SWISCA L2S Product

Algorithm Theoretical Basis Document

Ifremer Wind & Wave Operational Center

Modifications

Ver.	Rev.	Date	Object
0	0	25/05/18	Document creation: • initial ATBD draft structure for the prototype (version 1)
0	1	17/09/18	• Output format corrections • more complete description of SCAT
0	2	25/09/18	• New fields concerning wave information added • change of variable name logic: information from SCAT starts with prefix SCAT_, SWIM starts with prefix SWIM; Wave Watch III data starts with WW3 etc. • cross-callibration details
0	3	22/10/18	• updates after AR1 and ALGO1
0	4	30/10/20	• Updates for new ancillary fields

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Open points

Formatting note: open points may be accessed directly from the table below. They are mainly ideas to discuss, clarify and implement for the future versions of the prototype.

Table of Open Points

Open Point 1 Depending on user requests it is possible to add more variables or collocated model data to the SWISCA L2S product. Thus, additional changes and continuous evolution for SWISCA L2S data format are foreseen as result of scientific community feedback....31
Open Point 2 The size of averaging segment could be changed depending on the real SWIM measurement signal dispersion with respect to the simulated data. Strong irregularities caused by inhomogeneous wave field or large scale wave groups can deviate a signal from the expected signal profile....39
Open Point 3 More complicated mapping algorithms will be available upon request from the user community. 40
Open Point 4 The cross-calibrations coefficients can be estimated estimated only after the CFOSAT launch then the initial calibration is performed. Thus, the cross-calibration step is not implemented in the processor yet. However, initial studies have been started with the NSCAT and GPM models and will be based on results and generalization presented in [RD16]....44

List of TBC and TBD parameters

Section	Description

Table 1: TBC parameters

Section	Description

Table 2: TBD parameters

1 Introduction

1.1 Introduction

This document is intended to specify the physical and mathematical description of the algorithms to be used in the generation of SWIM L2S products at IWWOC center.

1.2 Document overview

The structure of the document is as follows:

- Chapter 1 gives information about acronyms, definitions, mathematical notations and reference documents.
- Chapter 2 presents the CFOSAT mission context and the SWIM instrument.
- Chapter 3 contains the general description of SWISCAT L2S processing.
- Chapters 4 to 8 describe in detail the different steps of the SWISCAT L2S processing.
- Chapter 9 gives information about L2S product.

1.3 Acronyms and definitions

1.3.1 Acronyms

Acronym	Signification
CERSAT	Centre ERS d'Archivage et de Traitement (Ifremer)
CFOSAT	China France Oceanography SATellite
CNES	Centre National d'Études Spatiales
CNSA	Chinese National Space Administration
CWDP	Cfosat Wind Data Processor
CWWIC	CNES Waves & Wind Instrument Center
FROGS	FRench Oceanographic Ground Segment
GMF	Geophysical Model Function
Ifremer	Institut Francais de Recherche pour l'Exploitation de la Mer
IRF	Impulse Response Function
IWWOC	Ifremer Wind & Wave Operational Center
LUT	LookUp Table
MTF	Modulation Transfer Function
NRCS	Normalized Radar Cross-Section
NRT	Near Real-Time

Acronym	Signification
PRF	Pulse Repetition Frequency
SCAT	Rotating Fan-beam SCATterometer
SST	Sea Surface Temperature
SWIM	Surface Waves Investigation and Monitoring
TBC	To Be Confirmed
TBD	To Be Defined
WVC	Wind Vector Cell
WWIII	Wave Watch III
TRMM	Tropical Rainfall Measuring Mission
GPM	Global Precipitation Measurements

Table 3: Acronyms

1.3.2 Definitions

Expression	Signification

Table 4: Definitions

1.3.3 Mathematical notations

Notation	Definition	Units
c_{seaice}	Sea-ice concentration	%
δr	Slant range resolution	m
δx	Ground range resolution	m
δx_i	Effective ground range resolution	m
Δk	Wavenumber spacing	rad/m
$\Delta \phi$	Azimuth spacing	rad
Δr	Slant range spacing	m
$\Delta \sigma_0$	NRCS fluctuations	*unitless*
Δx	Ground range spacing	m
e_{bathy}	Bathymetry elevation	m
hs	Significant wave height	m
k	Wavenumber	rad/m
L	Partition label	*unitless*
λ	Wavelength	m

Notation	Definition	Units
L_{dis}	Number of range gates used for on-board average	*unitless*
L_x	Ground range coverage	m
L_y	Footprint azimuthal ground length (at 3dB)	m
N_{imp}	number of pulses used for on-board average	*unitless*
N_k	Number of wavenumbers	*unitless*
N_r	Number of pixels in slant range dimension	*S2-LPunitless*
N_x	Number of pixels in ground range dimension	*unitless*
ϕ	Azimuth angle	rad
σ_0	NRCS (Normalized Radar Cross Section)	*unitless*
σ_{0t}	NRCS trend	*unitless*
σ_N	Wave spectrum noise level	m^2
S_f	Fluctuation spectrum	m
S_{ir}	Impulse response spectrum	*unitless*
S_s	Wave slope spectrum	m^2
S_{sp}	Speckle spectrum	m
S_m	Modulation spectrum	m
T	MTF (Modulation Transfer Function)	m^{-1}
θ	Incidence angle	rad
θ_c	Incidence angle at middle swath	rad
U	Wind speed	m/s

Table 5: Mathematical notations

1.4 Documentation

1.4.1 Reference documents

Notation	Reference
[RD1]	Algorithm Theoretical Baseline Document - Traitement des signaux SWIM – Niveau L1A, T. Grelier , CF-GSFR-SP-802-CNES
[RD2]	Algorithm Theoretical Baseline Document - Traitement des signaux SWIM – Niveau L1B des produits “vagues” D. Hauser, L. Delaye and N. Lamquin, CF-GSFR-SP-803-CNES
[RD3]	Algorithm Theoretical Baseline Document - SWIM signal processing - Preliminary

Notation	Reference
	specification of L2A non nadir level L. Delaye, N. Lamquin and D. Hauser CF-GSFR-SP-804-CNES
[RD4]	Portilla J., F. J. Ocampo-Torres and J. Monbaliu 2009: Spectral Partitioning and identification of Wind Sea and Swell Journal of Atmospheric and Oceanic Technology, 26, 107-122
[RD5]	Study on range bunching effect and directional properties of SWIM signal. IWWOC
[RD6]	Algorithm Theoretical Basis Document - SWIM L2S Product, IWWOC
[RD7]	CFOSAT RFSCAT L1B Product Format Specification Risheng Yun
[RD8]	CWDP L1B simulator and L2A processor Specification and User Manual Zhen Li, Anton Verhoef, Ad Stoffelen
[RD9]	Algorithm Theroretical Baseline Document Traitements des Signaux SWIM – Niveau L2A NADIR
[RD10]	Algorithm Theoretical Basis Document - SCAT L2S Product, IWWOC
[RD11]	Arctic & Antarctic sea ice concentration and Arctic sea ice drift estimated from special sensor microwave data User’s manual, version 2.1, February 2007 Robert Ezraty, Fanny Girard-Ardhuin, Jean-François Piollé
[RD12]	CWDP Top Level Design, 2018 Zhen Li, Anton Verhoef, Ad Stoffelen SAF/OSI/KNMI/TEC/TN/321
[RD13]	A. Verhoef, J. Vogelzang, J. Verspeek, and A. Stoffelen, “PenWP User Manual and Reference Guide,” de Bilt, the Netherlands, 2017.
[RD14]	Rascle, N., and Ardhuin F. "A global wave parameter database for geophysical applications. Part 2: Model validation with improved source term parameterization." *Ocean Modelling* 70 (2013): 174-188.
[RD15]	WW3 Tutorial: Run model with the toolbox WAVERUN, Version 6.0, July 5, 2017, IFREMER
[RD16]	Wave spectrometer tilt Modulation Transfer Function using near nadir Ku and Ka band GPM radar backscatter signal measurements V. Gressani, F. Nouguier, A. Mouche, F. Soulat, J. Tournadre 2018, IEEE Geoscience and Remote Sensing Letters (under review)
[RD17]	Wentz, F.J. and D.K. Smith, A model function for the ocean normalized radar cross section at 14 GHz derived from NSCAT observations J. Geophys. Res., 1999, 104, C5, 11499-11514
[RD18]	Lin, Wenming, et al. "A Perspective on the Performance of the CFOSAT Rotating Fan-Beam Scatterometer." IEEE Transactions on Geoscience and Remote Sensing 99 (2018): 1-13.
[RD19]	IMERG V06 Technical Documentation https://gpm.nasa.gov/resources/documents/IMERG-V06-Technical-Documentation

Table 6: Reference documents

2 General overview of mission and instrument

2.1 CFOSAT mission

The CFOSAT program is carried out through the 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 embark two payloads: SCAT, a wind scatterometer, and SWIM, a wave scatterometer to allow joint characterization of ocean surface winds and waves.

The SCAT instrument delivered by CNSA is directed to the global ocean vector wind measurement. As parts of the French ground segment (FROGS managed by CNES), CNES and Ifremer will deliver SCAT products:

- NRT instrumental and geophysical products from L0 to L2 will be processed at CWWIC (CNES).
- delayed time geophysical products (L2) will be processed at IWWOC(Ifremer)

The SWIM instrument delivered by CNES is dedicated to the measurement of the directional wave spectrum (height, direction and periodicity of waves).

As parts of the French ground segment (FROGS managed by CNES), CNES and Ifremer will deliver SWIM products:

- NRT instrumental and geophysical products (L0 to L2) will be processed at CWWIC (CNES). The data must be provided to users (meteorology agencies mainly) in NRT, i.e. in less than three hours from the acquisition.
- delayed time geophysical products (L2 to L4) will be processed at IWWOC.

Both instruments will contribute by its own and together to improve knowledge in the following fields:

- directional wave spectrum
- modeling 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 and marginal ice zones

- sea ice and iceberg movement monitoring
- land surfaces (surface soil moisture, soil roughness...)

2.2 SWIM instrument

2.2.1 Instrument overview

SWIM is a Ku-band (13.575 GHz) real aperture radar that illuminates the surface sequentially with 6 incidence angles: 0°, 2°, 4°, 6°, 8° and 10° with an antenna aperture of approximately 2°. In order to acquire data in all azimuth orientations, the antenna is rotating at a speed rate of 5.6 rpm.

SWIM aims at measuring the modulation of the backscattering coefficient of the sea surface which is linked to long waves. Actually, long waves (i.e. wavelength greater than a few decimeters) create slopes on the sea surface which will modify the backscattering compared to flat surfaces. The microwave backscatter from the sea occurs by means of quasi-specular reflections from wave facets oriented normal to the radar's line of sight. The modulation signal shall be mostly dependent on waves (i.e. long slopes) and not on surface wind (i.e. small roughness) for the incidence angles around 8° (see electromagnetic models). Radar measurements in Ku-band from TRMM and ENVISAT show that the backscattering coefficient of the surface is independent from small roughness (and, as consequence, from wind) around 8° to 10° of incidence angles (see Figure 2b). At these incidence angles, only the long slopes modulate the signal. Besides, only those surface waves whose phase fronts are "matched" to the satellite line of sight will survive the lateral averaging on azimuth. Therefore, a conical scan around nadir angle allows detecting the direction of the waves.

Table 7 summarizes the main parameters of SWIM. The six beams are illuminated sequentially with different PRF values for each incidence angle.

Frequency	13.575 GHz
Useful bandwidth	320 MHz
Useful pulse duration	50 µs
Peak power	120 W
Central elevation angles (on board)	0° - 2.3° - 3.7° - 5.55° - 7.4° - 9.25°
PRF	from 2 kHz to 6.3 kHz
Antenna rotation speed	5.6 rpm
Antenna diameter	90 cm
Antenna 3 dB aperture at nadir and 2°	1.6°
Antenna 3 dB aperture at 4°, 6°, 8° and 10°	> 1.75°
Polarization	Linear polarization and rotating

Table 7: SWIM main parameters

In a similar way as the Poseidon altimeter, the nadir beam allows to measure the distance between the satellite and the sea surface, and measures the backscattering coefficient, σ0, and its evolution in the swath. That allows estimating the significant wave height (SWH) and the wind speed (WS). The nadir processing is similar to a conventional Poseidon altimeter with searching and locking loops, but digital techniques are used in this case for the range compression. See full description of nadir level 2 (L2A_NADIR) product in [RD9].

