SCOOP

SAR Altimetry Coastal and Open Ocean Performance

-Input/Output Definitions Document (IODD), D2.1 -

Sentinel 3 For Science – SAR Altimetry Studies

SEOM Study 2. Coastal Zone and Open Ocean Study

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For ESA		

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1 Introduction

1.1 Scope

The scope of this document is to describe the Input and Output Products' definitions of the three processors SCOOP project:

- The Delay Doppler Processor: Processing Cryosat-2 FBR, and Sentinel-3 SRAL L1A data to LIB_S and L1B products. (isardSAT)
- The Echo Modelling / Re-tracking processor: Processing Sentinel-3 equivalent L1B to L2. (isardSAT)
- The RDSAR Processor, Processing Cryosat-2 FBR, and Sentinel-3 SRAL L1A data to RDSAR.

1.2 Document Organisation

The rest of the document is organised into four main sections, Section 2 provides some general definitions, and then there is a section describing the inputs/outputs for each of the processors.

1.3 Acronyms

AD	Applicable Document
ATBD	Algorithm Theoretical Basis Document
CHD	Characterisation File
CNF	Configuration File
CST	Constants File
DDP	Delay-Doppler Processor
DMP	Data Management Plan
ESA	European Space Agency
FBR	Full Bit Rate
FFT	Fast Fourier Transform
HRM	High Resolution Mode
IODD	Input Output Definitions Document
ISP	Instrument Source Packet
JSON	JavaScript Object Notation (data interchange format)
L1A	Output file with geo-located bursts of Ku echoes. All calibrations are applied. Each record contains 1 SAR burst of calibrated and aligned echoes
L1B-S	Output file with fully processed and calibrated SAR complex echoes, arranged in stacks after slant range correction and prior to echo multi-look.
L1B	Output file with fully calibrated pulse limited power echoes for LRM and fully calibrated multi-looked power echoes (SAR)
LRM	Low Rate Mode
LUT	Look Up Table
NetCDF	(Network common data form) – Set of software libraries and (self -describing, machine independent) data formats.
PLRM	Pseudo-LRM
POCCD	Processing Options Configuration Control Document
PSD	Product Specification Document
Pu	Waveform Power
PTR	Point Target Response
RADS	Radar Altimeter Database System (NOAA/EUMETSAT/TUDelft altimeter data base)
RD	Reference Document
RDSAR	Reduced SAR Product
ROI	Region Of Interest
SAR	Synthetic Aperture Radar
SAMOSA	SAR altimetry Mode Studies and Applications. ESA project and SAR Altimeter Waveform model
SCOOP	**S**AR Altimetry **C**oastal & **O**pen **O**cean **P**erformance Exploitation and Roadmap Study
Sentinel-3	ESA Remote Sensing mission in the Copernicus programme
SEOM	Scientific Exploitation of Operational Missions (element of ESA Earth Observation Envelope Programme 4)
Sigma-0	Surface Radar Backscatter at Nadir Incidence
SRAL	SAR model altimeter on Sentinel-3 satellite
SSB	Sea State Bias
SSH	Sea Surface Height
SWH	Significant Wave Height
USO	Ultra Stable Oscillator

1.4 References

1.4.1 Applicable Documents

AD. 1 **SCOOP – S**AR Altimetry **C**oastal & **O**pen **O**cean **P**erformance Exploitation and Roadmap Study. Sentinel 3 For Science – SAR Altimetry Studies Study 2 – Coastal Zone and Open Ocean Study. Proposal, January 2015.

AD. 2 SCOOP. Algorithm Theoretical Baseline Document (ATBD)- WP1000. SCOOP_D1.3_ATBD, issue 1.0, 2016/03/16.

AD. 3 SCOOP- isardSAT. Level-1B data sets: Volume Estimation- WP2000, ref. ISARD_ESA_SCOOP_REP_377, issue 1.b, 11th January 2016.

AD. 4 SCOOP. Processing options Configuration Control Document (POCCD)- WP1000. SCOOP_D1.4_POCCD, issue 1.0, 2016/03/16.

AD. 5 SCOOP. Product specification document (PSD): Level-1B/1B-S - WP3000. SCOOP_D2.3_PSD, issue 1.a, 2016/06/03.

AD.6 Makhoul-Varona, E., SAR Level-2: Algorithms Technical Baseline Document (ATBD), issue 1.a, 04 February 2019.

AD. 6 Makhoul-Varona, E., Escola, R., Product Specification Document: Level-2, issue 2.a, 12 November 2018.

1.4.2 Reference Documents

RD- 1 EUMETSAT/ESA. Sentinel-3 PDGS: File Naming Convention, ref. GMES-S3GS-EOPG-TN-09-0009, issue 1.3, 7th November 2012.

RD- 2 ACS/ESA. CryoSat Ground Segment IPF L1B: Product Specification Format, ref. CS-RS-ACS-GS-5106, issue 6.4, 30th Abril 2015.

RD- 3 ESA. SRAL Input / Output Definition Document for Product Level 1A/1B-S, ref. S3-TN-ESA-SR-0433, issue 1.4, 13th March 2014.

RD- 4 ESA. Product Data Format Specification-,SRAL/MWR Level 1 & 2 Instrument Products, ref. S3IPF.PDS.003, issue 2.0, 30th September 2015.

RD- 5 Salvatore Dinardo, “Guidelines for reverting Waveform Power to Sigma Nought for CryoSat-2 in SAR mode,” ref: XCRY-GSEG-EOPS-TN-14-0012.

RD- 6 Aresys/ESA, CryoSat Characterization for FBR users, ref. C2-TN-ARS-GS-5179, issue 2.0, 13th June 2016, 16 pages (incl. NetCDF file containing reference calibration corrections for CryoSat BaselineC FBR products).

RD- 7 Amarouche, L., P. Thibaut, O.-Z. Zanif´e, J.-P. Dumont, P. Vincent, and N. Steunou, Improving the Jason-1 ground retracking to better account for attitude effects, Mar. Geod., 27, 171–197, doi: 10.1080/01490410490465210, 2004.

RD- 8 Smith, W.H.F, and R. Scharroo (2011), Re-tracking range, SWH, sigma-naught, and attitude in CryoSat conventional ocean data, OST Science Team meeting, San Diego, 19 - 21 Oct 2011:

http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2011/oral/01_Wednesday/Splinter%201%20IP/03%20Smith%20WHFSmith_IP_CS2_2.pdf

RD- 9 Scharroo, Remko, RADS User Manual, version 4.3.5., 2 May, 2019: https://github.com/remkos/rads

RD-10 Scharroo, Remko, RADS Data Manual, version 4.3.5., 2 May, 2019: https://github.com/remkos/rads

RD-11 J. Lillibridge, R. Scharroo, S. Abdalla, and D. Vandemark, "One- and two-dimensional wind speed models for ka-band altimetry," Journal of Atmospheric and Oceanic Technology, vol. 31, no. 3, pp. 630–638, 2014. [Online]. Available: https://doi.org/10.1175/JTECH-D-13-00167.1

RD-12 Scagliola, M, M. Fornari, J. Bouffard, and T. Parrinello (2018), The Cryosat interferometer: End to end calibration and achievable performance, Advances in Space Research 62, issue 6, 1516-1525, https://doi.org/10.1016/j.asr.2017.09.024.

2 General Definitions

2.1 General Product Definitions

Based on the ESA product definition and more specifically on Sentinel-3 Mission, five levels of data can be found:

- Level-1A products containing unpacked L0 complex echoes that have been sorted and calibrated. Geo-location information is included in this product.
- Level-1B-S contain geo-located, calibrated, azimuth processed complex echoes after geometric correction application arranged in stacks and before power averaging (multilooking). Relevant ancillary data (e.g., beam angles, calibration information, statistical description of stack,…) is included.
- Level-1B products includes the SAR averaged measurements (20 Hz).
- Level-2 products are the Level 1 products re-tracked and with the geophysical corrections applied to give the final altimeter parameters including range, backscatter coefficient, wind speed and significant wave height.
- RDSAR products which are LRM equivalent products, generated by creating Pseudo LRM waveforms from the L-1A echoes, and then applying conventional LRM processing to generate a L2 RDSAR product.

2.2 Variable Types

Table 2-1 Variable Types

Variable Type	Description	Range
uc	8-bit unsigned integer (ubyte)	0 to 255
sc	8-bit signed integer (byte)	-128 to 127
us	16-bit unsigned integer	0 to 65535
ss	16-bit signed integer	-32768 to 32767
ul	32-bit unsigned integer	0 to 4294967295
sl	32-bit signed integer	-2147483648 to 2147483647
sll	64-bit signed integer	-9223372036854775808 to 9223372036854775807
fl	32-bit single precision floating point	1.17549e-38 (min) 3.4028e+38(max)
do	64-bit double precision floating point	2.22e-308(min) 1.79e+308(max)

3 Delay Doppler Processing L1A-L1B(S)

3.1 Overview of Processing Scheme

In the following lines a brief overview of the different processing stages of the SAR (aka Delay-Doppler) processor implemented in the SCOOP project is presented. Further details on the description and mathematical formulation of each of the processing stages please refer to the SCOOP deliverable D1.3 ATBD [AD. 2]. A schematic including the standard DDP processor as well as the different processing options included in the processor is shown in Figure 3-1

3.1.1 Standard Algorithm processing

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

1. Surface locations, Final burst datation and Window delay: compute the surface locations (and their corresponding datation and orbit parameters) defined by the intersection of the Doppler beams and the estimated surface positions along the satellite track.

2. Beam angles computation: compute angles between the nadir direction and the direction defined by the satellite location and each surface location.

