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SWIM PRODUCTS USERS GUIDE

Product description and Algorithm Theoretical Baseline Description

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CHANGES

Issue	Rev.	Date	Reference, Author(s), Reasons for evolution
01	00	18/05/2016	Creation of the document.
01	01	18/04/2018	Upgrade of the document to take into account some modifications in the definition of all level products. The product tables have been updated.
01	02	07/06.2019	Update of the document taking into account the evolution of the CWICC products generated through version 4.3.2 of the CWWIC processor

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List of TBC items:

none	none

List of TBD items:

none	none

ACRONYMS AND NOTATIONS

Notation	Definition
ϕ	Azimuth angle
σ_0	Radar backscattering coefficient
θ	Incidence angle
AOCS	Attitude and Orbit Control System
CDB	Common Data Base
CFOSAT	China France Oceanography SATellite
CHOGS	Chinese Oceanographic Ground Segment
CCSDS	Consultative Committee for Space Data Systems
CWICC	Cnes Wind & Waves Instrument Center
ECMWF	European Centre for Medium-Range Weather Forecasts
FROGS	French Oceanography Ground Segment
GPM	Global Precipitation Measurement
IWWOC	Ifremer Wind & Waves Oceanographic Center
LSB	Least significant bit
LUT	Look-Up Table
NIMP	Number of pulses per cycle
r	Radar range (distance between the sensor and the ground for one gate)
SCAT	SCATterometer (wind fan-beam scatterometer)
SWH	Significant Wave Height
SWEC	Swim Expertise Cell
SWIM	Surface Wave Investigation and Monitoring
TM	Telemetry
TRMM	Tropical Rainfall Measuring Mission
VCDU	Virtual Channel Data Unit
WS	Wind Speed

1. OVERVIEW

1.1. SCOPE

The French ground segment implemented for the CFOSAT mission (FROGS) will distribute products from the SWIM and SCAT instruments from level 1 up to level 4. **This document focuses on the products generated using the SWIM payload measurements.** This document aims at describing the content of these different products and the associated algorithms used to compute them. It should help the users to select and understand the content of the files to develop their own applications. An overview of the FROGS is provided as well as an overview of the processing steps. For each processing level, the algorithms are first described and then, each variable of the product files is explained.

1.2. DOCUMENT OVERVIEW

The SWIM Product Users Guide is organised as follows:

- chapter 2: overview of the CFOSAT mission, the SWIM instrument and the FROGS,
- chapter 3: explanation of the product distribution for the two entities of the FROGS (CWWIC and IWWOC),
- chapter 4: description of the CWWIC products,
- chapter 5: description of the IWWOC products.

1.3. APPLICABLE AND REFERENCE DOCUMENTS

1.3.1. Reference documents

Index	Reference	Title
DR1	CF-SYMI-SP-20-CNES 03/00	Mission requirement document
DR2	CF-SCPLSW-NT-2441-CNES 01/00	SWIM description for CDR
DR3		Jackson F. C., T.W. Walton, and P.L. Baker, Aircraft and satellite measurement of ocean wave directional spectra using scanning-beam microwave radars, Journal of geophysical research, Vol. 90, No. C1, Pages 987-1004, January 20,1985b
DR4		Jackson, F. C., W.T. Walton, and C.Y. Peng, A comparison of in situ and airborne radar observations of ocean wave directionality, Journal of Geophysical Research, 90(C1), 1005-1018, 1985a
DR5		J. Lillibridge, R. Scharroo, S. Abdalla, and D. Vandemark, One- and Two-Dimensional Wind Speed Models for Ka-Band Altimetry. J. Atmos. Oceanic Technol., 31, 630–638, 2014

		doi: http://dx.doi.org/10.1175/JTECH-D-13-00167.1
DR6		J. Tournadre et al., “Cloud and rain effects on ALTIKA/SARAL Ka band radar altimeter, Part II: Definition of a rain/cloud flag,” IEEE TGRS, 2009
DR7		Torrence C., Compo G., “A Practical Guide to Wavelet Analysis”. Bulletin of the American Meteorological Society. Vol.79, N°1, p.61-78, 1998
DR8		Gourrion, J., D. Vandemark, S. Bailey and B. Chapron, Satellite altimeter models for surface wind speed developed using ocean satellite crossovers. Report number IFREMER-DROOS-2000-02, May 17th, 2000. Available from http://www.ifremer.fr/droos/Perso/gourrion/rapport/rapport.html
DR9		E. Soussi, Contribution à la spécification et à l’analyse des performances du système VAGSAT pour la mesure spatiale des vagues à partir d’un radar à ouverture réelle, thèse de doctorat, université Paris VI, 1997
DR10		Hauser D., E. Soussi, E.,Thouvenot, L. Rey: SWIMSAT: A real aperture radar to measure directional spectra of ocean waves from space, Main characteristics and performance simulation, Jour. Atmos. and Oceanic Tech, vol 18 No3, 421-437, 2001
DR11		Rayney, R., Bamler, R., Cumming, I., et Wong, F., Precision SAR processing using chirp scaling, IEEE Transactions on Geoscience and Remote Sensing, 1994
DR12	CF-GSFR-SP-1649-CNES	ALGORITHM THERORETICAL BASELINE DOCUMENT TRAITEMENTS DES SIGNAUX SWIM – NIVEAU L2A NADIR
DR13		Hauser, D., G. Caudal, G.-J. Rijckenberg, D. Vidal-Madjar, Laurent G., and P. Lancelin. RESSAC: A New Airborne FM/CW Radar Ocean Wave Spectrometer. IEEE Transactions on Geoscience and Remote Sensing, 30(5): 981–995, 1992
DR14		Freilich M.H., and B.A Vanhoff, The Relationship between Winds, Surface Roughness, and Radar Backscatter at Low Incidence Angles from TRMM Precipitation Radar Measurements, J. Atmosph. and Oceanic Tech, vol 20, april 2003, p 549-562
DR15		Hanson J.L. and O.M. Phillips, J. Atmos. And Oceanic Tech., vol18, 2001, p 277-293
DR16		Portilla et al., Spectral identification of wind sea and swell, Journal of Atmospheric and Oceanic Technology, 26(1), 107-122, 2009
DR17		**ENVISAT – Ice Detailed Processing Model document, issue 3, rev 6, 12133/96/NL-GS-DPM**
DR18		**Etude du retracking des formes d'ondes altimétriques au dessus des calottes polaires", CNES report, CT/ED/TU/UD/96.188, CNES contract 856/2/95/CNES/0060, B.**

		Legresy, 1995.

1.3.2. Applicable documents

Index	Reference	Title
DA1	CF-GSFR-ICD-1094-CNES	SWIM NRT Format Specification

2. CONTEXT

2.1. CFOSAT MISSION

The CFOSAT program is carried out through cooperation between French and Chinese Space Agencies (CNES and CNSA respectively). CFOSAT aims at characterizing the ocean surfaces to better model and predict the ocean states and improve the knowledge in ocean/atmosphere exchanges. The CFOSAT products will help for marine and weather forecast and for climate monitoring. The CFOSAT satellite will carry two scientific payloads: SCAT, a wind scatterometer, and SWIM, a wave scatterometer to allow a joint characterization of ocean surface winds and waves.

Figure 1. Artist view of the CFOSAT satellite © CNES/Gekko. The SWIM antenna is on the left (six feed horns mounted on a rotating baseplate and illuminating a parabola oriented towards the Earth surface) and the SCAT antenna is at the bottom right (two rectangular slotted waveguide antennas, one for HH and one VV polarization).

The scientific requirements on the two instruments are detailed in [DR1].

2.2. FRENCH GROUND SEGMENT

The French ground segment of CFOSAT (FROGS) aims at processing the data of the two payloads (similarly as the

Chinese ground segment) and at delivering them to the users. The Figure 2 proposes an overview of the architecture of the complete CFOSAT ground segment.

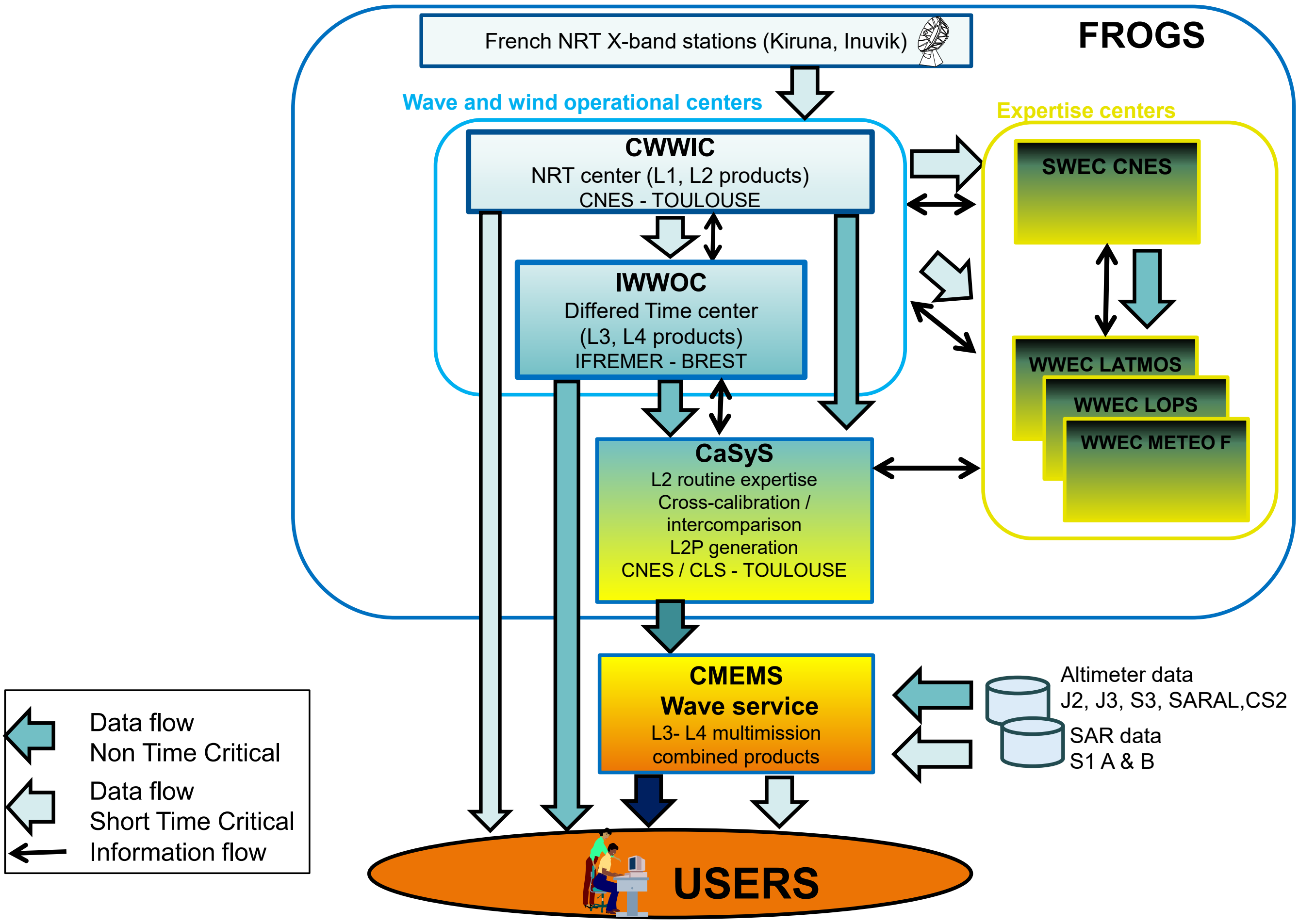


Figure 2. Overview of the French CFOSAT ground segment.

The FROGS is constituted from the following parts:

- the GSXB is the X-band polar ground stations which receives the data from the satellite (the stations are localized in Kiruna (Sweden) and Inuvik (Canada)),
- the CWWIC is the near-real time mission centre where the data are processed from the telemetry up to level 2 in less than three hours after the acquisition; it is localized at CNES (Toulouse, France),
- the IWWOC is the differed time mission centre where the data are processed from L2 to L4; it is localized at IFREMER (Brest, France),
- the SWEC is the SWIM expertise cell which expertise the SWIM L1 and nadir L2 data on-demand (NB: routine expertise activities are included in the CWWIC),
- the WWEC are the expert labs centre which perform CAL/VAL on the SWIM products with a special focus on L2, L3 and L4 products.

2.3. SWIM INSTRUMENT

The SWIM (Surface Wave Investigation and Monitoring) instrument delivered by CNES is dedicated to the measurement of the directional wave spectrum (density spectrum of wave slopes as a function of direction and wavenumber of the waves). It will contribute to improve the knowledge in the following fields:

- properties of the directional wave spectrum,
- modelling and prediction of ocean surface wind and waves,
- physical processes associated with surface wave evolution,
- wind-wave interactions,
- interactions between surface waves and atmosphere or ocean,
- wave evolution in coastal region,
- polar ice sheet,
- sea ice and iceberg characteristics,
- land surfaces (surface soil moisture, soil roughness…).

The data must be provided to operational users (meteorology agencies mainly) in nearly real time (i.e. in less than three hours from the acquisition). They are then available to the scientific community in less than 4 days on Aviso website (http://www.aviso.altimetry.fr/en/home.html).

SWIM is a Ku-band (13.575 GHz) real aperture radar which illuminates the surface sequentially with six incidence angles: 0°, 2°, 4°, 6°, 8° and 10° with an antenna aperture of approximately 2°. The antenna design is visible in Figure 1: it includes a plate on which six feed horns are fixed, oriented towards an offset parabola. This latter is oriented towards the Earth surface. In order to acquire data in all azimuth orientations, the feed horn plate has a rotating mechanism. When activated, its rotation speed is 5.6 rpm. In order to acquire data in all azimuth orientations, the antenna is rotating at a speed rate of 5.6 rpm. A detailed description of SWIM and its performance can be found in [DR2]. The paragraphs below provide the main information necessary to understand the content of the SWIM data and products.

2.3.1. Main parameters of SWIM

The SWIM instrument principle uses the fact that at low incidence angle (around 8°-10°), the normalized radar cross-section is sensitive to the local slopes related to the tilt of the long waves but almost insensitive to small scale roughness due to wind as well as to hydrodynamic modulations due to interaction of short waves and long waves This is in particular confirmed by the Ku-band TRMM measurements acquired between 0° and 18° incidence, which show that the backscattering coefficient of the surface is almost independent from wind) around incidences 8° to 10° [ref]. Besides, in case of a real aperture radar like SWIM, the measurement implies azimuthal averaging on the radar footprint so that only surface waves propagating along the beam's line of sight are measured. Therefore, a conical scan around nadir angle allows detecting all the direction of the waves.

The Table 1 summarizes the main parameters of SWIM. The six beams are illuminated sequentially with different PRF values for each incidence angle. The PRF are adaptive along the orbit to take into account the variations of the altitude in latitude.

Parameter	Value
Frequency	13.575 GHz
Useful bandwidth	320 MHz
Useful pulse duration	50 µs
Peak power	120 W
Central elevation angles (on board)	0° - 2.29° - 3.70° - 5.55° - 7.40° - 9.25°
PRF	~5 kHz for all beams
Antenna rotation speed	5.6 rpm
Antenna diameter	90 cm
Antenna 3dB aperture for Nadir and 2°	1.6°
Antenna 3dB aperture for 4°, 6°,8° and 10°	> 1.75°
Polarization	Linear polarization and rotating

Table 1. SWIM main parameters

In a way similar to radar altimeters, the nadir beam allows estimating the significant wave height (SWH) and the wind speed (WS). The nadir beam also allows the general synchronization of the instrument since it gives a relative altitude on-board and the sequential piloting of the other beams (2° to 10°).
The five non nadir beams allow measuring the backscattering coefficient, σ_0, and creating a σ_0 profile as a function of the incident angle. The 6°, 8° and 10° beams are called here the "spectrum beams" because these beams are used to estimate the wave spectrum. Note that due to some mechanical constraints in the design of the baseplate of the horns, the six incidence beams point towards the surface with a different azimuth angle (see Figure 3).

The next figure illustrates the geometry of the SWIM acquisition.

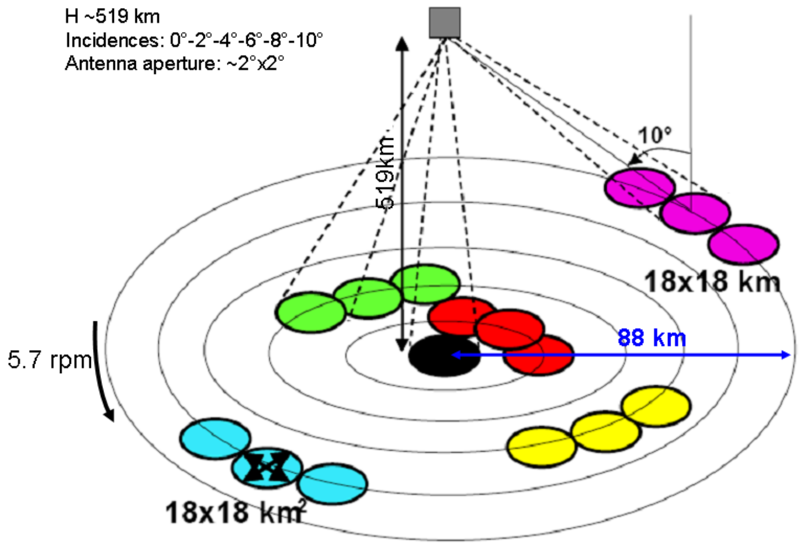


Figure 3. SWIM illumination pattern

Concerning the radar sampling, the following terminology is defined

- **cycle** of measurements (or cycle): it is the elementary sequence of data acquisition for a given incidence beam. It corresponds to the time spent for on-board data integration on a given incidence beam. Table 2 indicates for each cycle the number of samples averaged on board (constant number for each beam). Due to the variation of the satellite altitude along its orbit, the PRF is adapted along the orbit. As a consequence, the cycle duration of each beam slightly varies along the orbit. The minimum and maximum values are also indicated in Table 2.
- **macro-cycle** of measurements (or macrocycle): it is the set of the repeated successive cycles. The nominal macro-cycle is made of six cycles sampling successively all the incidence beams (0°, 2°, 4°, 6°, 8°, 10°). Alternative macro-cycles may be chosen as long as they respect the maximum consumption, the maximum duty-cycle and the maximum data rate. The macro-cycles (0°, 8°, 8°) and (0°, 6°, 8°, 10°) are good candidates for alternative sequencing.

	0°	**2°**	**4°**	**6°**	**8°**	**10°**
Ambiguity rank	18	18	18	18	18	18
Min PRF (Hz)	5093	5079	5079	5065	5037	5023
Max PRF (Hz)	5427	5427	5411	5395	5379	5348
Nimp	**264**	**97**	**97**	**156**	**186**	**204**
Max integration time length (ms)	51,8	19,1	19,1	30,8	36,9	40,6
Min cycle length (ms)	52,0	21,2	21,3	32,3	37,9	41,5
Max cycle length (ms)	55,4	22,6	22,6	34,4	40,5	44,2

Table 2. Chronogram of SWIM.

2.3.2. On-board processing

Because of the limitations on the telemetry rate and the huge data amount acquired by SWIM, on-board processing is mandatory. It aims at reaching the final range resolution and averaging in time and range to reduce drastically the data rate. For each cycle, only one averaged waveform is downloaded. The on-board processing is the following:

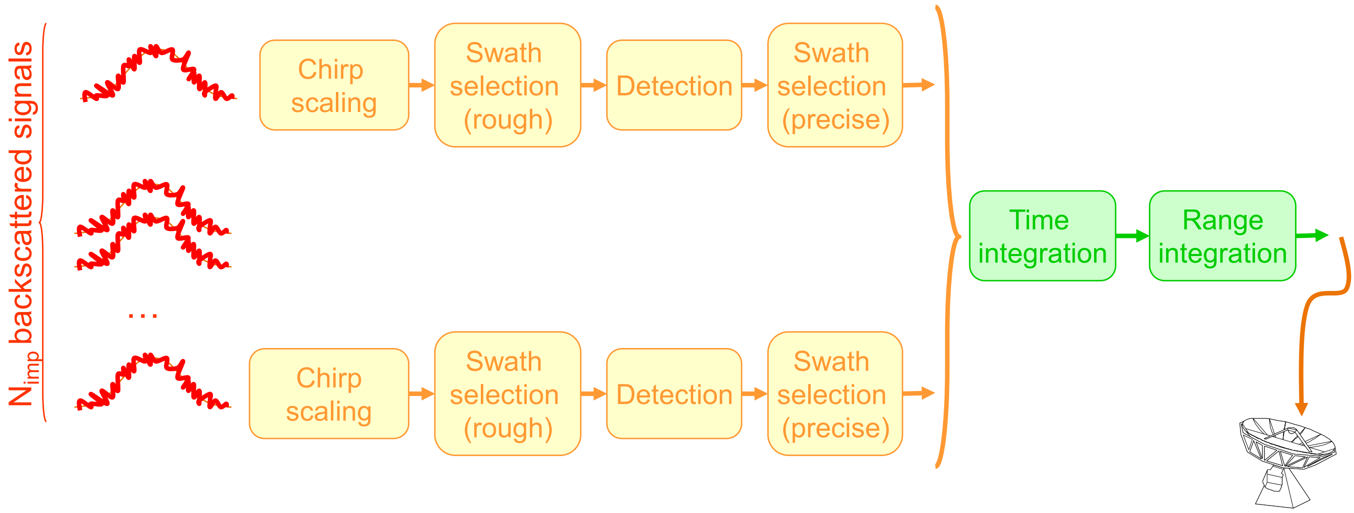


Figure 4. Nominal on-board processing

The first step of the nominal on-board processing is the range compression. The raw signal is badly resolved due to the long-time impulse. Yet, as the emitted signal is a chirp, a specific signal processing (simple convolution by a replica signal) delivers a well resolved signal. The resolution is inversely proportional to the bandwidth of the emitted signal (320MHz).
Nonetheless, due to the data rate limitation, a time averaging over the cycle is mandatory. Therefore, the range compression for SWIM cannot just be a convolution by the replica. During the acquisition of these N_{imp} pulses the satellite has moved forward and the antenna has rotated, inducing migrations in the measured signal. Thus, before averaging, it is required to co-register the signals from successive echoes. The chirp scaling algorithm [DR11] has been selected to achieve both the range compression and the co-registration at the same time. This is performed for the spectrum beams only (6°, 8° and 10°). The other beams do not require a precise registration.

The other steps of the on-board processing are simpler: selection of the swath, averaging in time and range. The table below presents the averaging parameters and the number of downloaded points per swath (after on board range averaging). The range averaging shall preserve the requirement on the effective resolution (< 35 m for spectrum beams). The effective resolution is the resolution of the signal obtained after the chirp scaling processing. This function cannot correct all the migrations of the signal. Therefore some registration errors remain leading to an effective resolution greater than the intrinsic resolution of each impulse taken individually.

	0°	2°	4°	6°	8°	10°
Nimp (time averaging)	264	97	97	156	186	204
Ldis (range averaging)	1	4	4	2	3	3
Number of pixels per swath (after range averaging)	512	1026	1458	2772	2784	3216

Table 3. Number of pixels (range cells) available per beam
The number of pulses (N_{imp}) and the number of range cells (L_{dis}) which are averaged on board are also specified in this table. The final number of pixels per swath includes the on-board averaging (L_{dis}).

2.3.3. Instrument modes

SWIM has different working modes as summarized in Figure 5. After the initialization, SWIM reaches the STAND-BY mode, waiting for a remote command to reach another mode:

- ANTENNA ROTATION mode: this mode enables to stop or to initiate the rotation of the antenna, no radar measurement are performed in this mode;

- CAL1 mode: this mode is for internal calibration (estimation of the instrument impulse response and the instrument gain).
  It is split in three sub-modes: CAL1_INT for internal calibration without the antenna, CAL1_TX and CAL1_RX for calibration including the antenna up to the feed horns through a calibration horn fixed at the side of the parabola.
- CAL2 mode: this mode is designed for the measurement of the gain variations in the reception window;
- ACQUISITION mode: in this mode, radar echoes are emitted from the nadir beam only; the nadir waveform is processed on board to determine the temporal reception window; once the nadir echo is well positioned in the acquisition window, SWIM goes automatically to the TRACKING mode;
- TRACKING mode: this is the science measurement mode in which the radar signal is emitted from the different beams according to the defined macro-cycle; it is possible to modify the macro-cycle and it is also possible to activate the TRACKING mode with the "speckle mode".
  The "speckle mode" is a variant of the on-board processing: instead of downloading one averaged power of the Nimp pulses, three averaged power over Nimp/3 pulses are downloaded. To maintain the telemetry data rate, the averaging in range (Ldis) is increased by a factor of 3.

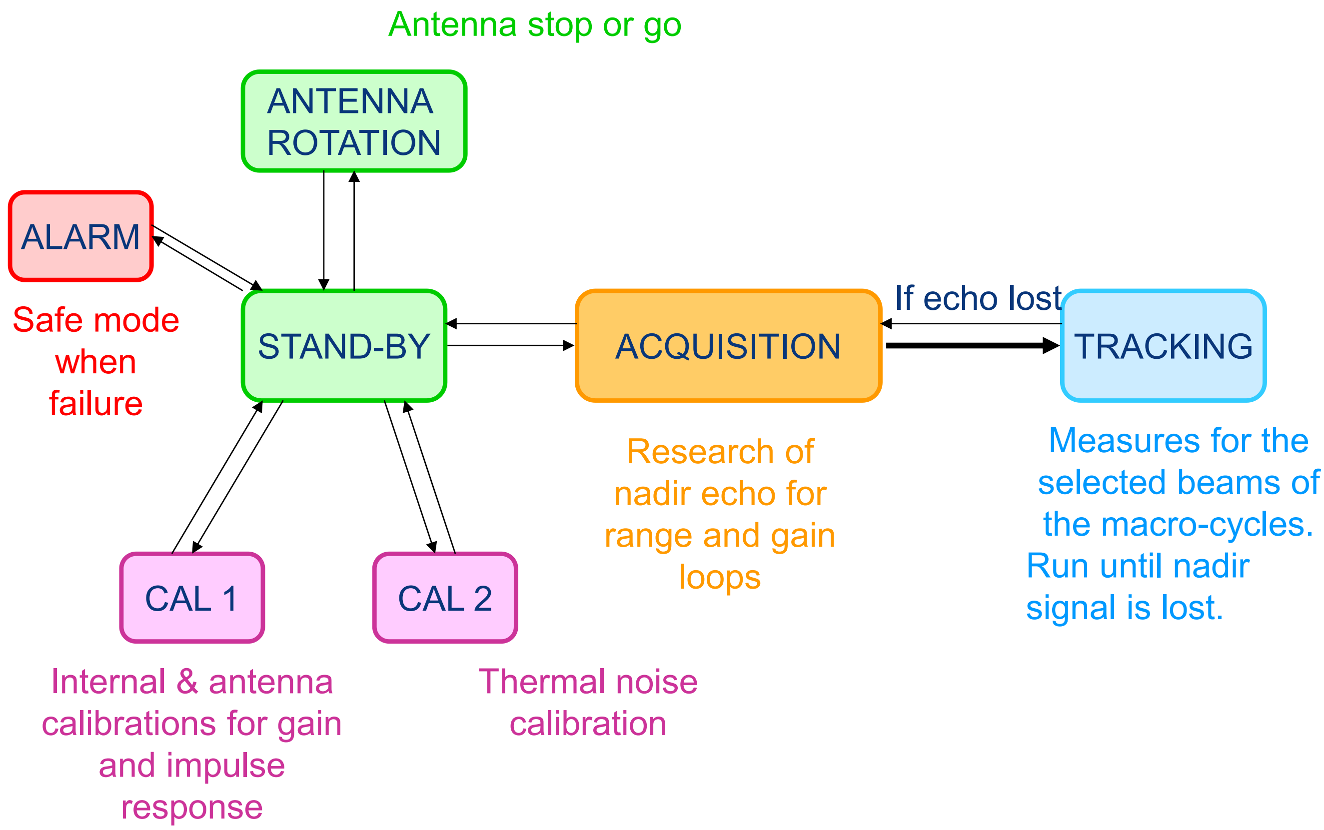


Figure 5. Overview of the SWIM modes. There is only one automatic transition between ACQUISITION and TRACKING.