The nadir beam allows the general synchronization of the instrument since it gives its relative altitude. This beam is needed for the synchronization and sequential piloting of the other beams (2° to 10°).

The five non nadir beams allow measuring the backscattering coefficient and creating a sigma0 profile as function of the incident angle. The 6°, 8° and 10° beams are called the “spectrum beams” and they are used to obtain the wave modulation spectrum (which is directly linked to the directional wave spectrum)

Figure 1 exhibits the geometry of the SWIM acquisition.

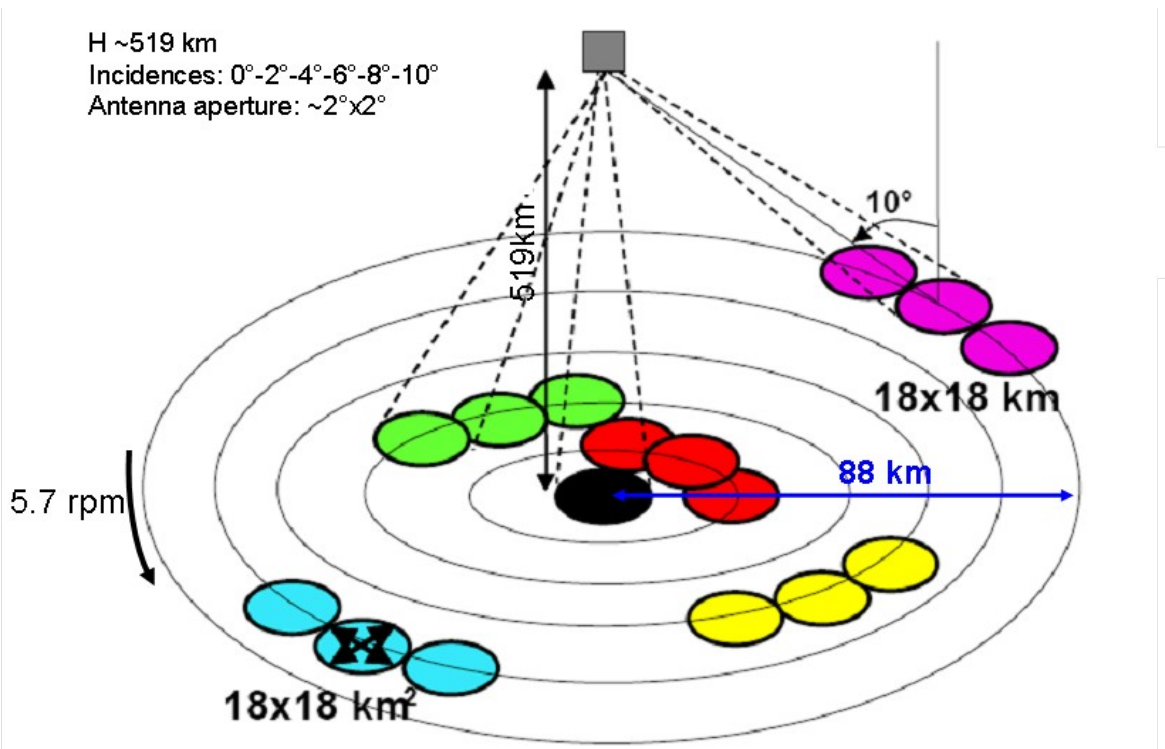


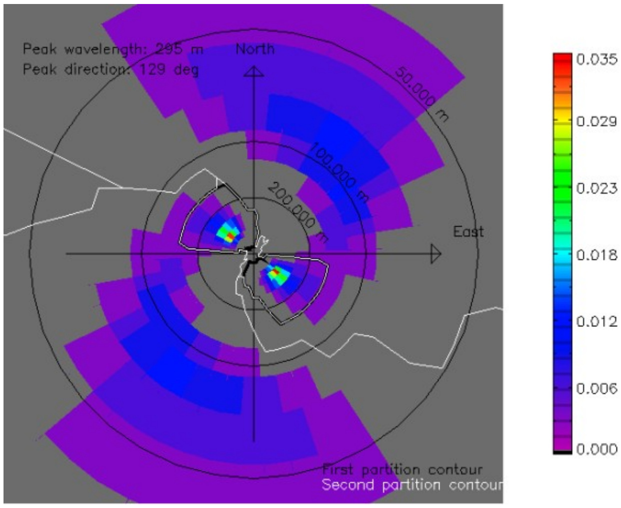
Figure 1: SWIM illumination pattern

2.2.2 Physical measurements

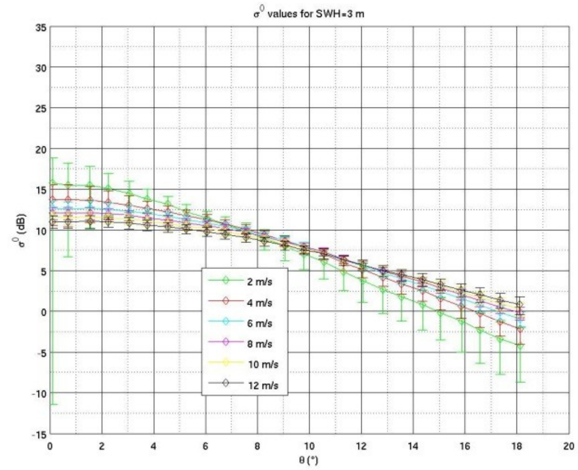
The SWIM products contain three main kinds of variables (see Figure 2):

- The backscattering profile σ_0 from 0° to 10°
- The wave spectrum from beams 6° to 10°

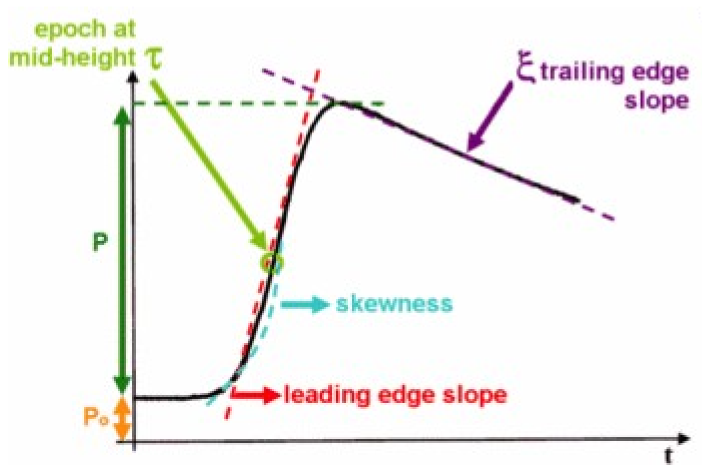
- SWH and WS from the nadir beam



(a) 2D wave spectrum



(b) Backscattering coefficient profiles



(c) Nadir waveform for SWH and WS estimation

Figure 2: Example of the three different scientific results from SWIM backscatter coefficient processing

Different operational modes have been defined for SWIM (see Figure 3). The scientific data are obtained in TRACKING mode and are processed by the CWWIC. In TRACKING mode, the instrument illuminates successively the incident angles specified by the macro-cycle as defined in Table 8.

The measurement of N_{imp} impulsions at a given incidence is a cycle. The time duration spent to cover all the beams is named macro-cycle. These macro-cycles can be:

- {0°, 2°, 4°, 6°, 8°, 10°} (nominal macro-cycle),
- {0°, 6°, 8°, 10°},
- {0°, 8°, 10°},

- {0°, 10°} or {0°, 10°, 10°} or {0°, 10°, 10°, 10°} (TBC),
- {0°, 8°} or {0°, 8°, 8°} or {0°, 8°, 8°, 8°} (TBC).

The order of the beams must always appear in the products, from L1A product onwards. Although some of the extracted parameters are only produced for the spectral beams the order is reminded by indexing parameters by the order of acquisition within the macro-cycle. Thus, each beam-depending parameter is suffixed by "_0", "_1",... "n_beam" where "n_beam" is the amount of beams (-1 if starts at 0) which cannot exceed 6 and the first cycle is always a nadir cycle. If a parameter is only defined for the spectral beams then these numbers are kept as a reference. In the case of the nominal macro-cycle these parameters will be suffixed by "_3", "_4", and "_5". There is only one type of macro-cycle per product and no confusion is possible.

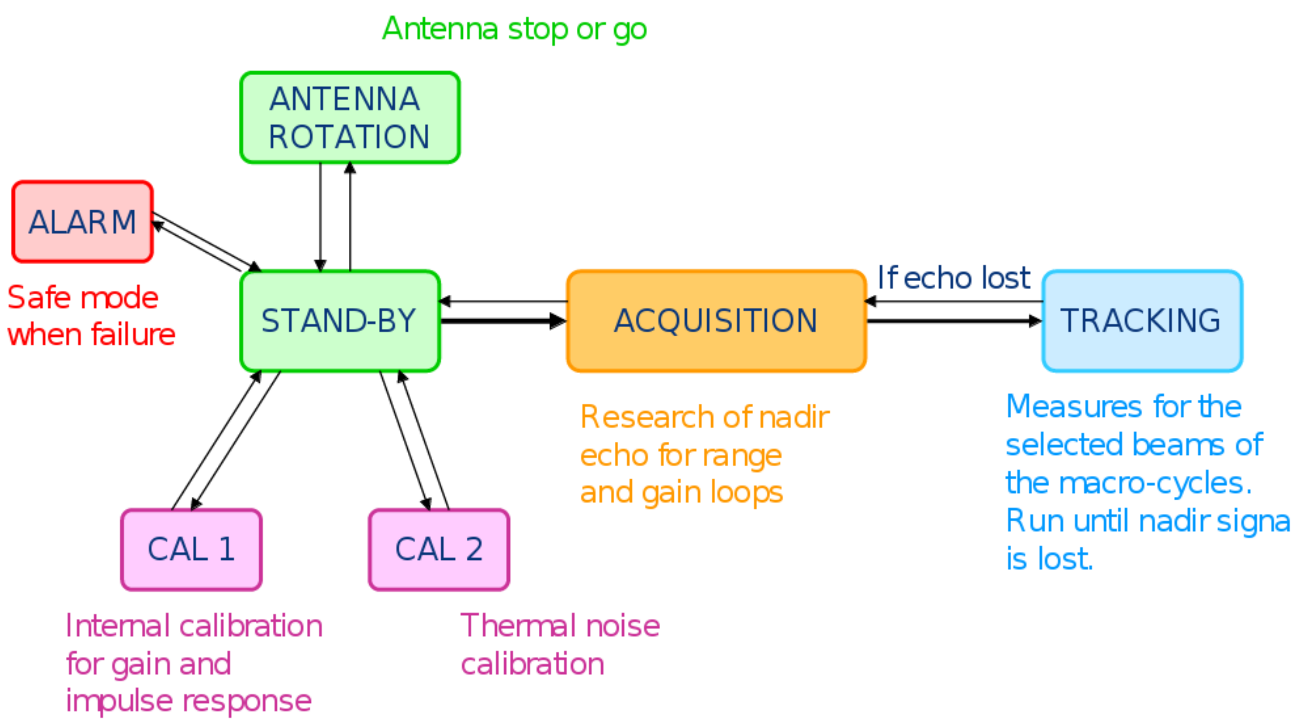


Figure 3: Main SWIM operating modes

	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
N_{imp}	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)	52.4	22.6	22.6	34.4	40.5	44.2

	0°	2°	4°	6°	8°	10°
On-board averaging L_{dis}	1	4	4	2	3	3

Table 8: SWIM chronogram parameters

2.2.3 SWIM L2S product

The main objective of SWIM L2 products is to provide directional wave spectra measures as well as the integrated parameters of the associated wave systems. The SWIM L2 level products produced by CWWIC and IWWOC centers:

- SWIM L2 product processed at CWWIC in NRT (see [RD2] and [RD3])
- SWIM L2S product processed at IWWOC in delayed time (this document) and serving as input for IWWOC L3 (statistics) and L4 (propagated waves and storm sources) products.