3. Azimuth processing (Delay-Doppler processing + Stacking): carry out the beam-forming operation, steering the beams to the different surface locations and generate the corresponding stacks.

4. Geometry corrections: perform the different compensations from the geometric standpoint in order to properly aligned the different beams within the stack.

5. Range compression: carry out the focusing in the range dimension to obtain the different compressed power waveforms.

6. Multi-looking: incoherent averaging of the different power waveforms forming the stack.

7. Scaling factor computation: extraction of the scaling factor used to convert the multi-looked power into sigma0 values.

3.1.2 Optional processing stages

A set of additional processing algorithms can be optionally activated by the user in order to potentially improve the expected performance when compared to conventional Sentinel-3 processing baseline. The different methods are summarized as follows: Burst azimuth weighting: reduce the side-lobes of the Doppler or beam PTR, minimizing the effect of possible land contamination being acquired by the side-lobes.

1. Azimuth processing method: areas with high topographic variability might be processed using the more computational demand exact method, while smooth scenarios can be efficiently processed with the approximate one.

2. Burst azimuth weighting: Specific windowing can be optionally applied within the burst to reduce the impact of the along-track side-lobes in the final stack[1].

3. Antenna weighting: inclusion of the along-track antenna pattern compensation as weighted average in the multi-look processing.

4. Multi-looking with zeros method: zero-valued samples (forced by the masking process) can be included or not in the incoherent processing.

5. Zero-padding in across-track (range oversampling factor): decreasing the range bin spacing offers a better sampling of the waveforms (potentially improve re-tracking for very specular returns with low SWH).

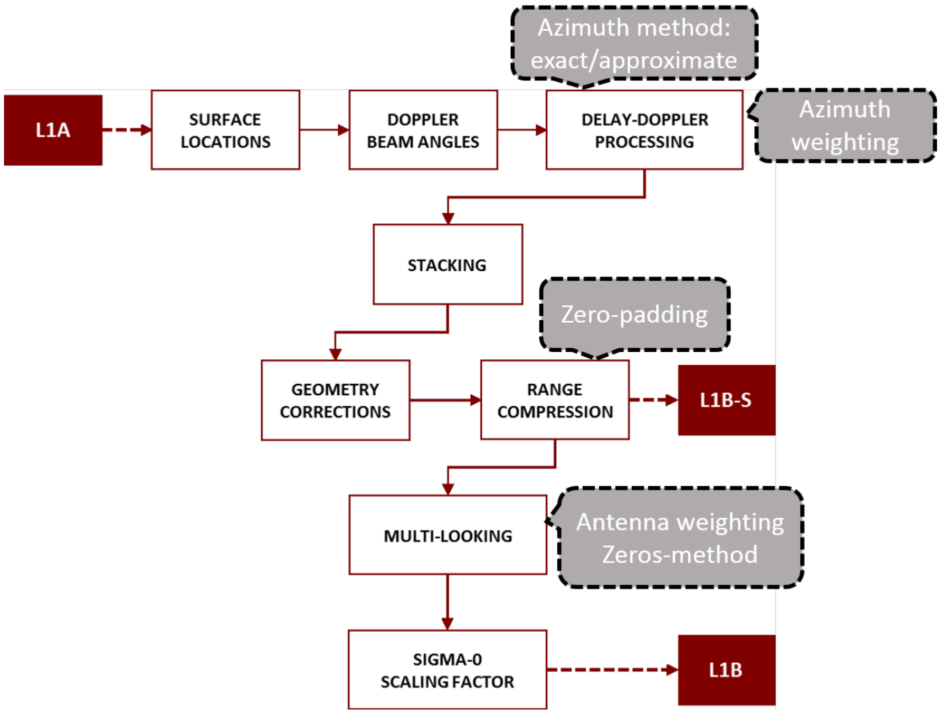

Figure 3-1 DDP processor flow chart (additional optional algorithms applying to each processing stages are included).

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3.1.3 DDP Data Flow

Based on the DPP block diagram in the high-resolution data flow is described, providing the list of input and output files for the high-resolution processor as indicated in Table 3-1 and Table 3-2. Further details can be found in the next sections.

Table 3-1 Input Files Specification

Input	File Type	Mandatory / Optional
L1A/FBR	ASCII binary (Cryosat-2)	M
Characterization file	.m (@Matlab script file)	M
Configuration file	.m (@Matlab script file)	M
Constants file	.m (@Matlab script file)	M
Characterization arrays file	NetCDF	M
Geographical mask	Kml	O

Table 3-2 Output Files Specification

Input	File Type	Mandatory / Optional
L1B	NetCDF (Sentinel-3 baseline)	M

3.2 Input Data Specifications

In the following the different input files to the DDP processor and their description is given.

The different input files can be classified in four different categories:

- **L1A**: calibrated, geo-located and datated complex echoes in a full bit rate basis (corresponds to the calibrated FBR[1] data for CryoSat-2)
- **Static auxiliary files**:
    - Characterization file (CHD)
    - Configuration file (CNF)
    - Constants file (CST)
    - Characterization arrays:
        - CAL2 masks corrections
        - CAL1 intra-burst corrections
        - Antenna weighting
    - Geographical mask (kml)

[1] No standard calibrated FBR product is available for CryoSat-2 and so the different calibrations need to be applied on the available FBR data to generate the equivalent L1A as in Sentinel-3, which to date is defined as fully calibrated L1A product according to the Sentinel-3 PSD [RD- 4].

3.2.1 L1A input files

It contains geo-located bursts of Ku/C echoes with all calibrations applied. These are the full rate complex waveforms, which are the starting point of the (SAR) high-resolution processing chain as described in Figure 3-1.

In case of CryoSat-2, since calibrated FBR data is not a standard product, the related calibration files are required to apply accordingly the corrections to obtain an equivalent L1A product. CryoSat-2 FBR data is a binary product file with specific ASCII header, further details on product format and structure can be found in [RD- **2**].

3.2.2 Static auxiliary files

3.2.2.1 Characterization file (CHD)

It contains the system on-ground characterization (time pattern, instrument, antenna, power scaling, clock…). The characterization file is an .m (@matlab) file and contains the parameters listed below in Table 3-3.

Table 3-3 Characterization file (CHD) data fieldsTable 3-3

Field Name	Description	Units
	Main	
wv_length_ku	Emitted wavelength in Ku-band	m
freq_ku_chd	Emitted frequency in Ku-band	Hz
bw_ku_chd	Ku-band bandwidth	Hz
mean_sat_alt_chd	Mean satellite altitude	m
	Time pattern	
N_bursts_cycle_sar_chd	Number of bursts in a tracking cycle	
N_ku_pulses_burst_chd	Number of Ku-band pulses per burst	
N_samples_sar_chd	Number of samples of each SAR pulse	
pulse_length_chd	Pulse duration/length	s
pri_sar_chd	Pulse repetition interval	s
bri_sar_chd	Burst repetition interval	s
PTR_width_chd	Point target response temporal width[1]	s
	Antenna	
Antenna_gain_ku_chd	Antenna gain for Ku-band	dB

[1] This width is used to compute the sigma0 scaling factor to transform the power at the antenna flange to sigma0 values according to [Error! Reference source not found.].

Field Name	Description	Units
Antenna_beamwidth_act_ku_chd	Antenna beamwidth at 3 dB for Ku-band in across-track dimension	rad
Power & scaling		
power_tx_ant_ku_chd	Transmitted peak power	Watts
ADC_mult_factor	Analog-to-digital converter multiplier factor[1]	
USO Clock		
uso_freq_nom_chd	USO nominal frequency	Hz
alt_freq_multiplier_chd	Factor to convert from USO frequency to altimeter frequency	

3.2.2.2 Configuration file (CNF)

In line with the definition made in the POCCD [AD. 4], the configuration files contain all the DDP processor switches (i.e., processing options), which can be modified without recompiling the S/W, and the configuration parameters. The configuration file is a .m (@matlab) file and contains the parameters listed below.

Table 3-4 Processing options configuration file data fields

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, …	

[1] This multiplication factor is considered in the gain corrections of the waveforms following [Error! Reference source not found.].

Field Name	Description	Value	Units
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 corrections (option 2 of flag "win_delay_ref_cnf")	Height in meters	
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	0: deactivated 1: activated	flag

[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

[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);

Field Name	Description	Value	Units
	threshold ("mask_look_angles_CR2_max_chd" and "mask_look_angles_CR2_min_chd")		
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_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)	Flat to remove the noisy beams in the stack following the Sentinel-3 baseline[1]	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	

Masking & Product & verbosity			
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

[1] 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.: $P_n^{stack} + \beta \cdot \sigma_n^{stack}$

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

3.2.2.3 Constants file (CST)

The constant file contains the basic physical constants definition to be used in the DDP. The constants file is an .m (@Matlab) file.

Table 3-5 Constants file data fields

Field Name	Description	Units
Semi_major_axis_cst	Semi-major axis of WGS84 ellipsoid	m
Semi_minor_axis_cst	Semi-minor axis of WGS84 ellipsoid	m
Flat_coeff_cst	Flattening coefficient of WGS84	-
Earth_radius_cst	Earth radius	m
Pi_cst	Pi number	
C_cst	Speed of light	m/s
Sec_in_dat_cst	Number of a seconds in a day	s

3.2.2.4 Characterization arrays file

The characterisation arrays file contains the default calibration corrections, and the antenna weighting array. The characterization arrays file is a netCDF file containing the following variables

- **CAL2 mask correction**: correspond to the instrument transfer function correction to be applied to the different waveforms in the frequency-domain before any SAR processing takes place
- **Intra-bursts corrections**: correspond to the CAL1-pulse-to-pulse corrections in phase and amplitude to be carried out before any SAR processing stage.
- **Antenna weighting** (built from antenna ground testing): contains the antenna pattern as a function of the angle from boresight (antenna pointing angle). It is applied at stack level prior the multi-looking process takes place in order to compensate for the real antenna pattern due to the different viewing geometry within the stack.