Focusing on the different modes which provide scientific products (excluding calibration and tracking), the different options are:

- Mode of macrocycle: the nominal mode is the sequence “0-2-4-6-8-10” but alternative modes may be chosen as 0-10-10 or 0-8-8 or 0-2-8-8-8 or 0-2-10-10 (other combinations are possible). Wave spectra are provided only if at least one of the beams at 6°, 8° or 10° is chosen in the sequence

- Mode for the antenna rotation: rotating or stopped. The mode antenna stopped is only used only for punctual inter-beam comparison of the normalized radar cross-sections

- Mode for the on-board processing: standard or« speckle”. The speckle mode, which corresponds to on-board averaging of the radar echoes in time over 1/3 of samples compared to the standard mode, is used for specific studies of the speckle noise. This mode also corresponds to on-board averaging of the radar echoes in range over a number of gates which is 3 times the one used for the standard mode

3. CWWIC PRODUCTS

The CWWIC products are in NetCDF 4.0 format (with C type ordering). All the SWIM files produced by the CWWIC are defined in [DA1].

The products are generated for each download. One download corresponds to 95 min of data in average (105 min maximum). There is no re-organization of the data pole-to-pole. One file covers thus all the measurements from one download to another, except if there is a change in the instrument configuration. In this case, separate files are generated, each one related to a given instrument configuration.

3.1. MAIN PRODUCTS

The SWIM data are inversed to retrieve three main kinds of geophysical products (Figure 6):

- the **backscattering coefficient profiles** sampled every 0.5° in incidence and 15° in azimuth (σ_0 averaged products),
- the 2D directional **wave spectra** (wave products),
- the **altimetry-like products** (nadir products), in particular the significant wave height SWH, the normalized radar-cross-section sigma0 and the wind speed WS.

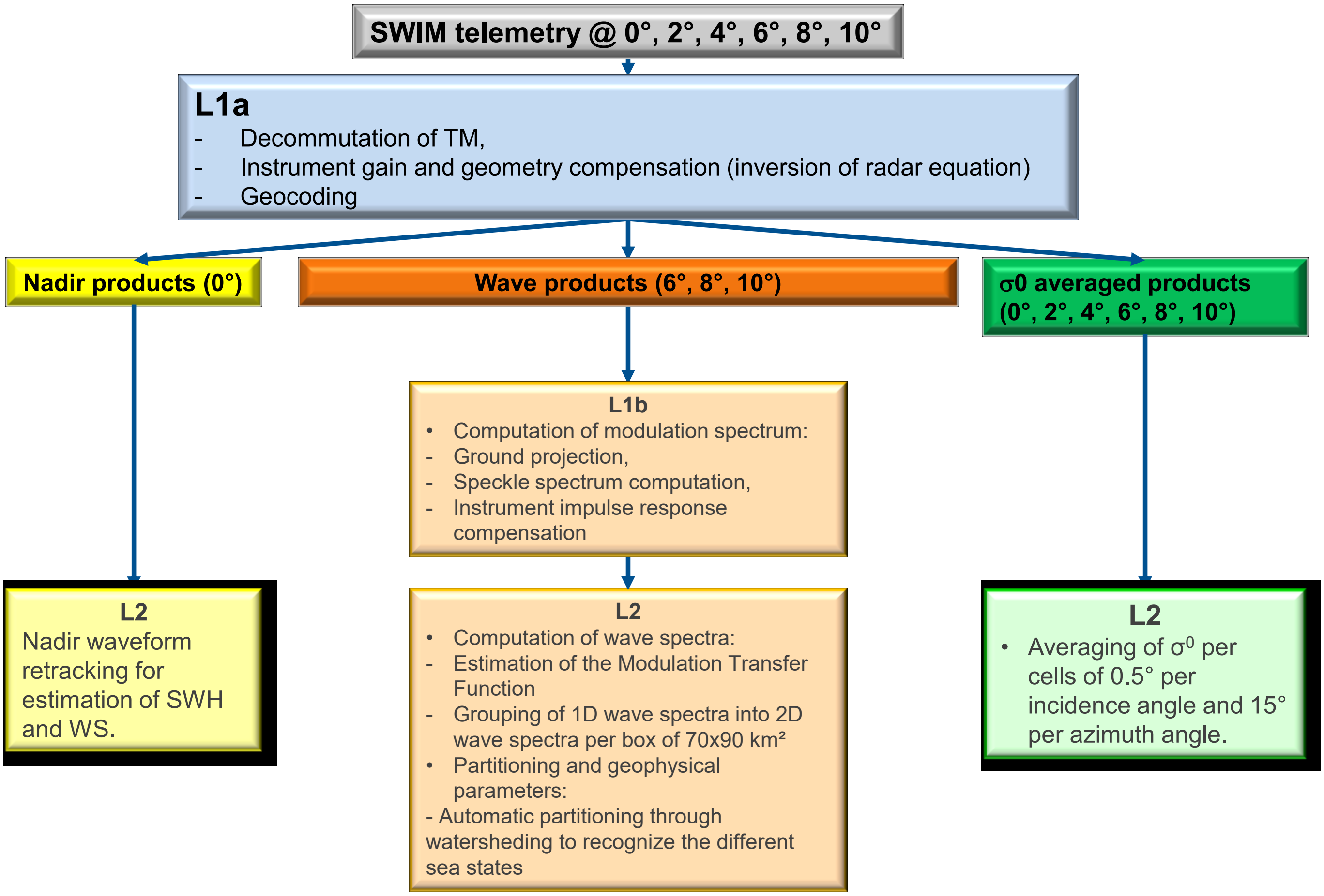


Figure 6. Overview of the main physical parameters estimated from the SWIM data. The levels of products are detailed in the following paragraphs.

Six kinds of files are made available to the users per download (Table 4). The exact content of these files is described in the paragraphs 3.5, 3.6, 3.7 and 3.8.

File Name	File Type	File Description	Update frequency
SWI_L1A___	L1a product	Contains calibrated and geocoded waveform	15 files per day
SWI_L1ALT1	Long term calibration product	Contains temporal mean of calibration parameters used to calibrate the waveform values (from CAL1 mode)	3 files per day [AC], sent by CNES to NSOAS once per week
SWI_L1ALT2	Long term calibration product	Contains temporal mean of calibration parameters used to calibrate the waveform values (from CAL2 mode)	3 files per day [AC], sent by CNES to NSOAS once per week
SWI_L1B___	L1b product	Contains the signal modulation (surface geometry), the fluctuation spectrum, the estimation of speckle and impulse response, and the modulation spectrum (fluctuation spectrum corrected from speckle and impulse response)	15 files per day
SWI_L2____	L2 product which contains L2SPEC, L2ANAD, L2ASIG variables	Contains the σ_0 profiles (L2ASIG), the SWH and the WS values (L2ANAD), the 2D wave spectra, the associated partitions and wave parameters (L2SPEC).	15 files per day
SWI_NRT___	NRT product delivered to meteorological agencies	Contains a subset of the L1B and L2 variables (modulation spectrum, 2D wave spectra, partitions, SWH, WS).	15 files per day
SWI_AUX_METEO	ECMWF Meteorological products sampled on SWIM data locations	Contains some meteorological variables sampled at the location of SWIM acquisitions.	15 files per day

Table 4. Available files at CWWIC for the SWIM data. Each file covers one download (~95 min in average). In case of modification of the instrument configuration, there will be more files.

The Figure 7, Figure 8 and Figure 9 show a schematic view of the processing chain and illustrations of some CWWIC products.

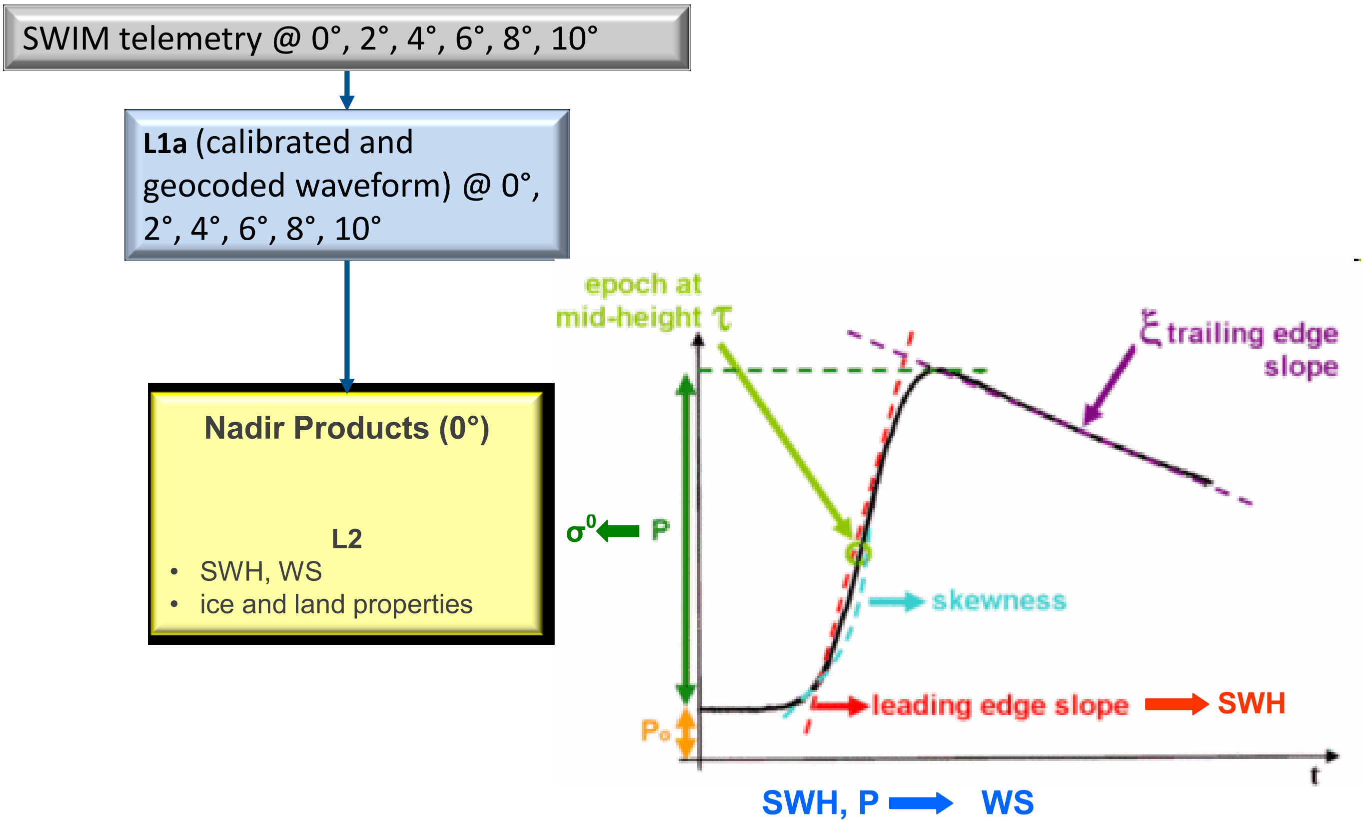


Figure 7. Simplified view of the nadir processing. This processing is a nadir retracking based on the adjustment of a nadir analytical waveform (Brown model) to the nadir measurement.

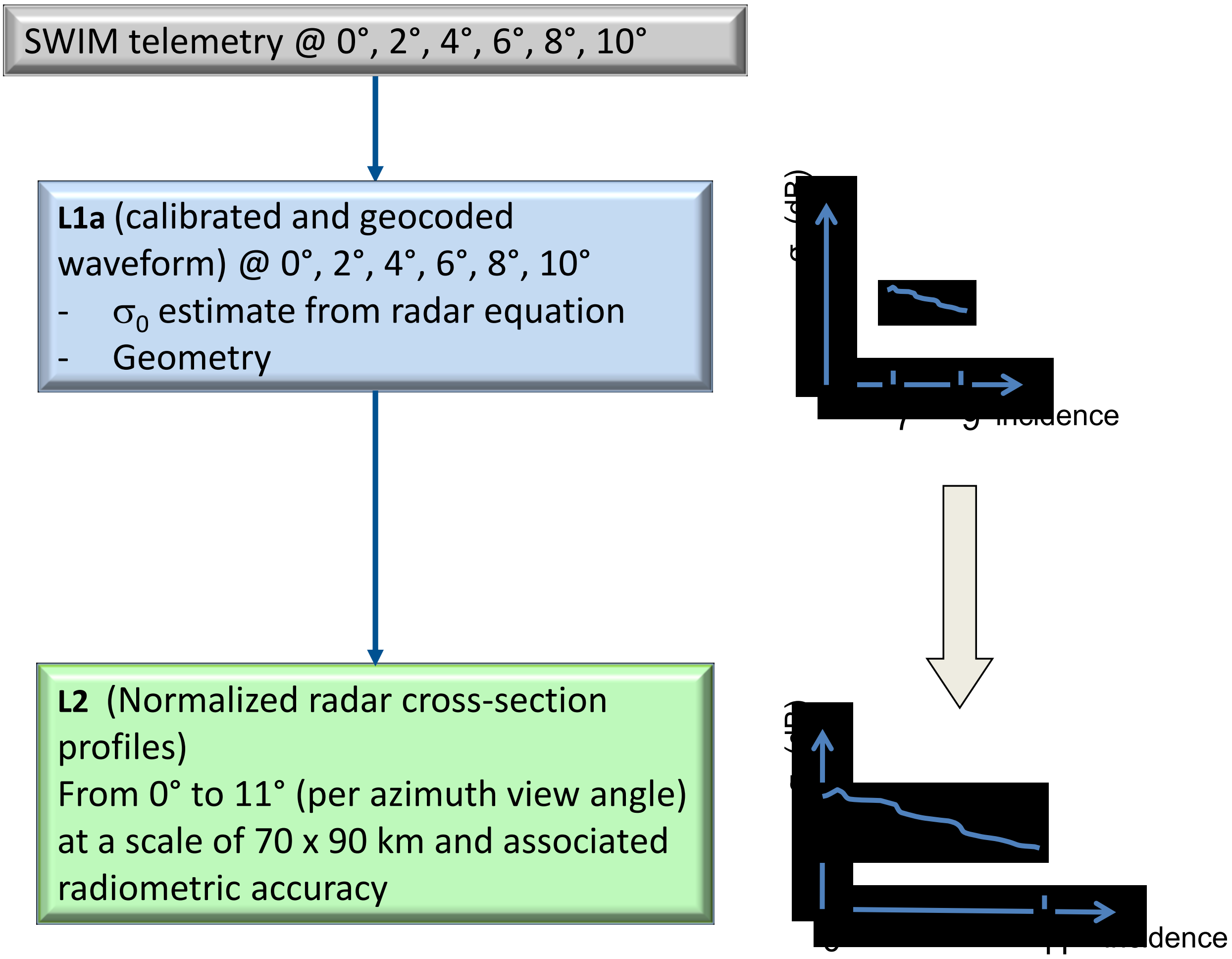


Figure 8. Simplified view of the σ^0 profile processing.

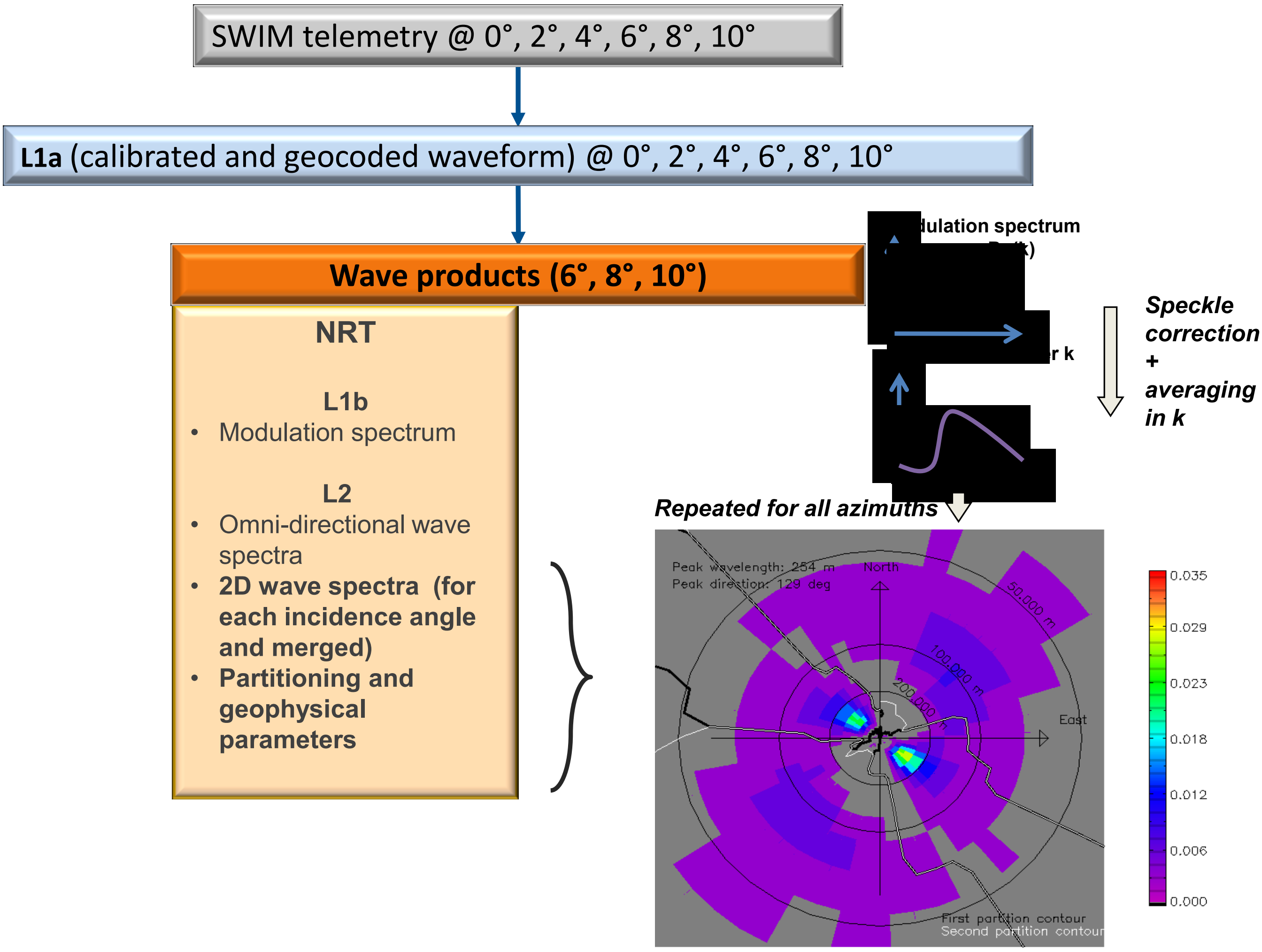


Figure 9. Simplified overview of the processing of the wave spectra.

3.2. OVERVIEW OF THE PROCESSING CHAIN

The processing chain is made of seven processors (Figure 10) to perform the processing from the telemetry (TLM_SWIM) up to the L2 files. The processors are named Fxxx, xxx indicating the name of the processor:

- F1ACAL: processing of the calibration data to get the SWI_L1ALT1 and SWI_L1ALT2 files,
- F1A: processing of the science data to get the SWI_L1A__ files,
- FECMWF: processing of meteorological ancillary data to get these data gridded on the SWIM data,
- F1B: processing of L1A products to inverse the signal to the modulation spectrum and get thus the SWI_L1B___ files,
- F2ANAD: processing of the nadir beam through nadir echo retracking,
- F2ASIG: processing of the σ_0 profiles from the L1A products,
- F2: inversion of the modulation spectrum to a wave spectrum and gathering of all L2 intermediate products to get the SWI_L2____ files.
- Rajouter la chaine qui produit les L2NRT????

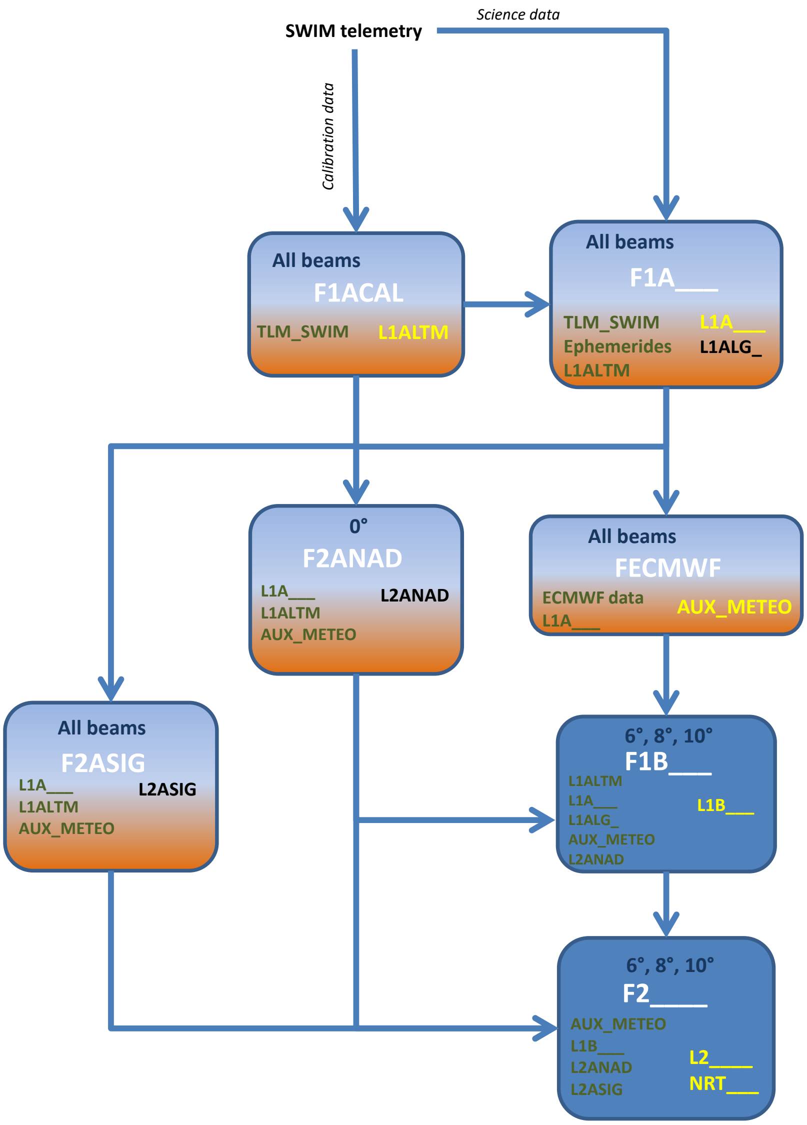


Figure 10. Schematic chain for the nominal case of SWIM. The output files which are available to the users are indicated in yellow. The inputs are written in green; the temporary files are in black. The blue boxes are for processors executed only for data over sea; the orange and blue boxes are for processors executed on

all surfaces. Note that the computational implementation could slightly differ from this schema.

If the antenna is not rotating, the L2____ product is reduced to nadir estimation and backscattering profiles. The NRT file content is reduced to L1b variables.

3.3. DISTRIBUTION OF THE CWWIC PRODUCTS

In a first step, CWWIC products (L1A, L1B and L2) will be made available only for Science Team members. They will be deposited on the following FTP server: ftp-access.aviso.altimetry.fr and can be retrieved using a dedicated account: st_cfosat. The password will be sent to list of people allowed to access to the products.

In a second step, when the CFOSAT project decide to open the CWWIC products access to all users (not before the first meeting of the CFOSAT Science Team which is planned for the end of September), a more detailed information regarding to:

- The web site,
- The registration process,
- The data policy

will be given in this document. We already know that CWWIC products will be available on AVISO+ web portal (https://www.aviso.altimetry.fr/en/home.html).

To be completed (web site + registration process + data policy document + time availability).

Simulated data are available on-line:

https://www.aviso.altimetry.fr/fr/missions/missions-futures/cfosat/access-to-simulated-data.html

A complete orbit cycle (13 days) has been simulated from ECMWF wave model (WAM) in September 2016. All products are available from level 1a up to level 2.

3.4. GLOBAL ATTRIBUTES FOR ALL FILES

All the NetCDF files produced by CWWIC contain global attributes which are detailed in the following table. Note that a given L1 or L2 file contains data acquired without any change on the on-board configuration. Indeed, each time there is a modification of the on-board configuration (corresponding to a passage towards the stand-by mode, see Fig 5), new L1 and L2 files are created. The NetCDF files are written with a C ordering type.