The particular motivations of the SWIM L2S processing are to:

- take advantage of the use of various ancillary data which are in NRT either not available (e.g. observations) or not the best estimates (e.g. model forecast). Ancillary data are particularly useful in order to increase the accuracy of the wave retrieval algorithm. Delayed time offers freedom to use suitable ancillary data, for example: ice mask product, best estimates of wind or wave model, wind from SCAT (on-board CFOSAT) or even propagated waves and storm sources from IWWOC L4 product in a feedback loop.
- handle complex situations such as coastal areas and heterogeneous seas. These complex situations are by nature of particular scientific interest (e.g. wind wave interactions, wave evolution in coastal region). It is also important to optimize the number and the representativeness of the wave observations with regard to IWWOC L3 and L4 products.
- build a flexible processing chain in order to facilitate algorithmic modifications and reprocessing. It is a key point for suggesting and testing alternative and original methodologies in the wave inversion scheme.

All variables in SWISCA L2S produced from SWIM measurements (SWIM L2 NADIR, SWIM L2A, SWIM L2S products) start with “SWIM_” prefix.

2.3 SCAT instrument

2.3.1 Instrument overview

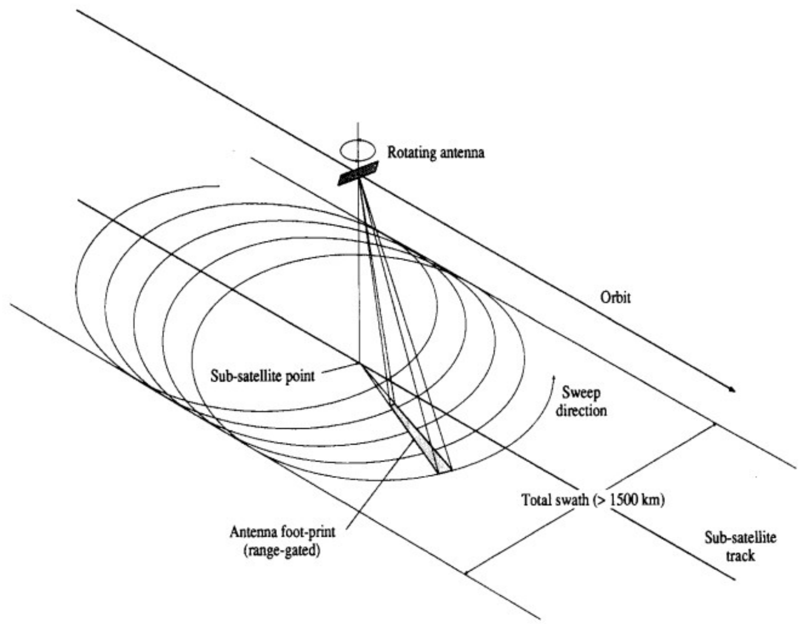


Figure 4: Illustration of SCAT swath and footprint

SCAT is another payload of CFOSAT. On-board Ku-band (13.256GHz) real aperture radar, with one vertically (V) polarized fan beam and one horizontally (H) polarized fan-beam sweeping earth's surface at medium incidence angles (~26°–51°). The radar receives echoes with the same polarization as the emitted pulses, such that it actually has VV and HH polarized beams. In the nominal case, SCAT transmits vertically and horizontally polarized pulses alternatively. Since one pulse cycle consists of 6.67 ms, the pulse repetition rates of VV and HH beams are both 75 Hz. The interval between each transmitted pulse and its corresponding echo is about 3.8 ms, see [RD18] for details.

Rotating fan-beam concept combines the advantages of fixed fan-beam and rotating pencil-beam designs. The fan-beam rotates when the satellite passes over the ocean such that its footprint sweeps a donut-shape on the observed surface (Figure 4). The footprint is also called as pulse and each pulse contains multiple slices. The coverage swath is more than 1100 km width and gives multiple views with various geometry at one WVC. The list of SCAT principle parameters is shown in the Table 9.

Frequency	Ku band (13.256 GHz)
Swath	1140 km
Footprint	320 km
Antenna scanning speed	0.356 rad/s
Pulse bandwidth	0.5 MHz
Polarization	VV and HH alternating
Incidence angle range	25.0~47.6 deg
Transmit power at HPA	120 W
Duration of transmit pulse	1.35 ms
Duration of receiving pulse	2.70 ms
Time offset of receive window	3.88 ms
Pulse repetition frequency	75 Hz
Pulse bandwidth	0.5 MHz
Antenna pointing angle	40 deg

Table 9: Scatterometer system parameters

2.3.2 Physical measurements and wind retrieval principles

In the inversion step of the wind retrieval, the radar backscatter observations in terms of the normalized radar cross-sections ($\sigma°$) are converted into a set of ambiguous wind vector solutions. In fact, a Geophysical Model Function (GMF) is used to map a wind vector (specified in terms of wind speed and wind direction) to the $\sigma°$ values. The GMF further depends not only on wind speed and wind direction, but also on the measurement geometry (relative azimuth and incidence angle), and beam parameters (frequency, polarisation). A maximum likelihood estimator (MLE) is used to select a set of wind vector solutions that optimally match the observed $\sigma°$. The wind vector solutions correspond to local minima of the MLE function:

$$MLE=\frac{1}{N}\sum_{i=1}^{N}\frac{(\sigma^0_{obs}(i)-\sigma^0_{GMF}(i))^2}{K_p(i)}$$

With N the number of independent $\sigma°$ measurements available within the wind vector cell, and K_p the covariance of the measurement error. This selection depends on the number of independent $\sigma°$ values available within the wind vector cell. The MLE can be regarded upon as the distance between an actual scatterometer measurement and the GMF in N-dimensional measurement space. The MLE is related to the probability P that the GMF at a certain wind speed and direction represents the measurement by

$$P \propto e^{-MLE}$$

Therefore, wind vectors with low MLE have a high probability of being the correct solution. On the other hand, wind vectors with high MLE are not likely represented by any point on the GMF.

For more details, see [RD 13] and [RD 14] which give scatterometer inversion theory and the description of the full probability density function of the vector wind (MSS).CWDP L1B simulator and L2A processor Specification and User Manual.

2.3.3 L2A products

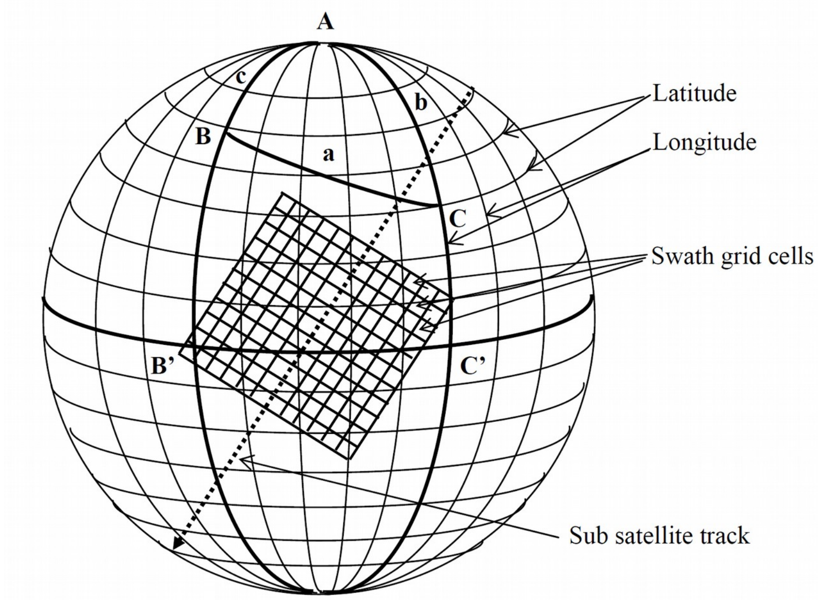


Figure 5: Earth spherical geometry and sub-satellite track grid

The transition from SCAT antenna geometry (L1B) to a regular grid spacing is performed with SCAT L2A processor. This processor was developed and provided by KNMI. Since geometrical spacing of SCAT L2S and SWISCA L2S products is mostly determined on L2A stage, below we introduce the short description of SCAT L2A processing.

L2A processor reads in L1B data and assigns slices along with their information onto proper WVCs. Time oriented L1B data is converted to WVC oriented data, Figure 5. Parameters are grouped explicitly by row and the σ_0 counts within a row are with a cross-track WVC index attached.

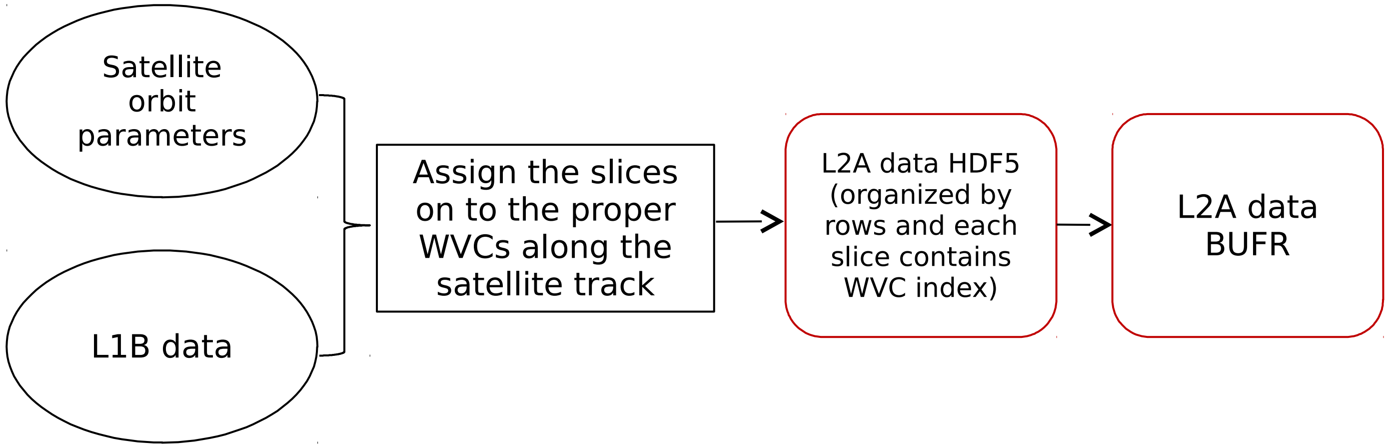


Figure 6:L2A processor work flow.

The base workflow of the processing is shown on the Figure 6. On the first step the processor assigns the slices onto proper WVCs with their attached information and write into HDF5 output. The second step of the processor aggregates the information of the slices in the WVC into views.

During the conversion slice σ_0 , instrument coefficients (A B C), SNR with the same view number and WVC number are aggregated. The slices in one WVC are first classified into views. The view definition is that all the pulses in one circle of the rotation is counted as one view, and the next successive circle is the next view and so on. The σ_0 in the same view are aggregated as

$$\sigma^\circ = \frac{\sum_s A_s^{-1} \sigma^\circ{}_s}{\sum_s A_s^{-1}} \quad (1)$$

where σ° is the WVC view backscatter, $\sigma^\circ{}_s$ is the slice backscatter and A_s is the slice instrument noise coefficient A. The weight A_s^{-1} are proportional to the estimated transmitted power contained in a slice (3.1.3) and thus the above weighting relates to a summation over backscattered power.

After HDF5 converted to BUFR, the output is converted into NetCDF format. The final output data is in BUFR, HDF5 and NetCDF formats.

Complete description of L2A processor and processing details is provided in [RD8] and [RD12].