3.2.2.4.1 Characterization arrays file netCDF dimensions

Table 3-6 Dimensions for characterization arrays file netCDF

Dimension Name	Description	Value
n_samples	Number of range samples in a waveform	# of samples: 128
np	Number of pulses in the burst	# of Ku pulses: 64
n_antenna_weights	Number of antenna weights (one per look or beam)	TBC (configurable)

3.2.2.4.2 Characterization arrays file netCDF variables

Table 3-7 Characterization arrays file variables

Variable Name	Description	Range or Value	Type	Dimension
CAL2 Mask corrections				
Cal2_mask_ku	Instrument transfer function[1]		do[2]	n_samples
Units	Unit name	Counts		1
Scale_Factor	The data must be multiplied by this factor	1e-6		1
Comment	CAL2 LPF amplitude correction to be applied to each echo in the bursts acquired in SAR mode.This correction has to be applied to the Fourier transform of each echo in the acquired bursts. The k-th sample of the Fourier Transform of the echo has to be multiplied by the k-th values of the correction. The echo can go then through Inverse Fourier Transform.[3]			1
Intra-burst corrections				
cal1_p2p_amplitude_sar_ku	CAL1 SAR pulse-to-pulse amplitude correction (Ku-band)		do	np
Units	Unit name	count		1
Scale_Factor	The data must be multiplied by this factor	1e-6		1
Comment	CAL1 Amplitude Pulse-to-Pulse correction to be applied to bursts acquired in SAR mode: the k-th echo			1

[1] It is known also as the CAL2 low pass filter (LPF) amplitude correction for SAR mode.

[2] Do stands for double type

[3] For CryoSat-2 case, a single transfer function is available, which is the result of temporally averaging all CAL2 SAR LPF corrections read from Baseline C CAL2 L1B products between 01/03/2011 and 08/11/2015.

Variable Name	Description	Range or Value	Type	Dimension
	in the received burst has to be multiplied by the k-th values of the correction.[1]			
cal1_p2p_phase_sar_ku	CAL1 SAR pulse-to-pulse phase correction (Ku-band)		do	np
Units	Unit name	radians		1
Scale_Factor	The data must be multiplied by this factor	1e-6		1
Comment	CAL1 Phase Pulse-to-Pulse correction to be applied to bursts acquired in SAR mode: the k-th echo in the received burst has to be multiplied by complex exponential of the k-th values of the correction.[2]			1
Antenna weighting				
antenna_weights_ku	Antenna weights (Ku-band)		do	n_antenna_weights
Units	Unit name	counts		1
Comment	The antenna weights are given as a function of the pointing angle. They are applied to the stack, prior multi-looking, in order to compensate each look for the real antenna pattern weighting. Its application requires a good knowledge of the antenna pointing, influenced mainly by the pitch.			1
antenna_weights_angles_ku	Angles associated to the surface polar weights (Ku-band)		do	n_antenna_weights
Units	Unit name	radians		1
Spacing		TBC (in radians)		1
Range		TBC (in radians)		1
Comment	Along track angles with respect to the actual antenna pointing			1

3.2.2.5 Geographical mask

It contains the geographical mask defined by a close polygon in a kml file, it can be generated from @Google Earth directly.

[1] For CryoSat-2 case, a single transfer function is available, which is the result of temporally averaging all CAL1 SAR pulse-to-pulse amplitude corrections read from Baseline C CAL1 L1B products between 01/03/2011 and 08/11/2015.

[2] For CryoSat-2 case, a single transfer function is available, which is the result of temporally averaging all CAL1 SAR pulse-to-pulse phase corrections read from Baseline C CAL1 L1B products between 01/03/2011 and 08/11/2015.

3.3 Output Data Specifications

This section provides a list of the science L1B files with a brief description, the full definition of each one of them can be found in the product specification document (PSD), see [AD. 5].

3.3.1 L1B

The L1B is the final output of the high-resolution processor. It contains geo-located and fully calibrated multi-looked high-resolution (fully SAR-processed) Ku-band power echoes.

The formatting of this product is in line with the Sentinel-3 L1B product, see [RD- 4], using a single data file in NetCDF 4 format.

4 L2 Processor / SAR Ocean Retracker (isardSAT)

4.1 Overview of Processing Scheme

In the following lines a brief overview of the different processing stages of the SAR Level-2 processor implemented by isardSAT in the SCOOP project, including the SAR ocean retracker, is presented. Further details on the description and mathematical formulation of each of the processing stages please refer to the ATBD [**Error! Reference source not found.**].

4.1.1 Standard Algorithm processing

The main processing stages of the 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.

4.1.2 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.

4.1.3 Data Flow

The list of input and output files for the SAR L2 processor are indicated in Table 3-1 and Table 3-2.

Table 4-1 Input Files Specification

Input	File Type	Mandatory / Optional
L1B	NetCDF	M
Characterization file	JSON	M
Configuration file	JSON	M
Constants file	JSON	M
LUTs f0 and f1	Binary @Matlab file	M
Atmospheric attenuation correction maps	NetCDF	O
Geographical mask	Kml	O

Table 4-2 Output Files Specification

Input	File Type	Mandatory / Optional
L2	NetCDF	M

4.2 Input Data Specifications

In the following the different input files to the SAR L2 processor and their description is given.

The different input files can be classified in four different categories:

- **L1B**: calibrated, geo-located and datated complex multi-looked waveforms echoes in a 20-Hz basis
- **Static auxiliary files**:
    - Characterization file (CHD)
    - Configuration file (CNF)

- Constants file (CST)
- Binary LUTs for f0 and f1 basis function:
- Atmospheric attenuation correction global maps (*NCEP GFS model,* [**Error! Reference source not found.**])
- Geographical mask in a KML format

4.2.1 L1B input files

It contains geo-located and calibrated multi-looked SAR waveforms at 20-Hz generated by the DDP processor described in [AD. 2].

4.2.2 Static auxiliary files

4.2.2.1 Characterization file (CHD)

It contains the system/instrument on-ground characterization parameters. The characterization file is a JSON file and contains the parameters listed below in Table 3-3

Table 4-3 Characterization file (CHD) data fields

Field name	Description	Value	Units
N_total_pulses_b_chd	Number of Ku-band pulses per burst	64	Flag
N_samples_chd	Number of samples per each SAR pulse	128	count
Number of bursts per radar cycle	Number of bursts per radar cycle	4	flag
freq_ku_chd	Carrier frequency	1.357509771780475e+10	Hz
prf_chd	Pulse repetition frequency	1.818181818181818e+04	Hz
brf_chd	burst repetition frequency	85.515218502072671	Hz
bw_rx_ku_chd	Receive bandwidth	320e+6	Hz
fs_clock_ku_chd	Sampling frequency	320e+6	Hz

Field name	Description	Value	Units
antenna_beamwidth_act_ku_chd	Antenna beamwidth across-track or range	0.021293016874331	radians
antenna_beamwidth_alt_ku_chd	Antenna beamwidth along-track or azimuth	0.019111355309338	Radians
PTR_forced_al[1]	Forced sigma along-track PTR	0.65	-
PTR_forced_ac[2]	Forced sigma across-track PTR	0.54351	-
PTR_Hamming	Sigma PTR with Hamming window. Sigma of Gaussian fitting to PTR with Hamming window, minimizing the RMSE	0.54351	-
PTR_Hanning	Sigma PTR with Hamming window. Sigma of Gaussian fitting to PTR with Hanning window, minimizing the RMSE	0.59824	-
PTR_Boxcar	Sigma PTR with Boxcar window	0.36012	-

4.2.2.2 Configuration file (CNF)

In line with the definition made in the POCCD [AD. 4], the configuration files contain all the processor switches (i.e., processing options), which can be modified without recompiling the S/W, and the configuration parameters. The configuration file is a JSON file and contains the parameters listed below.

Table 4-4 Configuration file (CNF) data fields

[1] This value is used when configuration parameter window_type_a is set to ‘forced’.

[2] This value is used when configuration parameter window_type_r is set to ‘forced’.

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 [1].	**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[2]	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[3]	Hamming Hanning Boxcar **Forced** Adaptive	flag
window_type_r	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

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

[2] 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.

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

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[1]	Flag
analytical_type_ of_fitting	Type of fitting when using analytical retracker: current option in SCOOP is SWH	SWH[2]	Flag
ref_sample_wd	Reference sample (zero-padded) for the window delay[3]	128	Count
mask_ROI_flag	Flag that activates filtering out those surfaces outside the kml mask	True: filter only surfaces within the defined mask[4] **False**: all the surfaces in the input L1B are considered	flag
mask_looks_fla g	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

[1] Analytical refers to the physical-based SAR ocean retracker implemented by isardSAT and based on the model proposed by Ray et a. 2015 [**Error! Reference source not found.**].

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

[3] 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).

[4] 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**[1]	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

[1] A normalzied 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]**[1]	[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[2]	**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

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

[2] 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

4.2.2.3 Constants file (CST)

The constant file contains the basic physical constants definition to be used in the DDP. The constants file is an xml file.