Tag name	Description of the variable content
history	List of the applications that have modified the original data (if any).
institution	CNES (institution name of the data provider).
references	References that describe the data or the methods used to produce it. (version of ICD document and of the Product User Guide (PUG) document
title	A descriptive title for the file.
Conventions	A text string identifying the NetCDF convention which is followed. This attribute should be set to "CF-1.7" to indicate compatibility with the Climate and Forecast CF-1.7.
date_created	Date the data file was created (UTC).
product_version	Release number of the data file with version and edition. Ex: “01.00” The number will increase while reprocessing.
netcdf_version_id	Version of the NetCDF library
contact	A free text string providing the primary contact for information about the data set.
generator_center	Name of the main generator center: "FROGS" or “CHOGS” (“FROGS” is expected for the CWWIC products).
generator_subcenter	Name of the generator subcenter. It can be: CWWIC or CFMC (“CWWIC” is expected in these products).
platform	Satellite identifier: "CFOSAT"
sensor	Sensor identifier: "SWIM" or "SCAT" (both are expected in the CWWIC products).
geospatial_lon_resolution	Resolution of the longitude coordinate if applicable, if not leave empty.
geospatial_lat_resolution	Resolution of the latitude coordinate if applicable, if not leave empty.
time_coverage_start	Start time of the product following ISO 8601. UTC time.

time_coverage_end	End time of the data following ISO 8601. UTC time.
time_coverage_duration	Temporal coverage of the product as a time range. Following the ISO 8601 norm.
geospatial_lat_max	Maximum north latitude in degrees , ranges from -90° to +90°
geospatial_lat_min	Minimum north latitude in degrees, ranges from -90° to +90°
geospatial_lon_max	Maximum east longitude in degrees, ranges from -180° to +180°, the reference being the Greenwich meridian
geospatial_lon_min	Minimum east longitude in degrees, ranges from -180° to +180°, the reference being the Greenwich meridian
file_quality_index	A code value : 0: unknown quality 1: excellent (no known problems) 2: suspect (occasional problems) • For example, the value 2 is used if the format of the netCDF is not fully compliant to the reference (missing a global attribute or a variable attribute) or if a variable is missing or if a field (dimension, variable, attribute) is missing
comment	Miscellaneous information.
processing_level	A textual description of the processing (or quality control) level of the data.
publisher_email	The email address of the person or group who distributes the data files.
publisher_name	Name of the person or group who distributes the data files.
publisher_url	URL of the person or group that distributes the data files.
summary	Description of the data contained within the file, expansion of the title to provide more information.
start_orbit_number	The orbit number that corresponds to the data at the beginning of the product.
stop_orbit_number	The orbit number that corresponds to the data at the end of the product. Note that the file contains all the data corresponding to one complete download over a polar ground station. The data are not reorganized per orbit. Therefore the stop_orbit_number can be different from the start_orbit_number as one data file may contain more than one orbit.
equator_crossing_longitude	The longitude where the spacecraft nadir track crosses the equator in the ascending direction.

equator_crossing_date	The date on which the spacecraft nadir track crosses the equator in the ascending direction.
cycle	Orbital cycle number (CFOSAT orbital cycle duration is about 13 days) and associated dates. As one file corresponds to all the data acquired between two “board to ground” downloads, it may cover more than one orbit cycle. For this reason, all the cycle numbers are indicated with the corresponding start and stop dates. The format is a succession of string (with “/” separator) like: “<number>_<start_date>_<stop_date> where number is a 3 characters string, start_date and stop_date are in ISO 8601 date format. Example: "017_2019-05-28T10:13:34Z_2019-06-10T10:13:54Z" for orbital cycle #017
trace	Orbit tracks numbers within the orbit cycle. Tracks are defined from pole to pole, ascending track have oddnumbers, descending tracks have even numbers. Several tracks can be covered by a SWIM file. It has the same format as the cycle parameter The format is a succession of string (with “/” separator) like: “<number>_<start_date>_<stop_date> where number is a 3 characters string, start_date and stop_date are in ISO 8601 date format. Example:"108_2019-05-31T22:57:32Z_2019-05-31T23:45:02Z/109_2019-05-31T23:45:02Z_2019-06-01T00:32:33Z"
swim_acquisition_mode	Defines the SWIM acquisition mode. Possibilities are: “speckle”, “nominal”, “calibration”.at
ground_station	Name of the ground station used for these data (“Inuvik” or “Kiruna”)
antenna	Antenna mode: “rotated” or “fixed” to indicate if the antenna is rotating or not.
cdb_version	Version and edition of the Common Data Base which is the ancillary file used for the processing. Ex: “"19_22"”
input_files	List of input files

3.5. AUX_METEO PRODUCT

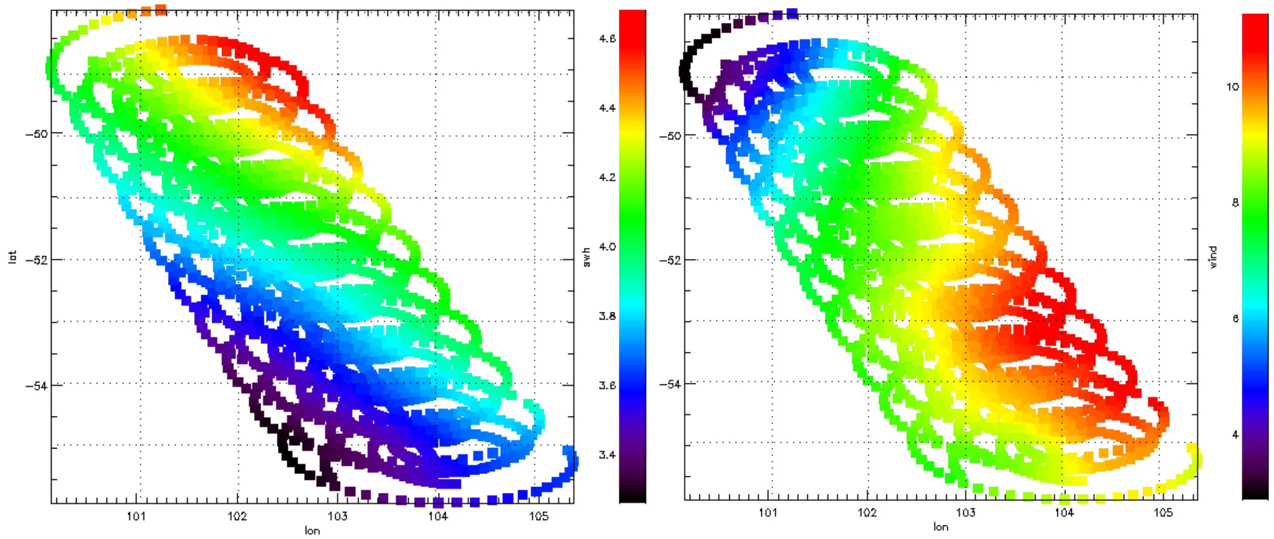
3.5.1. AUX_METEO data processing

3.5.1.1. Processing objective

The L1b and L2 processors need some meteorological variables which are obtained from the outputs of the ECMWF weather forecast model. The objective of the AUX_METEO processor is then to project ECMWF inputs (global map of geophysical products, either forecasts or reanalysis, on a GRIB format) on the SWIM product grid (macro-cycles and cycles) by establishing a spatiotemporal colocation. In the meantime, the AUX_METEO processor also computes the atmospheric attenuation using the total column liquid and water vapour contents from ECMWF data.

The processor is able to run through an operational mode or a reanalysis mode. The operational mode uses ECMWF forecasts as an input to have a prediction of the state of the sea and the atmosphere concomitant with SWIM acquisitions. The reanalysis mode uses ECMWF reanalysis data (instead of forecasts) as an input for a better assessment.
In operational mode, the forecast at 3 hours are used as inputs. These forecasts are available every 3 hours and they are run from two model networks (“0h” and “12h”) whose outputs are released respectively at 6h UTC and 18h UTC.

The processing output is a file containing all geophysical quantities required for the next levels. Its dimensions correspond to common dimensions used throughout the processing chain (macro-cycles/cycles). An example of two variables computed in AUX_METEO is shown on Figure 11.



(a) SWH (b) WS

Figure 11. Example of interpolated ECMWF data: significant wave height, SWH (left) and surface wind speed WS (right) at the centre of each incidence beam along a part of the track.

3.5.1.2. Overview of the processing

3.5.1.2.1. Spatiotemporal interpolation of ECMWF field variables

For each variable extracted from the ECMWF files, the processing is of two kinds:

1. Determination of the value at the centre of each incidence beam swath (for each cycle).
   The original ECMWF data are originally gridded on a N1280 grid. The values are interpolated with a bilinear

interpolation at the centre of each beam swath. The SWIM latitudes and longitudes are taken from the L1a files.

2. Temporal colocation to determine the values at the SWIM acquisition date.
   Two methods are possible: either use of the immediate anterior date from the 3 h forecast files or use of a linear interpolation between two surrounding dates. For linear interpolation, the forecast files are taken inside the same network.

3.5.1.2.2. Estimation of the atmospheric attenuation

The total atmospheric attenuation in Ku-Band is estimated from the integrated total liquid water and total water vapour contents and calculated at the centre of each swath for each cycle through [DR5]:

$$\text{Att\_sig0 (in dB)} = 0.094 - 0.177\,p' - 0.145\,t' + 0.274\,p'\,t' + 0.00145\,WVC + 0.0000066\,WVC^2 + 0.169\,LWC \qquad (1)$$

with:

- $p' = p / 1013$
- p = surface pressure in hPa
- $t' = 288.15 / (273.15 + t)$
- t = surface temperature in °C
- WVC = Water Vapour Content integrated in kg/m^2
- LWC = Liquid Water Content integrated in kg/m^2

3.5.2. Description of the product content

3.5.2.1. Specific global attributes

Tag name	Description of the attribute content
Source	Name of the processor which generates the file
ECMWF_start_forecast	Base time and time step of the first ECMWF model forecast file used.
ECMWF_end_forecast	Base time and time step of the last ECMWF model forecast file used.
interpolation_mode	Mode of data interpolation. Default is 0 which means that temporal interpolation mode is off. Set to 1 if temporal interpolation is done.
coeff_atm_corr	coefficients of the polynomial for atmospheric correction (from Eq 1.)
macrocycle_angle	The macro-cycle is the elementary sequence of incidence beams which transmit and receive the radar signal. The nominal macro-cycle sequence is (0°, 2°, 4°, 6°, 8°, 10°). The time spent on one single incidence beam is named cycle. This variable contains the values of the beam incidence, expressed as angle in degrees, for each cycle of the macro-cycle. For example, for the nominal macro-cycle the macrocycle_angle variable is [0, 2, 4, 6, 8, 10]. Among alternative macro-cycles one can find for example [0,8,8] or [0,10,10]
macrocycle_beam	Beam type, expressed as beam number, for each cycle of the macro-cycle.

	A macro-cycle is characterized by the succession of NB_CYCLES beams: [f0 f1 ….. fNB_CYCLES-1]. Here fk is an integer equal to 0, 1, 2, 3, 4 or 5 which indicates the beam with k= cycle number. For example, the use of all the incidence beams (nominal macro-cycle) is represented by f0=0, f1=1, f2=2, f3=3, f4=4, f5=5, i.e. macrocycle_beam = [0, 1, 2, 3, 4, 5]. Dependant on the number of cycles of the macro-cycle (for example only 3 values if macro-cycle = [6, 8, 10]). In this case, macrocycle_beam = [3, 4, 5].

3.5.2.2. Variables

Tag name	Description of the variable content	Accuracy
swh	Significant wave height interpolated from the ECMWF data at the (latitude, longitude) coordinates of the centre of the swath of each beam for each cycle. The interpolation is also made in time if interpolation_mode = 1.	0.01 m
u10	Wind speed component u10 at surface level interpolated from the ECMWF data at the (latitude, longitude) coordinates of the middle centre of the swath of each beam for each cycle. The interpolation is also made in time if interpolation_mode = 1.	0.01 m/s
v10	Wind speed component v10 at surface level interpolated from the ECMWF data at the (latitude, longitude) coordinates of the middle centre of the swath of each beam for each cycle. The interpolation is also made in time if interpolation_mode = 1.	0.01 m/s
sst	Sea surface temperature interpolated from the ECMWF data at the (latitude, longitude) coordinates of the centre of the swath of each beam for each cycle. The interpolation is also made in time if interpolation_mode = 1.	0.01 K
sic	Sea ice cover interpolated from the ECMWF data for the (latitude, longitude) of the middle of the swath of each beam for each cycle. The interpolation is also made in time if interpolation_mode = 1.	0.01
lsm	Land-sea mask interpolated from the ECMWF data at the (latitude, longitude) coordinates of the centre of the swath of each beam for each cycle. The interpolation is also made in time if interpolation_mode = 1.	0.01
Att_sig0	Atmospheric attenuation estimated from the following equation : Att_sig0 (in dB) = 0.094 – 0.177 p' – 0.145 t' + 0.274 p' t' + 0.00145 WVC + 0.0000066 WVC^2+ 0.169 LWC with:	0.01 dB

	• $p' = p / 1013$ • p = surface pressure in hPa • $t' = 288.15 / (273.15 + t)$ • t = surface temperature in ºC • WVC = water vapour content integrated in kg/m^2 • LWC = liquid water content integrated in kg/m^2 The parameters are interpolated from the ECMWF data at the (latitude, longitude) coordinates of the centre of the swath of each beam for each cycle. The interpolation is also made in time if interpolation_mode = 1.	

3.6. L1A PRODUCTS

3.6.1. L1a data processing (tracking mode)

3.6.1.1. Processing objective

The objective of Level 1a processing is to get calibrated and geocoded waveforms from the telemetry data, that is measurements corrected from instrument gains, acquisition geometry and geographically referenced. The calibrated power is therefore directly the normalized radar cross-section in each radar gate. A couple (latitude, longitude) in WGS84 geoid is associated to each radar gate. There is no projection on ground.

In order to calibrate the radar waveforms, the calibration signals (CAL1 and CAL2) are processed to get the impulse response of the instrument and its internal gain. The calibration parameters are computed taking into account the on-board parameters and they are used to inverse the data. This calibration procedure is applied for each calibration telemetry; it is performed independently from the L1a processor.

In addition, the waveforms are compensated for the thermal noise level. It is estimated from the first gates of the nadir and 2° beams. If the 2° beam is not available in the macro-cycle, the estimation is restricted to the nadir beam (which is always present in a macro-cycle by definition of the macro-cycles).

3.6.1.2. Overview of the processing

Figure 12 presents the overview of the L1A processing chain from SWIM telemetry up to SWI_L1A file.

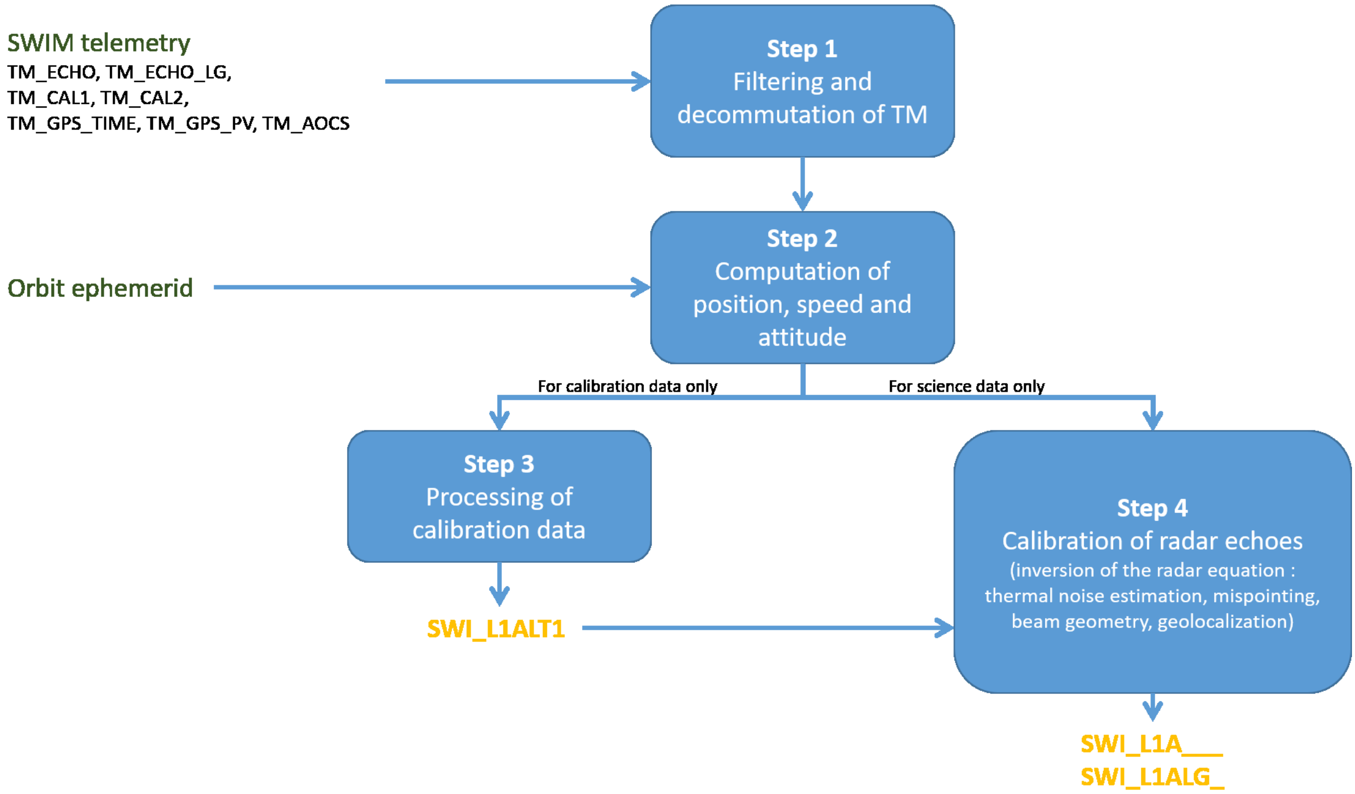


Figure 12: L1A processing chain. The input files are indicated in green and the output files in yellow.

The main steps of the processing are:

- filtering and decommutation of the telemetry,
- interpolation of ancillary data (ephemeris, AOCS TM, etc.) at the measurement times of SWIM,
- for calibration data:
  - computation of instrument gains and impulse response,
- for science data:
  - for speckle mode, computation of the equivalent nominal mode measured power (post-integration of the three successive powers),
  - thermal noise estimation from nadir beam (and 2° beam if available),
  - estimation of the geometric parameters: angles (azimuth, incidence, elevation, platform mispointing) and distance (altitude, radar range, ground range, Earth radius),
  - geocoding in (latitude, longitude),
  - calibration of the radar signals (inversion of the radar equation) and estimation of the Noise Equivalent σ_0.

The inputs of the L1a processor are:

- the science telemetry in nominal and speckle mode,
- the platform telemetry (GPS time and position, AOCS),
- the orbit ephemeris,
- the SWI_L1ALT1 file (output of the calibration processing of CAL1 data),
- the CDB file containing the instrument and processing parameters.

The outputs are:

- SWI_L1A__ file (in tracking mode),
- SWI_L1ALT1 and SWI_L1ALT2 (in calibration modes).

3.6.1.3. Algorithm definition

3.6.1.3.1. Step 1: filtering and decommutation

The VCDU packets are converted in CCSDS packets, after time-reorganization and suppression of duplicates.

The TM packets are then decommuted to go from the binary counts of the TM to the physical values. The transfer functions are applied.

Some high level controls are performed on the house-keeping fields of the TM to check the healthiness of the instrument. A flag (FLAG_AVAILABILITY) enables to flag if there is any problem in the data with respect to the instrument behaviour. In particular, this flag provides a piece of information in case of missing data inside a macro-cycle.

3.6.1.3.2. Step 2: computation of position, speed and attitude

The position, speed and attitude are computed for each cycle using the on-board time of the TM of the cycle.

For the position and satellite speed, the values are extrapolated from the ephemerides. The GPS measurements are not directly used; they are injected in the orbit model (external component) to produce the accurate ephemerides.

The AOCS data are available every 8s. They are interpolated at the cycle date with a polynomial interpolation (Everett or Neville-Aitken algorithm).

3.6.1.3.3. Step 3: processing of the calibration data

The calibration data are of different kinds and they are processed to estimate the instrument property.

CAL1_INT mode is used to get the impulse response (IR) of the instrument. This response should be very close to a cardinal sine function whose width of the main lobe corresponds to the effective range resolution. The properties of the estimated IR (main lobe width, dissymmetry between secondary maxima) are compared to the theoretical ones to check that the instrument reaches the requirements.
The IR is approximated by a perfect cardinal sine and by a Gaussian for simplified uses in the following processing. The corresponding parameters of these fitting functions are outputs of the processing.

CAL1_INT, CAL1_TX and CAL1_RX modes are combined to estimate the instrument gain from the total measured power in these three sub-modes. The instrument gain is a key parameter to convert the backscattered power into normalized radar cross-section. Each of these modes is also used to provide the impulse response function (IR) of the instrument in order to assess its stability.

CAL2 mode is a passive mode used to measure the noise level in the reception window and monitor the behaviour of the instrument. These measurements are not used in the inversion process.

The calibration sequences will be defined during the commissioning phase with respect to the SWIM behaviour towards temperature variations along the orbit. Before launch, three CAL1 calibrations are planned per day. CAL2 calibration should be performed on a less regular basis (once a month).

3.6.1.3.4. Step 4: calibration and geometry

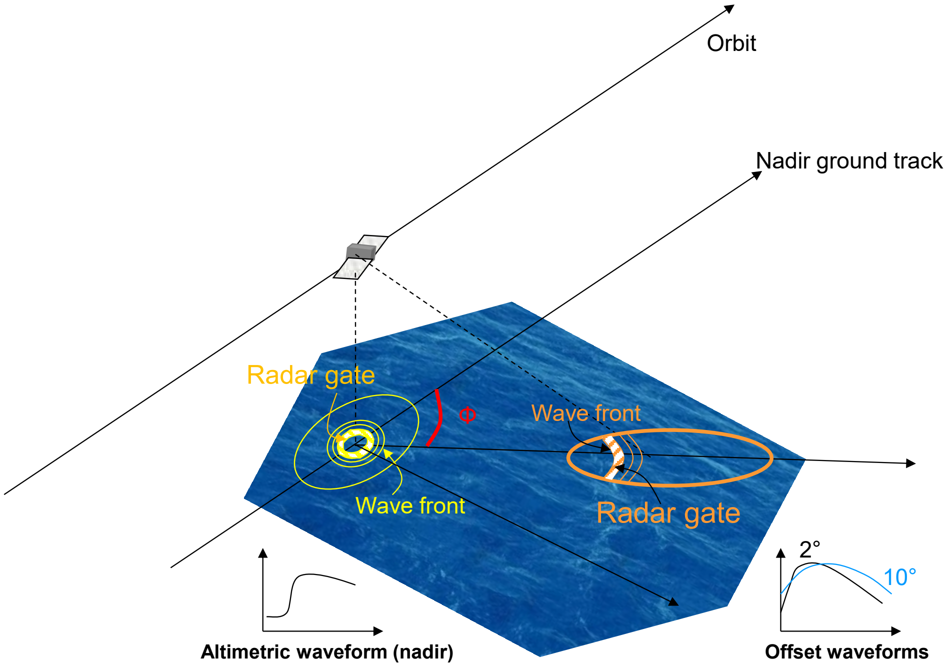


Figure 13. Radar geometry of the SWIM acquisitions.

The radar equation states that the received power is equal to:

$$P_r(r) = \frac{P_e \lambda^2 \sigma_0(r) G_{ins}}{(4\pi)^3 r^4 L_{propa}} \int_{r' \in \left[-\frac{\delta r}{2};\frac{\delta r}{2}\right]} \int_{\varphi \in [0,2\pi]} G_A^2(e(r'),\varphi)\, dS + N_T \qquad (2)$$

with:

- P_e the emitted power,
- λ the wavelength of the emitted signal,
- G_{INS} the instrument gain,
- G_A the antenna gain,
- r the radar to ground range,
- δr the range resolution (radar gate)
- e the elevation angle,
- L_{propa} the propagation loss,
- N_T the thermal noise.

σ_0 is the normalized radar cross-section and this is the geophysical parameter which shall be estimated. The aim of the step 4 is to invert the radar equation to estimate σ_0.

The step 4 processing estimates the different contributors to the radar equation. Some are static or semi-static parameters coming from on-ground measurement (P_e, λ, G_A), calibration measurement (G_{INS}) or models (L_{propa}), others are dynamic parameters which are estimated for each cycle (r, e, ϕ, N_T).

It is thus necessary to estimate the geometry of acquisition (r, e) and the ground projection of r (see Figure 14). All the geometry computations are performed with a WGS84 ellipsoid. The Cartesian positions of the impact points on the ellipsoid are converted into (latitude, longitude) coordinates.

The integrated antenna gain is computed over every radar gate taking into account the instrument mispointing. The antenna pattern measured on ground before launch is projected over the Earth surface to compute the antenna gain integrated in azimuth.

The thermal noise is estimated from the nadir and 2° beams by averaging the first gates of the echoes. If the macro-cycle does not include the 2° beam, only the nadir beam measurements are used. The thermal noise level of the other beams are deduced from the nadir and 2° measurements taking into account the gain variations which affect the noise figure of the reception chain.

Note that, at this stage, there is no correction of the atmospheric attenuation.

3.6.2. Description of the products contents

The file format is described in [DA1]. Here we detail the physical content of each variable and explain how it can be used. The variable type and LSB are detailed in [DA1]. The expected accuracy after the processing is given in this document for some variables.

NB: accuracy is different from LSB. It is the expected accuracy of each variable taking into account instrument property and processing accuracy.

3.6.2.1. SWI_L1A___

3.6.2.1.1. Specific global attributes

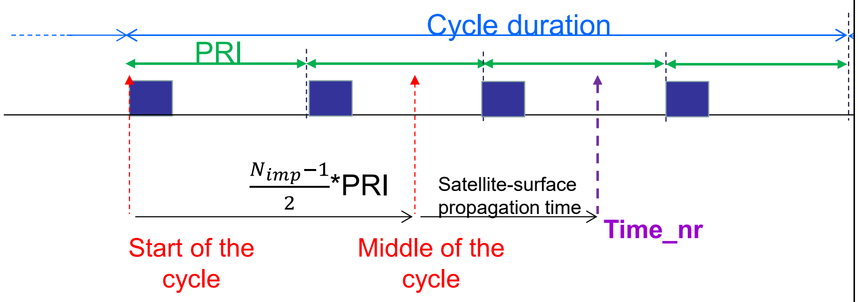
Note that each time there is a modification of on-board configuration leading to a change of one of the below attribute, a new file is generated.