2.3.4 SCAT L2S product

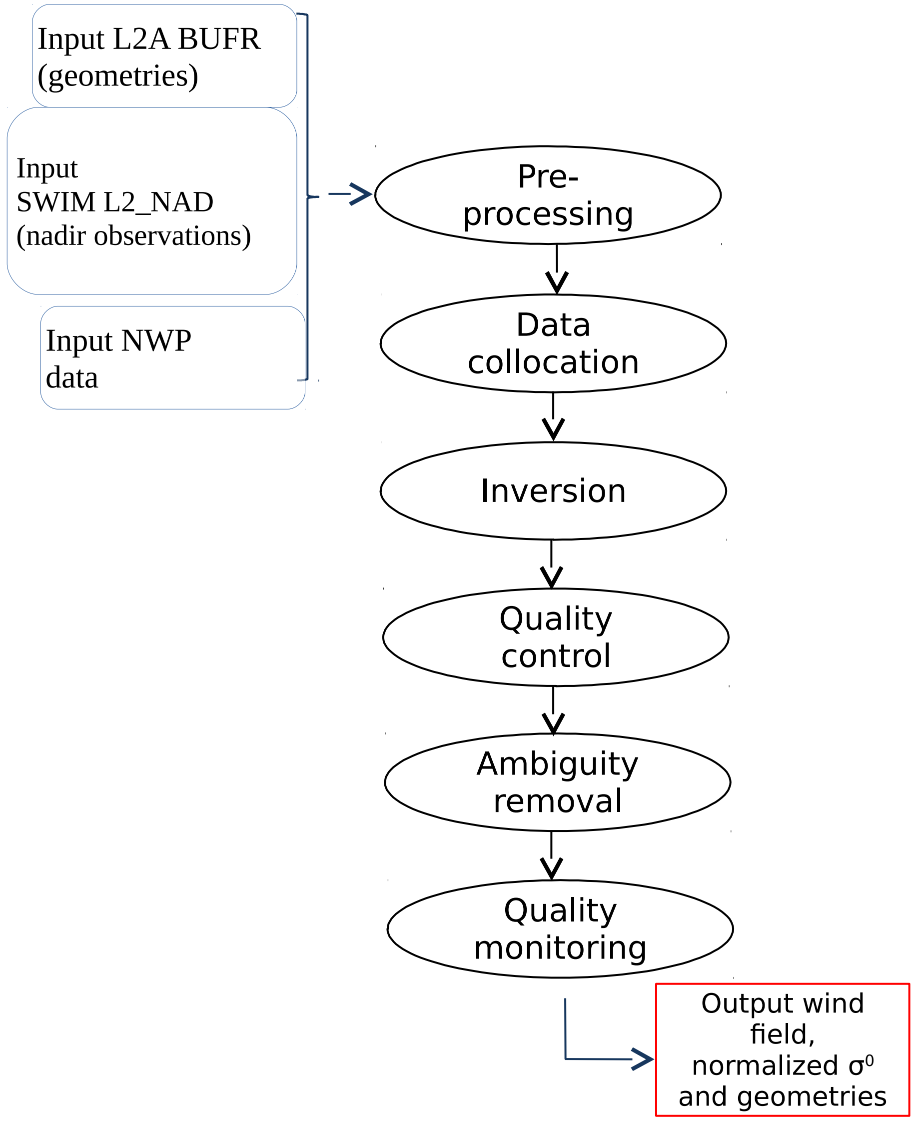


Figure 7: SCAT L2S processing work flow

The SCAT L2 processor is mainly based on CFOSAT Wind Data Processor (CWDP) as Python wrapper to original Fortran 90 and C routines. In its turn CWDP is an adaption from the PenWP (Pencil beam Wind Processor) [RD13]. SCAT L2A takes the SCAT L2A and SWIM L2 NADIR to retrieve ocean surface winds. It has the ability to perform wind retrieval, ambiguity removal with Two-Dimensional Variational Ambiguity Removal (2DVAR) method, and Multiple Solution Scheme (MSS). It also supports the output with selected winds, such as the first rank or the closest rank wind, for research purpose. The content of the SCAT L2S output consists of σ^0, geometries and wind vectors which represent surface winds within the ground swath oriented by WVCs. There are four wind solutions in the output, which are ranked by Maximum Likelihood Estimator (MLE) distance. SCAT L2S also needs Numerical Weather Prediction (NWP) model winds as a first guess for the Ambiguity Removal step.

Figure 7 is the general scheme of SCAT L2S processor. The NWP model GRIB input gives land-sea mask, sea surface temperature, ice mask and first guesses winds over the globe. SWIM L2 NADIR provide collocated σ^0 and wind speed data for central WVC. The processing steps are:

1. Pre-processing. The input L2A file is decoded and the radar backscatter (σ^0) values are written in the data structures of processor. Atmospheric attenuations are computed. The Ku-band radiation All variables produced from SCAT measurements (SCAT L2S product) start from SCAT_ prefix.is attAll variables produced from SCAT measurements (SCAT L2S product) start from SCAT_ prefix.enuated by the atmosphere. The attenuation is based on a climatology of water vapor, determined as a function of location and time of the year . The attenuation coefficients are stored in empirical look-up table (LUT). The attenuation correction is added to the beam $\sigma°$ in dB and the two-way nadir looking values (without incidence angle correction).

2. Collocation with NWP, ancillary and SWIM data. SWIM L2 NADIR data and NWP GRIB data are read and the values for land, sea surface temperature, ice fraction and first guess winds are interpolated and stored with the information of each WVC.

3. Inversion. The Normalized Radar Cross Sections ($\sigma°$) together with measurement geometries (azimuth angle and incidence angle) and beam parameters (frequency and polarization) are converted into a set of ambiguous wind vector solutions in this step with Geophysical Model Function (GMF). The GMF is NSCAT-4.

4. Ambiguity Removal. This procedure identifies the most probable solution using some form of external information. In this step, the selected wind in the output can be defined as 2DVAR solution, 1st rank solution, or closest rank solution. Same as CWDP the SCAT L2S processor uses a two-dimensional variational scheme (2DVAR) with no MSS. A cost function is minimized that consists of a background wind field and all solutions with their probability, using meteorological balance, mass conservation and continuity as constraints.

5. Quality Monitoring. The last step is to output quality indicators to an ASCII monitoring file and to write the results in output file.

Detailed description of processing algorithms and work flow of SCAT L2S and CWDP described in [RD8] and [RD10]

All variables in SWISCA L2S produced from SCAT measurements (SCAT L2S product) start with SCAT_ prefix.

2.4 Model and ancillary data

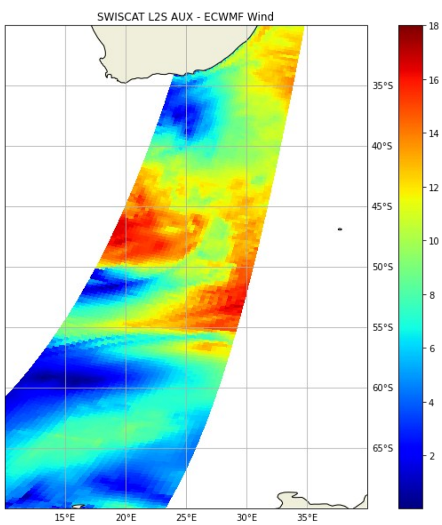
Several additional sources of data are added onto SCAT WWC grid, within the 'AUX' sub-product.

2.4.1 ECMWF data

Similar to most of the level 2 scatterometer products, ECMWF model is used as the reference and first guess model for the wind inversion algorithm, ice mask and SST information. The time resolution of NWP data is hourly with space step 0.125°.

All variables produced from ECMWF model start with "*ECMWF_*" prefix, and are listed below :

Variable	**Description**
ECMWF_sst	sea surface temperature, in kelvin
ECMWF_wind_u	10 metre U wind component, in m s-1
ECMWF_wind_v	10 metre V wind component, in m s-1



2.4.2 Wave Watch 3 model data

The reference sea surface wave information is provided by IFREMER WaveWatch3 model [RD14] which runs with 0.25° spatial resolution step and is calculated along every CFOSAT orbit. The forcing wind is provided by ECMWF model, same which is used for SCAT_L2B and SCAT_L2S inversion process.

More details on model properties and space-time collocation scheme is described in the section 3.5.1.

All variables produced or derived from WW3 model start with “WW3_” prefix, and are listed below:

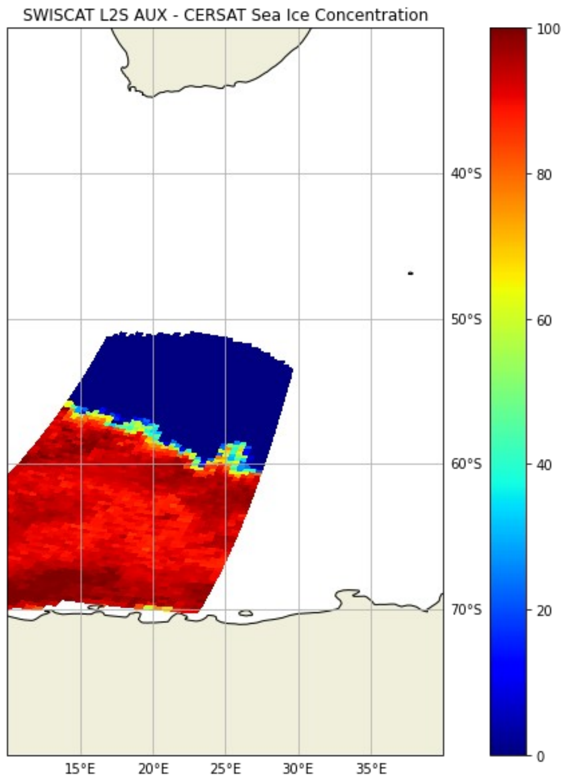
WW3_TIME	model time of a spectrum
WW3_HS	significant wave height
WW3_WAVE_PEAK	wave number of a partition spectra maximum (3 partitions)
WW3_WAVE_DIR	spectral partition direction of propagation (3 partitions)
WW3_efth	directional wave spectrum for corresponding WVC

2.4.3 Sea Ice Concentration data

Sea Ice Concentration is taken from CERSAT product [RD11], processed from SSM/I radiometer. The product is available daily, at 25km resolution.

All variables produced from CERSAT sea ice concentration product start with “CERSAT_” prefix, and are listed below :

Variable	**Description**
CERSAT_ice_concentration	sea-ice concentration
CERSAT_ice_concentration_quality	ice concentration quality flag

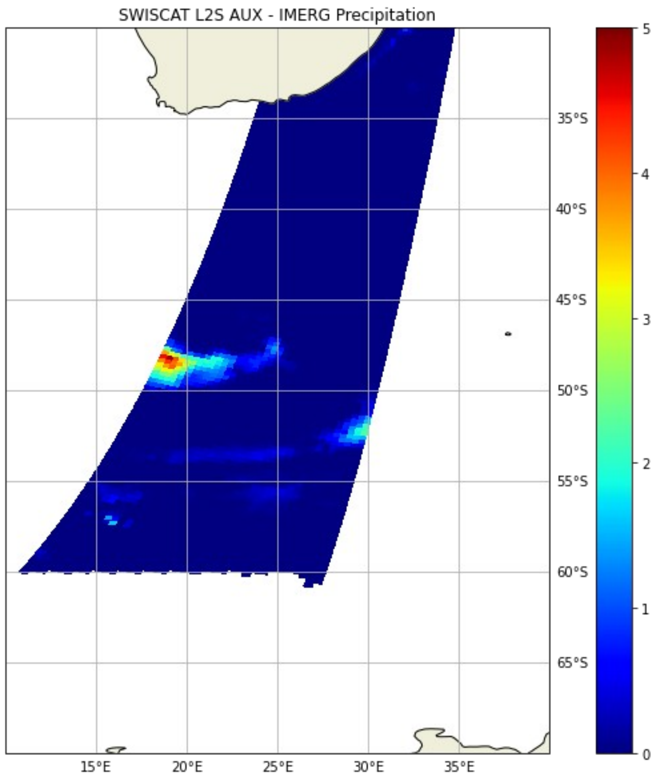


2.4.4 Precipitation

The precipitation rate is taken from IMERG v6b product [RD19], available 3 hourly at 0.1 resolution.