Table 4-5 Constants file data fields

Field name	Description	Value	Units
semi_minor_axis_cst	Semi-minor axis of the ellipsoid	6356752.3142	m
semi_major_axis_cst	Semi-major axis of the ellipsoid	128	count
flat_coeff_cst	Flattening coefficient of the reference ellipsoid	0.003352810664747	-
earth_radius_cst	Earth Radius	6378137	m
sec_in_day_cst	Seconds in a day	86400	s
Speed of light	Speed of light	299792458	m/s

Field name	Description	Value	Units
pi_cst	Pi number	3.14159265358979323846 2643383	radia ns

4.2.2.4 LUTs

The files LUT_f0.mat and LUT_f1 correspond to the look up tables of the basis functions f0 and f1 in a @Matlab binary format. f0(xi) and f1(xi) are tabulated for values of xi from -10 up to 50 with a step of 1e-5.

4.2.2.5 Atmospheric attenuation correction global maps

Global maps for the correction of the atmospheric attenuation on sigma0 are defined based on the *NCEP GFS model,* [**Error! Reference source not found.**]. 4 files per day are available (corresponding to 00H, 06H, 12H and 18H hours). The format of the files is NetCDF containing the following variables:

Table 4-6 Global atmospheric attenuation correction file variables

Variable Name	Description	Range or Value	Type	Dimension
lat	latitude		do	361
Long_name	Long name of the variable	Latitude		
Units	Unit name	Degrees_north		1
actual_Range	Range of values	-90.0,90.0		
lon	longitude		do	720
Long_name	Long name of the variable	longitude		
Units	Unit name	Degrees_east		
actual_Range	Range of values	0,359.5		
Sig0_atmos_corr			short	361x720
Long_name	Long name of the variable	atmospheric attenuation correction on backscatter coefficient		1
Units	Unit name	dB		1
Scale_factor	The data must be multiplied by this factor	0.001	do	1
Band	Operating band	Ku		1
_ChunkSizes		361,720		

4.2.2.6 Geographical mask

It contains the geographical mask defined by a close polygon in a kml file, it can be generated from @Google Earth directly.

4.3 Output Data Specifications

This section provides a list of the science L1B files with a brief description, the full definition of each one of them can be found in the product specification document (PSD), see [AD. 5].

4.3.1 L2

The L2 is the final output of the SAR Level-2 processor. It contains geo-located geophysical retrievals (sea surface height, significant wave height and sigma0) posted at 20-Hz, including the geophysical corrections applied.

The formatting of this product is described in [AD. 6].

5 RDSAR Processing L1A-L2 (RDSAR)

5.1 Overview of Processing Scheme

The processing of the SAR echoes is different from the traditional LRM. In the first case the complex echoes are averaged coherently: their phase is taken into account when summing the complex echoes. In the second case the echoes are averaged incoherently: their phase is not taken into account when summing just the power of the echoes. The intent of the RDSAR technique is to create waveforms that look like LRM mode waveforms but are not identical because in SAR mode the instrument is not transmitting at a constant rate but has waiting times between sending and receiving. That's why they are referred to as pseudo-LRM (PLRM) waveforms. For the creation of these PLRM waveforms we use the Level 1A product known as FBR (Full Bit Rate), which contains all the echoes that are received in complex form. The outputted PLRM waveforms are Level 1B products, quite similar to the standard LRM Level 1B product.

In RADS, PLRM data are merged with the LRM data and made available since 2012 through the RADS database (http://rads.tudelft.nl). The processing of CryoSat-2 LRM and PLRM data for the SCOOP project follows exactly the steps as done in RADS (NOAA/EUMETSAT/TU Delft) and as has been done in frame of the CP4O project. Details and references can be found in [AD. 2].

The processing of Sentinel-3 PLRM is not deviating from the methods adopted for CryoSat-2. Sentinel's altimeter instrument (SRAL) also makes use of the unfocused SAR with closed burst meaning that there are bursts of pulses and no continuous pulses at exactly the same frequency as CryoSat-2 (bursts of 64 pulses, though flanked with 2 C-band pulses – see Figure 5-1.

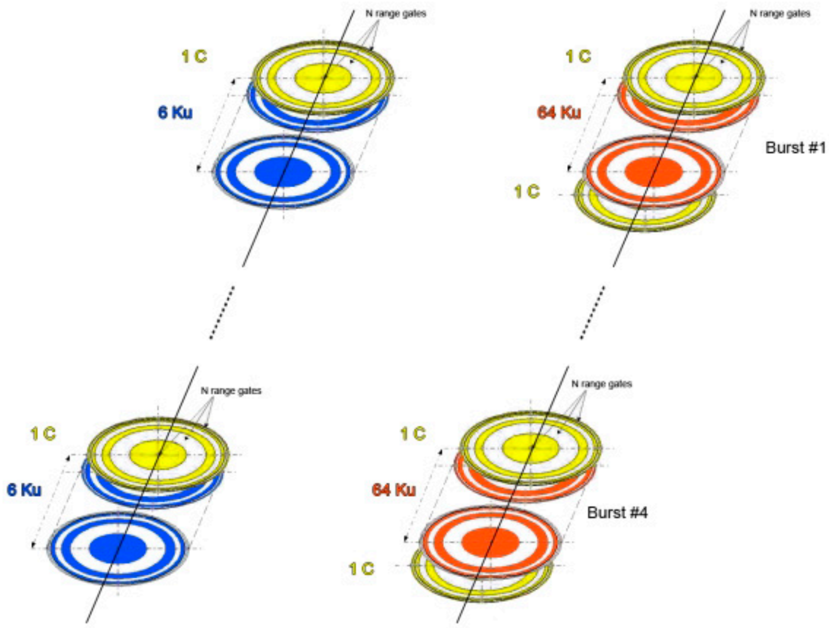

Figure 5-1 Sentinel-3 LRM radar cycle transmitting pattern (left) and SAR radar cycle transmitting pattern (right). Later on, the LRM mode was dismissed. The SAR radar cycles contain four bursts, each of these bursts have sequences of 1 C - 64 Ku -1 C pulses (Thales Alenia Spazio).

5.1.1 L1A to L1B: FBR to PLRM waveforms

The L1A-L1B RDSAR technique produces pseudo LRM waveforms (L1B PLRM) and consists of the following steps, using the CryoSat-2 Baseline C L1A full bit rate (FBR) product as input data and applying the information from the Aresys “CryoSat Characterization for FBR users” document [RD-6]:

- Gather 4 bursts of 64 echoes.
- Adjust the FAI for each burst.
- Align the echoes horizontally.
- Align the echoes vertically (optional).
- Correct echo amplitude and phase (CAL1 from CryoSat Users Characterization file).
- Zero-pad the echoes to prepare for the FFT procedure.
- Perform a 1-dimensional FFT, horizontally, resulting in 256 noisy individual waveforms
- Incoherently average these individual waveforms, by summing the powers
- Apply low-pass filter correction (CAL2 LPF correction from CryoSat Users Characterization file).
- Rescale the waveform (power conversion).

These steps are described in detail in the SCOOP ATBD document [AD. 2], and Figure 5-2 illustrates the overall process. The results are 20-Hz waveforms similar to those found on the L1B LRM product. After these steps, the L1B PLRM data can be processed to L2 as if they were real LRM data, and the satellite to sea surface distance (range) and other geophysical parameters can be computed. This is explained in the next section.

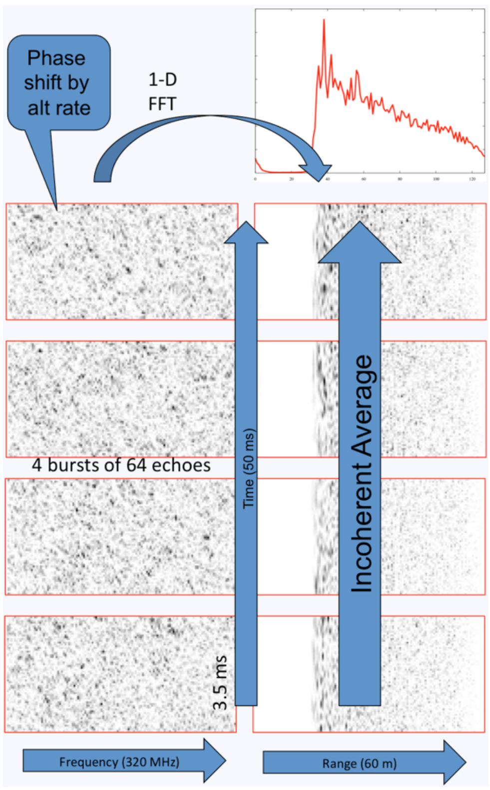

Figure 5-2 Four bursts of 64 complex echoes (left) are phase shifted so that after 1-D FFT the individual waveforms are all aligned (right). Those waveforms are then incoherently averaged to form

a single 20-Hz PLRM waveform. Zero padding is not shown. Of the echoes and individual waveforms only the power is shown, not the phase, however each are built of complex numbers.

Since the power of the waveforms is scaled such that the maximum value for any sample is always 65535, a special treatment of the power amplification is needed. A detailed description of the power amplification is also given in the SCOOP ATBD document [AD. 2].

5.1.2 L1B to L2: PLRM waveform to range, SWH and wind speed

The RADS implementation of processing the PLRM waveforms (L1B) into a range product (L2) applies a 3-parameter estimation to the waveforms: range (epoch midpoint leading edge), SWH (width/gradient), and wind (amplitude). This is referred to as MLE3, where MLE stands for maximum likelihood estimator. However, a compensation for the mis-pointing of the antenna is also needed. For this we use information from the on-board star trackers (off-nadir angle). In fact, this makes the RADS implementation similar to an MLE4, albeit that the 4th parameter is not estimated from the waveform (decay) itself. Mis-pointing can have a significant influence on the performance of the altimeter instrument. If the off-nadir angle is zero or very small a straightforward MLE3 would be the preferred re-tracker for open ocean, but for the CryoSat-2 platform the mis-pointing cannot be neglected, and either an MLE3 methodology can be applied in conjunction with very precise attitude information, or an MLE4 method should be adapted (this is described in the ATBD as well [AD. 2]. The attitude information for CryoSat-2 was updated in Baseline D according to the outcome of the analysis in RD-12. To exploit current Baseline C CryoSat-2 products in combination with the Baseline D-like attitude information, users can consider the attitude data available at the following link https://earth.esa.int/web/guest/missions/esa-eo-missions/cryosat/str-attref. This dataset contains the attitude information already corrected for the aberration of light. [RD-12]. The SCOOP dataset does not consider this corrected attitude information.