Tag name	Description of the attribute content
macrocycle_angle	The macro-cycle is the elementary sequence of incidence beams which transmit and receive the radar signal. The nominal macro-cycle sequence is (0°, 2°, 4°, 6°, 8°, 10°). The time spent on one single incidence beam is named cycle. This variable contains the values of the beam incidence, expressed as angle in degrees, for each cycle of the macro-cycle. For example, for the nominal macro-cycle the macrocycle_angle variable is [0, 2, 4, 6, 8, 10]. Among alternative macro-cycles one can find for example [0,8,8] or [0,10,10]
macrocycle_beam	Beam type, expressed as beam number, for each cycle of the macro-cycle. A macro-cycle is characterized by the succession of NB_CYCLES beams: [f0 f1 ….. fNB_CYCLES-1]. Here fk is an integer equal to 0, 1, 2, 3, 4 or 5 which indicates the beam with k= cycle number. For example, the use of all the incidence beams (nominal macro-cycle) is represented by f0=0, f1=1, f2=2, f3=3, f4=4, f5=5, i.e. macrocycle_beam = [0, 1, 2, 3, 4, 5]. Dependant on the number of cycles of the macro-cycle (for example only 3 values if macro-cycle = [6, 8, 10]). In this case, macrocycle_beam = [3, 4, 5].
ldis	Number of range cells which are averaged on board, varying with the incidence beam. The nominal values for the six beams are, respectively, 1, 4, 4, 2, 3, 3 for the six beams from 0° to 10°. In speckle mode, ldis is multiplied by 3 on the spectrum beams, so the values are changed to 1, 4, 4, 6, 9, 9 for the six beams from 0° to 10°.
nimp	Number of pulses averaged on board per cycle. For nominal macro-cycle, Nimp = [264,97,97,156,186,204]
antenna_rotation_speed	Mean antenna rotation speed. Nominal value =5.6 rpm (with antenna rotating). Value = 0 rpm when antenna stopped.
beam_elevation	One-way 3dB Beamwidth in elevation. 1 value per beam, in degrees. The number of values is dependant on the number of cycles of the macro-cycle (for example only 3 values if macro-cycle = [6; 8; 10]). Values come from CDB Example for the nominal macrocycle: 0.000000;2.300000;3.700000;5.550000;7.400000;9.250000
beam_width	One-way 3 dB beam-widths in azimuth of the antenna for each beam of the macro-cycle. Example for the nominal macrocycle: 1.510000;1.530000;1.740000;1.860000;1.860000;1.890000
signal_sampling_in_radar_geometry	Δr , slant range sampling for radar echo, after on-board processing which includes averagings over Ldis range gates

	Δr = Ldis * c/(2*Fe) Nominal values: 0.374741;1.498962;1.498962;0.749481;1.124222;1.124222
signal_resolution_in_radar_geometry	δr, radar range resolution for each radar echo, after on-board processing which includes averages over Ldis range gates δr = Ldis * c/(2*B_{chirp}) Values correspond to nominal mode Nominal values 0.468426;1.873703;1.873703;0.936851;1.405277;1.405277 (ref: CF-SCPLSM-373-CNES, "SWIM description") In the "speckle" acquisition mode, the averaging step is multiplied by a factor of 3: Ldis=Ldis*3:

3.6.2.1.2. Variables

Tag name	Description of the variable content	Accuracy
echo_l1a_x	Calibrated and geocoded power for the x^{th} beam of the macro-cycle (x=0,…, 5). Note that the 0 beam is always the nadir beam. The radar equation has been inverted for each radar gate. This variable corresponds thus to the backscattering coefficient σ_0 per range gate, integrated over the azimuth direction. The following corrections have been applied to all beams: • thermal noise compensation, • antenna gain pattern compensation, • geometry loss compensation, • instrument gain compensation including integration of antenna gain pattern in azimuth. There is no correction of the atmospheric attenuation at this level. The radar geometry is kept. There is no additional averaging after the one performed on-board. The on-board processing based on Chirp Scaling algorithm enables a range compression combined with a migration compensation. The migration compensation cannot correct the azimuthal migration (no azimuth sampling) and some approximations are made in the processing. Each point of the footprint is affected by a different residual error, depending also on the latitude and the antenna azimuth position. The final resolution is the integration over each radar gate weighted by the antenna gain pattern. Simulations taking into account the gain weighting indicated an effective resolution on ground better than 25 m for the three spectrum beams. In case of speckle mode, this variable corresponds to the mean of the individual values obtained from the three successive values downloaded per cycle.	$\leq \pm$ 0.9 dB for absolute value of backscattered signal $\leq \pm$ 0.25 dB for relative values between every beams Effective range resolution < 35xsin(incidence_x)
time_nr	Time in seconds and microseconds of each Near Range measurement, for each cycle and each incidence, relative to the reference time.	Couple of two values in seconds and

	The time is computed for the first point in the swath at the middle of the cycle (see figure below). 	microseconds
phi	Azimuth angle in local orbital frame (in radians), i.e. with respect to the orbit ground track (in clockwise rotation). Phi=0 rad corresponds to an azimuth along track in the direction of satellite advection. (see Φ_{OL} angle on Figure 14, bottom panel).	
phi_azimuth	Azimuth angle (in radians) in SWIM antenna frame	Azimuth accuracy of SWIM < 0.01° ($1.7.10^{-4}$ rad)(with rotation and without)
phi_geo	Azimuth angle values (in radians) with respect to geographical North (in clockwise rotation). It is deduced from phi taking into account the orbit inclination. (see Φ_{GEO} angle on Figure 14, bottom panel)	
lat_l1a_x	Latitude of x^{th} beam measurement for each cycle (x=0,…, 5). The latitude is computed at the centre of each radar gate. Degrees in WGS84 referential.	Translate localization accuracy into lat and lon accuracy
lon_l1a_x	Longitude of x^{th} beam measurement for each cycle (x=0,…, 5). The longitude is computed at the centre of each radar gate. Degrees in WGS84 referential.	Translate localization accuracy into lat and lon accuracy
radar_range_x	Values of the range distance r in the radar geometry, associated to each gate of the swath, for each cycle of the x^{th} beam measurement for each cycle (x=0,…, 5).	Sampling = 0.375 m
elevation_x	Values of the elevation e, associated to each gate of the swath, for each cycle of the x^{th} beam measurement for each cycle (x=0,…, 5). The elevation angle is illustrated in Figure 14, top pannel.**Erreur ! Source du renvoi introuvable.**	• < 0.001° for elevation_x > 0.05° • < 0.0001° for elevation_x > 0.5°
incidence_x	Values of the incidence angle θ associated to each gate of the swath, for the x^{th} beam measurement for each cycle (x=0,…, 5). The incidence angle is illustrated in Figure 14, top panel.	Expected accuracy
ground_range_x	Values of the ground distance X between nadir and each gate of the swath for each cycle of the x^{th} beam (x=0, …,5).	Sampling = 0.375/sin(incidence_x)

Att_code	On-board attenuation gain	NA
altitude	Altitude of the satellite. It is derived from nadir measurements.	A few meters
earth_radius	Local earth radius. The local Earth radius is computed for each cycle as follows: $$R_T = \sqrt{X_{SAT}^2 + Y_{SAT}^2 + Z_{SAT}^2} - H$$ with : • H the satellite altitude • $(X_{SAT}, Y_{SAT}, Z_{SAT})$ the satellite coordinates in in WGS84 frame	<100m
orbital_velocity	Orbital velocity of the satellite (m/s) $$V_{SAT} = \sqrt{V_X^2 + V_Y^2 + V_Z^2}$$ with (V_X, V_Y, V_Z) the coordinates of satellite velocity vector $\vec{V}_{SAT}$ in WGS84 frame	Compute from altitude accuracy and error in equations. 10-20 m (TBC)
projected_velocity	Projected velocity of the satellite on the ground $$V_{SAT\_GD} = \frac{R_T}{R_T + H} \left\Vert \vec{X}_{SAT} \wedge \vec{V}_{SAT} \right\Vert$$ with : • R_T the local earth radius • H the satellite altitude • $\vec{X}_{SAT} = \frac{(X_{SAT}, Y_{SAT}, Z_{SAT})}{\sqrt{X_{SAT}^2 + Y_{SAT}^2 + Z_{SAT}^2}}$ with $(X_{SAT}, Y_{SAT}, Z_{SAT})$ the satellite coordinates in in WGS84 frame	Compute from altitude accuracy and error in equations.
ly	Ground length of azimuth beam footprint (at 3dB) per beam. $$L_Y = \frac{R_{moy}\beta_{3dB}(k)}{2\sqrt{2\ln 2}}$$ With R_{moy} the sensor-ground distance at the centre of the beam, $\beta_{3dB}(k)$ the 3dB antenna aperture for the beam k.	Expected accuracy.
nesig0	Noise equivalent Sigma0 per beam. The noise equivalent σ_0 is the σ_0 such as SNR equal 1. It is computed from the maximum value of the backscattered power (before instrumental corrections) and the estimated thermal noise level.	± 1dB (including the estimation error on thermal noise <0.1dB)
cal_ratio_x	Instrument ratio for sigma0 calibration for the x^{th} beam (x=0,…, 5). This ratio is estimated from the calibration mode data.	
pri	Pulse repetition interval (= 1/PRF).	Accuracy = LSB

pseudo_misp	Squared mispointing elevation angle computed from nadir waveform (in rad^2). The elevation mispointing is estimated from the slope of the leading edge of the nadir waveform. This estimation can be affected by surface or atmospheric inhomogeneity. It is used in level 2 processing for rain flag computation.	0.1° (when no perturbation on the waveform occurs)
echo_l1_0_nt	Thermal noise (consistent with echo_L1_0). The thermal noise is estimated from the noise floor, averaged over the 60 first gates of the 2° echo , where there is no backscattering signal from the ground. It is averaged over 2 seconds.	
echo_l1_0	Power for nadir beam with only instrument automatic gain compensation. This gain is the automatic gain control loop which is adapted from one cycle to another to guarantee an appropriate dynamic ranging. The constant instrument gain, the propagation loss, the antenna gain and the thermal noise are not corrected. This nadir waveform is useful for nadir retracking.	
echo_l1_0_std_nt	Standard deviation of thermal noise. This standard deviation is associated to the averaging over the 2 seconds for the estimation of the thermal noise.	
att_code	Attenuation coefficients applied to the tracking signal. Coefficients come from the attenuation coefficients table, measured during calibration phase and stacked in CDB.	
flag_vit_ant	Flag on antenna rotation speed This flag checks the stability of the antenna rotation speed. •0 : vit_ant stability OK, •1 : vit_ant stability NOK (variation higher than threshold) •2 : vit_ant undetermined	Expected to be stable at 1.5%
flag_dep	Flag on mispointing angle This flag checks the consistency between the pseudo-misp variable and the combination of reference roll and pitch mispointing angles, both defined in CDB. •0 : consistency OK, mispointing value within limit threshold •1 : consistency NOK, mispointing value within limit threshold 2 :consistency OK, mispointing value is invalid (masked value)	
flag_availability	Flag on raw data validity This flag checks the validity of the TM data with respect to instrument housekeeping criteria (checking on temperature, current, data validity, etc.). If the flag is raised, it means that there may be some values of instrument housekeeping out of range or missing data inside a macro-cycle. The possible flag values are listed hereafter: •0: no valid data •1: valid data	

	•2: “degraded” data •3: missing data •4: CAL1_PHASE performed before the measurement. Possible bias on the distance measurement (<3m)	
Cycle_duration	Cycle duration in a macrocycle for each beam (s)	
alpha_r_p	Roll mispointing angle estimated by minimising the distance between model and measured sigma0 (rad)	< 0.01°
alpha_t_p	Pitch mispointing angle estimated by minimising the distance between model and measured sigma0 (rad)	< 0.01°
flag_fit	Flag showing the status of the minimization function used to estimated alpha_r_p and alpha_t_p variables. The possible flag values are: • 0: minimization converged • 1: minimization aborted because number of iterations reached masimum authorized iterations (CDB parameter) • 2: minimization aborted due to an increase of the cost function • 3: minimization aborted due to invalid values of one or more of the minimization parameters	
flag_dep_allbeams	Flag on roll and pitch mispointing angles estimated in the L1A processing. These angles correspond to the alpha_r_p and alpha_t_p variables. This flag checks the consistency between the alpha_r_p and alpha_t_p variables, and reference roll and pitch angles, both defined in CDB. Alpha_r_p and alpha_t_p variables are estimated using a minimisation function. •0: minimization function converged and both alpha_r_p and alpha_t_p are consistent with respect to reference values in CDB •1: minimization function converged and either alpha_r_p or alpha_t_p or both variables are inconsistent with respect to reference values in CDB •2: minimization function did not converge	
Reliable_swath_x	Variable showing weather the radar gate in the swath is reliable or not (if gain correction of the echo matches specifications). This variable can have two different values: • 0: the considered radar gate is not reliable (correction of the antenna gain is not within specifications) • 1: the considered radar gate is reliable and fits within the -3dB limit of the normalized antenna gain.	

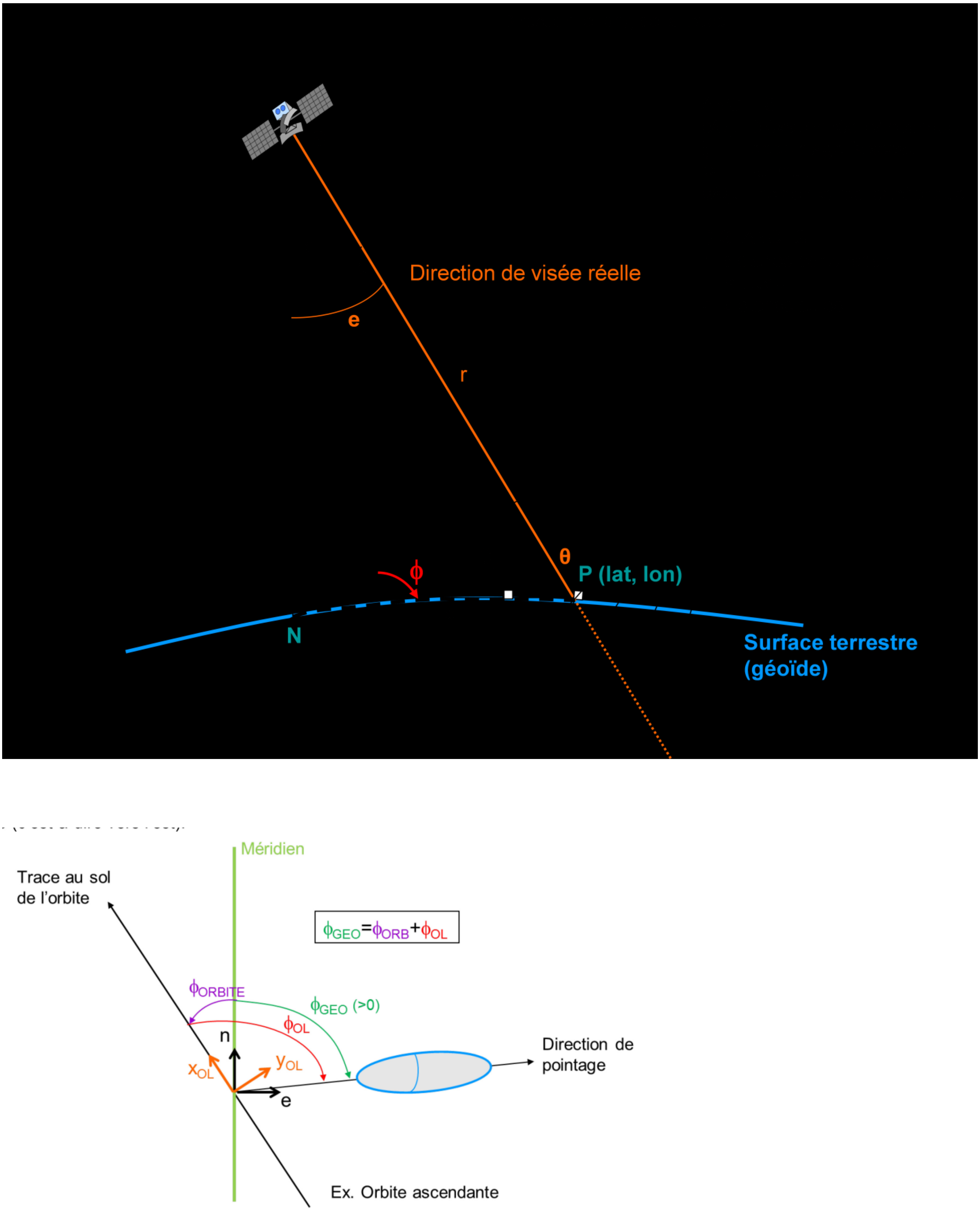


Figure 14: SWIM geometry. Top: Definition of elevation and incidence angles, e and θ respectively (among other angular and distance data). Bottom: definition of azimuth angles

3.6.2.2. SWI_L1ALT1

This file keeps the historic of the calibration measurements performed in CAL1 mode. The first values contain the calibration results made on ground. These values are the reference values for the mission; they will be used to qualify any shift in the SWIM behaviour.

3.6.2.2.1. Specific global attributes

None.

3.6.2.2.2. Variables

Tag name	Description of the variable content	Accuracy
tpg	Estimated internal TPG (Time Delay Group) of the emission/reception chain of SWIM.	Accuracy ?ns
flag_tpg	Flag on TPG. It is raised if tpg variable differs too much from a reference value which is defined in CDB (calibration part). 0: tpg value OK 1: tpg too far from reference value	
g_ins	Instrument gain of the emission/reception chain of SWIM (function of beam and azimuth). This gain is used to invert the radar equation in the σ_0 estimation. This gain is the combination of the maximum values measured in CAL1_INT, CAL1_RX and CAL1_TX.	0.8 dB
flag_g_ins	Flag on instrument gain. It is raised if g_ins differs too much from a reference value which is defined in CDB. The distance threshold between measured and reference instrument gains is also defined in CDB. 0: g_ins value OK 1: g_ins too far from reference value	
ri _int	Impulse response (IR) of SWIM from the measurements in CAL1_INT mode with a step equal to 1/64th of the original step (0.375 m). There are 16384 samples.	NA
param_ri_sinc_int	The IR obtained in CAL1_INT mode is fitted by a cardinal sine function defined by $\boldsymbol{RI\_SINC}(\boldsymbol{r}) = \boldsymbol{A}\ \boldsymbol{sinc}^2\left(\frac{r-r_c}{L}\right)$. This variable provides the three parameters (A, r_c, L) which defines the cardinal sine. r is the index of the sample.	NA
param_ri_sinc_tx	The IR obtained in CAL1_TX mode is fitted by a cardinal sine function (cf. param_ri_sinc_int) . This variable provides the three parameters which defines the cardinal sine.	NA
param_ri_sinc_rx	The IR obtained in CAL1_RX mode is fitted by a cardinal sine function (cf. param_ri_sinc_int). This variable provides the three	NA

	parameters which defines the cardinal sine.	
param_ri_norm_int	The IR obtained in CAL1_INT mode is fitted by a Gaussian function defined by $\boldsymbol{RI\_GAUSS}(\boldsymbol{r}) = \boldsymbol{a} * \mathbf{exp}\left(-\frac{(r-\mu)^2}{2\sigma^2}\right)$. This variable provides the three parameters which defines the Gaussian function (a, μ, σ). The Gaussian approximation may be required for some algorithms. But this approximation is less accurate than the sine cardinal one.	NA
flag_ri_fit_int	Flag on cardinal sine IR fitting residuals in CAL1_INT mode. This flag is defined to help detect distortions on IR.	
flag_ri_fit_tx	Flag on cardinal sine RI fitting residuals in CAL1_TX mode. This flag is defined to help detect distortions on IR.	
flag_ri_fit_rx	Flag on cardinal sine RI fitting residuals in CAL1_RX mode. This flag is defined to help detect distortions on IR.	
pow_ri_int	Integrated power over the reception window of the IR measured in CAL1_INT	Accuracy ?
pow_ri_tx	Integrated power over the reception window of the IR measured in CAL1_TX	Accuracy ?
pow_ri_tx	Integrated power over the reception window of the IR measured in CAL1_RX	Accuracy ?
start_date_1	The SWI_L1ALT1 file compiles all the calibration sequences performed during the satellite lifetime (CAL1 mode). For each consecutive sequence, the date of the first calibration measurement is indicated as well as the date of the last measurement (end_date). These two dates enable to localize in time a calibration sequence. Note that a calibration sequence may contain several calibration modes.	< 1 µs
end_date_1	End time of CAL1 sequence. See start_date.	< 1 µs
start_position_1	Start position along the orbit of CAL1 sequence in latitude and longitude.	Accuracy ?<10 m
end_position_1	End position along the orbit of CAL1 sequence in latitude and longitude.	Accuracy ?<10 m

3.6.2.3. SWI_L1ALT2

This file keeps the historic of the calibration measurements performed in CAL2 mode. The first values contain the calibration results made on ground. These values are the reference values for the mission; they will be used to qualify any shift in the SWIM behaviour.

3.6.2.3.1. Specific global attributes

None.

3.6.2.3.2. Variables

Tag name	Description of the variable content	Accuracy
g_ins_fr_dB	Coefficients of the second-order polynomial which is used to modelize the normalized variation of the instrument gain in reception window vs range. This gain filter is obtained in CAL2 mode and it describes the variation of the instrument gain over the swath.	Accuracy ?
start_date_2	The SWI_L1ALT2 file compiles all the calibration sequences performed during the satellite lifetime (CAL2 mode). For each consecutive sequence, the date of the first calibration measurement is indicated as well as the date of the last measurement (end_date). These two dates enable to localize in time a calibration sequence. Note that a calibration sequence may contain several calibration modes.	<ms
end_date_2	End time of CAL2 sequence. See start_date.	Accuracy ?<ms
start_position_2	Start position along the orbit of CAL2 sequence in latitude and longitude.	Accuracy ?<10 m
end_position_2	End position along the orbit of CAL2 sequence in latitude and longitude.	Accuracy ?<10 m

3.7. L1B PRODUCT

3.7.1. L1b data processing

3.7.1.1. Processing objective

The L1b processing addresses only the beams 6°, 8° and 10° over sea surfaces, with a rotating antenna. It aims at estimating the modulation spectra of the waves at each cycle. These modulation spectra express, in the Fourier domain, the energy repartition of the modulation of the radar cross-section due to the long waves.
The modulation spectrum is the power density spectrum of the modulation signal:

$$P_m(k,\phi) = |FT(m(x,\phi))|^2 \text{ with } m(x,\phi) = \frac{\int G^2(\varphi)\,\alpha(\theta)\frac{\partial\xi}{\partial X}d\varphi}{\int G^2(\varphi)d\varphi} \qquad (3)$$

G is the antenna gain, ξ the elevation of the sea and α the modulation transfer function.

The principle is to link this modulation of the radar signal inside the beam footprint to the long waves. At incidence angles close to 8°, the modulations are essentially proportional to the slopes of the surface and depend barely on the wind [DR3, DR4]. In the Fourier domain, the modulation spectrum is thus proportional to the wave slope spectrum. The processing of level 1b computes the modulation spectra from the L1a signal. They are then converted into 2D wave slope spectrum at level 2 (§ 3.8).

$$P_m(k,\phi) = \frac{\sqrt{2\pi}}{L_Y}\alpha(\theta)k^2F(k,\phi) \qquad (4)$$

with F the wave spectrum defined as $F(k_x,k_y) = \left|FT(\xi(x,y))\right|^2$

Yet, the modulation signal cannot be directly estimated from the radar signal. It is a fluctuation signal which is estimated. It is proportional to the modulation signal but it is altered by speckle noise and sensor impulse response. The fluctuation spectrum is equal to:

$$P_{\delta\sigma_0}(k) \approx P_{IR}(k)P_m(k) + P_{sp}(k) \qquad (5)$$

with P_{sp} the speckle spectrum, P_{IR} the impulse response spectrum and P_m the modulation spectrum to be estimated.

At the end of the processing, the spectrum of the fluctuation signal is corrected from speckle and impulse response to get the modulation spectrum P_m.

This quantity is computed for every cycle, thus for successive azimuth angles. It is a spectral density of the modulation (no physical unit), written $P_m(k,\phi)$, function of the wavenumber k of the waves for a given azimuth direction ϕ as shown in Figure 15.

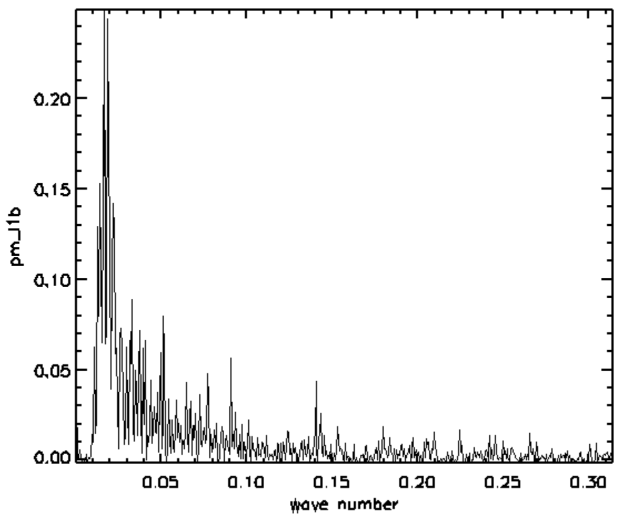


Figure 15. Modulation spectrum pm_l1b for 10° incidence beam as a function of wavenumber for a given azimuth direction.

3.7.1.2. Overview of the processing

The Figure 16 provides an overview of the processing chain at L1B level.

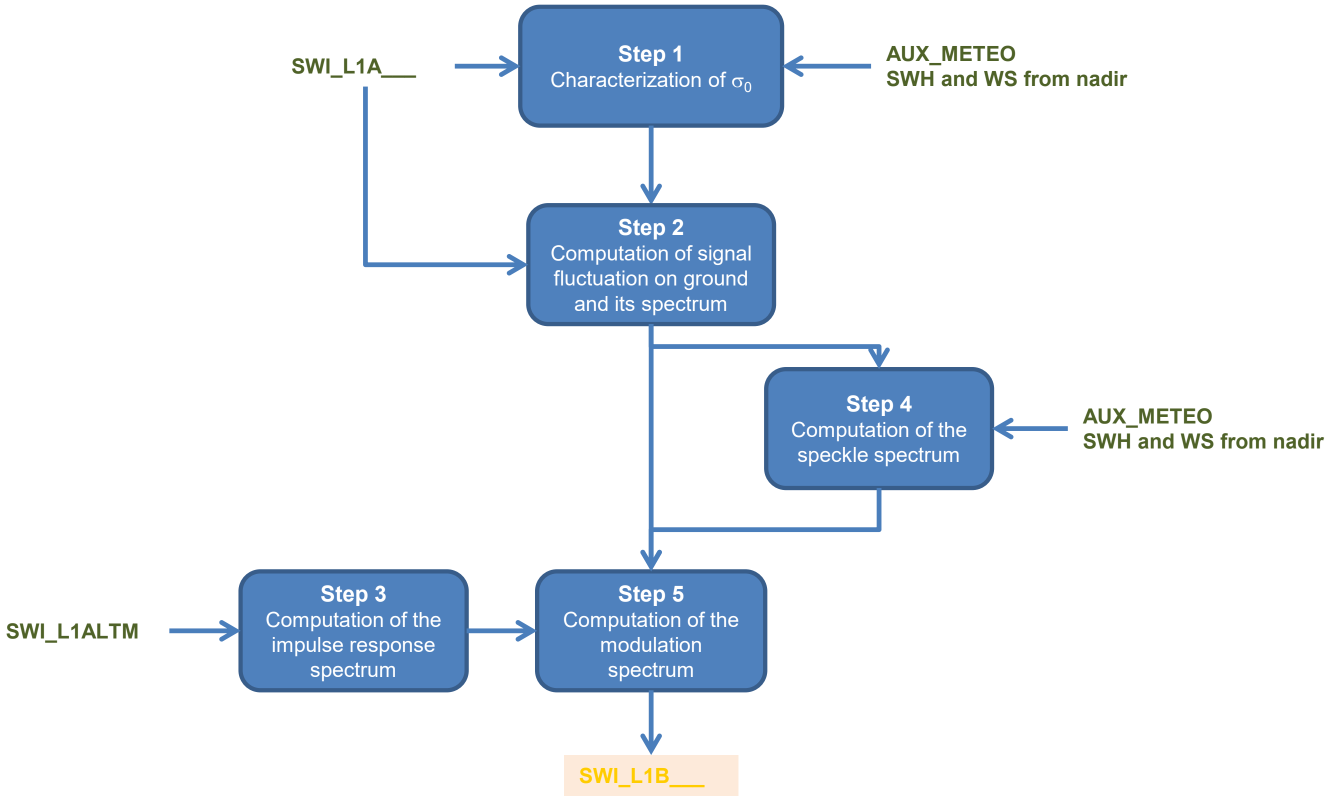


Figure 16. L1B processing chain..

The L1b processing main steps are:

- For each cycle:
  - characterization of the scene from the average trend of σ_0 (mean value at the beam centre, slope and curvature to detect any abnormal scene)
  - computation of the fluctuation signal and its associated statistics,
  - computation of the fluctuation spectra (spectra before corrections of speckle and impulse response),
  - estimation of the impulse response and speckle spectrum,
  - computation of the modulation spectra.

The inputs of the L1B processing are:

- the SWI_L1A___ file,
- the CDB file containing the instrument and processing parameters.
- the AUX_METEO file
- the SWI_L2Anad file (internal file)

The output of the L1B processing is:

- the SWI_L1B___ file.

3.7.1.3. Algorithm definition

All these algorithms are applied on each cycle at 6°, 8° and 10° on sea surfaces only. All the cycles are processed independently.