All variables produced from IMERG precipitation product start with “IMERG_” prefix, and are listed below :

Variable	**Description**
IMERG_precipitationCal	multi-satellite precipitation estimate, in mm hr-1
IMERG_precipitationQualityIndex	quality Index for IMERG precipitationCal field
IMERG_probabilityLiquidPrecipitation	probability of liquid precipitation phase, in percent
IMERG_randomError	random error for IMERG_precipitationCal, in mm hr-1

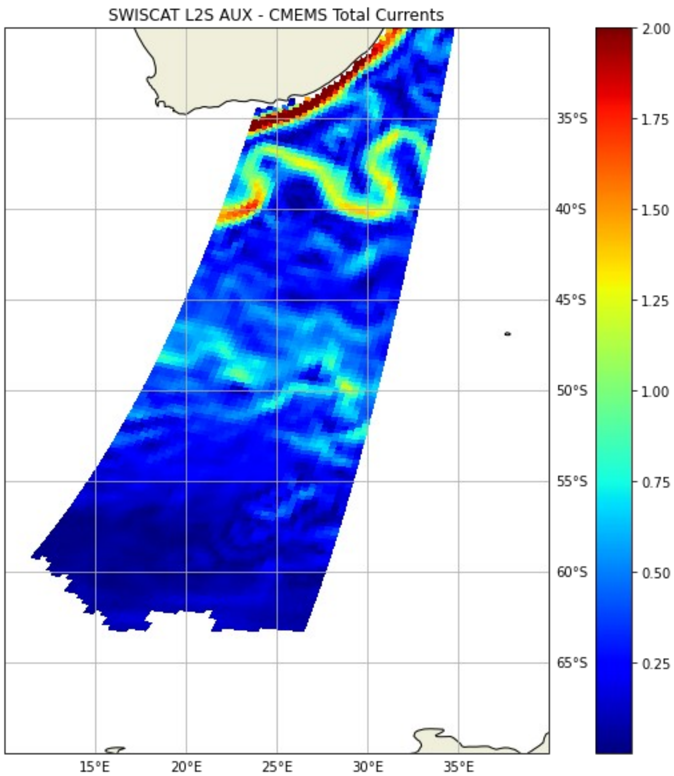


2.4.5 CMEMS currents

The total surface currents (geostrophy + Ekman) derived from altimetry are taken from CMEMS current product MULTIOBS_GLO_PHY_NRT_015-003 (follow up to GlobCurrent) which is 6-hourly and 0.25° resolution.

All variables produced from CMEMS current product start with “CMEMS_current_” prefix, and are listed below :

Variable	**Description**
CMEMS_current_u	sea surface U current component, in m s-1
CMEMS_current_v	sea surface V current component, in m s-1



Open Point 1 Depending on user requests it is possible to add more variables or collocated model data to the SWISCA L2S product. Thus, additional changes and continuous evolution for SWISCA L2S data format are foreseen as result of scientific community feedback.

3 General overview of SWISCA L2S processing

3.1 Description

The main objective of SWISCA L2 product is to propose a full set of CFOSAT based collocated data: wind vector, directional wave spectra, ice mask and concentration and other auxiliary parameters of the associated environment. The data from various sources is structured and normalized in the unified geometry and physical framework and maximally adapted for the use in wide range of scientific research and monitoring tasks in ocean remote sensing field.

The SWISCA L2 level is the part of level 2 products produced by CWWIC and IWWOC centers:

- SWIM L2 product processed at CWWIC in NRT (see [RD2] and [RD3])
- SWIM L2S product processed at IWWOC in delayed time and serving as input for IWWOC L3 (statistics) and L4 (propagated waves and storm sources) products.
- SCAT L2B product processed at KNMI in NRT (see [RD8], [RD9])
- SCAT L2S product processed at IWWOC in delayed time and providing enhanced wind vector information with use of SWIM nadir observations (see [RD10])
- SWISCA L2S product processed at IWWOC in delayed time (this document) and provides collocated data for wind and wave research or monitoring.

The particular motivations of the SWISCA L2S processing are to:

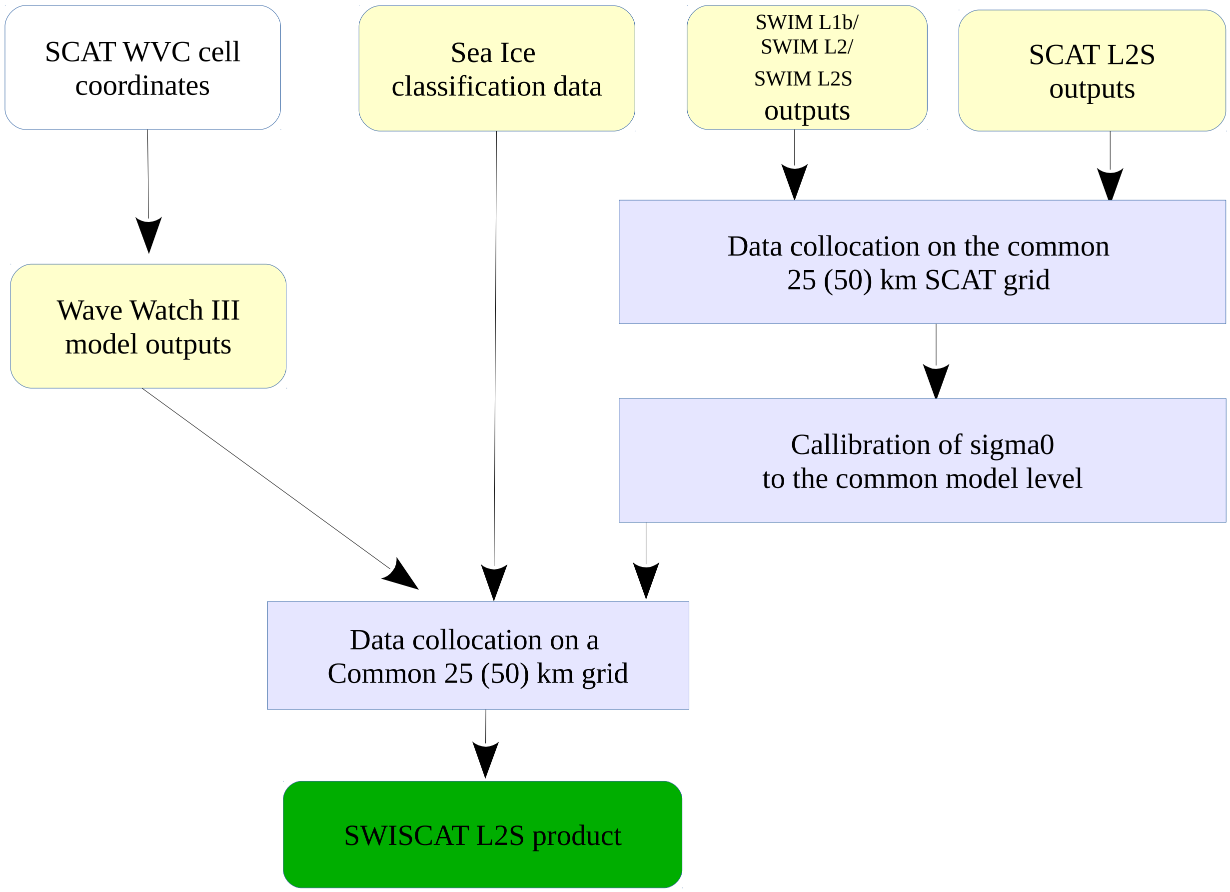
- provide collocated multi-source of wind and wave data within common geometrical and model framework. The SWISCA L2S product combines and adapts multiple instrument and model products to the form suitable for the joint use. In this way, validated data with common time-spatial resolution and adjusted radar signal level will be ready for the analysis and ocean-atmosphere model development and validation.
- provide valuable dataset for study and monitoring of wave-wind natural variability and its coupled physical behavior, validation and development of new near-nadir and moderate angle GMF functions.
- build a flexible and adaptable processing chain in order to facilitate the implementation of recent inversion and processing algorithms and its modifications. Since SWISCA L2S is mainly based on scientific level SWIM L2S and SCAT L2S the future modification of these products will be automatically incorporated in SWISCA L2S. The key point of IWWOC L2S products architecture

is the fast delivering of latest inversion and reprocessing method results to the end user community.

In practice, the SWISCA L2S product is divided in three different sub-products, generated independently, all provided on the SCAT product geometry (wind vector cells - WVC) :

- L2A : sigma0 from SWIM and SCAT
- L2B : geophysical data from SWIM (waves) and SCAT (winds)
- AUX : model and ancillary data (wave, wind, sst, currents, sea ice concentration, precipitation)

3.2 Main block diagram



8: SWISCAT L2S processor work flow

Figure 8 illustrates the main block diagram of SWISCAT L2S processing. The data from multiple sources collocated on the common WVC grid, inherited from SCAT L2S product. NRSC from SWIM and SCAT instruments bring to the common geometry by averaging of the SWIM signal profiles. The common GMF level of and to common level with cross-calibration procedure.

3.3 Step 1: SWIM and SCAT data collocation

3.3.1 SCAT geometry and partitioning details

In the SWISCA L2S the partitioning of SCAT and SWIM observations is based on the partitioning of SCAT L2A input, Figure 5. The same way, the collocated data and parameters are grouped explicitly by cross-track rows of WVC with specified size (25 × 25 km^2 by default or 50 × 50 km^2). This approach allows SWISCA L2S product outputs geometry to be intercomparable with other scatterometer products: SCAT L2A, SCAT L2B, SCAT L2S.

3.3.2 SWIM observation geometrical layout

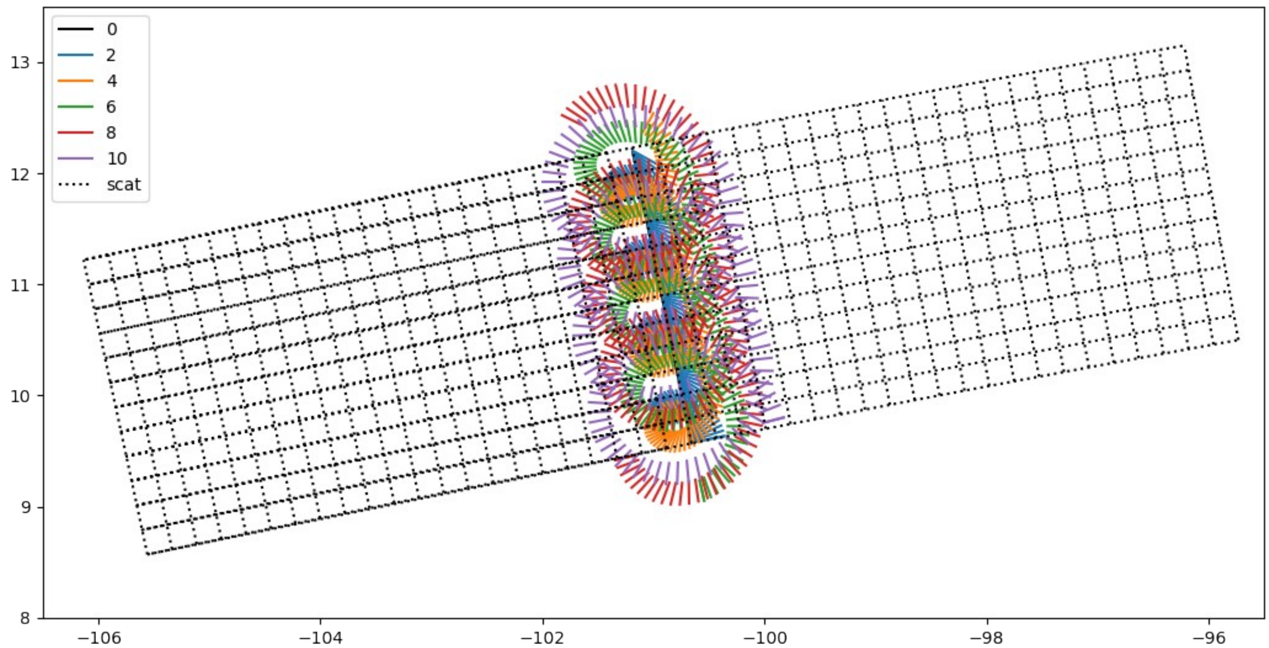


Figure 9: CFOSAT instruments swaths overlap. Solid lines represent central axes of SWIM measurement footprints.

SWIM observation swath width is about 190 km which corresponds roughly to 8 SCAT WVCs (default 25 × 25 km^2 WVC spacing), Figure 9. This means that joint SCAT and SWIM collocated observations and measured sea state parameters will be available only for near-nadir central part of the SCAT swath. Figure 10, which represents a more close look at the Figure 10, shows the details of SWIM footprint pattern within SCAT WVC grid. For demontration purposes, one circle shows the size of single SCAT measurement and its geometry with respect to single scatterometer WVC. The number of superposed SWIM and SCAT measurements will vary for each WVC depending on distance from nadir and rotation angle of antenna plate.