As the classical 'Brown model' for fitting a curve through the open ocean waveform assumes a circular antenna pattern, and knowing that the antenna pattern for CryoSat-2 is slightly elliptical we average CryoSat-2's beam width over all azimuths. Then the azimuthally averaged half-power beam width (HPBW) is the harmonic mean of the major and minor elliptical HPBWs. We re-track the CryoSat-2 waveforms with a circular beam theory using this approximation, which was showed to be allowed for conventional LRM waveforms by Amarouche et al., 2004 [RD- 7]

The RADS re-tracker as developed by Smith and Scharroo 2011 [RD- 8] allows selection of any (or all) of these parameters to be fitted: epoch, width, amplitude, mis-pointing, and noise level. As said, the default solution chosen for RADS is an MLE3 with a fixed mis-pointing of the platform attitude based on the star trackers data, which is given in the ESA FDM and LRM 1b products. However, it was also necessary to estimate platform attitude biases in the pitch and roll data. Again, this is all described in more detail in the SCOOP ATBD document [AD. 2].

5.1.3 L2 to RADS

The final step in the RADS processing is taking the L2 PLRM product (the re-tracked L1B product) and process it such that it can be put in the RADS database directly, so with the name and format conventions for all the variables as defined in RADS. Another step is archiving the data in cycles and combine track segments to pole to pole passes. For CryoSat-2, in the RADS cycle definition (identical to the definition by CNES) we have the following sequence of revolutions: 4 * (29 + 29 + 27) + 29 = 369 days, where the 29-day and 27-day are the so-called sub-cycles. Additionally, some auxiliary data is added like SSB (hybrid model), more recent tide, mean sea surface (MSS) and geoid models, an improved orbital height (CNES GDR_E) and a CryoSat-2 specific sigma-naught bias is applied. More details about RADS and its data can be found in [RD- 9] and [RD-10].

5.1.4 The complete L1A to L2 processing flow

The output product of the whole L1A to L2 processing chain is a netcdf file that adheres to the RADS format and variables name convention and carries both the end product (L2) and the intermediate product (waveforms or L1B product). It is in fact a mixed L1B/L2 product.

The next verbatim describes the order and call of the different subroutines involved in the RADS RDSAR processing, and which led to the phase 1 RDSAR test data set:

```
# do FBR to L1R conversion
for TGZ in $(find /Volumes/scoop/harvest -type f -path "*.TGZ" -print | sort); do
   tar -xzf $TGZ "*.DBL"
   FBR=`basename $TGZ .TGZ`.DBL
   cs2_fbr_to_l1r -j -m3 -w -D. < $FBR
   rm -rf $FBR
done

# do L1R to RADS conversion
find . -type f -path "*CS*.nc" -print | sort | rads_gen_c2_l1r –sat c2/a -m -w

# fix 3.04 sigma-naught bias
rads_fix_c2 --sat c2/a --all

# add ssb
rads_add_ssb --sat c2/a --all

# add latest tide model
rads_add_tide --sat c2/a --models got410

# add some recent mss geod models
rads_add_grid --sat c2/a --var mss_cnescls11
rads_add_grid --sat c2/a --var mss_dtu13
rads_add_grid --sat c2/a --var mss_cnescls15
rads_add_grid --sat c2/a --var mss_dtu15
rads_add_grid --sat c2/a --var geoid_eigen6

# add sla field
rads_add_sla --sat c2/a
rads_add_sla --sat c2/a --multi-hz
```

The input for the different subroutines (command line options) is explained in the next verbatim.

Process L1A to RADS L1R (generating PLRM waveforms and re-tracking) with cs2_fbr_to_l1r:

```
usage:cs2_fbr_to_l1r [options] < FBRfile.DBL

      where [options] are:
      -i           : incoherent averaging (default), same as -SAP
      -c           : coherent averaging (SARlite), same as -S64
      -j           : use 256 samples, same as -SAJ
      -S<nr>       : partial coherent (<nr> pulses)/incoherent averaging
      -m<type>     : Set retracking model, where <type> is one of:
                     3 = MLE3, 4 = MLE4, 5 = MLE5, f = FFT, F = FFT with sinc2 PTR
                     (default is MLE3 for SAP, FFT for others)
      -f[<scale>] : fixed AGC scale
      -I[0|1|2]    : dump image before FFT, after 1-D FFT, after 2-D FFT
      -D<dir>      : Write files to <dir> (file name is determined automatically)
      -d<level>    : Set compression level for netCDF file (default is none)
      -w           : Add waveforms to output file (default is not)
      -a|A         : Write average waveform to ASCII file (scaled or absolute)
      -y           : Do waveform averaging
      -p|P         : Print ascii output (additionally to netCDF or only ascii)
```

Write CryoSat-2 L1R data to RADS with rads_gen_c2_l1r:

```
Usage: rads_gen_c2_l1r [rads_dataselectors] < list_of_L1R_file_names

Optional [rads_dataselectors] are:
  -S, --sat SAT[/PHASE]     Specify satellite [and phase] (e.g. e1/g, tx)
  -C, --cycle C0[,C1]       Select data for one or more cycles
  --time T0,T1              Specify time selection (optionally use --ymd, --doy,
                            or --sec for [YY]YYMMDD[HHMMSS], YYDDD, or SEC85)

Common [rads_options] are:
  --help                    Print this syntax massage
  --log FILENAME            Send statistics to FILENAME (default is standard output)
  -q, --quiet               Suppress warning messages (but keeps fatal error messages)
  -v, --verbose             Increase verbosity level
  --debug LEVEL             Set debug/verbosity level
  --version                 Version info

Program specific [program_options] are:
  -m, --with-20hz           Include 20-Hz variables in addition to 1-Hz variables
  -w, --with-wvf            Include waveforms (implies --with-20hz)

This program converts CryoSat-2 L1R files to RADS data
files with the name $RADSDATAROOT/data/c2/F/pPPPP/c2pPPPPcCCC.nc.
The directory is created automatically and old files are overwritten.
```

Fix some CryoSat-2 related issues with rads_fix_c2:

```
Usage: rads_fix_c2 [rads_dataselectors] [processing_options]

Required argument is:
  -S, --sat SAT[/PHASE]     Specify satellite [and phase] (e.g. e1/g, tx)

Additional [processing_options] are:
  --drift                   Correct sigma0 for apparent drift (Baseline B only)
  --meteo                   Set dry, wet, IB (and iono) to NaN when zero
  --sig0                    Correct sigma0 for biases
  --all                     All of the above
```

Add sea state bias SSB with rads_add_ssb:

```
Usage: rads_add_ssb [rads_dataselectors] [processing_options]

Required argument is:
  -S, --sat SAT[/PHASE]     Specify satellite [and phase] (e.g. e1/g, tx)

Additional [processing_options] are:
  -s, --ssb [MODEL]         Add/replace SSB model (default: ssb_hyb)
  -w, --wind                Compute altimeter wind speed from ECMWF model
  --all                     All of the above
```

Add extra tide models with rads_add_tide:

```
Usage: rads_add_tide [rads_dataselectors]

Required argument is:
  -S, --sat SAT[/PHASE]     Specify satellite [and phase] (e.g. e1/g, tx)

Additional [processing_options] are:
  -m, --models MODEL[,...]  Select tide models

Currently available MODELs are:
  fes04  : FES2004 ocean and load tide
  fes12  : FES2012 ocean tide
  got00  : GOT00.2 ocean and load tide
  got47  : GOT4.7 ocean and load tide
  got48  : GOT4.8 ocean and load tide
  got49  : GOT4.9 ocean and load tide
  got410 : GOT4.10 ocean and load tide
```

Add recent MSS/Geoid models with rads_add_grid:

```
Usage: rads_add_grid [rads_dataselectors] [processing_options]

Required argument is:
  -S, --sat SAT[/PHASE]     Specify satellite [and phase] (e.g. e1/g, tx)

Additional [processing_options] are:
  -V, --var NAME[,...]      Select variable name(s) for interpolation (required)
```

Add (precomputed) sea level anomaly (SLA) with default corrections with rads_add_sla (see Section 5.3):

```
Usage: rads_add_sla [rads_dataselectors] [processing_options]

Required argument is:
  -S, --sat SAT[/PHASE]     Specify satellite [and phase] (e.g. e1/g, tx)

Additional [processing_options] are:
  --all                     (Has no effect)
  -m, --multi-hz            Do multi-Hertz SLA (only)
  -x, --ext EXT             Produce field ssha_EXT (e.g. mle3 or plrm)
  -u, --update              Update files only when there are changes
```