3.7.1.3.1. Step 1: characterization of the σ_0

First, the analysis window in range [r_{min}, r_{max}] is determined such as:

$$\forall r \in [r_{min}, r_{max}],\ \ \sigma_0(r) \geq 2\ Ne\sigma_0(x, R) \quad (6)$$

with $Ne\sigma 0(x, R) = Ne\sigma 0(x) \dfrac{cal\_ratio\_x(R)}{\frac{1}{\mathrm{N\_NESIG}} \sum_{r=\frac{\mathrm{NS\_GD(x)-N\_NESIG}}{2}}^{\frac{\mathrm{NS_{GD(x)}+N\_NESIG}}{2}-1} cal\_ratio\_x(R)}$

ND_GD, the number of points in the swath, N_NESIG the number of swath points used to determine $Ne\sigma_0(x)$ in L1a.

Over this interval [r_{min}, r_{max}], a second order regression is performed over the σ_0 values estimated in L1a processing. The result of this quadratic fit is named σ_{0_mean} later.

This mean trend is compared to a reference LUT built with ancillary data (such as TRMM or GPM measurements). This LUT is function of the incidence angle θ, the wind speed WS and the significant wave height SWH. The comparison with the LUT is made with:

- the value at the beam centre estimated from the fit is compared with the corresponding LUT value for the centre of the beam, with WS and SWH coming from the nadir beam (or from AUX_METEO product if not available); the comparison interval is defined by ± three times the standard deviation of the LUT;
- the slope at the beam centre of σ_{0_mean} compared with the slope of the LUT values within an interval defined by the lowest and highest slopes in the LUT;
- the curvature at the beam centre of σ_{0_mean} compared with the maximum value of the curvature in the LUT.

These comparisons enable to flag unexpected behavior of the σ_0. Any difference from the LUT can underline the following points:

- error in the on-board or L1a processing,
- non-standard scene with presence of rain, cloud, slicks, isles, sea-ice, coasts in the footprint.

The reliability of this flag will be checked during the validation phase. Additional indicators may be necessary to reject all abnormal scenes.

3.7.1.3.2. Step 2: computation of signal fluctuation on ground and its spectrum

The fluctuation signal in radar geometry $\delta\sigma_{0\_R}$ is equal to:

$$\delta\sigma_{0\_R}(r) = \frac{\sigma_0(r) - \sigma_{0\_mean}(r)}{\sigma_{0\_mean}(r)} \quad (7)$$

This signal has to be centred on zero. So, finally:

$$\delta\sigma_{0\_R}(r) = \delta\sigma_{0\_R}(r) - \langle \delta\sigma_{0\_R}(r) \rangle \quad (8)$$

Then, the fluctuation signal is projected on ground using a quadratic interpolation on the ground_range_x variable of the L1a product. The ground sampling is defined by the variable ΔX (global attribute of L1b file). ground_range_x(i) is the ground range value corresponding at the radar gate r_i.

N_i is the number of gates which verifies: $x_j - \frac{\Delta X}{2} \leq ground\_range\_x(i) \leq x_j + \frac{\Delta X}{2}$

Some statistics are computed on $\delta\sigma_{0\_X}$ (mean, variance, skewness and kurtosis) and they are compared to reference values which are indicated in the attributes of the L1b file.

$\delta\sigma_{0\_X}$ is available over a window size L_X. The spectral analysis is always performed on a window of L'_X size ($L'_X=\Delta X.N_{fft}$ with N_{fft} the number of samples of the $P_{\delta\sigma 0}$ signal). Two cases can be encountered:

- $L_X < L'_X$: the signal is completed by zero-padding,
- $L'_X \geq L_X$: the signal is truncated (truncation is performed symmetrical on the edges of the swath).

A Hanning weighting h is applied on $\delta\sigma_{0\_X}$. Finally, the fluctuation spectrum is defined by:

$$P_{\delta\sigma_0}(k,\phi) = \frac{1}{2\pi L'_X} 2C_{norm} \left| FT\left(h(x)\delta\sigma_{0\_X}(x)\right)\right|^2 \quad (10)$$

C_{norm} is an overall normalization coefficient which guarantees the conservation of energy between the spectral and the range modulation domains.

Only the positive part of the wavenumber is kept.

3.7.1.3.3. Step 3: computation of the impulse response

The impulse response density spectrum $P_{IR}(k)$, is estimated in the Fourier domain from the impulse response of SWIM measured in CAL1 mode and its approximation by a cardinal sine function.

$$P_{IR}(k) = \left[tri\left(\frac{k}{2\pi}\frac{L\,c}{2\,sin\theta}\right)\right]^2 \quad (11)$$

where tri is the triangle function (Fourier transform of the cardinal sine function), Lc is the width of the sine function provided in the calibration file (SWI_L1ALT1) converted in units of meters, and θ is the incidence angle at the centre of the footprint.

3.7.1.3.4. Step 4: computation of the speckle spectrum

There are several methods for the speckle spectrum estimation. The choice made for the processing is indicated in the variable speckle_information.

<u>Analytical method:</u>

The speckle spectrum is modelled by the following equation:

$$\boldsymbol{P_{sp\_Nind}(k)} = \frac{\boldsymbol{L\,c}}{\boldsymbol{4\,\pi\,N_{sp}}}\frac{\boldsymbol{1}}{\boldsymbol{sin\,\theta}}\,\boldsymbol{tri}\left(\frac{\boldsymbol{k}}{\boldsymbol{2\pi}}\frac{\boldsymbol{L\,c}}{\boldsymbol{2\,sin\,\theta}}\right), \quad (12)$$

where L is the width of the sine function (in s) approximating the IR function and N_{sp} the number of independent averaged samples (by definition, $N_{sp} \leq N_{imp}$). In this approach, there are two options to fix N_{sp}:.

- method 1a: $N_{sp} = N_{imp}$,
- method 1b: $\boldsymbol{P_{sp\_Nind}}$ estimated for each cycle as a weighted sum of a 2nd order polynome and a triangle function of the type of (12). Coefficients of these functions depend on azimuth with respect to satellite track. Estimation of the appropriate coefficients is under progress at the time of writing this document. Their values will be inserted in the CDB files used as input. This method has been implemented after results from the CAL/VAL study, which show that close to the along-track direction the statistics and density spectrum of noise is different from the case of other azimuths, due to the reduced Doppler bandwidth (and associated increase of correlation between successive radar echoes averaged during on-board processing).

<u>Noise floor level method:</u>

The speckle spectrum is estimated as the noise floor level in the estimated spectrum in the domains where there is a minimum of signal fluctuation, i.e. no impact on waves in these fluctuations.

- Method 2a: for each cycle, the speckle spectrum is estimated in the wavenumber domain [k_{lim},k_{max}] (k_lim global attribute) assuming that there is no wave signal at high wavenumber. This option must not be used for the speckle mode data because in this case k_{lim} is not large enough to exclude an impact of waves in the signal fluctuations.
- method 2b: estimated from the density spectrum of fluctuation spectrum in the azimuth direction where its energy is the lowest per half rotation. This option must not be used for fixed antenna.

Cross-spectrum method (method 3 or 3LG in speckle mode):

Computation of the cross-spectrum between two adjacent cycles at a given incidence or between two partial cycles of the Speckle mode (see method 4). The cross-spectrum XS is defined as:

$$XS(k,\phi) = TF\left[\delta\sigma_{0\_X}(X,\phi_n,t_n)\right]TF^*\left[\delta\sigma_{0\_X}(X,\phi_{n-1},t_{n-1})\right] Migr(k,\phi) \quad (13)$$

with n the cycle number (or partial cycle number) and taking into account for migration, $Migr(k,\phi) = \exp(i\Delta\mathrm{L}k)$, ΔL = Vcosϕ ΔT, V is the projected velocity of the satellite, ϕ azimuthal angle, ΔT the time step between two acquisitions.

The cross-spectrum is considered free of speckle thanks to the time difference of the two samples for which the speckle noise of the two samples are uncorrelated.

The comparison between the co-spectrum and the cross-spectrum enables to estimate the speckle spectrum.

This method will be assessed during the validation phase. In particular, it may not be applicable for all SWIM operation modes. The most favorable conditions are probably those where acquisition with a same incidence is repeated at intervals of a few tens of ms which will ensure an appropriate tradeoff between superposition of the scenes, and uncorrelated samples with respect to speckle noise (example macrocyle 0-8-8-8 or 0-10-10-10).

Combination of spectra obtained with two time integrations of the modulations (method 4):

In the speckle mode (see §2.3), the cycle duration is split into three parts: the 3 echoes averaged on NIMP/3 pulses are downloaded, instead of only one echo. The counter part is an average in range on a higher number of range gates compared to the nominal mode in to keep the on-board data rate constant.

The speckle spectrum is evaluated as proposed in [DR3]:

$$P_{sp} = \frac{\langle P_{\delta\_\sigma_0\_i}\rangle_i - P_{\delta\sigma_0}}{N_l - 1} \quad (14)$$

with N_l=NIMP/3, $\langle P_{\delta\_\sigma_0\_i}\rangle_i$ the fluctuation spectrum averaged over the three partial cycles and $P_{\delta\sigma 0}$ the fluctuation spectrum over the entire cycle.

3.7.1.3.5. Step 5: computation of the modulation spectrum

The modulation spectrum is computed (for all acquisition modes except in the cross-spectrum mode) as:

$$P_m(k,\phi) = \frac{P_{\delta\_\sigma_0}(k,\phi) - P_{sp}(k)}{P_{IR(k)}} \quad (15)$$

For cross-spectrum mode (speckle method 3): $P_m(k,\phi) = \frac{REAL\_PART(XS(k,\phi))}{P_{IR(k)}}$

In order to reduce the noise on P_m, an averaging over two wavenumber bins is performed at this level (L1b):

$$P_m(k_j) = \frac{1}{2}\left(P_m(k_{2j}) + P_m(k_{2j+1})\right), j \in \left[0, \frac{Nfft}{4}\right] \quad (16)$$

3.7.2. Description of the product content

The file format is described in [DA1]. We detail here the physical content of each variable and explain how it can be used. The variable type and LSB are precised in [DA1]. The expected accuracy after the processing is given in this document.

3.7.2.1. Specific global attributes

Note that each time there is a modification of on-board configuration leading to a change of one of the below attributes, a new file is generated.

Tag name	Description of the attribute content
macrocycle_angle	Beam type, expressed as angle in °, for each cycle of the macro-cycle. A macro-cycle is characterized by the succession of NB_CYCLES beams : [f0 f1 ….. fNB_CYCLES-1] where fk is an integer equal to 0, 2, 4, 6, 8 or 10 which indicates the estimated angle value of the beam. For example, the use of all the incidence beams (nominal macro-cycle) is represented by f1=0, f2=2, f3=4, f4=6, f5=8, f6=10, ie macro-cycle = [0; 2; 4; 6; 8; 10].
Macrocycle_beam	Beam type, expressed as beam number, for each cycle of the macro-cycle. A macro-cycle is characterized by the succession of NB_CYCLES beams: [f0 f1 ….. fNB_CYCLES-1]. Here fk is an integer equal to 0, 1, 2, 3, 4 or 5 which indicates the beam. For example, the use of all the incidence beams (nominal macro-cycle) is represented by f1=0, f2=1, f3=2, f4=3, f5=4, f6=5, ie macrocycle_beam = [0; 1; 2; 3; 4; 5].
macrocycle_L1b	Same as macrocycle angle but for beam spectra only (6°, 8°,10°)
nimp	Number of pulses which are averaged on board, varying with the incidence value only for spectral beams. See Table 3
delta_x	Binning at the surface (m) used in the resampling of the variables originally provided as a function of range in the line of sight.
Nfft	Number of points of the Fast Fourier Transform
speckle_information	Name of the speckle estimation method (1A, 1B, 2A, 2B, 3, 3LG or 4) used to calculate the modulation spectrum at Level1b.
valid_swath_percentage_average	Average of valid_swath_percentage product value
flag_sigma0_mean_success_amount	Amount of success (in %) in the file of sigma0 flag for mean value.

	This flag qualifies the consistency between the estimated sigma0 and the expected sigma0 from reference shapes (empirical models derived from external observations such as TRMM and GPM). The flag_sigma0_mean_success_amount flag is equal to the percentage of cycles where FLAG_SIGMA0_MEAN = 0 (i.e. estimated sigma0 consistent with the expected sigma0). The expected sigma0 is extracted from a reference database knowing the sea state condition (SWH, WS). The sea state condition is computed from the nadir beam or from the ECMWF data when retracking of the nadir beam fails.
flag_sigma0_slope_success_amount	Amount of success (in %) in the file of sigma0 flag for slope value. This flag qualifies the consistency between the estimated slope of sigma0 (trend with incidence) and the expected slope of sigma0 from reference shapes (empirical models derived from external observations such as TRMM and GPM). This flag provides the percentage of cycles where FLAG_SIGMA0_SLOPE = 0 (i.e. sigma0 slope inside the expected values).The sigma0 slope are compared to the reference database knowing the sea state condition (SWH, WS).
flag_sigma0_shape_success_amount	Amount of success (in %) in the file of sigma0 flag for shape value. This flag qualifies the consistency between the estimated curvature of sigma0 (trend with incidence) and the expected curvature of sigma0 from reference shapes (empirical models derived from external observations such as TRMM and GPM). This flag provides the percentage of cycles where FLAG_SIGMA0_SHAPE = 0 (i.e. sigma0 shape inside the expected values). The sigma0 curvature are compared to the reference database knowing the sea state condition (SWH, WS).
flag_land_sea_success_amount	Percentage of cycles (%) in the file where the sea flag is equal to 0 (no land). Sea/land flag for each cycle is based on values of the ECMWF WAM model provided in AUX_METEO.
flag_sea_ice_success_amount	Percentage of cycles (%) in the file where the sea ice flag is equal to 0 (no sea ice). Sea ice flag for each cycle is based on the sea ice fraction indicator of the ECMWF WAM model provided in AUX_METEO.
k_lim_1	Minimum wavenumber for estimating mean noise floor of speckle with method 2A. Speckle is estimated using the modulation spectrum values in [k_lim_1, k_lim_2].
k_lim_2	Maximum limit wavenumber for estimating mean noise floor of speckle with method 2A. Speckle is estimated using the modulation spectrum values in [k_lim_1, k_lim_2].
k_max	Maximum wavenumber of the modulation and fluctuation spectra provided in the file
delta_r_radar	Radar resolution (m)
threshold_low_variance	Low limit for variance of sigma0 modulations used to flag the σ_0 modulation.
threshold_high_variance	High limit for variance of sigma0 modulations used to flag the σ_0 modulation.
threshold_low_kurtosis	Low limit for kurtosis of sigma0 modulations used to flag the σ_0 modulation.

threshold_high_kurtosis	High limit for kurtosis of sigma0 modulations used to flag the σ_0 modulation.
threshold_low_skewness	Low limit for skewness of sigma0 modulations used to flag the σ_0 modulation.
threshold_high_skewness	High limit for skewness of sigma0 modulations used to flag the σ_0 modulation.
default_ecmwf_wind	Default value of wind speed if needed. ??? why ecmwf in the name ?? Explain the use of this value.
default_ecmwf_significant_wave_height	Default value of SWH if needed. ??? why ecmwf in the name ?? Explain the use of this value.
sea_ice_fraction_rejection_threshold	Threshold of sea ice fraction (given in AUX_METEO) for raising to 1 the flag for sea_ice.
dom_threshold	Minimum percentage of range bins of the footprint required to compute the fluctuation and modulation spectra
coeff_nesig0	Mutiplicative factor applied to signal to noise ratio to select only sigma0 values above noise level
resample_mode	Set to 1 if resampling was done over wavenumber, to 0 if not.
Use_L2anad	Value is 1 if the nadir parameters are used in the flags on sigma0 0 if the ECMWF parameters are used in these flags

3.7.2.2. Variables

Tag name	Description of the variable content	Accuracy
k_spectra	Wave number vector	
nesig0	Noise equivalent Sigma0 per beam, for spectral beam only. The noise equivalent σ_0 is the σ_0 such as SNR equal 1. It is computed from the maximum value of the backscattered power (before instrumental corrections) and the estimated thermal noise level.	± 1dB (including the estimation error on thermal noise <0.1dB)
lat_l1b	Latitude of the footprint centre for all the spectral beams.	0.01°
lon_l1b	Longitude of the footprint centre for all the spectral beams.	0.01°
flag_availability	Flag on raw data validity (instrument flag relating any abnormal behaviour of SWIM regarding temperature, current voltage or data availability). 0: error, 1: valid, 2: warning, 3: no data	
flag_sigma0_mean	Flag for value of sigma0 for each beam. The sigma0 value at the beam center, estimated from the mean trend (see 3.71.1.3.1) is compared to a reference table (look up table or LUT) built outside the L1b processing from an empirical model derived from GPM observations, taking into account surface conditions (significant wave height, wind speed). The variable flag_sigma0_mean provides a flag on the similarity with the empirical model for the value at the centre of the beam. The comparison uses	

	the significant wave height and wind speed provided from the nadir beam L2a product, or, if not available, from the ECMWF forecast data. Value of the flag: 0: conformity with the empirical model (within the confidence interval) 1: non conformity or doubts on conformity due to missing points to interpolate from the LUT 2: fitting quadratic form on sigma0 failed 4: no valid data	
flag_sigma0_slope	Flag for value of sigma0 mean trend for each beam. The slope of sigma0 with incidence is estimated at the beam centre (see 3.71.1.3.1) and compared to a reference table (look up table or LUT) built outside the L1b processing from an empirical model derived from GPM observations, taking into account surface conditions (significant wave height, wind speed). The variable flag_sigma0_slope provides a flag on the similarity with the empirical model for the slope of sigma0 versus incidence, at the beam centre. The comparison uses the significant wave height and wind speed provided from the nadir beam L2a product, or, if not available, from the ECMWF forecast data. 0: conformity with the empirical model (within the interval from min to max values of the slopes in the LUT) 1: non conformity or doubts on conformity due to missing points to interpolate from the LUT 2: fitting quadratic form on sigma0 failed 4: no valid data	
flag_sigma0_shape	Flag which indicates the conformity of the sigma0 shape (convexity or concavity) within GPM data behavior The curvature of sigma0 profile is estimated from the coefficient of the 2nd order term in the adjusted quadratic form (coeff_mean_trend product) and compared to a reference table (look up table or LUT) built outside the L1b processing from an empirical model derived from GPM observations, taking into account surface conditions (significant wave height, wind speed). The variable flag_sigma0_shape provides a flag on the similarity with the empirical model for the curvature of sigma0 versus incidence. The comparison uses the significant wave height and wind speed provided from the nadir beam L2a product, or, if not available, from the ECMWF forecast data. 0: conformity with the empirical model (within the interval from min to max values of the curvature in the LUT) 1: non conformity or doubts on conformity due to missing points to interpolate from the LUT 2: fitting quadratic form on sigma0 failed 4: no valid data	
flag_sea_ice	The flag is 0: no sea ice, 1: presumed sea ice, 2: no valid data. The flag is built as follows: the sea-ice fraction comes from the ECMWF model data interpolated onto the position of the footprint centre of each cycle is compared to a threshold (sea_ice_fraction_rejection_threshold) to determine whereas the signal is impacted by ice or not. The flag is attributed to the entire cycle.	
flag_land_sea	The flag is 0: scene over sea, 1: scene over land, 2: no valid data. The flag is built as follows: the sea/land mask (lsm) value comes from the ECMWF model data interpolated onto the position of the footprint centre of each cycle. The flag is raised as soon as lsm is greater than	

	0. The flag is attributed to the entire cycle.	
flag_stat	Comparison of the signal statistics to the reference ones. FLAG_STAT=0: the signal statistics (variance, skewness and kurtosis) are within the expected intervals. FLAG_STAT=1: the skewness or the kurtosis are out of the expected bounds FLAG_STAT=2: the variance is out of the expected bounds but the skewness and the kurtosis are ok. FLAG_STAT=3: variance, skewness, and kurtosis are all outside the expected bounds FLAG_STAT=4: other cases	
valid_swath_percentage	Percentage of range bins within the footprint which are kept after comparing the sigma0 values to the noise equivalent sigma0 (one value per cycle)	
phi	Azimuth angle in the local orbital frame, i.e. with respect to the orbit ground track (in clockwise rotation). Phi = 0° corresponds to an azimuth along track in the direction of satellite advection.	10^{-3}
phi_geo	Azimuth angle with respect to geographical North. It is deduced from phi taking into account the orbit inclination. North is 0 or 360°, East is 90°, South is 180° and West is 270°	10^{-3}
C_norm	Normalization coefficient used for the computation of the fluctuation spectrum from the fluctuation signal. $P_{\delta\sigma_0}(k) = \frac{1}{2\pi L'_X} 2C_{norm} \left\|TF(\delta\sigma_{0\_X})\right\|^2 \; pour \; k \in [0, k_{\max}]$ L_X' is the time analysis window. $C_{norm} = C_{FFT}\, C_{zpad}\, C_{Hann}$ C_{FFT} is a FFT coefficient to guarantee the conservation of Parseval theorem; it depends from the code language. C_{zpad} is the zero-padding coefficient to guarantee energy conservation after zero-padding. C_{Han} is the Hanning coefficient to guarantee energy conservation after Hanning weighting.	0.1
Nx	Number of data points in fluctuation signal prior to FFT transform	
altitude	Altitude of the satellite in meters.	10^{-3} m
ly	Ground length of azimuth beam footprint (at 3dB) per spectral beam (computed in L1a).	0.01 m
central_incidence	Incidence of the central gate of the swath in radians.	10^{-5} rad
time_l1b	Time at the footprint centre for each cycle of the spectral beams. The time is computed for the signal on the ground and at the middle of the	1 µs

	cycle.	
coeff_mean_trend	Coefficients a, b and c of the 2nd order polynomial fitted to the sigma0 values as a function of incidence: $\sigma_0(\theta) = a\theta^2 + b\theta + c$. The L1a sigma0 mean trend (in dB) is approximated by a 2nd order polynomial as a function of incidence (in degrees) for each cycle. This polynomial is used to suppress the mean trend σ_{0_moy} before estimating the fluctuation spectrum. These coefficients are the coefficients of the estimated polynomial. The coefficients in the polynomial are stored in descending powers. (i.e. first a, then b, then c).	10^{-3}
pir_l1b	Impulse response spectrum as a function of wavenumber. See 3.7.1.3.3	10^{-3}
pdsig_l1b	Fluctuation spectrum for each cycle of the spectral beams as a function of wavenumber. The fluctuation spectrum is the spectral density function of the fluctuation signal (delta_sigx_l1b).	10^{-4}
psp_l1b	Density spectrum of the speckle for each cycle as a function of wavenumber. The speckle spectrum can be estimated with different methods. The method is indicated in the global attribute speckle_information. The different methods are defined in §3.7.1.3.4.	10^{-6}
pm_l1b	Density spectrum of modulation as a function of wavenumber for each cycle of all spectral beams: obtained from pdsig_l1b which is corrected from density spectrum of speckle and of the impulse response (Eq.5)	10^{-4}
delta_sigx_l1b	Signal fluctuations in the surface geometry for all spectral beams. Fluctuations are estimated from the L1a σ_0 values given in range bins as relative difference from the mean trend (Eq. (7). This signal is then projected on ground.	10^{-3}

3.8. L2 PRODUCT

3.8.1. L2 data processing

3.8.1.1. Processing objective

The general objective of the Level 2 processing is to provide geophysical products, which aggregate within the SWIM swath, results from the L1a (radar cross-section), and from L1b to reconstruct the 2D observations (directional wave spectra and their associated parameters and partitions). It also transforms them to geophysical units. For this, we define product cells (also called “boxes” here below). These product cells cover, on each side of the nadir track, contiguous areas delimited by successive complete azimuthal scans over 180°, which correspond to areas of about 70 km x 90 km (see below, Figure 17). Several geophysical parameters are computed over these boxes: σ_0 profiles, SWH and WS from nadir retracking, 2D wave spectra and associated sea state partitioning.

The main inputs of this Level 2 come from Level 1a and Level1b products:

- from Level 1a, the main inputs are the normalized radar cross-sections provided in the geometry of the radar sampling for each beam (0, 2, 4, 6, 8, 10°) and for each macro-cycle,
- from Level 1b, the main inputs are the density spectra of modulations associated to the waves (corrected from speckle effects), provided for each cycle, i.e. for each "spectrum beam" (6, 8, 10°) and for each macro-cycle.

The boxes are defined as the areas on the left and the right sides of the nadir track which covers half an antenna's rotation. The Figure 17 illustrates the definition of the boxes.

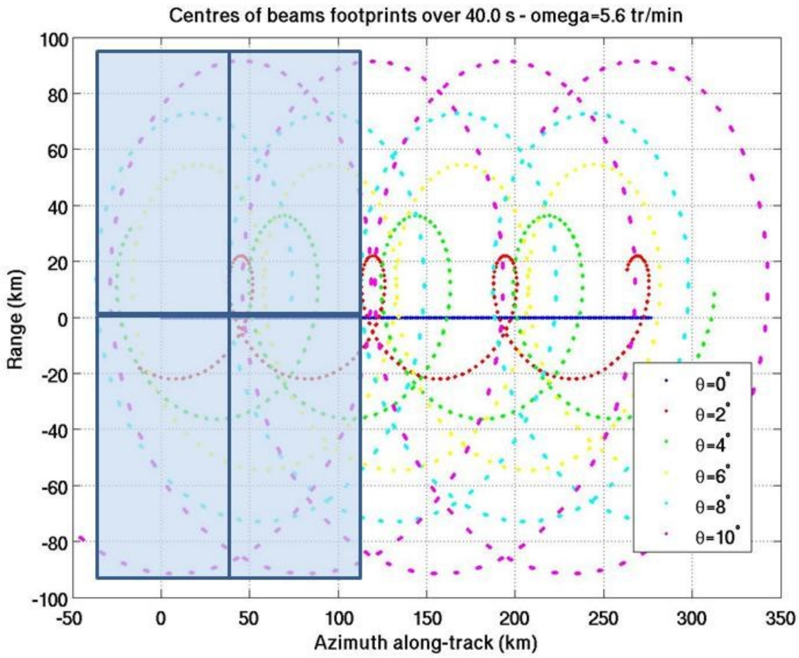


Figure 17. Horizontal sampling of SWIM data. The coloured dots indicate the centre of each antenna footprint according to the radar geometry and followed by the Level 1a data. The shaded light blue boxes illustrate the area of the "product cells" (boxes) used to generate the Level 2 products.

The processing of level 2 is completely applied when the antenna rotation mode is on. When the antenna rotation mode is off, a specific processing is applied and the processing stops at the end of step 3 (Figure 18).

We recall now the main equations governing the relation between the density spectrum of modulations corrected from speckle and impulse response function (output of Level1b product, noted here $\boldsymbol{P_m(k,\phi)}$ and the density spectrum of wave slopes $\boldsymbol{k^2E(k,\phi)}$.

It has been shown by Jackson [DR3, DR4] that at small incidence and in the conditions of large azimuth footprint with respect to wavelength or wavecrest, $\mathrm{P_m(k,\phi)}$ can be approximated as proportional to the directional wave slope spectrum, $\mathrm{F(k,\phi) = k^2E(k,\phi)}$:

$$\mathbf{P_m(k,\phi)} = \frac{\sqrt{2\pi}}{\mathbf{L_y}}\boldsymbol{\alpha}^2(\boldsymbol{\theta})\mathbf{k^2E(k,\phi)} \quad (17)$$

where k is the wave number, ϕ the azimuth direction, $\boldsymbol{E(k,\phi)}$ is the 2D wave height spectrum, L_y a dimension related to the azimuth beam width, and α the sensitivity coefficient.