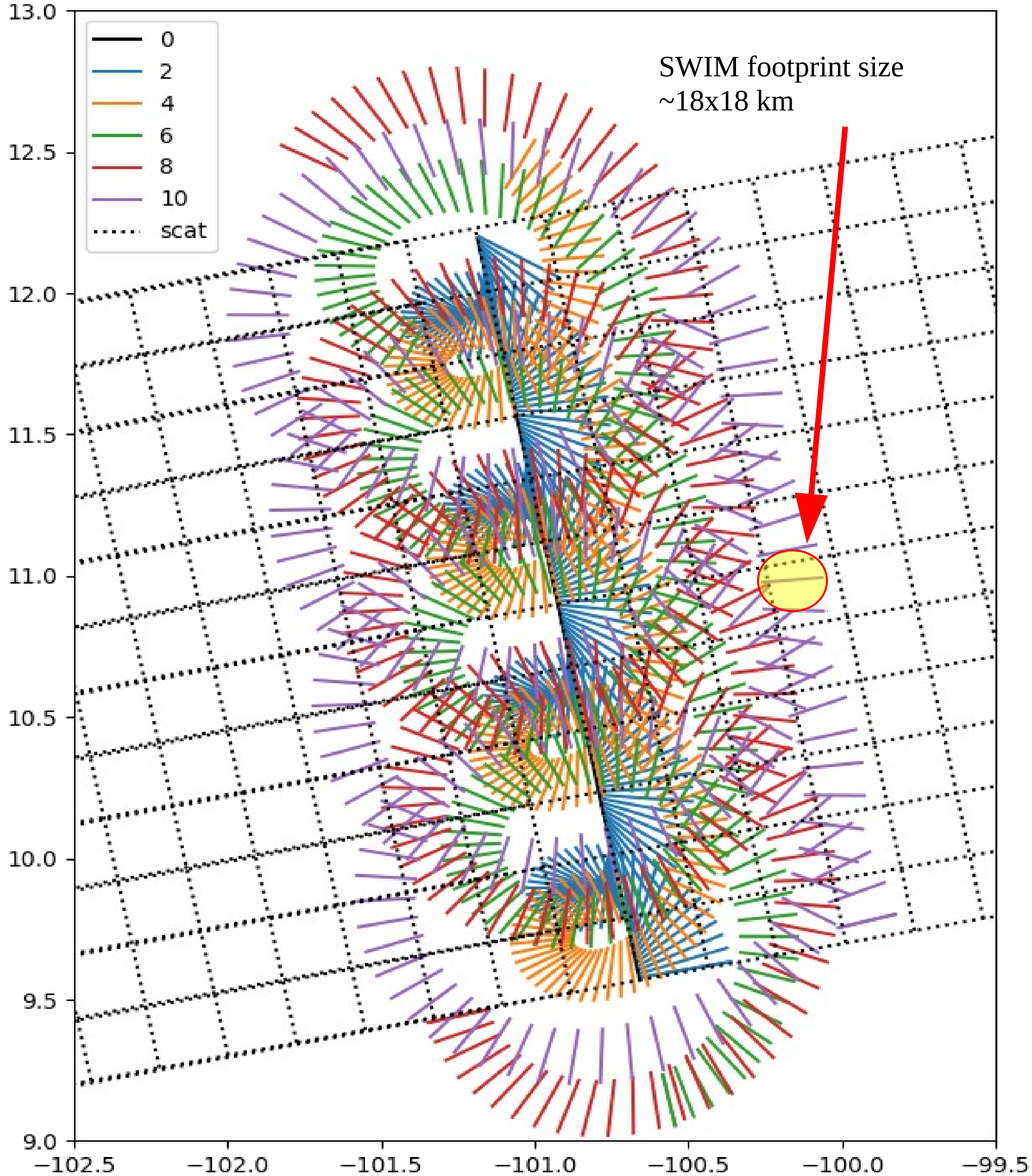


Figure 10: Schematic representation of SWIM observation pattern over the SCAT WVC partitioning. Solid lines represent central axes of SWIM measurement footprints. Solid yellow circle demonstrates actual geometry of SWIM beam with respect to SCAT WVC

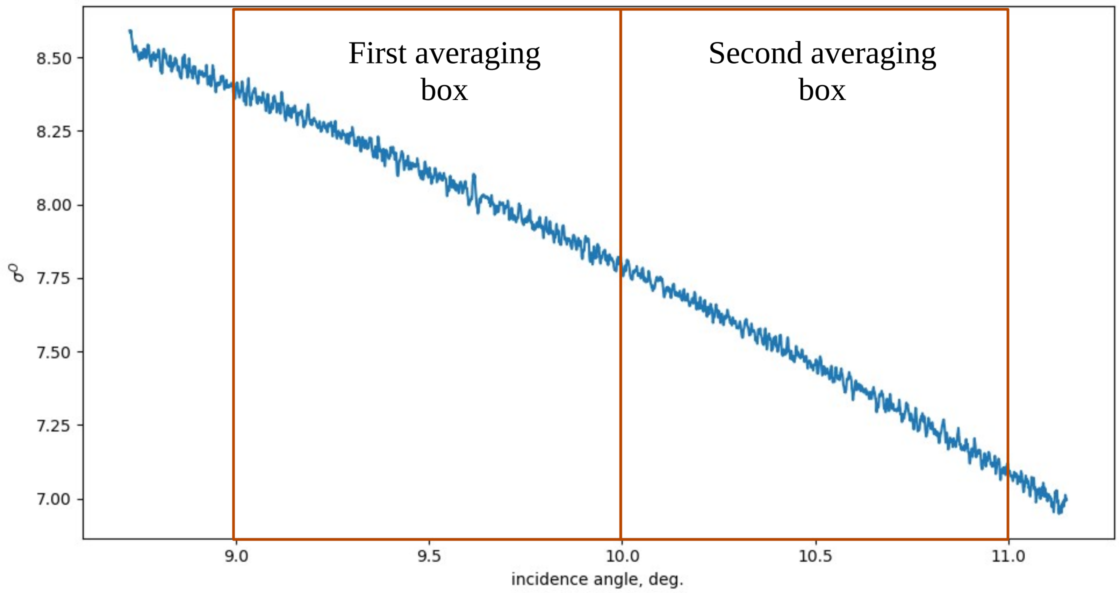


Figure 11: Example of SWIM σ^0 varition for 10° beam (from SWIM L1b product). Rectangular boxes denote the averaging intervals.

3.3.3 Mapping SWIM NRCS to SCAT WVC

Figure 11 shows simulated example of single SWIM σ^0 measurement for 10° beam. In order to match SWIM data to SCAT WVC, the original SWIM NRCS profiles for every beams is truncated by segments with size Δ degrees. The the mean value

$$\langle \sigma_\theta^0 \rangle = \frac{1}{N} \sum_{\theta > (\theta_0 - \Delta/2)}^{\theta < (\theta_0 + \Delta/2)} \sigma^0(\theta) \ ,$$

where N denotes the number of radar gates in the interval $(\theta - \Delta/2) < \theta < (\theta + \Delta/2)$. In actual version of the processor the size of averaging step is selected $\Delta = 1°$. This ensures the number of averiging gates to be at least N=1300 for 6° and 8° beams and N= *1550* for 10° beam.

After averaging, each $\langle \sigma^0 \rangle$ is attributed to a nearest SCAT WVC by central point of its coordinates.

Open Point 2 The size of averaging segment could be changed depending on the real SWIM measurement signal dispersion with respect to the simulated data. Strong irregularities caused by inhomogeneous wave field or large scale wave groups can deviate a signal from the expected signal profile.

3.3.4 Mapping SWIM wave spectrum to SCAT WVC

The maximum achievable resolution of SWIM directional wave spectrum is variable along the track and determined by the necessary quantity of observations to cover the azimuthal range $\Delta\phi \geqslant 180°$. As it is clear from the Figure 10 the wave spectrum individual information cannon be retrieved for every SCAT WVC.

In order to get reliable estimates, in level 2 SWIM products the wave spectrum information is limited within fixed-size by boxes (90 x 70 km). Accordingly, in SWISCA_L2S the wave information is attributed to appropriate WVC as the closest L2 spectrum box (segment) within SWIM and SCAT swaths overlap.

Open Point 3 More complicated mapping algorithms will be available upon request from the user community.

3.3.5 Output variables

- SIGMA0 – original SCAT and SWIM σ^0 values
- INC_ANGLE – incidence angle of observed σ^0 values
- AZIMUTH – azimuth angle of observed σ^0
- VIEW_TYPE – source (instrument) of data and polarization: 1 - SCAT HH, 2 - SCAT VV, 3 – SWIM, 0 – no data or error
- SCAT_KPA – kp alpha
- SCAT_KPB – kp beta
- SCAT_KPC – kp gamma
- SWIM_STD – standard deviation of SWIM σ^0 estimated from the averaged part of signal profile
- SWIM_HS – significant wave height from SWIM measurements
- SWIM_PEAK_WAVENUMBER – wave number spectral maximum for every spectral partition (3 partitions)
- SWIM_WAVE_DIR – spectral partition direction of propagation (3 partitions)
- SWIM_WAVE_SPEC – directional wave spectrum for corresponding WVC
-

3.3.6 SCAT L2S unchanged variables

In order to provide the most complete dataset of collocated data, part of data is transferred from other products in unchanged form. Table shows complete list of variables and flags inherited directly from the SCAT_L2S product, see the [RD10] for the complete description.

SWISCA_L2S variable name	SCAT_L2S variable name	Short description
ECMWF_WIND_SPEED	MODEL_WIND_SPEED	model wind speed
ECMWF_WIND_DIR	MODEL_WIND_DIR	model wind direction
ECMWF_SST	MODEL_SST	modeled SST values
ECMWF_SEA_ICE_FLAG	SEA_ICE_FLAG	sea ice flag
LAND_SEA_FLAG	LAND_SEA_FLAG	land sea flag
SCAT_RAIN_FLAG	RAIN_FLAG	flag for the presence of rain
SCAT_WIND_QUALITY_FLAG	WVC_QUALITY_FLAG	wind vector cell quality

3.4 Step 2: SWIM and SCAT data calibration

3.4.1 SWIM and SCAT data calibration specificity

Similar to most other Ku-band scatterometers, SCAT σ^0 values calibrated to conform the NSCAT-4 GMF [RD17]. The calibration step is done at SCAT L2B or SCAT L2S processing levels with use of instrument specific empirical calibration tables (see [RD8] and [RD10] for the details). This approach makes SCAT observations to be comparable for all scatterometers with the same radar frequency band and makes processing algorithms and processing criteria to be equally applicable to all Ku-band scatterometer missions.

In its turn SWIM L2A and SWIM L2S NRCS calibrated to its own instrument-dependent signal level which is more common to Tropical Rainfall Measuring (TRMM) and Global Precipitation Measurements (GPM) missions. The SWIM calibration will be performed independently from SCAT with different calibration approach. Two different calibration levels of SCAT and SWIM do not allow to use collocated σ^0 data in common tasks, e.g. wind inversion.

The main idea of cross-calibration step is to adjust SWIM and SCAT σ^0 to the common GMF level. This way, the homogenized dataset will be suitable for the use within common framework corresponding to the wide range of incidence angles from 0° to 50°.

3.4.2 Common model for near-nadir and moderate angle radar cross-section

Figure 12 illustrates the examples of near-nadir (GPM) and moderate angle (NSCAT-4) σ^0 dependencies with an incidence angle for the same azimuth angle $\phi=0$ and two different wind speeds. In the SWISCA L2S the NSCAT-4 GMF is selected as the reference model for all σ^0 values. Thus, only SWIM values need to be recallibrated during this processing step.

On the figure there is a small gap for $18° < \theta < 20°$ due to the lack of observation data. In the case of the SWIM instrument the maximum angle will be only $\theta = 11°$, however, could be compensated with use of data from other similar-type missions.

After the initial calibration of all CFOSAT instruments is performed, the correction of SWIM measurements will be calculated as

$$\sigma°(\theta,\phi)_{crosscal} = A(\theta,\phi)_{GMF}\,\sigma°(\theta,\phi)$$

where A_{GMF} is the transition coefficient from original GMF to generalized NSCAT GMF. The generalized NSCAT GMF will be based on scatterometer NSCAT-4 GMF and near nadir GPM-based GMF, e.g. by [RD16]. In general case, the table of transition coefficients can be calculated simply as the relation between SWIM and SCAT GMFs. For example, if original SWIM data is calibrated to GPM and SCAT data calibrated to NSCAT-4, the value of transition coefficient will be simply

$$A_{GMF} = \frac{GMF_{NSCAT4}}{GMF_{GPM}},$$

where GMF_{GPM} is the near nadir function empirically extended up to moderate angles (subject of ongoing research).