For the Phase 2 data set, the procedure was not altered (incoherent averaging, MLE3 re-tracking, 3.04dB sigma0 fixing, and SSB adding), but more and newer corrections and models were added to the final product, among which an improved orbit (GDR_E):

```
ncdump c2p0001c049.nc | grep “global attributes”

:Conventions = "CF-1.7" ;
:title = "RADS 4 pass file" ;
:institution = "EUMETSAT / NOAA / TU Delft" ;
:source = "radar altimeter" ;
:references = "RADS Data Manual, Version 4.2 or later" ;
:featureType = "trajectory" ;
:ellipsoid = "TOPEX" ;
:ellipsoid_axis = 6378136.3 ;
:ellipsoid_flattening = 0.00335281317789691 ;
:filename = "c2p0001c049.nc" ;
:mission_name = "CRYOSAT2" ;
:mission_phase = "a" ;
:cycle_number = 49 ;
:pass_number = 1 ;
:equator_longitude = 0.931316 ;
:equator_time = "2013-12-28 10:31:07.609223" ;
:first_meas_time = "2013-12-28 10:42:56.437961" ;
:last_meas_time = "2013-12-28 10:52:56.766993" ;
:original = "L1R (2.06) from L1B (SIR1SAR/4.5) data of 2015-11-27 02:13:23\n",
      "CS_LTA__SIR_SAJ_1B_20131228T104256_20131228T105257_C001.nc" ;
:log01 = "2019-02-02 | rads_gen_c2_l1r -Sc2 -m -w: RAW data from L1R (2.06) from L1B
    (SIR1SAR/4.5) data of 2015-11-27 02:13:23" ;
:history = "2019-02-02 12:02:58 : rads_gen_c2_l1r -Sc2 -m -w\n",
      "2019-02-02 12:11:04 : rads_add_ncep -Sc2 -gs\n",
      "2019-02-02 12:11:12 : rads_fix_c2 -Sc2 --all\n",
      "2019-02-02 12:11:17 : rads_add_ssb -Sc2 --all\n",
      "2019-02-02 12:11:24 : rads_add_orbit -Sc2 -Valt_gdre --equator --loc-7 --rate\n",
      "2019-02-02 12:11:31 : rads_add_orbit -Sc2 -Valt_eig6c\n",
      "2019-02-02 12:11:44 : rads_add_grid -Sc2 -Vdist_coast,inv_bar_mog2d_mean,gia,
mss_cnescls11,basin\n",
      "2019-02-02 12:12:04 : rads_add_grid -Sc2 -Vgeoid_egm2008,mss_cnescls15\n",
      "2019-02-02 12:12:40 : rads_add_grid -Sc2 -Vtopo_dtu10,mss_dtu13,
mss_dtu15,mss_dtu18\n",
      "2019-02-02 12:13:10 : rads_add_grid -Sc2 -Vgeoid_eigen6,topo_srtm30plus\n",
      "2019-02-02 12:13:16 : rads_add_grid -Sc2 -Vgeoid_xgm2016\n",
      "2019-02-02 12:14:32 : rads_add_grid -Sc2 -Vtopo_srtm15plus\n",
      "2019-02-02 12:14:40 : rads_add_grid -Sc2 -Vprox_coast\n",
      "2019-02-02 12:14:47 : rads_add_surface -Sc2\n",
      "2019-02-02 12:14:56 : rads_add_surface -Sc2 -s\n",
                  "2019-02-02 12:15:20 : rads_add_tide -Sc2 --models=stide,ptide,fes04,
got48,got410,annual\n",
      "2019-02-02 12:17:52 : rads_add_tide -Sc2 --models=fes14,lptide\n",
      "2019-02-02 12:18:38 : rads_add_refframe -Sc2\n",
      "2019-02-02 12:18:45 : rads_add_sst -Sc2 --all\n",
      "2019-02-02 12:19:24 : rads_add_ncep -Sc2 --dry --wet --air\n",
      "2019-02-02 12:23:23 : rads_add_era -Sc2 --dry --wet\n",
      "2019-02-02 12:38:48 : rads_add_ecmwf -Sc2 --all\n",
      "2019-02-02 12:39:09 : rads_add_iono -Sc2 --all\n",
      "2019-02-02 12:41:03 : rads_add_mog2d -Sc2\n",
      "2019-02-02 12:44:44 : rads_add_ww3_222 -Sc2 --all\n",
      "2019-02-02 12:44:51 : rads_add_sla -Sc2\n",
      "2019-02-02 12:45:00 : rads_add_sla -Sc2 --multi-hz\n",
      "2019-02-05 02:45:18 : rads_add_uporto --sat c2/a --all" ;
```

After evaluation it was decided, as a test, to apply the MLE4 re-tracker instead of the MLE3, to two regions of interest. The only change in the procedure as described above is the option of the m-switch in the very first processing step:

```
> cs2_fbr_to_l1r -j -m4 -w -D. < $FBR
```

5.2 Input Data Specifications

As the input for our processing chain is FBR/L1A CryoSat Baseline C data, the input data specification is compliant with the FBR SAR Measurements Data Sets (MDS) Record Structure given in the CryoSat L1 products format specification document [RD- 2]:

Field	Description	Units	Bytes	Format
Mode – Time and Orbit Group				
1	Data Record Time (MDSR Time Stamp)	TAI	12	sl+2*ul
2	USO Correction	10^{-15}	4	sl
3	Mode ID		2	us
4	Source Sequence Counter		2	us
5	Instrument Configuration		4	ul
6	Burst Counter (always starts from 1 and incremented at group rate)		4	ul
7	Latitude of measurement	10^{-1} µdeg	4	sl
8	Longitude of measurement	10^{-1} µdeg	4	sl
9	Altitude of COG above reference ellipsoid (interpolated value)	mm	4	sl
10	Instantaneous altitude rate derived from orbit	mm/s	4	sl
11	Satellite velocity vector [3] (in CRF)	mm/s	3*4	sl
12	Real beam direction vector [3] (in CRF)	µm	3*4	sl
13	Interferometer baseline vector [3] (in CRF)	µm	3*4	sl
14	FBR Measurement Confidence Data (flag word)		4	ul
Measurements Group				

15	Window Delay (2-way) uncorrected for instrument delays	10^{-12} s	8	sll
16	H0 Initial Height Word	48.8 ps	4	sl
17	COR2 Height Rate	3.05 ps/rc	4	sl
18	Coarse Range Word LAI	12.5 ns	4	sl
19	Fine Range Word FAI	12.5/256 ns	4	sl
20	AGC_1 (not corrected)	dB/100	4	sl
21	AGC_2 (not corrected)	dB/100	4	sl
22	Total Fixed Gain Rx 1	dB/100	4	sl
23	Total Fixed Gain Rx 2	dB/100	4	sl
24	Transmitter Power	µWatts	4	sl
25	Doppler range correction (Radial component)	mm	4	sl
26	Instrument Range Correction tx-rx antenna (from CAL1)	mm	4	sl
27	Instrument Range Correction rx only antenna (from CAL1)	mm	4	sl
28	Instrument Gain correction, tx-rx antenna (from CAL1)	dB/100	4	sl
29	Instrument Gain correction, rx only antenna (from CAL1)	dB/100	4	sl
30	Internal Phase Correction	µradians	4	sl
31	External Phase Correction	µradians	4	sl
32	Noise Power measurement	dB/100	4	sl
33	Phase Slope Correction	µradians	4	sl
34	Spares		4*1	uc
Corrections Group				
35	Dry Tropospheric Correction	mm	4	sl
36	Wet Tropospheric Correction	mm	4	sl

37	Inverse Barometer Correction	mm	4	sl
38	Dynamic Atmospheric Correction	mm	4	sl
39	GIM Ionospheric Correction	mm	4	sl
40	Model Ionospheric Correction	mm	4	sl
41	Elastic Ocean Tide	mm	4	sl
42	Long Period Ocean Tide	mm	4	sl
43	Ocean Loading Tide	mm	4	sl
44	Solid Earth Tide	mm	4	sl
45	Geocentric Polar Tide	mm	4	sl
46	Surface type flag	-	4	ul
47	Spare	-	4*1	uc
48	Correction status flags		4	ul
49	Correction error flags		4	ul
50	Spare	-	4*1	uc
	Sub-Total Size		3424 bytes	
Waveform group (SAR)				
51	Complex Echo Waveform [64, 128, 2]		64*128*2	sc
52	Number of pulses in burst		2	us
53	Flag		2	us
	Sub-Total Size		327760 bytes	
	Total Record Size		331184 bytes	

Table 5-1: FBR MDS Records

5.3 Output Data Specifications

After the first processing step `cs2_fbr_to_l1r` a netcdf file is created with the same name as the input DBL file but with extension nc instead of DBL. This netcdf file has the dimensions time (number of data records), meas_ind (=20 because of the 20Hz data resolution), wf_ind(=256, the number of waveform indices), and the following variables (Table 5-2):

name	**long_name**	**index**	**units**	**scale_ factor/ add_o ffset**	**format**
time_20hz	time	time, meas_ind	seconds since 2000-01-01	-	double
lat_20hz	latitude	time, meas_ind	degrees _north	1.e-07	int
lon_20hz	longitude	time, meas_ind	degrees _east	1.e-07	int
alt_20hz	orbital altitude	time, meas_ind	m	0.001	int
alt_rate_20hz	orbital altitude rate	time, meas_ind	m/s	0.001	int
doppler_corr_20hz	Doppler correction	time, meas_ind	m	0.001	short
uso_corr_20hz	USO correction factor	time, meas_ind	count	1.e-15	int
instr_config_flags	Instrument configuration flag	time, meas_ind	count	-	int
fbr_mcd_20hz	FBR measurement confidence data	time, meas_ind	count	-	int
attitude_pitch_20hz	attitude pitch	time, meas_ind	radians	1.e-06	short
attitude_roll_20hz	attitude roll	time, meas_ind	radians	1.e-06	short
attitude_yaw_20hz	attitude yaw	time, meas_ind	radians	1.e-06	short

