing Options
Apply the low-pass filter correction	Retrieved from IPFDB file: CS_OPER_AUX_IPFDBA_20101111T101900_99999999T999999_0002.EEF
Rescale the waveform	No processing Options
Power Conversion	Scale Factor: To be adjusted for Sentinel-3
Waveforms to Range, SWH, sigma0: MLE3 retracker	The RADS re-tracker as developed by Walter Smith from NOAA (Smith and Scharroo [2011]) allows selection of any (or all) of these parameters to be fitted: 1. Epoch, x_0 2. Width, s 3. Amplitude, A 4. Mispointing, $k(\xi^2)$, ξ is off-nadir angle 5. Noise level, N and any of these can be free parameters to be fitted, while others are held fixed
To fill the remainder of fields in the to be produced RADS RDSAR NETCDF files the RADS standard will be followed (including the 'best' and most up-to-date models and corrections) and maybe other auxiliary data can be included which has to be decided on. It is clear that when use is made of uncalibrated FBR that CAL1 and CAL2 information will be needed.	

3 Table(s) 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

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5 List of Symbols

Symbol	Definition
A	Amplitude (from altimeter waveform)
BW	Receiver Bandwidth
BRI	Burst repetition interval
f_c	Frequency, Central Frequency
$k(\xi^2)$	MIs-pointing (from altimeter waveform)
N	Noise level (from altimeter waveform)
$\boldsymbol{N_b, N_l, N_p}$	Number of beams, number of looks, number of pulses
PRF	Pulse Repetition Frequency
s	Width (from altimeter waveform)
x_0	Epoch (from altimeter waveform)
α_p	Point Target Response width
$\boldsymbol{\theta_{pitch}, \theta_{roll}}$	Pitch bias, roll bias
θ_x, θ_y	Along track and across track beam width
ξ	off-nadir angle
$\boldsymbol{\tau_p, \tau_u}$	Pulse length, useful pulse length

6 List of acronyms

ATBD	Algorithm Theoretical Baseline Documents
CAL1	Calibration Mode 1
CAL2	Calibration Mode 2
DDP	Delay Doppler Processor
ESA	European Space Agency
FAI	Fine range word
FBR	Full Bit Rate
FFT	Fast Fourier Transform
IPFDB	Instrument Processing Facility Data Base
isardSAT	isardSAT, SCOOP Partner
Ku-Band	Primary altimeter operating frequency for most satellite altimeters (13.575GHz for CryoSat-2)
L0	Level zero (instrument telemetry)
L1A	Level 1A
L1B (S)	Level 1B (Stack)
L2	Level 2
LAI	Coarse range word
LUT	Look Up Table
NetCDF	(Network common data form) – Set of software libraries and (self - describing, machine independent) data formats.
POCCD	Processing Options Configuration Document
PTR	Point Target Response
RADS	Radar Altimeter Data System (NOAA/TUDelft/EUMETSAT)
RDSAR	Reduced resolution SAR mode data (used to generate PLRM)
Rx	Receiver
RMC	Range Migration Correction
SAMOSA	SAR altimetry Mode Studies and Applications
SAR	Synthetic Aperture Radar
SatOC	Satellite Oceanographic Consultants
Sentinel-3	ESA Remote sensing mission in the Copernicus programme
Sigma0	Radar Backscatter at nadir
SNR	Signal to Noise Ration
SRAL	Synthetic Aperture Radar Altimeter on Sentinel-3
STARLAB	SCOOP Partner
SWH	Significant Wave Height
TBC	To Be Confirmed
TUDelft	Delft University of Technology
XML	EXtensibleMarkup Language
zp	zero-padding