The proportionality coefficient between the modulation spectrum, P_m (k,ϕ), and the wave slope spectrum, $k^2E(k,\phi)$, is called Modulation Transfer Function (MTF).

$$\boldsymbol{MTF(\theta,\phi) = \frac{\sqrt{2\pi}}{L_y}\alpha^2(\theta)} \tag{18}$$

where Ly is the azimuth length of the footprint given by:

$$\boldsymbol{L_y = \mathbf{r}\frac{\beta_\Phi}{2\sqrt{2ln2}}} \tag{19}$$

with r is the radial distance at the beam centre, β_Φ the antenna 3dB beam-width in azimuth (one-way). L_y is provided in the L1a products.

As shown by [DR2, DR3], the general expression for α is:

$$\boldsymbol{\alpha = cotan(\theta) - \frac{1}{\sigma_0}\frac{\partial\sigma_0}{\partial\theta}} \tag{20}$$

where θ is the incidence angle (at the surface), σ_0 is the normalized radar cross-section (in linear units).

Assuming that the backscattering can be represented by a quasi-specular scattering model (Geometrical Optics or GO model), then:

$$\sigma_0 cos^4(\theta) \propto p(\tan(\theta)) \tag{21}$$

where p is the probability density function (pdf) of surface slopes evaluated for the specular condition (local slope = tan θ)

With these assumptions, Eq. 20 becomes:

$$\alpha(\theta) = cotan(\theta) - 4\,tan(\theta) - \frac{1}{cos^2(\theta)}\frac{\partial ln[p(tan(\theta))]}{\partial tan(\theta)} \tag{22}$$

Assuming in addition that the slope pdf is Gaussian distribution of slopes, the α sensitivity coefficient may be expressed as:

$$\boldsymbol{\alpha(\theta) = cotan(\theta) - 4\,tan(\theta) + \frac{1}{mss}\frac{2tan(\theta)}{cos^2(\theta)}} \tag{23}$$

where mss (mean square slope) is the variance of the surface slopes contributing to the backscatter (i.e. for wavelengths two or three times longer than the radar wavelength). As shown by various authors mss depends mainly on the wind speed.

For the L2 processing, the default option is to consider α as given by Eq.(20) but an alternative option using (23) and a parameterization of mss with wind speed is also possible.

3.8.1.2. Overview of the processing

The Figure 18 provides an overview of the processing chain at L2 level.

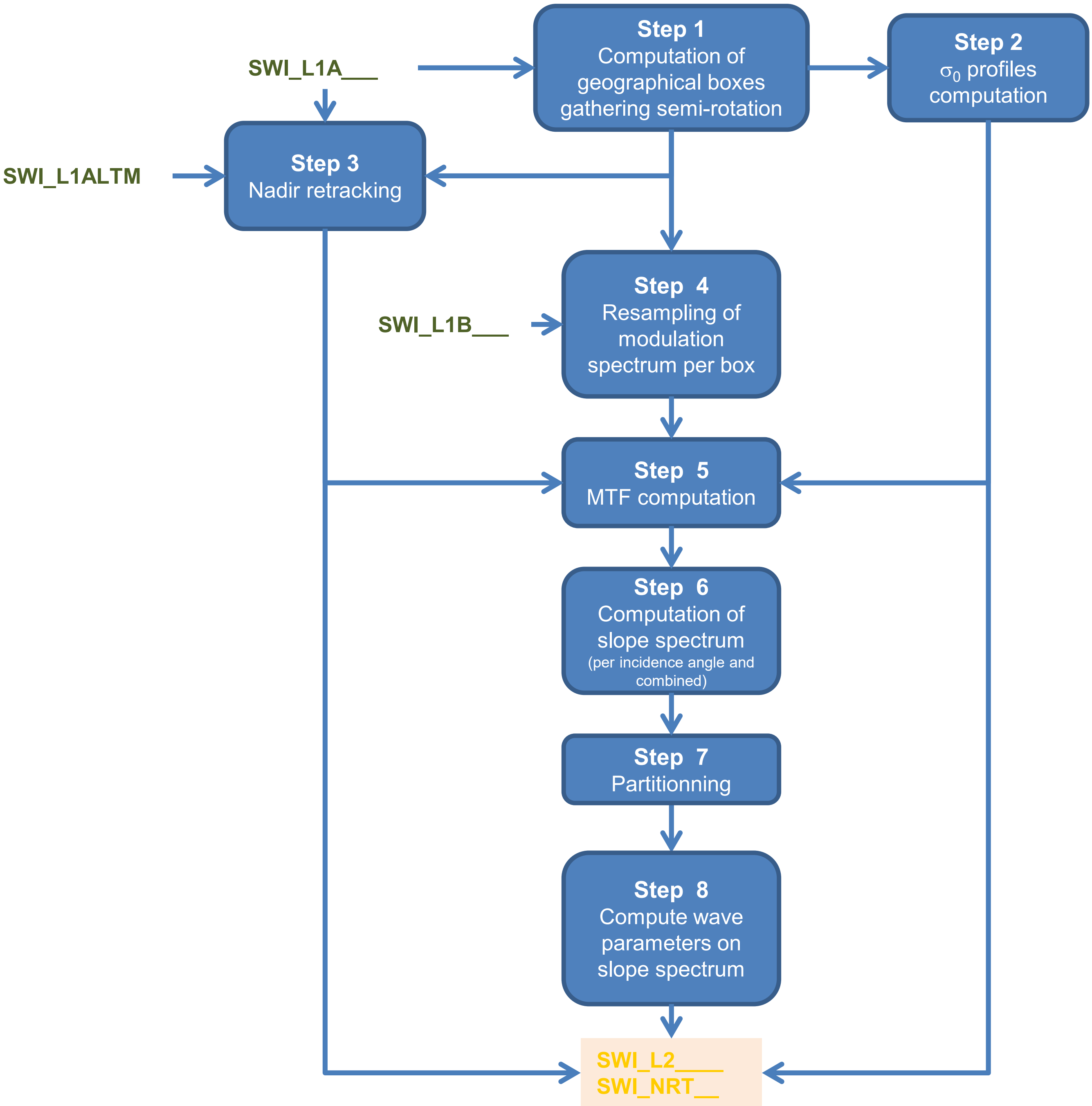


Figure 18. L2 processing chain. The input files are indicated in green and the output files in yellow.

The main steps of the processing are:

- the determination of the product cells (boxes);
- the computation of averaged values of sigma0 per bins of 0.5° in incidence and 15° in azimuth. It is carried out for the 6 beams (0°, 2°, 4°, 6°, 8°, 10°) and for all kinds of surface areas (land and sea);
- the retracking of the nadir waveform to estimate SWH and WS;
- the computation of the modulation transfer function (MTF) for the 6°, 8° and 10° beams; this MTF allows the conversion of the modulation spectrum into a wave slope spectrum;
- the computation of density spectra of wave slopes, at the scale of the product cells, for the 6°, 8° and 10° beams over the sea, including smoothing calculations and resampling in wavenumber and direction;
- the calculation of confidence interval per wavenumber and azimuth bin;
- the calculation of the omni-directional wave spectra and associated confidence intervals;
- the computation of up to 3 wave partitions which may characterize different wave systems;

- the computation of parameters associated to the full directional spectra and to the partitions (significant wave height, peak direction, peak wavelength).

The inputs of the L2 processing are:

- the SWI_L1A___ file,
- the SWI_L1B___ file,
- the AUX_METEO file,
- the CDB file containing the instrument and processing parameters.

The outputs of the L2 processing are:

- the SWI_L2____ file,
- the SWI_NRT file, which is a subset of the L2 results for distribution in Near Real Time to the meteorological agencies.

3.8.1.3. Algorithm definition

3.8.1.3.1. Step 1: computation of geographical boxes

At this step, the principle is to merge data over areas where the sea-state is supposed to be homogeneous in order to get a representative set of directional wave spectra over geographic cells (or boxes) useful for applications. A prior task is therefore to determine these areas (or "boxes") as well as the spatially-coincident measurements consisting in lists of specific macro-cycles.

Figure 17 shows the acquisition geometry considered in along-track and across-track coordinates as well as the first boxes in shaded blue. The extremes of the swath (beginning and end of the orbit pass) do not necessarily contain all incidence footprints (because high incidence footprints are far away from the nadir coordinate). Because the wave spectrum is supposed to have a 180°-symmetry, only half a rotation is needed to estimate the directional wave spectrum. Thus, two series of boxes, each one gathering samples overs 180° in azimuth, are determined on each side of the nadir track. Note that the size of each box in the along-track direction will depend on the rotation speed of the antenna which is not expected to vary significantly.

To determine the boxes, the nadir acquisition time and position are used as a reference and the along-track and across-track coordinates of each point are used. First the periodicity of the antenna rotation is used to determine the number of boxes in the product. The corresponding along-track coordinate obtained for the nadir beam determines which non-nadir measurements fall within a given box or not. The across-track coordinate (calculated from the projection of the radial range coordinate on the nadir track) then allows to distinguish between the boxes with positive and negative ranges with respect to the nadir satellite track (i.e. on the right/left sides of the nadir track).

Therefore, two dimensions are defined for discriminating between the boxes

- nbox is the total number of along-track boxes of the whole product (~1 orbit)
- posneg is the number of across-track boxes to be considered: 2 if one decides to distinguish the left and right sides, 1 in the opposite case where both left and rights sides are considered to build the 2D spectrum (in this case over 360° azimuth angles). In the first case (posneg=2), the values of 1 or 2 will denote respectively positive ranges (right side of the nadir track) or negative ranges (left side of the nadir track). Note that left or rights sides are defined with respect to the satellite velocity direction.

The output of this step is, per box and per beam, a series of indices of the macro-cycles which are spatially-coincident with the box. The azimuthal offset between the different incidence beams within one macro-cycle results in footprints possibly belonging to different boxes. However each footprint belongs to unique box and posneg, except nadir footprints which are common to both posneg cases.

The lists of indices may be called by any procedure requiring a selection of one or more beams within one specific box, for example the determination of the mean latitude/longitude of the box, or further selection by azimuth values inside the box.

For analysing and debugging purposes the lists of macro-cycles are provided in the L2 product.

3.8.1.3.2. Step 2: computation of σ_0 profiles

For each beam a first requirement is the computation of mean values of σ_0 per bins of 15° in azimuth and 0.5° in incidence within each box and of the associated standard deviation around the mean value. We call the output of this step "mini-profiles" of σ_0. It is easy to do that because the previous step (determining boxes) has already identified the indices of the corresponding macro-cycles per box. These mini-profiles are corrected at this step from atmospheric attenuation.

In the case of non-nominal macro-cycles such as (0°, 8°, 8°) or (0°, 10°, 10°), products are computed per incidence angle per box (i.e. we combine 8° and 8° data in one product for (0°, 8°, 8°) macro-cycle).

In the event that the antenna rotation mode is off, only one bin of azimuth per box is filled by sigma0 profile. The rest of the box is filled with "fill values", and there is no wave spectrum product in this case .

As we can see in Figure 19, depending on the incidence beam and azimuth angle, there is either one, two or several backscattered signals of a given incidence beam available to compute the mean value in each 15° azimuth bin.

As concerns the number of original σ_0 values (at Level 1a in the radar geometry) contributing to mean values of σ_0 per 0.5° incidence bins, it will depend on the incidence, due to the non-linear relation between range r and incidence. So it depends on the incidence beam, on the incidence bin for each beam and also on the altitude of the satellite.

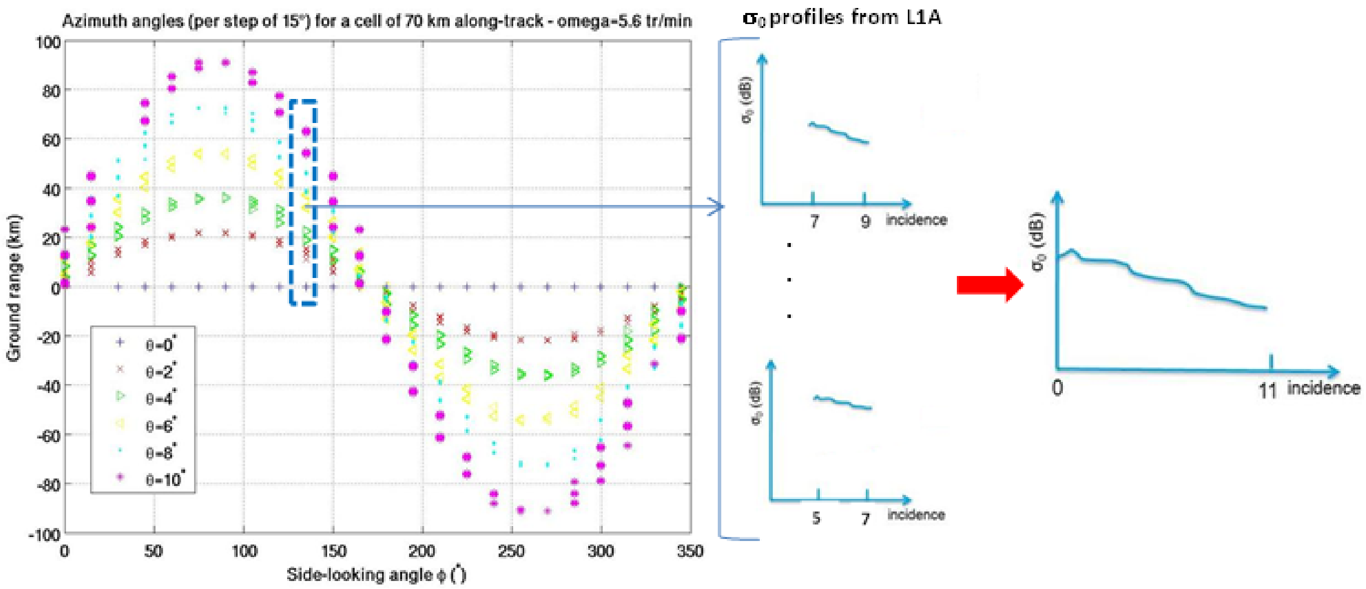


Figure 19. On the left, example of ground footprint for different elevation angles as function of azimuth per step of 15° in azimuth. We use all points at the same incidence bin to compute mini profiles from sigma0 L1a and combined full profiles as shown on the right part of the figure.

The averaged value of σ_0 from the nadir beam is also computed following the same sampling in azimuth as the other beams (even if the azimuth angle has no real geometric meaning for the nadir beam).

In addition, the processing includes for each azimuth bin (15°), a fitting process on σ_0 to represent the mean dependence σ_0 as function of the incidence angle. The model fitted on the mini-profiles assumes that the backscatter mechanism is quasi-specular (Eq. 21) and that the surface slopes contributing to the backscatter can be approximated by a Gaussian distribution. When expressed in dB $\boldsymbol{\sigma_0}$ is hence modeled as :

$$\boldsymbol{\sigma_0}\ (\mathbf{dB}) + \frac{\mathbf{10}}{\mathbf{ln(10)}}\mathbf{ln}(cos^4\theta) = \mathbf{A} + \mathbf{B}tan^2\theta\ . \quad (24)$$

A linear regression fit is applied to sigma0 mini-profiles to derive A and B coefficients by minimizing the cost function: $\chi^2 = \sum_{i=0}^{N}(\frac{y_i - Ax_i - B}{\sigma_i})^2$ where σ_i = err in dB, and A, B the coefficients of the fit. Prior to the fitting process mean bias from one beam to another are eventually compensated so as to take into account possible remaining offsets non-compensated in the L1 process.

An example of result (obtained from simulations- is shown in Figure 20.

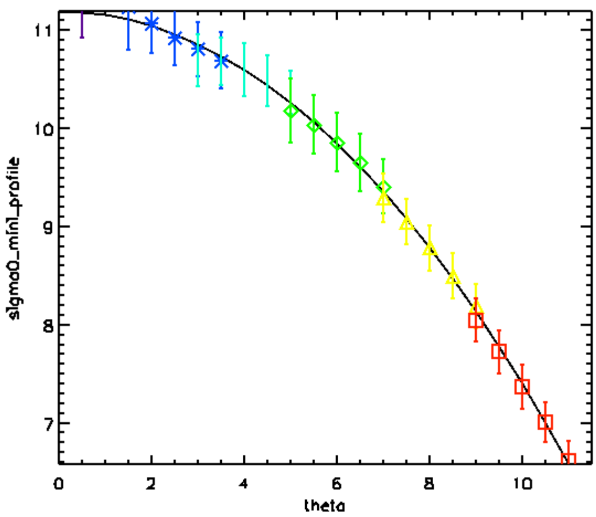


Figure 20: Fit (black line) applied on the combination of mini-profiles (color symbols) to generate a sigma0 profile as function of incident angle

This last step takes into account possible overlaps of the mini-profiles σ_0 from contiguous antenna beams.

3.8.1.3.3. Step 3: nadir signal retracking

Similarly to the case of satellite altimeter missions, the words "nadir signal retracking" means extraction of geophysical parameters from the nadir echo waveform, except that for SWIM no information is provided on the epoch or height because CFOSAT is not an altimeter mission (no precise orbit determination, no microwave radiometry nor dual wavelength measurement for delay correction). The primary objective of this step is hence to provide the significant wave height (SWH), the normalized radar-cross-section σ_0 and the wind speed (WS) over ocean surfaces. These parameters are similar to those provided in altimeter mission products. For CFOSAT, depending on the options chosen for the 2D wave spectrum retrieval, they are also used as constraints in the 2D wave spectrum inversion. In addition, the properties of the waveform are also analyzed to provide a rain flag according to [DR6, DR7], as well as the normalized radar cross-section and some parameters specifically defined for continental applications (leading edge width, trailing edge slope…). The corresponding algorithms are described in [DR12].

3 retracking algorithm are applied :

ICE1: applied on all surfaces waveforms

The ice-1 retracking algorithm is defined in [DR17]. The aim of the ice-1 retracking algorithm is to determine the tracking offset (or epoch) and the amplitude of the waveform, from an Offset Center Of Gravity parameterization

ICE2: applied on all surfaces waveforms

The ice-2 retracking algorithm is an adaptation to the ENVISAT RA-2 background, of the algorithm designed by GRGS to process ERS data over continental ice sheets [DR18].The aim of the ice-2 retracking algorithm is to make the measured waveform coincide with a return power model, according to Least Square estimators.

Adaptive retracking: applied on ocean and sea ice surface waveforms

The adaptive retracking algorithm main principle is described here below. The specificities of this retracking are

- the model used, which accounts for mean square slope instead of pseudo-mispointing,
- the inversion algorithm (Nelder-Mead instead of Newtion-Raphson),
- consideration of the real point target response instead of a model.

The description given below focuses on ocean measurements processing (adaptive retracking).

Waveform model fitting

The principle of the retracking is to make a model waveform match with the signal received by the instrument. The model is based on a formulation of the Brown echo model, taking into account four parameters: amplitude (Pu), epoch, sigma composite (σ_c), mean square slope (MSS). In this formulation, the mispointing is an input; the value comes from AOCS data. The same fitting is made over continental data; only the model is different (more peaky).

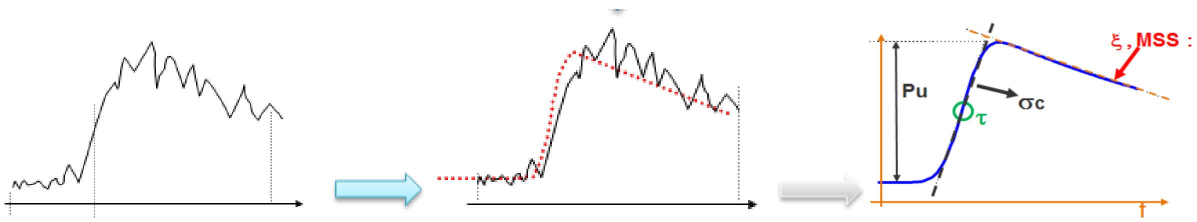


Figure 21. Retracking schematic principle.

Geophysical parameter estimation from a parametric model

Once the fitting between the model and measurements has been optimized, for each cycle, the two geophysical parameters SWH and backscatter coefficient ($\sigma 0$) are estimated from parametric model using eq. 25 and 26:

$$SWH = 2c.\sqrt{\sigma_c^2 - \sigma_p^2} \tag{25}$$

with: σ_C the sigma composite and σ_p the point target response width.

$$\sigma_0 = K_{cal} + 10.\log_{10}(P_u) \tag{26}$$

with K_{cal} the scaling factor, relative to geometry and instrument characteristics.

Geophysical parameter averaging and correction

To reduce the noise in geophysical parameter estimates, an averaging is performed over a period of NSEC seconds (indicated in the product) and by box. Then different corrections are applied. SWH and σ_0 are corrected from instrumental and modeling biases and from atmospheric attenuation. Finally the wind speed is derived from σ_0 and SWH using eq. 27 (cf. DR8):

$$WS = \frac{U - b_{wind}}{m_{wind}} \tag{27}$$

with:

- $U = \dfrac{1}{1 + e^{-(W_2 X + b_2)}}$ with W_2 two values vector and b_2 scalar,
- $X = \dfrac{1}{1 + e^{-(W_1 P + B_1)}}$ with W_1 2x2 matrix et B_1 two values vector,
- $P = \begin{pmatrix} m\sigma 0 + b \\ m_{SWH} SWH + b_{SWH} \end{pmatrix}$

The coefficients to be used in these equations will be confirmed after the commissioning phase.

Rain flag determination

In order to indicate the reliability of the geophysical parameter estimates, a rain flag is determined for each cycle. It is known that when the instrument is above a rain cell, the nadir measurement is disturbed (mostly on the trailing edge part of the waveform), and the geophysical parameter estimates cannot be properly exploited.

The rain flag determination method is based on the mispointing derived from the measured waveform. This value is a good marker as it is directly disturbed by the impact of rain cells on the signal; it is coupled with the detection of signal attenuations. The method used is a matching pursuit algorithm based on wavelet analysis as defined in [DR6, DR7].

3.8.1.3.4. Step 4: resampling of modulation spectrum per box

This step is dedicated to compute the modulation spectrum at the scale of the “product cell” (also called “box”).
It includes two parts:
- averaging in azimuth,
- resampling in wave number.

It is applied only on sea surfaces.

In the case of non-nominal macro-cycles such as (0°, 8°, 8°) or (0°, 10°, 10°), products are computed per incidence angle per box (i.e. we combine 8° and 8° data in one product for (0°, 8°,8°) macro-cycle).
In the event that the antenna rotation mode is off, only one bin of azimuth per box is filled by sigma0 profile. The rest of the box is filled with “fill values”, and there is no wave spectrum product in this case .

Averaging in azimuth

Each box contains samples from SWIM measurements covering 180° in azimuth, although all samples do not necessarily belong to the same antenna rotation sequence. To combine these data, twelve azimuth bins of 15° each are considered. The azimuth vector phi with dimension n_phi = 12 goes from 7.5° to 172.5° by step of dphi = 15°.

We compute the average of modulation spectrum from L1b processing to compose a 2D modulation spectrum $\boldsymbol{P_m(k,\phi)}$**.** With a nominal rotation speed of about 5.6 rpm and a nominal macro-cycle of ~219 ms covering all beams [0°, 2°, 4°, 6°, 8°, 10°], the averaging process combines about 2 samples per 15° azimuth bin. For alternative macro-cycles the number of L1b modulation spectra averaged in this step is different.

Azimuth angles are referenced in the meteorological convention (referred to North-0°, clockwise rotation).

Resampling in wave number

Modulation spectra from L1b processing are provided on $\boldsymbol{N_k = 512}$ wave number bins of equal size. The objective of this step is to decrease the statistical noise of these L1b products, by averaging and resampling the energy density in $\boldsymbol{N_{k\_L2}}$ bins. We choose an irregular sampling dk, with bin size increasing with wavenumber k so as to keep constant the ration dk/k over N_{k_L2} = 65.

With boundary conditions $k_{min} = k_0$, and dk/k = 0.1 (corresponding to the resolution specification), we get the following solution for wavenumber binning:

$$\boldsymbol{k(i)} = \mathrm{k_o}\, \boldsymbol{e^{\frac{i}{10}}} \tag{28}$$

with i ranging from 0 to N_{k_L2} -1 and k_{max} ~0.27 m^{-1}.

The modulation spectrum is resampled by averaging values of the L1b product within each k(i) bin.

Computation of signal-to-noise ratio (SNR)

For each spectrum and box, we compute a signal-to-noise ratio as the ratio between the maximum energy of a modulation spectrum (pm) and the noise level of the fluctuation spectrum in the azimuthal direction of the maximum (average of pdsig for k > klim).

Sea-ice and land-sea flags

And the end of this step, as for the previous step, we compute the percentage of flags sea-ice and land-sea falling into each box considering this time only spectral beams individually or together.

3.8.1.3.5. Step 5: MTF computation

Four different options may be activated for the MTF estimation. The first two are based on Eq.(18) but with different options for the estimation of the α coefficient. The L2 product corresponds to the one specified in the global attributes of the product (mtf_method). Alternative options will be used only for expert use. The four methods are described here below.

- The first method, MTF1, uses Eq. (20) relating the α coefficient to the derivative of σ_0 with incidence. This derivative is estimated from the fitted profiles of σ_0 calculated in step 2 over all available incidences above 2°, and for each azimuth bin. So, in this case, the computed MTF depends on the azimuth.

- The second and third method (MTF2a and MTF2b) use nadir information but there is no need of data from the other beams. In this case the computed MTF does not depend on the azimuth angle. For this method, there are two possible options:

  - Option a) Using Eq. (20) with an estimate of the trend of sigma0 with incidence θ provided from the LUT established from the TRMM or GPM empirical model as a function of wind speed and significant wave height (WS and SWH), these latter parameters being provided by the L2a nadir analysis.

  - Option b) Using Eq. (23) with θ being the mean incidence of the beam. mss is a function of wind speed, which is itself provided by the L2a nadir analysis (WS). At the satellite launch the expression that will be used is that given in DR14:

    $mss = A_{mss}U + B_{mss}$, with A_{mss}= 0.0016, B_{mss} = 0.016 (Freilich & Vanhoff, 2003) or A_{mss}= 0.0028, B_{mss} = 0.009 (Jackson et al. 1985). The Freilich & Vanhoff model is the one used at the present time.

- Finally in the MTF3 method, the SWH provided by the nadir analysis is used as a normalization factor to convert the modulation spectrum in terms of wave height spectrum

The advantage of method 1 is that it does not need external data or empirical models of sigma0 or mss. It accounts for variations of the MTF with azimuth, but assumes that the mean profile of sigma0 with incidence is homogeneous at the scale of the box along each looking direction. Its drawback is that it is sensitive to errors in sigma0 profiles (due to uncertainties in antenna pattern corrections, remaining bias between incidence beams or to bias due to atmospheric or coastal effects).

In the opposite, method 2 uses only the products provided by the nadir beam processing, whose performance will be assessed more easily than the profiles of sigma0, thanks to the long experience in altimeter products. This method also assumes homogeneity at the scale of the box. The drawback is that it does not account for variations of the MTF with azimuth and that it relies on empirical models that represent a mean sea state only.