instr_range_corr_20hz	instrument correction to range	time, meas_ind	m	0.001	int
range_20hz	tracker range	time, meas_ind	m	0.001	int
drange_20hz	retracker range correction	time, meas_ind	m	0.001	short
swh_20hz	significant wave height	time, meas_ind	m	0.001	short
xi_sq_20hz	off-nadir angle squared	time, meas_ind	degrees ^2	0.0001	short
noise_20hz	pre-arrival noise	time, meas_ind	dB	0.001	int
echo_scale_20hz	echo scale factor	time, meas_ind	dB	0.001	int
agc_20hz	automatic gain control	time, meas_ind	dB	0.01	short
dagc_eta_20hz	flat earth correction to backscatter	time, meas_ind	dB	0.001	short
dagc_alt_20hz	altitude correction to backscatter	time, meas_ind	dB	0.001	short
dagc_xi_20hz	off-nadir angle correction to backscatter	time, meas_ind	dB	0.001	short
dagc_swh_20hz	significant wave height correction to backscatter	time, meas_ind	dB	0.001	short
agc_amp_20hz	retracker backscatter	time, meas_ind	dB	0.001	int
mqe_20hz	mean square error of retracker fit	time, meas_ind	count	-	float
peakiness_20hz	waveform peakiness	time, meas_ind	count	0.01	short
retrack_flag_20hz	retracking status flag	time, meas_ind	count	-	byte
nr_iter_20hz	number of retracker iterations	time, meas_ind	count	-	byte

nr_echoes_20hz	number of echoes averaged in waveform	time, meas_ind	count	-	short
waveform_flags_20hz	wave form flags	time, meas_ind	count	-	short
time	time	time	seconds since 2000-01-01	1	double
lat	latitude	time	degrees _north	1.e-07	int
lon	longitude	time	degrees _east	1.e-07	int
alt	orbital altitude	time	m	0.001	int
nr_valid	number of 20-Hz values	time	count	-	byte
dry_tropo	dry tropospheric correction	time	m	0.001	short
wet_tropo	wet tropospheric correction"	time	m	0.001	short
inv_baro	inverse barometer correction	time	m	0.001	short
dac	dynamic atmospheric correction	time	m	0.001	short
iono_gim	GIM ionospheric correction	time	m	0.001	short
iono_model	model ionospheric correction	time	m	0.001	short
tide_ocean	equilibrium ocean tide	time	m	0.001	short
tide_lp	long-period tide	time	m	0.001	short
tide_load	loading tide	time	m	0.001	short
tide_solid	solid earth tide	time	m	0.001	short
tide_pole	pole tide	time	m	0.001	short
surface_type	surface type	time	count	-	byte

corr_status_flags	correction error flags	time	count	0.001	short
corr_error_flags	correction error flags	time	count	0.001	short
sig_amp_20hz	formal error of waveform amplitude	time, meas_ind	count	0.1	short
rho_amp_range_20hz	correlation between amplitude and range	time, meas_ind	count	0.0001	short
sig_range_20hz	formal error of tracker range	time, meas_ind	m	0.001	short
rho_amp_swh_20hz	correlation between amplitude and SWH	time, meas_ind	count	0.0001	short
rho_range_swh_20hz	correlation between range and SWH	time, meas_ind	count	0.0001	short
sig_swh_20hz	formal error of significant wave height	time, meas_ind	m	0.001	short
waveform_20hz	waveform	time, meas_ind, wf_ind	count	-/ 32768	short

Table 5-2: Netcdf variables of intermediate RDSAR L2 product (l1r file). Global attributes of netCDF files are discussed in the PSD document [AD. 5]

As explained in 5.1.4, the final RDSAR L2 product is in fact a combined L1B and L2 product as it carries both the final geophysical parameters as range, significant wave height and wind speed, as the waveforms themselves. With this an end-user can also choose to apply his/her own re-tracker targeted to a specific use (like a coastal re-tracker). For this purpose and to be able to be able to put the data product directly into the RADS data base, the intermediate product is reformatted to adhere to the RADS format and standards by the processing module `rads_gen_c2_l1r`, after which a few other RADS processing steps follow to fix a number of CryoSat-2 issues, such as a bias in the sigma0 (3.04 dB), and to add newer and other corrections and models among which a sea state bias (SSB) and an improved orbital height (GDR_E standard). The reader is referred to the RADS user and data manuals that can be found at https://github.com/remkos/rads ([RD- 9], [RD-10]). The final SCOOP RDSAR product is a netcdf file that has the dimensions time (number of data records), meas_ind (=20 because of the 20Hz data resolution), wf_ind(=256, the number of waveform indices), and the following variables (Table 5-3):

name	long-name	index	units	scale/ offset	format
time	time	time	seconds since	-	double

			1985-01-01 UTC		
meas_ind	elementary measurement index	meas_ind	1	-	byte
wvf_in	waveform index	wvf_in	1	-	short
time_20hz	20-Hz time	time, meas_ind	seconds since 1985-01-01 UTC	-	double
lat	latitude	time	deg_north	1.e-07	int
lat_20hz	20-Hz latitude	time, meas_ind	deg_north	1.e-07	int
lon	longitude	time	deg_east	1.e-07	int
lon_20hz	20-Hz longitude	time, meas_ind	deg_east	1.e-07	int
alt_rate	orbital altitude rate	time	m/s	0.002	short
alt_cnes	CNES orbital altitude	time	m	0.0001/ 700000	int
alt_cnes_20hz	20-Hz CNES orbital altitude	time, meas_ind	m	0.0001/ 700000	int
drange_cal	internal calibration correction to range	time	m	0.001	short
drange_fm	Doppler correction to range	time	m	0.001	short
flags	flag word	time	-	-	short
range_ku	Ku-band range corrected for instr. effects	time	m	0.0001/ 700000	int
range_20hz_ku	20-Hz Ku-band range corrected for instr. effects	time, meas_ind	m	0.0001/ 700000	int
range_used_20hz_ku	20-Hz flag for utilization in the computation of 1-Hz Ku-band range	time, meas_ind	-	-	byte
range_rms_ku	std dev of Ku-band range	time	m	0.0001	short

range_numval_ku	number of valid Ku-band measurements	time	1	-	byte
swh_20hz_ku	20-Hz Ku-band significant wave height	time, meas_ind	m	0.001	short
swh_ku	Ku-band significant wave height	time	m	0.001	short
swh_rms_ku	std dev of Ku-band significant wave height	time	m	0.001	short
agc_ku	Ku-band automatic gain control	time	dB	0.01	short
sig0_20hz_ku	20-Hz Ku-band backscatter coefficient	time, meas_ind	dB	0.01	short
sig0_ku	Ku-band backscatter coefficient	time	dB	0.01	short
sig0_rms_ku	std dev of Ku-band backscatter coefficient	time	dB	0.001	short
off_nadir_angle2_wf_ku[1]	off-nadir pointing angle squared from waveform	time	deg^2	0.0001	short
off_nadir_angle2_wf_rms_ku[1]	std dev of off-nadir pointing angle squared from waveform	time	deg^2	0.0001	short
attitude_pitch	platform pitch angle	time	deg	0.0001	short
attitude_pitch_20hz	20-Hz platform pitch angle	time, meas_ind	deg	0.0001	short
attitude_roll	platform roll angl	time	deg	0.0001	short
attitude_roll_20hz	20-Hz platform roll angle	time, meas_ind	deg	0.0001	short
attitude_yaw	platform yaw angle	time	deg	0.0001	short
attitude_yaw_20hz	20-Hz platform yaw angle	time, meas_ind	deg	0.0001	short

[1] Data item only available in MLE4 products (off-nadir pointing is estimated in the MLE4 process)

off_nadir_angle2_pf	off-nadir pointing angle squared from platform	time	deg^2	0.0001	short
flags_star_tracker	star tracker flags	time	-	-	byte
peakiness_20hz_ku	20-Hz Ku-band peakines	time, meas_ind	1	0.01	short
peakiness_ku	Ku-band peakiness	time	1	0.01	short
mqe_20hz_ku	20-Hz mean quadratic error of Ku-band waveform fit	time, meas_ind	-	0.001	short
mqe	mean quadratic error of waveform fit	time	-	0.001	short
noise_floor_20hz_ku	20-Hz Ku-band noise floor of waveforms	time, meas_ind	dB	0.001/ -20	short
noise_floor_ku	Ku-band noise floor of waveforms	time	dB	0.001/ -20	short
noise_floor_rms_ku	std dev of Ku-band noise floor of waveforms	time	dB	0.001	short
range_tracker_20hz_ku	20-Hz Ku-band tracker range corrected for instr. effects	time, meas_ind	m	0.0001/ 700000	int
agc_20hz_ku	20-Hz Ku-band automatic gain control	time, meas_ind	dB	0.01	short
waveform_scale_20hz	waveform scale factor	time, meas_ind	dB	0.001	int
waveform_20hz	waveform data	time, meas_ind, wvf_ind	-	-/32768	short
dry_tropo_ecmwf	ECMWF dry tropospheric correction	time	m	0.0001	short
wet_tropo_ecmwf	ECMWF wet tropospheric correction	time	m	0.0001	short
iono_bent	Bent ionospheric correction	time	m	0.0001	short
iono_gim	JPL GIM ionospheric correction	time	m	0.0001	short

inv_bar_static	static inverse barometer correction	time	m	0.0001	short
inv_bar_mog2d	MOG2D dynamic atmospheric correction	time	m	0.0001	short
tide_solid	solid earth tide	time	m	0.0001	short
tide_ocean_got00	GOT00.2 ocean tide	time	m	0.0001	int
tide_load_got00	GOT00.2 load tide	time	m	0.0001	short
tide_pole	pole tide	time	m	0.0001	short
tide_equil	long-period equilibrium ocean tide	time	m	0.0001	short
dsig0_atmos_ku[1]	Ku-band backscatter coefficient correction due to atmosphere/attitude	time	dB	0.01	short
water_vapor_content_gfs[2]	NOAA/GFS water vapor content	time	kg/m^2	0.01	short
liquid_water_gfs[2]	NOAA/GFS liquid water content	time	kg/m^2	0.01	short
wind_speed_alt	altimeter wind speed	time	m/s	0.01	short
ssb_hyb	hybrid sea state bias	time	m	0.0001	short
alt_gdre	CNES GDR-E orbital altitude	time	m	0.0001/ 700000	int
alt_eig6c	ESOC EIGEN-6C orbital altitude	time	m	0.001	int
dist_coast	distance to coast	time	km	-	short
inv_bar_mog2d_ mean	local mean MOG2D dynamic atmospheric correction	time	m	0.0001	short
gia	ICE5G GIA correction	time	m	0.0001	short