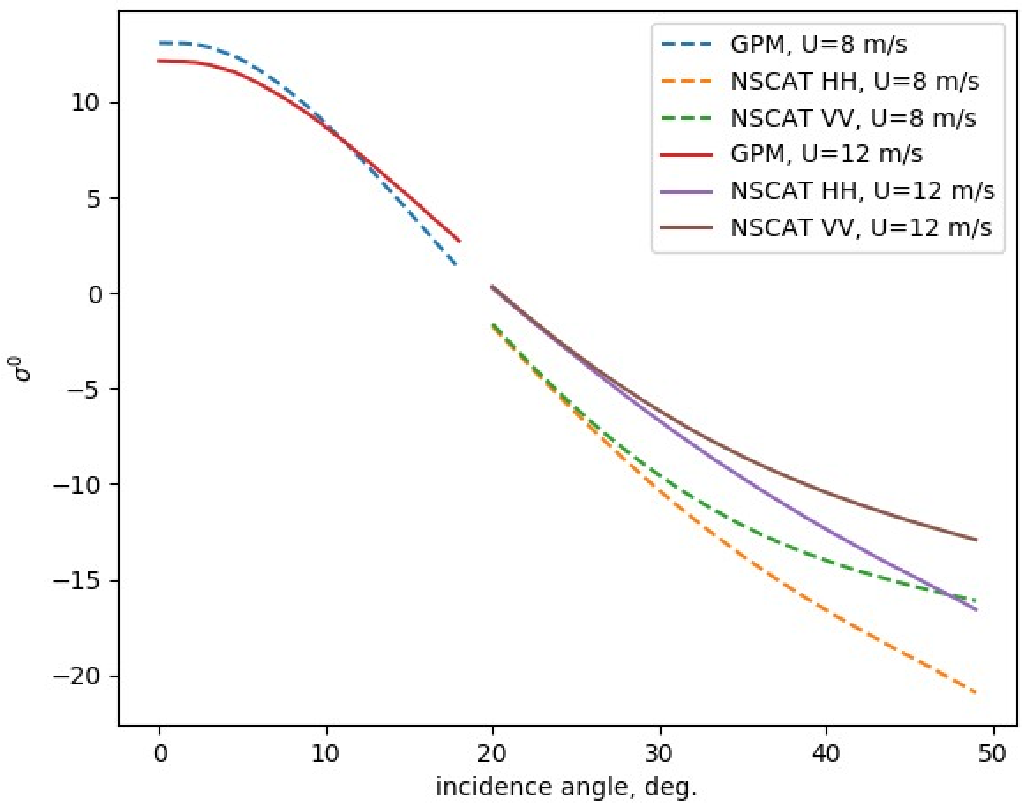


Figure 12: GPM and NSCAT GMFs for the same azimuth angle $\phi = 0$ and two different wind speeds. σ^0 in dB

According to the preliminary calibration plan, the SWIM will be calibrated to the level of another near nadir mission (TRMM). In this case the correction table A_{GMF} could be reduced to a single coefficient which is valid for all incidence and azimuthal angles.

Open Point 4 The cross-calibrations coefficients can be estimated estimated only after the CFOSAT launch then the initial calibration is performed. Thus, the cross-calibration step is not implemented in the processor yet. However, initial studies have been started with the NSCAT and GPM models and will be based on results and generalization presented in [RD16].

3.4.3 Output variable

- CALIBRATED_SIGMA0 – cross-calibrated σ^0 values

3.5 Step 3: Model and ancillary data collocation

3.5.1 Wave Watch III collocation algorithm

For the collocation of CFOSAT and wave model data is performed with the standard dedicated toolbox (WAVERUN) which was developed by IFREMER for collocalisation of WW3 and satellite remote sensing products [RD15].

As input the WAVERUN program takes a list of WVC coordinates which is produced from SCAT L2A product. Further, the nearest output from the WWIII model grid is attributed to each WVC. At the moment, the resolution of wave model is lower than spacing of SCAT grid, hence for some neighbor WVC will be attached same model spectrum and sea state parameter variables.

3.5.2 Other ancillary data

Other ancillary variables are collocated using closest neighbor or linear interpolation.

4 SWISCA L2S product

4.1 File naming and organization

Similar to other SCAT L2 products the SWISCA L2S product is split by single CFOSAT orbits. Three sub-products, in a different NetCDF file, are created for each orbit:

- the L2A level sub-product, containing sigma0 from SWIM and SCAT
- the L2B level sub-product containing the geophysical parameters from SWIM and SCAT (SCA L2S product). This sub-product will be added once the SCA L2S processor is completed.
- the AUX level sub-product containing all the model and ancillary fields

The file naming convention is defined as follow:

CFO_OPER_SWISCA_L2S_<level>__F_<start>_<end>_<version>.nc

where:

- *level* is the sub-product type (A for L2A, B for L2B, AUX for AUX)
- *start* and *end* are respectively the acquisition start and end time of the orbit (as YYYYMMDDTHHMMSS)
- *version* is the processor version, as x.y.z

The data files are organized as follow:

swisca_l2s___

    |- <*level*> (l2a, l2b, aux)

        |- <*year*> (YYYY)

            |- <*day*> (DDD)

4.2 Data volume

The size of each orbit file is approximately as follow, for each sub-product:

SWISCA L2S L2A	12 MB

SWISCA L2S L2B	TBD
SWISCA L2S AUX	90 MB

4.3 NetCDF file format

4.3.1 L2A level

```
netcdf CFO_TEST_SWISCA_L2S_A__F_20201022T124744_20201022T143002_0.0.3 {
dimensions:
	row = 1757 ;
	cell = 42 ;
	view = 900 ;
variables:
	float lat(row, cell) ;
		lat:_FillValue = -400.f ;
		string lat:long_name = "WVC latitude" ;
		string lat:units = "degrees north" ;
	float lon(row, cell) ;
		lon:_FillValue = -400.f ;
		string lon:long_name = "WVC longitude" ;
		string lon:units = "degrees east" ;
	double time(row, cell) ;
		time:_FillValue = NaN ;
		string time:units = "seconds since 2020-10-22 12:49:37" ;
		string time:calendar = "proleptic_gregorian" ;
	float wvc_azimuth(row, cell, view) ;
		wvc_azimuth:_FillValue = -400.f ;
		string wvc_azimuth:long_name = "sigma0 azimuth" ;
		string wvc_azimuth:units = "degree" ;
		string wvc_azimuth:coordinates = "time lat lon" ;
	float wvc_incidence(row, cell, view) ;
		wvc_incidence:_FillValue = -999.f ;
		string wvc_incidence:long_name = "sigma0 incidence angle" ;
		string wvc_incidence:units = "degree" ;
		string wvc_incidence:coordinates = "time lat lon" ;
	byte wvc_quality_flag(row, cell) ;
		wvc_quality_flag:_FillValue = -1b ;
		string wvc_quality_flag:long_name = "wind vector cell quality flag" ;
		string wvc_quality_flag:flag_values = "0, 1, 5" ;
		string wvc_quality_flag:flag_meanings = "valid  cell_in_coastal_area
poor_quality_or_corrupted_data" ;
		string wvc_quality_flag:coordinates = "time lat lon" ;
	double wvc_sigma0(row, cell, view) ;
```

```
		wvc_sigma0:_FillValue = -999. ;
		string wvc_sigma0:description = "CFOSAT collocated linear sigma0. Includes SWIM 0°, 2°, 4°, 6°, 8°, 10° beams and SCAT dual-polarization observations" ;
		string wvc_sigma0:long_name = "linear sigma0 collocated observations" ;
		string wvc_sigma0:coordinates = "time lat lon" ;
	byte wvc_sigma0_quality_flag(row, cell, view) ;
		wvc_sigma0_quality_flag:_FillValue = -1b ;
		string wvc_sigma0_quality_flag:long_name = "sigma0 quality flag" ;
		string wvc_sigma0_quality_flag:flag_values = "0, 1" ;
		string wvc_sigma0_quality_flag:flag_meanings = "valid poor_quality_or_corrupted_data" ;
		string wvc_sigma0_quality_flag:coordinates = "time lat lon" ;
	short wvc_sigma0_type(row, cell, view) ;
		wvc_sigma0_type:_FillValue = -999s ;
		string wvc_sigma0_type:long_name = "sigma0 type and origin" ;
		string wvc_sigma0_type:flag_values = "0, 2, 4, 6, 8, 10, 20, 21" ;
		string wvc_sigma0_type:flag_meanings = "nadir_swim_beam_0 swim_beam_2 swim_beam_4 swim_beam_6 swim_beam_8, swim_beam_10 scat_hh_polarization scatt_vv_polarization" ;
		string wvc_sigma0_type:coordinates = "time lat lon" ;
	double wvc_sigma_nv(row, cell, view) ;
		wvc_sigma_nv:_FillValue = -999. ;
		string wvc_sigma_nv:long_name = "sigma0 normalized variance" ;
		string wvc_sigma_nv:description = "computed from linear sigma0" ;
		string wvc_sigma_nv:coordinates = "time lat lon" ;

// global attributes:
		string :title = "IWWOC CFOSAT Level 2S 25.0 km Ocean Wave and Surface Wind Vector Product" ;
		string :title_short_name = "CFOSAT-L2S-25km" ;
		string :netcdf_version_id = "4.3.0 of Jul 8 2013 12:17:12" ;
		string :id = "CER_L2S_WND_GLO_025_CFOSAT_IWWOC" ;
		string :summary = "Colocated wind vector and wave spectra measurements from SCAT and SWIM instriments onboard CFOSAT, along-swath at 25km resolution" ;
		string :scientific_project = "Ifremer Wind and Wave Operation Center (IWWOC)" ;
		string :institution = "Institut Francais de Recherche pour l\'Exploitation de la mer, Centre National d’Études Spatiales" ;
		string :institution_abbreviation = "Ifremer/Cersat, CNES" ;
		string :cdm_data_type = "swath" ;
		string :program = "CNES CFOSAT" ;
		string :contributor_name = "CNES/Ifremer, CERSAT/eOdyn" ;
		string :contributor_role = "IWWOC is funded by CNES and Ifremer, Ifremer/CERSAT produced the data, and eOdyn provided the algorithm model" ;
		string :Conventions = "CF - 1.6, ACDD - 1.3, ISO 8601" ;
		string :naming_authority = "fr.ifremer.cersat" ;
		string :platform = "CFOSAT" ;
		string :platform_vocabulary = "CEOS" ;
```

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string :instrument_vocabulary = "CEOS" ;
string :keywords = "Oceans, Ocean Winds, Surface Winds" ;
string :keywords_vocabulary = "NASA Global Change Master Directory (GCMD) Science Keywords" ;
string :standard_name_vocabulary = "NetCDF Climate and Forecast (CF) Metadata Convention" ;
string :metadata_link = "N/A" ;
string :acknowledgement = "Please acknowledge the use of these data with the following statement: these data were obtained from the Ifremer/CNES IWWOC center" ;
string :license = "CFOSAT IWWOC data use is free and open" ;
string :publisher_name = "ifremer/cersat" ;
string :publisher_url = "cersat.ifremer.fr" ;
string :publisher_email = "cersat@ifremer.fr" ;
string :publisher_institution = "Ifremer/Cersat" ;
string :creator_name = "IWWOC" ;
string :creator_url = "http://www.iwwoc.org" ;
string :creator_email = "cersat@ifremer.fr" ;
string :creator_institution = "Ifremer, CNES" ;
string :scientific_support_contact = "Alexey Mironov (alexey.mironov@eOdyn.com)" ;
string :technical_support_contact = "cersat@ifremer.fr" ;
:software_identification_level_1 = 2018LL ;
:instrument_calibration_version = 0LL ;
:software_identification_wind = 2018LL ;
string :pixel_size_on_horizontal = "25.0 km" ;
string :service_type = "N/A" ;
string :processing_type = "?" ;
string :contents = "???" ;
string :granule_name = "L2S_a_25km_20201022T124744_20201022T143002.nc" ;
string :processing_level = "L2S" ;
:orbit_number = 0LL ;
string :time_coverage_duration = "PT31M27S" ;
string :time_coverage_resolution = "PT1S" ;
:cycle_number = 0LL ;
string :time_coverage_start = "2020-10-22T12:49:37" ;
string :time_coverage_end = "2020-10-22T14:32:22" ;
string :geospatial_bounds = "POLYGON ((-180. -90., -180. 90., 180. 90., 180. -90., -180. -90.))" ;
string :geospatial_bounds_crs = "EPSG:4326" ;
string :spatial_resolution = "25 km" ;
:geospatial_lat_min = -90LL ;
:geospatial_lat_max = 90LL ;
string :geospatial_lat_units = "degrees_north" ;
:geospatial_lon_min = -180LL ;
:geospatial_lon_max = 180LL ;
string :geospatial_lon_units = "degrees_east" ;
:geospatial_vertical_min = 10LL ;

```
		:geospatial_vertical_max = 10LL ;
		string :geospatial_vertical_units = "meters above mean sea level" ;
		string :geospatial_vertical_positive = "up" ;
		string :references = "CFOSAT Wave and Wind Product User Manual,
http://wwz.ifermer.fr" ;
		string :comment = "Orbit period and inclination are constant values. All wave and wind
directions in oceanographic convention (0 deg. flowing North)" ;
		string :date_created = "2020-10-26T10:54:45" ;
}
```