With method 3, the advantage is to provide a self-consistent product between SWH extracted from the nadir signal and the 2D spectrum provided by the spectral beams. The drawback is that it assumes that nadir and off-nadir measurements are sensitive to the same scale of wavelengths.

3.8.1.3.6. Step 6: computation of 2D slope spectrum

The wave slope spectrum is defined by:

$$\boldsymbol{E(k,\phi)} = \frac{\boldsymbol{Pm(k,\phi)}}{\boldsymbol{MTF}} \tag{29}$$

where ϕ is the direction and k the wavenumber. Depending on the method used to derive the MTF, MTF will be a function of ϕ or a constant.

The wave height spectrum is defined by:

$$\mathbf{F}(\boldsymbol{k},\boldsymbol{\phi}) = \frac{\boldsymbol{E(k,\phi)}}{\boldsymbol{k^2}} \tag{30}$$

A 2D wave slope spectrum is provided for each SWIM spectrum beam (6°, 8°, 10° if available). In addition, a combined product is computed by merging the 2D wave spectra available from these different spectrum beams.

This combined 2D spectrum is computed as a weighted average of the wave slope spectrum of each incidence beam (each beam referenced with index i below). Possible bias between the different estimated are first compensated.

$$pp_{combined}(k,\phi) = \frac{1}{Ndof(k,\phi)} \sum_{i=1}^{n} E_i(k,\phi) w_i - b_i \quad (31)$$

where b_i is the bias correction, w_i the weight defined as w_i = DOF_i (k,ϕ), which is the number of degrees of freedom for the wave spectrum from the beam i (i = 6°, 8° or 10°). $Ndof(k,\phi)$ is the total degrees of freedom for each (k,ϕ) couples of the combined spectrum.

Confidence intervals and degrees of freedom

A confidence interval is associated to each spectral density. It is calculated by using the number of degrees of freedom (DOF) estimated on the fluctuation spectra (i.e. not corrected from speckle in order to keep statistics following χ^2 law):

$$DOF(k,\phi) = 2\frac{\langle P_{\delta\sigma 0}\rangle^2}{\langle P_{\delta\sigma 0}^2\rangle} \quad (32)$$

where the brackets denote averaging process over each wavenumber and direction bins defined for the L2 products. Given the DOF per bin of wavenumber and direction, the 95% confidence intervals are estimated from probability extracted from a pre-tabulated chi-square distribution.

Similarly the number of DOF and the 95% confidence interval is estimated for the omni-directional wave spectrum

3.8.1.3.7. Step 7: partitioning

Partitioning methods aim to identify automatically the different wave components that are present in a directional wave spectrum. To partition the spectrum, an adapted version of the watershed method (see [DR15] and [DR16]) is used. The algorithm detects up to three partitions, each defined by a domain of contiguous wavenumbers and directions (called the mask of the partition)

To delimitate the partitions, the first step is to resample and smooth the slope spectrum to filter out noise effects. First, we remove energy from slope spectrum where the energy is too close to the background noise, i.e. where the energy is less than a signal threshold computed at k > 0.2 m^{-1}, times a certain coefficient depending on the incidence ("coeff_signal_threshold" in global attributes). Then, truncates the spectrum to keep only values between k = klim_min = 0.01 m^{-1} and k = klim_max = 0.2 m^{-1} (corresponding to λ ~ 30 m). This is to avoid small high energetic peaks at small wavenumber and non-physical partitions at high wave number.

In addition to the resampling in wavenumber dimension done in step 3 (section 3.8.1.3.3), a Gaussian smoothing is applied here in wavenumber and azimuthal direction. In addition, the density spectrum is sampled in energy by choosing discrete levels. The number of discrete levels n_{levels} depends on the energy maximum of slope spectrum such as:

if max(E(k,ϕ)) > $E_{threshold}$, n_{levels}= 5 else n_{levels}= 10 (respectively "ngrey_min" and "ngrey_max" in global attributes).

Then the watershed method is iteratively applied three times on the spectrum. At each iteration, only the maximum energetic partition is retained, then removed from the slope spectrum before running again the watershed function on the remaining spectrum. This enables to improve the determination of the boundaries of the second and third partitions. The algorithm does not allow more than 3 partitions in a spectrum in order to avoid non-physical components.

Only partitions with H_{s_part}/H_{stot} > 25 % i.e. total energy greater than 6.25 % of the total energy of the slope spectrum or H_{s_part} greater than 1 m are kept in the product.

An example of result is shown in Figure 22: a 2D slope spectrum with 3 partition contours detected.

The watershed method has the advantage to not depend on a prior and can be easily applied on any type of data. It only requires to adapt the limits of detection in wavelength and in energy depending on the type of observations. However, depending on the noise level, weak component can be difficult to detect and very close components may not be possible to separate. Sometimes third partitions detected are not physically related to a real wave component, so we need to improve the rejected criterion of partitions.

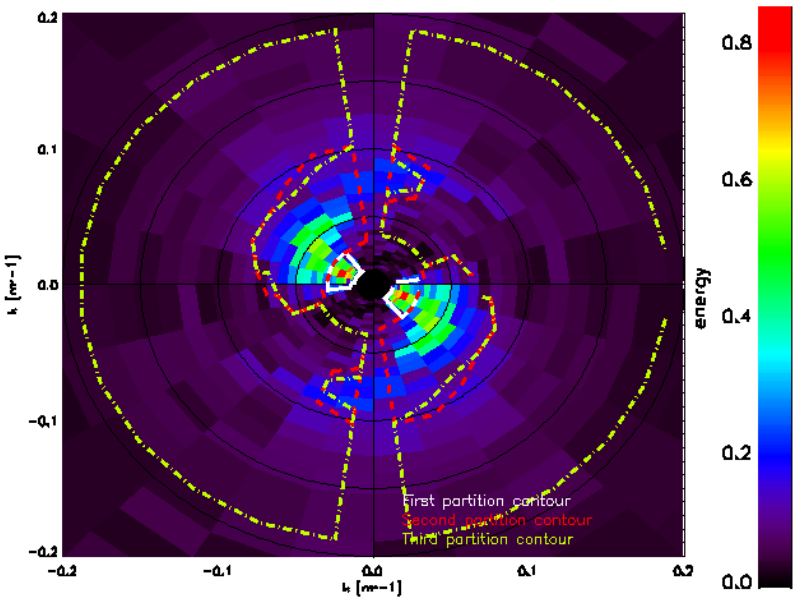


Figure 22: Example of detected partitions in a 2D modulation spectrum composed of a wind sea and a swell

3.8.1.3.8. Step 8: Estimation of mean wave parameters

Wave parameters (the significant wave height (SWH), the wavelength of the peak and the dominant propagation direction) are computed on the complete slope 2D spectrum and over each detected partition, and for each slope spectrum coming from the different spectral beams as well as for the slope spectrum combining all spectral beams.

• significant wave height

The significant wave height is estimated for each partition and for the complete spectra as:

$$SWH = 4\sqrt{E_{tot}} \quad (33)$$

where Etot is the total energy in the partition, defined as:

$$E_{tot} = \iint \frac{E_{part}(k,\phi)dkd\phi}{k} \quad (34)$$

where E_{part} is either the energy density of the slope spectra restricted to one partition or of the complete spectra

Then, we determine for each partition and for the whole spectrum, the location of the peak (k_{max}, Φ_{max}).

The wave number peak and the dominant direction are peak position average weighted by the energy around the peak, region defined where $E_{part}(k, \Phi)$ is greater than 2/3 of the maximum energy of the peak. The peak position is determined on a smoothed spectrum.

- dominant wavelength:

The wave number peak is then defined as the wave number weighted by the energy around the 2/3 of the maximum energy of the peak:

$$\boldsymbol{k_p} = \frac{\iint \mathrm{k}\boldsymbol{E_{part}}(\boldsymbol{k},\phi)\boldsymbol{dkd\phi}}{\iint E_{part}(\boldsymbol{k},\phi)\boldsymbol{dkd\phi}} \tag{35}$$

The dominant wavelength is:

$$\lambda_p = \frac{2\pi}{k_p} \tag{36}$$

- dominant direction:

The dominant direction (in range [0;180°]) of each wave train and of the whole spectrum is computed as the direction weighted by the energy around the 2/3 of the maximum energy of the peak

$$\phi_\mathrm{p} = \frac{\iint \phi\mathrm{E_{part}}(\boldsymbol{k},\phi)\boldsymbol{dkd\phi}}{\iint E_{part}(\boldsymbol{k},\phi)\boldsymbol{dkd\phi}}\ MOD\ 180° \tag{37}$$

3.8.2. Description of the product content

The file format is described in [DA1]. We detail here the physical content of each variable and explain how it can be used. The variable type and LSB are given in [DA1]. The expected accuracy after the processing is given in this document.

Note that during the CALVAL phase, expertise teams identified an issue of enhanced noise along the track of the CFOSAT satellite. This was identified as being due to a shortcoming in the estimation of the density spectrum of speckle, which was defined as independent of the azimuth, whereas the reduced Doppler bandwidth in azimuthal directions close to the direction of the platform advection (satellite track) induces an increase of the energy density of speckle noise. This perturbation affects very significantly the partitioning step (with a large number of partitions found along these perturbed directions) and the wave parameters calculated either from the full spectra or the partitions. Work is under progress to propose an alternative empirical model for speckle correction. Meanwhile, it was decided to provide two types of wave spectra , namely with an without a mask applied in the perturbed azimuthal directions (about ±15° with respect to satellite track direction). The omni-directional spectra, partitions and mean parameters of the spectra are calculated in this version with the application of a mask. The mask is also given in the product for information.

3.8.2.1. SWI_L2___

3.8.2.1.1. Specific global attributes

Note that each time there is a modification of on-board configuration leading to a change of one of the below attribute, a new file is generated.

Tag name	Description of the attribute content
mtf_method	Name of the MTF method used in the inversion (1, 2A, 2B or 3).
dphi	Discretization in azimuth direction of the 2D spectrum (15°).
Ethreshold	Energy threshold considered to set the number of discretization energy levels in the partitioning algorithm.
ngrey_min	Minimum number of energy levels in partitioning algorithm.
ngrey_max	Maximum number of energy levels in partitioning algorithm.
wlmin	Minimum wavelength considered for partitions in partitioning algorithm.
wlmax	Maximum wavelength considered for partitions in partitioning algorithm.
klim_min	Minimum wave number considered for significative energy in spectra
klim_max	Maximum wave number considered for significative energy in spectra
coeff_signal_threshold	Mutiplicative factor of the energy floor detected at high wave numbers, used to filter out noise before partitioning and computing wave parameters, for spectral beam and combined spectrum
tot_energy_bias	Total energy bias of slope spectrum, for each spectral beam estimation (used for the combined spectrum estimation only). Note that bias is positive when estimated energy

	of spectrum is greater than reference energy.
swh_relative_threshold	Threshold used to consider (or not) the partition parameters as valid. Here the threshold is expressed as the ratio of significant wave weight of the partition with respect to the total significant wave height of the full spectrum
swh_absolute_threshold	Threshold used to consider (or not) the partition parameters as valid. Here the threshold is given as absolute value of the wave height partition (in m)
ars	Expected antenna rotation speed (theoretical value). This value is used to compute the geographical box in case of non-rotated antenna.
NSEC	Time duration (in seconds) used in one of the averaged nadir products (4.5sec corresponding to the same number of independent samples as for 1hz standard altimeter products like Jason3)
theta_ticks_mini_profile	Centre values of the incidence bins which define the sigma0 mini-profile. These values are relative to the nominal incidence of each beam from -2° to +2° by step of 0.5°. Sigma0_mini_profiles (defined per beam, box, posneg and azimuthal sector) are computed by binning sigma0 values on incidence angle intervals ranging from -2.25° to +2.25° around each macrocycle_angle, by step of 0.5°. theta_ticks_mini_profile corresponds to the set of centre values of these sampling intervals, ranging from -2° to +2° (by step of 0.5°). To get the incidence values for a given beam, one needs to add theta_ticks_mini_profile to the value of the considered incidence beam
theta_ticks_profile	Centre values of the incidence bins on which sigma0 profile is defined.
beam_sigma0_offsets	Sigma0 offsets for each beam. This table is used to compensate for possible σ_{00} relative calibration errors between beams, in addition to the corrections applied at L1a. The offset values are established from the in-flight calibration and from external calibrations.
sea_ice_fraction_rejection_threshold	Threshold of sea ice fraction for setting the sea_ice flag to 1
macrocycle_angle	Beam type, expressed as angle in °, for each cycle of the macro-cycle. A macro-cycle is characterized by the succession of NB_CYCLES beams : [f0 f1 ….. fNB_CYCLES-1] where fk is an integer equal to 0, 2, 4, 6, 8 or 10 which indicates the estimated angle value of the beam. For example, the use of all the incidence beams (nominal macro-cycle) is represented by f1=0, f2=2, f3=4, f4=6, f5=8, f6=10, ie macro-cycle = [0; 2; 4; 6; 8; 10].
Macrocycle_beam	Beam type, expressed as beam number, for each cycle of the macro-cycle. A macro-cycle is characterized by the succession of NB_CYCLES beams: [f0 f1 ….. fNB_CYCLES-1]. Here fk is an integer equal to 0, 1, 2, 3, 4 or 5 which indicates the beam. For example, the use of all the incidence beams (nominal macro-cycle) is represented by f1=0, f2=1, f3=2, f4=3, f5=4, f6=5, ie macrocycle_beam = [0; 1; 2; 3; 4; 5].
macrocycle_L2	Incidence beams corresponding to the L2 processing (for the nominal macro-cycle, it is the same as macrocycle_angle; for (0°,8°,8°) it is (0°,8°) because both 8° beams are merged).
Amss	Coeff A of the linear relationship relating mss to wind speed in MTF2B (see § 3.8.1.3.5)
Bmss	Coeff B of the linear relationship relating mss to wind speed in MTF2B (see § 3.8.1.3.5)

Use_L2ANAD	1 if wind/wave parameters from L2a_nadir are used in MTF2A or MTF2B, 0 if wind/wave parameters from AUX_METEO are used

3.8.2.1.2. Variables

In the following table we indicate by the orange , yellow and pink color the variables that are specific respectively to the nadir product, sigma0 product (all incidence beams as selected in the choice of macrocyle mode) and wave products (from 6, 8, and 10° beams as selected in the choice of macrocycle mode)

Tag name	Description of the variable content	Accuracy
lat_nadir_l2	Mean latitude of nadir beam samples in each box.	
lon_nadir_l2	Mean longitude of nadir beam samples in each box.	
phi_orbit_box	Mean angle between orbit plane and geographical North per box	
time_nadir_l2	Mean time of nadir beam samples in each box.	
lat_l2	Mean latitude over all beams and macrocycles considered in each box.	
min_lat_l2	Minimum value of the latitude over all beams and macrocycles considered in each box.	
max_lat_l2	Maximum value of the latitude over all beams and macrocycles considered in each box.	
lon_l2	Mean longitude over all beams and macrocycles considered in each box	
min_lon_l2	Minimum value of the longitude over all beams and macrocycles considered in each box	
max_lon_l2	Maximum value of the longitude over all beams and macrocycles considered in each box	
wave_sp_along_track_dim	Size along track of each box, regions defining 2D spectrum	
wave_sp_across_track_dim	Size across track of each box, regions defining 2D spectrum	
swh_ecmwf	Significant wave height from ECMWF data per box at position (lat_spec_l2, lon_spec_l2).	
u10_ecmwf	Zonal wind component (m/s) from ECMWF data per box at (lat_spec_l2, lon_spec_l2). Positive for a west to east flow (eastward wind)	
v10_ecmwf	Meridional Wind component (m/s) from ECMWF data per box at (lat_spec_l2, lon_spec_l2) Positive for south to north flow (northward wind).	
lat_spec_l2	Mean latitude of spectral beams used to make 2D spectrum over coverage area	

lon_spec_l2	Mean longitude of spectral beams used to make 2D spectrum over coverage area	
time_spec_l2	Mean time of spectral beams used to make 2D spectrum over coverage area	
time_l2	Mean time of all beams and macrocycles used to build the box	
start_time_l2	Start time over all beams and macrocycles used to build the box	
stop_time_l2	Stop time over all beams and macrocycles used to build the box	
indices_boxes	Indices of macro-cycles within each box. This variable enables to link the macrocycles from Level 1 with the box to identify wich macro-cycles are used in a given box. In order to compress this variable, the indices are save as start and stop indices of the continuous series of macrocycles for each beam, as a convention we save them with the order “start_group_1, stop_group_1,... start_group_N, stop_group_N”.	
lat_l1a_0	Latitude of nadir beam measurement for each cycle	
lon_l1a_0	Longitude of nadir beam measurement for each cycle	
time_nadir_native	Date of the nadir data in seconds for each nadir cycle	
Pseudo_misp	Pseudo mispointing estimated from nadir waveform	
wf_surf_Flag	Surface type : this flag indicates the type of the surface observed : • 0 : ocean • 1: sea ice • 2 : land This flag is computed based on AUX_METEO data (lsm and sic parameter)	
flag_PTR	PTR type used for processing PTR used for nadir retracking: 0 : PTR issued from CAL1_INT measurements 1 : reference PTR, built on ground.	
flag_dep	Flag on mispointing angle This flag checks the consistency between the pseudo-misp variable and the combination of reference roll and pitch mispointing angles, both defined in CDB. •0 : consistency OK, mispointing value within limit threshold 1 : consistency NOK, mispointing value within limit threshold 2 :consistency OK, mispointing value is invalid (masked value)	
nadir_Wf_native_validity	Native waveform validity flag. Indicates if the waveform has significant characteristics : -significant leading edge, -significant maximum amplitude	
Nadir_rain_flag	Rain flag, 0: no event identified	

	1: sigma bloom 2: rain cf. §3.8.1.3.3 Rain flag determination for more details.	
flag_GINS	Instrument gain type used for processing. Valid (0) invalid (1) no data (2)	
nadir_native_MQE	Mean Quadratic error between input signal and fitted echo after retracking.	
Nadir_native_retracking	Retracking algorithm used for geophysical paramter estimation : 0 : adaptive retrackin 1 : ICE2 2 : ICE1 Retracking utilisé pour sortir les résultats	
Nadir_native_retracking_validity	Retracking quality flag : 0 : converged 1 : no convergence	
nadir_sigmac_native	Native Sigma composite value from nadir processing Nadir waveform is retracked for each cycle. This variable is an output of the retracking at the cycle rhythm.	
nadir_sigmac_native_validity	native sigma composite value validity flag : 0 : valid 1 : invalid	
nadir_swh_native	Native SWH value. This value is derived from the nadir_sigmaC_native value	$\leq$ max(10%, 40 cm)
nadir_swh_native_validity	Native SWH value validity flag.This flag checks :If SWH estimated value is out of specified limits (put to a default value) . If the retracking process has converged: • 0: SWH value OK (retracking converged) • 1: default SWH value or non-converged retracking process	
radar_range_0_nadir	radar range values associated to each gate of the swath, for each cycle of the nadir measurement	
nadir_scaling_factor	Native scaling factor applied for sigma0 calculation	
nadir_sigma0_native	Native sigma0 value from nadir processing. Nadir waveform is retracked for each cycle. This variable is output of the retracking at the cycle rhythm.	
nadir_sigma0_native_validity	Native sigma0 validity flag.This flag checks if the retracking process has converged: • 0 : sigma0 value OK (retracking converged) • 1: non-converged retracking process	
nadir_sigma0_ICE1_native	Native sigma0 value from obtained with the ICE1 retracking algorithm, The ICE1 processing is applied for all measurements (all surfaces)	
nadir_sigma0_ICE1_native_validity	Native sigma0 validity flag for ICE1 processing. This flag checks the ICE1 retracking convergence • 0 : ICE1 retracking converged • 1: ICE1 retracking non-converged	
nadir_mss_native	Native Mean Square Slope value from nadir processing Nadir waveform is retracked for each cycle. This variable is an output of the retracking at the cycle rhythm.	

Nadir_mss_native_validity	native MSS validity flag.This flag checks : If MSS estimated value is out of specified limits (put to a default value) If the retracking process has converged: • 0 : SWH value OK (retracking converged) • 1: default MSS value or non-converged retracking process	
nadir_sigmaL_native	Native width of the leading edge. Value computed via ICE2 retracking	
nadir_sigmaL_native_validity	Validity flag of the sigmaL variable. This flag checks if a leading edge is detected by the ICE2 retrackinf and if the ICE2 retracking converged: • 0 : ICE2 retracking converged • 1: no leading edge detected by the ICE2 retracking and/or ICE2 retracking non-converged	
slope1_trail_edge	Slope of the first part of the logarithm of the trailing edge. Value computed via ICE2 retracking	
flag_Slope1 trail_edge	Validity flag of the slope of the first part of the trailing edge. This flag checks if a leading edge is detected by the ICE2 retrackinf and if the ICE2 retracking converged: • 0: ICE2 retracking converged • 1: no leading edge detected by the ICE2 retracking and/or ICE2 retracking non-converged	
slope2_trail_edge	Slope of the second part of the logarithm of the trailing edge. Value computed via ICE2 retracking	
flag_Slope2_trail_edge	Validity flag of the slope of the second part of the trailing edge. This flag checks if a leading edge is detected by the ICE2 retracking and if the ICE2 retracking converged: • 0: ICE2 retracking converged • 1: no leading edge detected by the ICE2 retracking and/or ICE2 retracking non-converged	
slopeM__trail_edge	Slope of the logarithm of the trailing edge for mispointing Value computed via ICE2 retracking	
flag_SlopeM_trail_edge	Validity flag of the slope M. This flag checks if a leading edge is detected by the ICE2 retracking and if the ICE2 retracking converged • 0 : ICE2 retracking converged • 1: no leading edge detected by the ICE2 retracking and/or ICE2 retracking non-converged	
nadir_swh_NSEC	SWH value from nadir processing compressed on NSEC seconds. The valid variables estimated at the cycle rhythm are averaged over NSEC seconds. The averaging is combined with editing to delete the data which are three times the standard deviation of the series See NSEC specific global attribute for more detail.	
nadir_swh_NSEC_std	SWH standard deviation on NSEC seconds. See NSEC specific global attribute for more detail.	
nadir_swh_NSEC_used_native	Number of native SWH value used for compression over NSEC seconds.	
flag_valid_ swh_NSEC	Quality of SWH value over NSEC seconds. This flag checks if the number of valid native values for compression is sufficient (above a threshold) and if the standard deviation to the	

	compressed value is under a threshold. • 0 : number of valid native values sufficient, standard deviation under threshold, • 1: number of valid native values not sufficient, standard deviation higher than threshold	
nadir_wind_NSEC	Wind speed value from nadir processing, estimated over NSEC seconds. See section 3.8.1.3.3 fot the wind retrieval algorithm	≤max(10%, 2 m/s)
flag_valid_ wind_NSEC	Quality of wind speed value. This flag checks if the SWH and sigma0 values used for wind calculation are valid (combination of flag_valid_swh_NSEC and flag_valid_ sigma0_NSEC) • 0 : SWH and sigma0 values quality OK • 1: SWH and/or sigma0 value quality KO	
nadir_sigma0_NSEC	sigma0 value from nadir processing on NSEC seconds. The valid variables estimated at the cycle rhythm are averaged over NSEC seconds. The averaging is combined with editing to delete the data which are three times the standard deviation of the series See NSEC specific global attribute for more detail.	
nadir_sigma0_NSEC_std	sigma0_ standard deviation on NSEC seconds. See NSEC specific global attributefor more detail.	
nadir_sigma0_NSEC_used_native	Number of native sigma0 value used for averaging over NSEC seconds.	
flag_valid_ sigma0_NSEC	Quality of sigma0 value averaged over NSEC seconds. This flag checks if the number of valid native values for compression is sufficient (above a threshold) and if the standard deviation to the compressed value is under a threshold. • 0 : number of valid native values sufficient, standard deviation under threshold • 1: number of valid native values not sufficient, standard deviation higher than threshold	
nadir_sigma0_NSEC_L1A_Coher	Consistency between Nadir sigma0 over NSEC seconds and L1A sigma0 values. The σ^0 is computed in L1A processing and also through the retracking of the nadir waveform. We do expect the same value (at approximately 0.1 dB). This variable states if the two values are consistent between them or not. 0 = difference higher than 0.1 dB 1 = the two values are similar	
nadir_atmo_cor_NSEC	Atmospheric correction applied to the nadir beam compressed at NSEC seconds. The atmospheric correction is coming from the AUX_METEO files.	
nadir_atmo_cor_NSEC_std	Atmospheric correction standard deviation over NSEC seconds	
nadir_MSS_NSEC	Mean square slope value from nadir processing compressed on NSEC seconds The valid variables estimated at the cycle rhythm are averaged over NSEC seconds. The averaging is combined with editing to delete the data which are three times the standard deviation of the series See NSEC specific global attribute for more detail	
nadir_MSS_ NSEC _std	Mean square slope standard deviation on NSEC seconds See NSEC specific global attribute for more detail	

nadir_MSS_ NSEC_used_native	Number of native mss value used for compression	
Flag_valid_ MSS_ NSEC	Quality of Mean square slope value	
nadir_swh_box	Mean SWH value from nadir processing averaged over each box. The valid variables estimated at the cycle rhythm are averaged over each box. The averaging is combined with editing to delete the data which are three times the standard deviation of the series.	
nadir_swh_box_std	SWH standard deviation corresponding to the samples used for nadir_swh_box.	
nadir_swh_box_used_native	Number of native SWH values used for averaging of the SWH over each box. See nadir_swh_box for more details on the compression.	
flag_valid_ swh_box	Quality of SWH value by box. This flag checks if the number of valid native values for averaging is sufficient (above a threshold) and if the standard deviation with respect to the mean value is under a threshold. • 0: number of valid native values sufficient, standard deviation under threshold • 1: number of valid native values notsufficient, standard deviation higher than threshold	
nadir_wind_box	Mean wind speed value from nadir processing averaged by box. See nadir_swh_box for more details on the compression. See nadir_swh_box for more details.	≤max(10%, 2 m/s)
flag_valid_ wind_box	Quality of wind value. This flag checks if the SWH and σ_0 values used for wind calculation are valid (combination of flag_valid_ swh_box and flag_valid_ sigma0_box) • 0: SWH and sigma0 values quality OK • 1: SWH and/or sigma0 value quality KO	
nadir_sigma0_box	σ_0 value from nadir processing averaged by box. The valid variables estimated at the cycle rhythm are averaged over each box. The averaging is combined with editing to delete the data which are three times the standard deviation of the series.	
nadir_sigma0_box_std	Sigma0 standard deviation corresponding to the samples used for nadir_sigma0_box	
nadir_sigma0_box_used_native	Number of native sigma0 values used for averaging by box. See nadir_sigma0_box for more details on the compression.	
flag_valid_ sigma0_box	Quality of sigma0 value. This flag checks if the number of valid native values used in the average is sufficient (above a threshold) and if the standard deviation to the compressed value is under a threshold. • 0: number of valid native values sufficient, standard deviation under threshold • 1: number of valid native values not sufficient, standard deviation higher than threshold	
nadir_sigma0_box_L1A_Coher	Consistency between Nadir sigma0 by box and L1A sigma0 values. The σ^0 is computed in L1A processing and also through the retracking of the nadir waveform. We do expect the same value (at approximately 0.1 dB). This variable states if the two values are consistent between them or not. 0 = difference higher than 0.1 dB 1 = the two values are similar	

nadir_atmo_cor_box	Atmospheric correction for the nadir beam compressed by box. The atmospheric correction is coming from the AUX_METEO files.	
nadir_atmo_cor_box_std	Atmospheric correction standard deviation by box.	
nadir_MSS_box	Mean square slope value from nadir processing averaged by box. The valid variables estimated at the cycle rhythm are averaged over each box. The averaging is combined with editing to delete the data which are three times the standard deviation of the series.	
nadir_MSS_ box _std	Mean square slope standard deviation corresponding to the samples used for nadir_MSS_box	
nadir_MSS_ box_used_native	Number of native mss values used for averaging by box. See nadir_MSS_box for more details on the compression.	
Flag_valid_MSS box	Quality of MSS value by box. This flag checks if the number of valid native values for averaging is sufficient (above a threshold) and if the standard deviation with respect to the mean value is under a threshold. • 0: number of valid native values sufficient, standard deviation under threshold • 1: number of valid native values not sufficient, standard deviation higher than threshold	
coeff_sigma0_trend	A and B coefficients of linear regression on sigma0 values from the mini_profiles: $\boldsymbol{\sigma_0}\ (\mathbf{dB}) + \frac{\mathbf{10}}{\mathbf{ln(10)}} \mathbf{ln}(cos^4\theta) = \mathbf{A} + \mathbf{B}\ tan^2\theta$	
flag_atmos_att_corr	Flag indicating if sigma0 is or not corrected from atmospheric attenuation coefficient: 0 if sigma0 is corrected, 1 if not.	
flag_availability_L2_0	Rate in the cell (in %) of flag_availability raised in Level 1A with a 0 value (rate of raw data error) for each beam	
flag_availability_L2_1	Rate in the cell (in %) of flag_availability raised in Level 1A with a value of 1 (valid data) for each beam	
flag_availability_L2_2	Rate in the cell (in %) of flag_availability raised in Level 1A with a value of 2 (warnjng) for each beam	
flag_availability_L2_3	Rate in the cell (in %) of flag_availability raised in Level 1A with a value of 3 (no data) for each beam	
flag_availability_L2_4	Rate in the cell (in %) of flag_availability equal to 4: CAL1_PHASE done on the way before measurement (at the risk of distance measurement bias (<3m)	
nadir_rain_index	Occurrence (in %) of rain flags raised (nadir_rain_flag = 2) in each box according to the nadir_rain_flag (cf. §3.8.2.2) of each SWIM cycle	
nadir_sigma_bloom_index	Occurrence (in %) of sigma_bloom flags (nadir_rain_flag = 1) raised for the spectral beam in each box, according to the nadir_rain_flag (cf. §3.8.2.2) of each SWIM cycle	
sigma0N_mini_profile	Vector of the number of points used to compute the mean values of the “mini profile” for each incidence beam. Use theta_ticks_mini_profile given in global attributes to build the incidence vector around nominal incidence of each beam.	