[1] Data item only available in MLE4 products (correction to sigma0, based on MLE4 estimated off-nadir pointing)

[2] Data item not SCOOP RDSAR specific: recently added as part of RADS 'common' auxiliary info: source NOAA GFS system

mss_cnescls11	CNES-CLS11 mean sea surface height	time	m	0.0001	int
basin	basin code	time	1	-	byte
geoid_egm2008	EGM2008 geoid height	time	m	0.0001	int
mss_cnescls15	CNES-CLS15 mean sea surface height	time	m	0.0001	int
topo_dtu10	DTU10 topography	time	m	-	short
mss_dtu13	DTU13 mean sea surface height	time	m	0.0001	int
mss_dtu15	DTU15 mean sea surface height	time	m	0.0001	int
mss_dtu18	DTU18 mean sea surface height	time	m	0.0001	int
geoid_eigen6	EIGEN6 geoid height	time	m	0.0001	int
topo_srtm30plus	SRTM30_PLUS topography	time	m	-	short
geoid_xgm2016	XGM2016 geoid height	time	m	0.0001	int
topo_srtm15plus	SRTM15_PLUS topography	time	m	-	short
prox_coast	coastal proximity parameter	time	-	0.01	byte
surface_type	surface type	time	-	-	byte
surface_class	surface classification	time	-	-	byte
tide_ocean_fes04	FES2004 ocean tide	time	m	0.0001	int
tide_load_fes04	FES2004 load tide	time	m	0.0001	short
tide_ocean_got48	GOT4.8 ocean tide	time	m	0.0001	int
tide_load_got48	GOT4.8 load tide	time	m	0.0001	short
tide_ocean_got410	GOT4.10c ocean tide (extrapolated)	time	m	0.0001	int
tide_load_got410	GOT4.10 load tide	time	m	0.0001	short

mss_annual	annual variation of mean sea level	time	m	0.0001	short
tide_ocean_fes14	FES2014b ocean tide	time	m	0.0001	int
tide_load_fes14	FES2014a load tide	time	m	0.0001	short
tide_non_equil	long-period non-equilibrium ocean tide	time	m	0.0001	short
tide_ocean_webtide[1]	WebTide ocean tide	time	m	0.0001	int
ref_frame_offset	reference frame offset	time	m	0.0001	short
seaice_conc	sea ice concentration	time	%	-	byte
sst	sea surface temperature	time	deg C	0.01	short
sst_mean	local mean sea surface temperature	time	deg C	0.01	short
dry_tropo_ncep	NCEP dry tropospheric correction	time	m	0.0001	short
wet_tropo_ncep	NCEP wet tropospheric correction	time	m	0.0001	short
dry_tropo_airtide	air tide correction to the dry tropospheric correction	time	m	0.0001	byte
dry_tropo_era	ERA dry tropospheric correctio	time	m	0.0001	short
wet_tropo_era	ERA wet tropospheric correction	time	m	0.0001	short
iono_iri2007	IRI2007 ionospheric correction	time	m	0.0001	short
iono_nic09	NIC09 ionospheric correction	time	m	0.0001	short
swh_ww3	WaveWatch3 significant wave height	time	m	0.01	short

[1] Data item not SCOOP RDSAR specific: recently added as part of RADS ‘common’ auxiliary info: source Bedford Institute of Oceanography

ssha	sea surface height anomaly, default corrections applied	time	m	0.0001	short
ssha_20hz	20-Hz sea surface height anomaly, default corrections applied	time, meas_ind	m	0.0001	short
wet_tropo_uporto[1]	UPORTO wet tropospheric correction	time	m	0.0001	Short

Table 5-3: Netcdf variables of final RDSAR L2 product (RADS c2#pass#cycle.nc file). Global attributes of netCDF files are discussed in the PSD document [AD. 5]

From the information in the final product the end-user can calculate the sea level anomaly to his/her own liking choosing certain correction and models that fit their research purpose. Normal procedure is to use:

$$SLA = alt - range - dry_{tropo} - wet_{tropo} - iono - dac - tide_{solid} - tide_{ocean} - tide_{load} - tide_{pole} - ssb - mss - refframe_{offset}$$

The added fields ssha and ssha_20hz in the final product are precomputed SLAs using the above-mentioned formula and using the default corrections and models:

alt_gdre, range_ku, dry_tropo_ecmwf, wet_tropo_ecmwf, iono_gim, inv_bar_mog2d, tide_solid, tide_ocean_fes14, tide_load_fes14, tide_pole, ssb_hyb, mss_dtu15, ref_frame_offset for the 1 Hz data, and applying the same variables to range_20hz_ku for the 20 Hz data.

The flags flag word is explained in Table 5-4, and in more detail in the RADS data manual [RD-10].

[1] Data item available when the command “rads_add_uporto –sat c2/a -all” has been executed; it is only readily available in later SCOOP RDSAR products (when it became available). It is also not used as default correction in the SLA calculations. The UPorto wet tropospheric correction though is available as a separate SCOOP data set and can be applied “offline” if not in the RDSAR netcdf.

Variable	field	name	values	sat
flag_alt_oper_mode	2516	bit 0: hardware/software status	0 = nominal, 1 = bad	pn tx
	2516	bit 0: altimeter operating mode	0 = Side A, 1 = Side B	j1 j2 j3 n1
	2516	bit 0: altimeter operating mode	0 = LRM, 1 = SAR	3a 3b c2
qual_sptr	2516	bit 0: SPTR availability		e1
qual_attitude	2501	bit 1: quality of attitude	0 = ok, 1 = bad	3a 3b e2 j1 j2 j3 n1 tx sa
		bit 1: quality of attitude	0 = ok, 1 = suspect	g1 gs pn
qual_dh	2502	bit 2: dH status	1 = suspect	gs
flag_rad_oper_mode	2502	bit 2: TMP 21 GHz Channel status	0 = A, 1 = B	pn tx
flag_continental_ice	2502	bit 2: continental ice flag	0 = no, 1 = yes	3a 3b c2 j1 j2 j3 n1 sa
qual_iono_alt	2503	bit 3: quality of dual-frequency iono corr	0 = ok, 1 = bad	3a 3b j1 j2 j3 n1 tx
flag_water	2504	bit 4: water/dry flag	0 = open ocean or enclosed sea or lake, 1 = land	all
flag_ocean	2505	bit 5: ocean/land flag	0 = open ocean, 1 = land or enclosed sea or lake	all
surface_type_rad	2506	bit 6: radiometer land flag	0 = water, 1 = land	all but c2 gs
qual_alt_rain_ice	2507	bit 7: altimeter rain/ice flag	0 = no rain/ice, 1 = rain/ice	3a 3b g1 j1 j2 j3 n1 pn sa tx
qual_rad_rain_ice	2508	bit 8: radiometer rain/ice flag	0 = no rain/ice, 1 = rain/ice	3a 3b e1 e2 j1 j2 j3 n1 pn tx
qual_rad_tb	2509	bit 9/10: radiometer quality flag	0 = ok, 1 = interp. near land, 2 = extrap., 3 = interp. failed	pn tx
			0 = ok, 1 = bad tb238, 2 = bad tb365, 3 = both bad	3a 3b e1 e2 n1
			0 = ok, 1 = bad tb220, 2 = bad tb370, 3 = both bad	g1
			0 = ok, 1 = bad tb187/tb238, 2 = bad tb340, 3 = both bad	j1 j2 j3
			0 = ok, 1 = bad tb238, 2 = bad tb370, 3 = both bad	sa
qual_range	2511	bit 11: quality of range	0 = ok, 1 = some 10Hz invalid	gs
			0 = ok, 1 = suspect	other
qual_swh	2512	bit 12: quality of SSB	0 = ok, 1 = suspect	gs
		bit 12: quality of SWH	0 = ok, 1 = suspect	other
qual_sig0	2513	bit 13: quality of wind speed	0 = ok, 1 = suspect	gs
		bit 13: quality of sigma0	0 = ok, 1 = suspect	other
flag_alt_track_mode	2514	bit 14: altimeter tracking mode	0 = nominal, 1 = preset	e1 e2
			0 = nominal, 1 = coarse or acquisition	gs tx
			0 = nominal, 1 = C-band coarse	j1
			0 = nominal, 1 = acquisition	pn
qual_orbit	2515	bit 15: orbital quality flag	0 = ok, 1 = suspect	all
surface_type		surface type	0 = open ocean, 2 = enclosed sea or lake, 3 = land, 4 = continental ice	all
surface_class		surface class	0 = open ocean, 1 = land, 2 = continental water, 3 = aquatic vegetation, 4 = continental ice or snow, 5 = floating ice, 6 = salted basin	all

Table 5-4: The individual bits of the flag word flags. In general, 0 means no or OK, 1 means yes or bad.