4.3.2 AUX level

```
netcdf CFO_OPER_SWISCA_L2S_AUX_F_20200807T043020_20200807T060548_0.0.4 {
dimensions:
	row = 1673 ;
	cell = 42 ;
	WW3_k = 32 ;
	WW3_dir = 24 ;
variables:
	short CERSAT_ice_concentration(row, cell) ;
		CERSAT_ice_concentration:_FillValue = -1s ;
		string CERSAT_ice_concentration:long_name = "CERSAT sea-ice concentration" ;
		string CERSAT_ice_concentration:units = "percent" ;
		string CERSAT_ice_concentration:coordinates = "time lon lat" ;
	short CERSAT_ice_concentration_quality(row, cell) ;
		CERSAT_ice_concentration_quality:_FillValue = -999s ;
		string CERSAT_ice_concentration_quality:long_name = "CERSAT ice concentration
quality flag" ;
		string CERSAT_ice_concentration_quality:description = "< to add flag description from
CERSAT docs>" ;
		string CERSAT_ice_concentration_quality:coordinates = "time lon lat" ;
	float CMEMS_current_u(row, cell) ;
		CMEMS_current_u:_FillValue = -999.f ;
		string CMEMS_current_u:long_name = "sea surface U current component" ;
		string CMEMS_current_u:units = "m s-1" ;
		string CMEMS_current_u:coordinates = "time lon lat" ;
	float CMEMS_current_v(row, cell) ;
		CMEMS_current_v:_FillValue = -999.f ;
		string CMEMS_current_v:long_name = "sea surface V current component" ;
		string CMEMS_current_v:units = "m s-1" ;
		string CMEMS_current_v:coordinates = "time lon lat" ;
	float ECMWF_sst(row, cell) ;
		ECMWF_sst:_FillValue = -999.f ;
		string ECMWF_sst:long_name = "ECMWF sea surface temperature" ;
		string ECMWF_sst:units = "K" ;
```

```
                string ECMWF_sst:coordinates = "time lon lat" ;
        float ECMWF_wind_u(row, cell) ;
                ECMWF_wind_u:_FillValue = -999.f ;
                string ECMWF_wind_u:long_name = "ECMWF 10 metre U wind component" ;
                string ECMWF_wind_u:units = "m s-1" ;
                string ECMWF_wind_u:coordinates = "time lon lat" ;
        float ECMWF_wind_v(row, cell) ;
                ECMWF_wind_v:_FillValue = -999.f ;
                string ECMWF_wind_v:long_name = "ECMWF 10 metre V wind component" ;
                string ECMWF_wind_v:units = "m s-1" ;
                string ECMWF_wind_v:coordinates = "time lon lat" ;
        float IMERG_precipitationCal(row, cell) ;
                IMERG_precipitationCal:_FillValue = -999.f ;
                string IMERG_precipitationCal:long_name = "IMERG multi-satellite precipitation
estimate" ;
                string IMERG_precipitationCal:units = "mm/hr" ;
                string IMERG_precipitationCal:coordinates = "time lon lat" ;
        short IMERG_precipitationQualityIndex(row, cell) ;
                IMERG_precipitationQualityIndex:_FillValue = -999s ;
                string IMERG_precipitationQualityIndex:long_name = "IMERG quality Index for
IMERG precipitationCal field" ;
                string IMERG_precipitationQualityIndex:coordinates = "time lon lat" ;
        float IMERG_probabilityLiquidPrecipitation(row, cell) ;
                IMERG_probabilityLiquidPrecipitation:_FillValue = -999.f ;
                string IMERG_probabilityLiquidPrecipitation:long_name = "IMERG probability of
liquid precipitation phase" ;
                string IMERG_probabilityLiquidPrecipitation:units = "percent" ;
                string IMERG_probabilityLiquidPrecipitation:coordinates = "time lon lat" ;
        float IMERG_randomError(row, cell) ;
                IMERG_randomError:_FillValue = -999.f ;
                string IMERG_randomError:long_name = "IMERG random error for
IMERG_precipitationCal" ;
                string IMERG_randomError:units = "mm/hr" ;
                string IMERG_randomError:coordinates = "time lon lat" ;
        float WW3_dir(WW3_dir) ;
                WW3_dir:_FillValue = -400.f ;
        float WW3_dk(WW3_k) ;
                WW3_dk:_FillValue = -999.f ;
                string WW3_dk:long_name = "Wave Watch 3 wave number spectral bin width" ;
                string WW3_dk:units = "rad2 m-2" ;
        float WW3_efth(row, cell, WW3_k, WW3_dir) ;
                WW3_efth:_FillValue = -999.f ;
                string WW3_efth:long_name = "Wave Watch 3 sea surface wave directional variance
spectral density" ;
                string WW3_efth:units = "m2 s rad-1" ;
                string WW3_efth:coordinates = "time lon lat" ;
        float WW3_f2k(WW3_k) ;
```

```
                WW3_f2k:_FillValue = -999.f ;
                string WW3_f2k:long_name = "Wave Watch 3 frequency to wave number jacobian" ;
        byte WW3_flag(row, cell) ;
                WW3_flag:_FillValue = -1b ;
                string WW3_flag:long_name = "Wave Watch 3 spectra interpolation status flag" ;
                string WW3_flag:flag_values = "-1 , 1, 2, 3, 4, 5, 6" ;
                string WW3_flag:flag_meanings = "no_valid_data_available
using_original_spectrum_on_the_distance_less_than_12km
interpolated_from_spectra_on_a_distance_between_12km_and_20km
using_original_spectrum_on_the_distance_between_12km_and_20km
interpolated_from_spectra_on_a_distance_between_20km_and_40km
using_original_spectrum_on_the_distance_between_40km_and_80km" ;
                string WW3_flag:coordinates = "time lon lat" ;
        float WW3_k(WW3_k) ;
                WW3_k:_FillValue = -999.f ;
        float WW3_k1(WW3_k) ;
                WW3_k1:_FillValue = -999.f ;
                string WW3_k1:long_name = "Wave Watch 3 wave number of lower band" ;
                string WW3_k1:units = "rad m-1" ;
        float WW3_k2(WW3_k) ;
                WW3_k2:_FillValue = -999.f ;
                string WW3_k2:long_name = "Wave Watch 3 wave number of upper band" ;
                string WW3_k2:units = "rad m-1" ;
        float lat(row, cell) ;
                lat:_FillValue = -400.f ;
                string lat:long_name = "WVC latitude" ;
                string lat:units = "degrees north" ;
        float lon(row, cell) ;
                lon:_FillValue = -400.f ;
                string lon:long_name = "WVC longitude" ;
                string lon:units = "degrees east" ;
        double time(row, cell) ;
                time:_FillValue = NaN ;
                string time:units = "seconds since 2020-08-07 04:31:13" ;
                string time:calendar = "proleptic_gregorian" ;

// global attributes:
                string :title = "IWWOC CFOSAT Level 2S 25.0 km Ocean Wave and Surface Wind
Vector Auxiliary Data Product" ;
                string :title_short_name = "CFOSAT-L2S-AUX-25km" ;
                string :netcdf_version_id = "4.3.0 of Jul 8 2013 12:17:12" ;
                string :id = "CER_L2S_WND_GLO_025_CFOSAT_IWWOC" ;
                string :processor_version = "0.0.4" ;
                string :summary = "Collocated auxiliary model output data in SCAT instrument onboard
CFOSAT, along-swath at 25km resolution" ;
                string :scientific_project = "Ifremer Wind and Wave Operation Center (IWWOC)" ;
```

string :institution = "Institut Francais de Recherche pour l\'Exploitation de la mer, Centre National d’Études Spatiales" ;
string :institution_abbreviation = "Ifremer/Cersat, CNES" ;
string :cdm_data_type = "swath" ;
string :program = "CNES CFOSAT" ;
string :contributor_name = "CNES/Ifremer, CERSAT/eOdyn" ;
string :contributor_role = "IWWOC is funded by CNES and Ifremer, Ifremer/CERSAT produced the data, and eOdyn provided the algorithm model" ;
string :Conventions = "CF - 1.6, ACDD - 1.3, ISO 8601" ;
string :naming_authority = "fr.ifremer.cersat" ;
string :platform = "CFOSAT" ;
string :platform_vocabulary = "CEOS" ;
string :instrument = "SCAT, SWIM" ;
string :instrument_vocabulary = "CEOS" ;
string :keywords = "Oceans, Ocean Winds, Surface Winds, Ocean Waves, Ocean Currents" ;
string :keywords_vocabulary = "NASA Global Change Master Directory (GCMD) Science Keywords" ;
string :standard_name_vocabulary = "NetCDF Climate and Forecast (CF) Metadata Convention" ;
string :metadata_link = "N/A" ;
string :acknowledgement = "Please acknowledge the use of these data with the following statement: these data were obtained from the Ifremer/CNES IWWOC center" ;
string :license = "CFOSAT IWWOC data use is free and open" ;
string :publisher_name = "ifremer/cersat" ;
string :publisher_url = "cersat.ifremer.fr" ;
string :publisher_email = "cersat@ifremer.fr" ;
string :publisher_institution = "Ifremer/Cersat" ;
string :creator_name = "IWWOC" ;
string :creator_url = "http://www.iwwoc.org" ;
string :creator_email = "cersat@ifremer.fr" ;
string :creator_institution = "Ifremer, CNES" ;
string :scientific_support_contact = "Alexey Mironov (alexey.mironov@eOdyn.com)" ;
string :technical_support_contact = "cersat@ifremer.fr" ;
:software_identification_level_1 = 2018LL ;
:instrument_calibration_version = 0LL ;
:software_identification_wind = 2018LL ;
string :pixel_size_on_horizontal = "25.0 km" ;
string :service_type = "N/A" ;
string :processing_type = "?" ;
string :contents = "???" ;
string :granule_name = "L2S_AUX_25km_20200807T043020_20200807T060548.nc" ;
string :processing_level = "L2S" ;
:orbit_number = 0LL ;
string :time_coverage_duration = "PT31M27S" ;
string :time_coverage_resolution = "PT1S" ;
:cycle_number = 0LL ;

```
		string :time_coverage_start = "2020-08-07T04:31:13" ;
		string :time_coverage_end = "2020-08-07T06:09:03" ;
		string :geospatial_bounds = "POLYGON ((-180. -90., -180. 90., 180. 90., 180. -90., -
180. -90.))" ;
		string :geospatial_bounds_crs = "EPSG:4326" ;
		string :spatial_resolution = "25 km" ;
		:geospatial_lat_min = -90LL ;
		:geospatial_lat_max = 90LL ;
		string :geospatial_lat_units = "degrees_north" ;
		:geospatial_lon_min = -180LL ;
		:geospatial_lon_max = 180LL ;
		string :geospatial_lon_units = "degrees_east" ;
		:geospatial_vertical_min = 10LL ;
		:geospatial_vertical_max = 10LL ;
		string :geospatial_vertical_units = "meters above mean sea level" ;
		string :geospatial_vertical_positive = "up" ;
		string :references = "CFOSAT Wave and Wind Product User Manual,
http://wwz.ifermer.fr" ;
		string :comment = "Orbit period and inclination are constant values. All wave and wind
directions in oceanographic convention (0 deg. flowing North)" ;
		string :date_created = "2020-11-04T08:04:49" ;
}
```