sigma0_fit_quality	Quality of the fit of Eq. 24 on sigma0 (chi square goodness of fit)	
sigma0_mini_profile	Vector of the mean σ_0 profile (versus incidence angle) for each beam: each "mini profile" corresponds to ± 2° of incidence range around the nominal value. The incidence step is 0.5° leading to potentially nine values. Use theta_ticks_mini_profile given in global attributes to build the incidence vector around nominal incidence of each beam.	
sigma0_mini_profile_all_azim_cor	Vector of the sigma0 profile for each incidence beam averaged on all azimuths of each box and corrected from inter-beam offsets. Use theta_ticks_mini_profile given in global attributes to build the incidence vector around nominal incidence of each beam.	
sigma0_std_mini_profile_all_azim_cor	Vector of the standard deviation associated to each value of sigma0_mini_profile_all_azim_cor. Use theta_ticks_mini_profile given in global attributes to build the incidence vector around nominal incidence of each beam.	
sigma0std_mini_profile	Vector of the standard deviation relative to the mean values of the "mini profile". Use theta_ticks_mini_profile given in global attributes to build the incidence vector around nominal incidence of each beam.	
CI_inf_dir	2D slope spectrum corresponding to inferior confidence interval for pp_mean (at 5%)	
CI_inf_dir_combined	2D slope spectrum corresponding to inferior confidence interval for p_combined (at 5%)	
CI_inf_omni	Omni-directional spectrum corresponding to inferior confidence interval for pp_omni (at 5%)	
CI_inf_omni_combined	Omni-directional spectrum corresponding to inferior confidence interval for pp_omni_combined (at 5%)	
CI_sup_dir	2D slope spectrum corresponding to superior confidence interval for pp_mean (at 95%)	
CI_sup_dir_combined	2D slope spectrum corresponding to superior confidence interval for p_combined (at 95%)	
CI_sup_omni	Omni-directional spectrum corresponding to superior confidence interval for pp_omni (at 95%)	
CI_sup_omni_combined	Omni-directional spectrum corresponding to superior confidence interval for pp_omni_combined (at 95%)	
DOF	Number of degrees of freedom DOF(k,ϕ) of pp_mean_raw	
DOF_combined	Number of degrees of freedom of p_combined DOF(k,ϕ). See Eq. (32)	
f_2d	2D symmetrized height spectrum for each incidence beam, obtained from pp_mean	
f_2d_combined	2D symmetrized height spectrum combining all incidence beams	
f_2d_combined_quality_indicator	Quality indicator of f_2d_combined 2D wave height spectra corresponding to signal-to-noise ratio	
f_2d_quality_indicator	Quality indicator of f_2d_ 2D wave height spectra corresponding to signal-to-noise ratio	
flag_partition	Number of detected partitions on pp_mean (0 to 3)	

flag_partition_combined	Number of detected partitions in p_combined (0 to 3)	
flag_sigma0_mean_box	Quality indicator on sigma0 mean value for each azimuth bin, each incidence beam and in each box (0 if ALL sigma0 MEANS ARE compliant, 1 if at least one value is not compliant)	
flag_sigma0_mean_box_all_azim	Same as flag_sigma0_mean_box but combining all azimuths (and all incidence beams)	
flag_sigma0_mean_box_combined	Same as flag_sigma0_mean_box but combining all incidence beams for each azimuth	
flag_sigma0_slope_box	Quality indicator on sigma0 mean trend (slope at mid-beam) for each azimuth bin, each incidence beam and in each box 0 if all sigma0 slope falling into the box are compliant with reference LUT, 1 if at least one sigma0 slope value is not compliant (details as for flag_sigma0_mean_box)	
flag_sigma0_slope_box_combined	Same as flag_sigma0_slope_box but combining all incidence beams for each azimuth	
flag_sigma0_slope_box_all_azim	Same as flag_sigma0_slope_box but combining all incidence beams and all azimuths within each box	
flag_sigma0_shape_box	Quality indicator on sigma0 shape/curvature value for each azimuth bin, each incidence beam and in each box (0 if ALL sigma0 shape ARE compliant, 1 if at least one value is not compliant)	
flag_sigma0_shape_box_all_azim	Same as flag_sigma0_shape_box but combining all azimuths (and all incidence beams)	
flag_sigma0_shape_box_combined	Same as flag_sigma0_shape_box but combining all incidence beams for each azimuth	
k_nrt	Wave number vector for preparing the NRT product . It is defined as a subset of the k_spactra vector obtaiend by limuting to k > klim1_L2 (klim1_L2 given in the CDB (presently 0.01 rad/m)	
k_spectra	Wavenumber vector corresponding to all spectral information (modulation spectrum and wave slope spectrum). The wave number are defined as $2\pi/\lambda$ where λ is the wavelength	
land_coverage	Occurrence of Land-sea flag raised in each box for each spectral beam	
land_coverage_combined	Occurrence of Land-sea flag raised in each box combined all spectral beams	
mask	Mask of detected partitions on slope spectrum pp_mean. The partitioning is based on a watershed method. A maximum of three partitions is searched for.	
mask_combined	Mask of each detected partitions on combined slope spectrum p_combined. The partitioning is based on a watershed method. A maximum of three partitions is searched for. For each mask_combined the value is 0 (elements not in the partition) or 1 (element in the partition)	
mask_combined_nrt	Same as mask_combined but for the NRT file (with k-nrt wavenumbers)	
mtf	Modulation transfer function computed with the prescribed method (MTF1, MTF2a, MTF2b or MTF3). See 3.81.3.5	

phi_nrt	Wave direction vector (centre of azimuth bins and from 0 to 360°) for the NRT products corresponding to all spectral information (modulation spectrum and wave spectrum). it is given in the meteorological convention with a 180° ambiguity: 0°= from or towards North, 90°= from or toward East. 180°= from or towards South. 270°= from or towards west	
phi_vector	Wave direction vector (centre of azimuth bins and fril 0 to 180°) corresponding to all spectral information (modulation spectrum and wave spectrum). phi_vector is given in the meteorological convention with a 180° ambiguity: 0°= from North or from South, 90°= from or East or frim West	
pm_2d	2D symmetrized modulation spectrum for all spectral beams . Same as pp_mean but defined over the dimensions k_nrt and phi_nrt.	
pm_mean	2D modulation spectrum for each spectral beam in each box. A box corresponds to a coverage of 180° in azimuth. Values are kept in all azimuth (no mask)	
pp_mean_raw	2D wave slope spectrum for each spectral beam. This is the inversion of the corresponding pm_mean taking into account the MTF function. pp_mean = pm_mean/MTF. Values are kept in all azimuth (no mask)	
pp_mean	Same as pp_mean_raw but with values forced to 0 in an angular sector of about ±15° on each side of the satellite track if attribute along_track_masking is equal to 1. pp_mean is equal to pp_mean_raw if along_track_masking is equal to 0.	
p_combined	Mean slope spectrum obtained by combining all incidence beams: combination of the pp_mean variables to get only one combined slope spectrum per box. (Eq. (31)	
pp_omni	Omni-directional slope spectrum (integration of pp_mean over azimuth)	
pp_omni_combined	Omni-directional slope spectrum corresponding to p_combined ((integration of p_combined over azimuth)	
sea_ice_coverage	Percentage of Sea-ice flag raised for each spectral beam and in each box	
sea_ice_coverage_combined	Percentage of Sea-ice flag raised for all spectral beams and in each box	
snr	Signal-to-noise ratio of modulation spectra in azimuthal direction of maximum signal intensity	
wave_param	Wave parameters of the whole spectrum of pp_mean (SWH, dominant wavelength, dominant direction). The computation of the three parameters on the entire wave spectrum follows the same equation as the computation on each partition, except that The MASK variable is equal to identity.	Expected accuracy: • Energy error ≤15%, • Wavelength error ≤10-20%, • Azimuth error ≤15°
wave_param_combined	Wave parameters of the whole spectrum p_combined (SWH, dominant wavelength, dominant direction).	Expected accuracy:

		• Energy error ≤15%, • Wavelength error ≤10-20%, • Azimuth error ≤15°
wave_param_part	Wave parameters of each partition (SWH, dominant wavelength, dominant direction). For each partition, the parameters are computed as following. • SWH: $E_p = \sum_{i=0}^{N_{k\_resample}-1} \sum_{j=0}^{N_\phi -1} mask_p(k_i, \phi_j) \times \frac{pp\_mean(k_i,\phi_j)}{\mathrm{k}_i} \Delta k_i \Delta \phi_j$ $SWH = 4\sqrt{\mathrm{E_p}}$ • dominant wavelength: weighted by the energy around the peak (i_{max}, j_{max}) $\boldsymbol{k_p} = \frac{\sum_i \sum_j \mathrm{k_{grid}(i,j)\ pp\_mean(i,j)}}{\sum_i \sum_j \mathrm{pp\_mean(i,j)}}$ where (i, j) correspond to indices of selected points in mask delimiting 2/3 around the maximum and k_{grid} of dimension (Nk, Nϕ) is k vector replicate Nϕ times. $\lambda_p = \frac{2\pi}{k_p}$ • dominant azimuth: weighted by the energy around the peak location (i_{max}, j_{max}): $\boldsymbol{\phi_p} = \frac{\sum_i \sum_j \mathrm{\phi_{grid}(i,j)\ pp\_mean(i,j)}}{\sum_i \sum_j \mathrm{pp\_mean(i,j)}}\ MOD\ delta\_phi$ where (i, j) correspond to indices of select points in mask delimiting 2/3 around the maximum, ϕ_{grid} of dimension (Nk, Nϕ) is ϕ vector replicate Nk times, and delta_phi = Nphi * dphi	Expected accuracy: • Energy error ≤15%, • Wavelength error ≤10-20%, • Azimuth error ≤15°
wave_param_part_combined	Wave parameters of each partition of p_combined (SWH, dominant wavelength, dominant direction).	Expected accuracy: • Energy error ≤15%, • Wavelength error ≤10-20%, • Azimuth error ≤15°
mask_along_track_box	Indicator of the mask applied to obtain pp_mean from pp_mean_raw: 0 if the mask has been applied in the azimuth bin , 1 in the other case	

3.8.2.2. SWI_NRT___ Product

This product contains variables extracted from different SWIM files generated by the CWWIC and seen above.

These variables are:

- Modulation spectrum corrected from the speckle (pm_l1b) and quality flags associated (SNR of modulation/speckle and statistical data on the modulations)
- For each incidence, 2D wave height spectra (f_2d_x°)
- For each incidence, 2D wave slope spectra (pp_mean and pp_combined)
- Backscattered coefficient profiles and radiometric accuracy (SIGMA0_PROFILE)
- Nadir Backscattered coefficient (SIGMA0_NAD)
- SWH
- WS
- 2D Wave spectra with all beams merged (f_2d)
- Wave Spectrum partitions and associated geophysical parameters (PARTITIONS, wave_param_part)

3.8.2.2.1. Specific global attributes

Tag name	Description of the attribute content
macrocycle_angle	Beam type, expressed as angle in °, for each cycle of the macro-cycle. A macro-cycle is characterized by the succession of NB_CYCLES beams : [f0 f1 ….. fNB_CYCLES-1] where fk is an integer equal to 0, 2, 4, 6, 8 or 10 which indicates the estimated angle value of the beam. For example, the use of all the incidence beams (nominal macro-cycle) is represented by f1=0, f2=2, f3=4, f4=6, f5=8, f6=10, ie macro-cycle = [0; 2; 4; 6; 8; 10].
Macrocycle_beam	Beam type, expressed as beam number, for each cycle of the macro-cycle. A macro-cycle is characterized by the succession of NB_CYCLES beams: [f0 f1 ….. fNB_CYCLES-1]. Here fk is an integer equal to 0, 1, 2, 3, 4 or 5 which indicates the beam. For example, the use of all the incidence beams (nominal macro-cycle) is represented by f1=0, f2=1, f3=2, f4=3, f5=4, f6=5, ie macrocycle_beam = [0; 1; 2; 3; 4; 5]. Dependant on the number of cycles of the macro-cycle (for example only 3 values if macro-cycle = [6; 8; 10]). In this case macrocycle_beam = [3; 4; 5].
macrocycle_L2	incidence beams corresponding to L2 processing (for nominal macrocycle, it is the same as macrocycle_angle, for (0°,8°,8°) it is (0°,8°) because both 8° beams are merged.
nimp	Number of pulses which are averaged on board, varying with the incidence value only for spectral beams. For the nominal macro-cycle mode, nimp = [156; 186; 204] for beams 6, 8, and 10° respectively
Delta_x	Surface resampling range value.
speckle_information	Name of the speckle estimation method (1A, 1B, 2A, 2B, 3, 3LG or 4) used to calculate the modulation spectrum at Level1b.
Mtf_method	number of the MTF method used in the inversion (1, 2A, 2B or 3)
dphi	Azimuth interval in degrees

Ethreshold	Energy threshold for level of discretization in the partitioning algorithm
ngrey_min	Minimum number of energy levels
ngrey_max	Maximum number of energy levels
wlmin	Minimum wavelength considered for partitions
wlmax	Maximum wavelength considered for partitions
klim_min	Minimum wave number considered for significant energy in spectra
klim_max	Maximum wave number considered for significant energy in spectra
swh_relative_threshold	Threshold used to consider (or not) the partition parameters as valid. Here the threshold is expressed as the ratio of significant wave weight of the partition with respect to the total significant wave height of the full spectrum
swh_absolute_threshold	Threshold used to consider (or not) the partition parameters as valid. Here the threshold is expressed as the ratio of significant wave weight of the partition with respect to the total significant wave height of the full spectrum . Here the theshold is given as absolute value of the wave height partition (in m)
sea_ice_fraction_rejection_threshold	Threshold of sea ice fraction for rejection (presently 30%)
coeff_signal_threshold	Mutiplicative factor of the energy floor detected at high wave numbers, used to filter out noise before partitioning and computing wave parameters, for spectral beam 6°, 8°, 10° and combined spectrum respectively
tot_energy_bias	Total energy bias of slope spectrum, for each spectral beam estimation (used for the combined spectrum estimation only). Note that the bias is set positive when the estimated spectral energy is greater than a reference energy.
theta_ticks_mini_profile	Centre values of the incidence bins which define the sigma0 mini-profile. These values are relative to the nominal incidence of each beam from -2° to +2° by step of 0.5°. To get the incidence values for a given beam, one needs to add theta_ticks_mini_profile to the value of the considered incidence beam
beam_sigma0_offsets	Sigma0 offsets for each beam. This table is used to compensate for possible σ_{00} relative calibration errors between beams, in addition to the corrections applied at L1a. The offset values are established from the in-flight calibration and from external calibrations.
NSEC	Period of averaging for nadir estimation compression in seconds

3.8.2.2.2. Variables

In the following table we indicate by the orange , yellow and pink color the variables that are specific respectively to the nadir product, sigma0 product (all incidence beams as selected in the choice of macrocyle mode) and wave products (from 6, 8, and 10° beams as selected in the choice of macrocyle mode)

Tag name	Description of the variable content	Accuracy

k_spectra	Wavenumber vector	
Phi_vector	Azimuth vector (center of azimuthal bin defined over 360°)	
lat_spec_l2	Mean latitude of 2D spectrum coverage area	
lon_spec_l2	Mean longitude of 2D spectrum coverage area	
phi_orbit_box	Mean angle between orbit plane and geographical North per box	
wave_sp_along_track_dim	Along-track length of the wave cells,(boxes) defining 2D spectrum	
Wave_sp_across_track_dim	Across-track length of the wave cells,(boxes) defining 2D spectrum	
nadir_rain_index	Occurrence of rain flag raised to 1 (%) in each box taking into account of the nadir_rain_flag	
nadir_sigma_bloom_index	Occurrence of bloom flag raised to 1 (%) in each box taking into account of the nadir bloom flag	
flag_partition_combined	Flag giving the number of detected partitions (0 to 3) of f_2D_combined	
flag_sigma0_mean_box_all_azim	Quality indicator on sigma0 mean value (0 if all sigma0 means are compliant with LUT values, 1 if at least one values is not compliant) considering all spectral beams together in the box	
flag_sigma0_slope_box_all_azim	Quality indicator on sigma0 mean slope value (0 if all sigma0 slopes are compliant with LUT values, 1 if at least one values is not compliant) considering all spectral beams together in the box	
flag_sigma0_shape_box_all_azim	Quality indicator on sigma0 curvature values (0 if all sigma0 slopes and curvatures are compliant with reference LUT values, 1 if at least one value is not compliant) considering all spectral beams together in the box	
f_2D_combined_quality_indicator	Quality indicator on 2D wave spectrum f_2D_combined computed as the minimum of SNR of spectra among the spectral beams	
time_spec_l2	Mean time of 2D spectrum coverage area	
sigma0_mini_profile_all_azim_cor	Vector of the sigma0 profile for each incidence beam averaged on all azimuths of each box and corrected from inter-beam offsets. Use theta_ticks_mini_profile given in global attributes to build the incidence vector around nominal incidence of each beam.	
sigma0_std_mini_profile_all_azim_cor	Vector of the standard deviation associated to each value of sigma0_mini_profile_all_azim_cor. Use theta_ticks_mini_profile given in global attributes to build the incidence vector around nominal incidence of each beam.	

f_2D_quality_indicator	Quality indicator on 2D wave spectrum f_2D computed as SNR (Signal-to-noise ratio) of modulation spectra in azimuthal direction of maximum signal intensity	
wave_param_combined	Wave parameters of the whole spectrum f_2D_combined: significant wave height, peak wavelength, peak direction. SIGNIFICANT WAVE HEIGHT, PEAK WAVELENGTH, PEAK DIRECTION	Expected accuracy: • Energy error ≤ 15%, • Wavelength error ≤ 10-20%, • Azimuth error ≤15°
wave_param_part_combined	Wave parameters of each partition of f_2D_combined (SWH, wavelength, direction)	Expected accuracy: • Energy error ≤ 15%, • Wavelength error ≤ 10-20%, • Azimuth error ≤15°
f_2D_combined	2D mean height spectrum combining all spectral beams without ambiguity removal.	
mask_combined	Mask of detected partitions of f_2D_combined	
pm_2D	2D modulation spectrum for each spectral beam without ambiguity removal.	
f_2D	2D mean height spectrum for all spectral beams without ambiguity removal over 0° to 360°.	
Time_nadir_native	Time of native nadir data (each nadir measurement included in the wave box).	
lat_l2anad_0	Latitude for native nadir data (each nadir measurement included in the wave box).	
lon_l2anad_0	Longitude of nadir beam measurement for each cycle	
Nadir_ rain_flag	Rain flag (cf. SWI_L2___ description)	
pseudo_misp	Mispointing angle estimated from nadir waveform (for each nadir measurement within the wave box)	
nadir_swh_1HZ	SWH value from nadir processing compressed on 1 second. The valid variables estimated at the cycle rhythm are averaged over 1SEC seconds. The averaging is combined with editing to delete the data which are TBD times the standard deviation of the series	
nadir_swh_1HZ _std	SWH standard deviation on NSEC seconds.	
nadir_swh_1HZ_used_native	Number of native SWH value used for compression over 1 second.	
Flag_valid_ swh_1HZ	Quality of SWH value over NSEC seconds. This flag checks if the number of valid native values for compression is sufficient (above a threshold) and if the standard deviation to the compressed value is under a threshold.	

	0 : number of valid native values sufficient, standard deviation under threshold, 1: number of valid native values not sufficient, standard deviation higher than threshold	
nadir_wind_1HZ	Wind speed value from nadir processing , estimated at a 1 Hz sampling. See section 3.8.1.3.3 for the wind retrieval algorithm	
Flag_valid_ wind_1HZ	Quality of wind speed value. This flag checks if the SWH and sigma0 values used for wind calculation are valid (combination of flag_valid_swh_1HZ and flag_valid_ sigma0_1HZ) 0 : SWH and sigma0 values quality OK 1: SWH and/or sigma0 value quality KO	
nadir_sigma0_1HZ	sigma0 value from nadir processing on 1 second. The valid variables estimated at the cycle rhythm are averaged over 1 second. The averaging is combined with editing to delete the data which are TBD times the standard deviation of the series	
nadir_sigma0_1HZ _std	sigma0_ standard deviation on 1 second. A.1.2.	A.1.3.
nadir_sigma0_1HZ_used_native	Number of native sigma0 value used for averaging over 1 second.	
Flag_valid_ sigma0_1HZ	Quality of sigma0 value averaged over 1 second. This flag checks if the number of valid native values for compression is sufficient (above a threshold) and if the standard deviation to the compressed value is under a threshold. 0 : number of valid native values sufficient, standard deviation under threshold 1: number of valid native values not sufficient, standard deviation higher than threshold	
Nadir_atmo_cor_1HZ	atmospheric applied on 1s averaged data	
Nadir_atmo_cor_ 1HZ _std	atmospheric correction standard deviation on 1s	
nadir_MSS_1HZ	Mean square slope value from nadir processing compressed on 1 second The valid variables estimated at the cycle rhythm are averaged over 1 second. The averaging is combined with editing to delete the data which are three times the standard deviation of the series	
nadir_MSS_1HZ _std	Mean square slope standard deviation on NSEC seconds	
nadir_MSS_1HZ_used_native	Number of native mss value used for compression	
Flag_valid_ MSS_1HZ	Quality of Mean square slope value	
nadir_swh_NSEC	SWH value from nadir processing compressed on	

	NSEC seconds. The valid variables estimated at the cycle rhythm are averaged over NSEC seconds. The averaging is combined with editing to delete the data which are three times the standard deviation of the series See NSEC specific global attribute for more detail.	
nadir_swh_NSEC_std	SWH standard deviation on NSEC seconds. See NSEC specific global attributefor more detail.	
nadir_swh_NSEC_used_native	Number of native SWH value used for compression over NSEC seconds.	
Flag_valid_ swh_NSEC	Quality of SWH value over NSEC seconds. This flag checks if the number of valid native values for compression is sufficient (above a threshold) and if the standard deviation to the compressed value is under a threshold. • 0 : number of valid native values sufficient, standard deviation under threshold, • 1: number of valid native values not sufficient, standard deviation higher than threshold	
nadir_wind_NSEC	Wind speed value from nadir processing estimated over NSEC seconds. See section 3.8.1.3.3 for the wind retrieval algorithm.	
Flag_valid_ wind_NSEC	Quality of wind speed value. This flag checks if the SWH and sigma0 values used for wind calculation are valid (combination of flag_valid_swh_NSEC and flag_valid_ sigma0_NSEC) • 0 : SWH and sigma0 values quality OK 1: SWH and/or sigma0 value quality KO	
nadir_sigma0_NSEC	sigma0 value from nadir processing on NSEC seconds. The valid variables estimated at the cycle rhythm are averaged over NSEC seconds. The averaging is combined with editing to delete the data which are three times the standard deviation of the series See NSEC specific global attributefor more detail.	
nadir_sigma0_NSEC_std	sigma0_ standard deviation on NSEC seconds. See NSEC specific global attributefor more detail.	
nadir_sigma0_NSEC_used_native	Number of native sigma0 value used for averaging over NSEC seconds.	
Flag_valid_ sigma0_NSEC	Quality of sigma0 value averaged over NSEC seconds. This flag checks if the number of valid native values for compression is sufficient (above a threshold) and if the standard deviation to the compressed value is under a threshold. • 0 : number of valid native values sufficient, standard deviation under	

	threshold • 1: number of valid native values not sufficient, standard deviation higher than threshold	
Nadir_atmo_cor_NSEC	atmospheric correction on NSEC	
Nadir_atmo_cor_ NSEC _std	atmospheric correction standard deviation on 1s	
nadir_MSS_NSEC	Mean square slope value from nadir processing compressed on NSEC seconds The valid variables estimated at the cycle rhythm are averaged over NSEC seconds. The averaging is combined with editing to delete the data which are three times the standard deviation of the series See NSEC specific global attribute for more detail	
nadir_MSS_ NSEC _std	Mean square slope standard deviation on NSEC seconds See NSEC specific global attribute for more detail	
nadir_MSS_ NSEC_used_native	Number of native mss value used for compression	
Flag_valid_ MSS_ NSEC	Quality of Mean square slope value	
sea_ice_coverage_combined	Occurrence of sea-ice flag raised (in percentage) in each box	
land_coverage_combined	Occurrence of land flag raised (in percentage) in each box	

4. IWWOC PRODUCT

4.1. OVERVIEW OF THE PROCESSING CHAIN

4.2. DISTRIBUTION OF THE IWWOC PRODUCTS

4.3. L2S PRODUCT

4.4. L3 PRODUCT

4.5. L4 PRODUCT