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SWIM PRODUCT SIMPLIFIED HANDBOOK

Written by:	**Date :**	23/01/2020
CNES		

CHANGES

Issue	Rev.	Date	Reference, Author(s), Reasons for evolution
01	00	11/03/2020	Creation of the document.
02	00	18/06/2020	Document update : - nadir data first acces guide update - addition of : normalized radar cross-section (sigma0) and mean normalized radar cross-section profiles first access guide

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ACRONYMS AND NOTATIONS

Notation	Definition
σ_0	Radar backscattering coefficient
AOCS	Attitude and Orbit Control System
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
PRF	Pulse Repetition Frequency
SCAT	SCATterometer (wind fan-beam scatterometer)
NRCS	Normalized Radar Cross-section
SWH	Significant Wave Height
SWEC	Swim Expertise Cell
SWIM	Surface Wave Investigation and Monitoring
TM	Telemetry
WS	Wind Speed

1. OVERVIEW

1.1. SCOPE

The French ground segment implemented for the CFOSAT mission (FROGS) distributes products from the SWIM and SCAT instruments from level 1 up to level 4. **This document focuses on the SWIM products.**

This document aims at describing the main parameters for a first use of the SWIM products. Some high level specifications are given about algorithms. The full description of the product, parameters and algorithms principles is given in [1].

Visualization tools are described, those tools are jupyter notebook and associated python script when needed, they are available on aviso CFOSAT mission web page : https://www.aviso.altimetry.fr/en/missions/current-missions/cfosat.html. Please note that most of those visualization tools need the python **cartopy** package.

1.2. REFERENCE DOCUMENTS

[1] C. Tison, D.Hauser, P. Castillan, "SWIM Products User Guide", CNES, Toulouse France, specification. CF-GSFR-MU-2530-CNES, 2019 https://www.aviso.altimetry.fr/fileadmin/documents/data/tools/SWIM_ProductUserGuide.pdf

[2] Hauser D., C. Tison, T. Amiot, L. Delaye, N. Corcoral et al, "SWIM: the first spaceborne wave scatterometer", *IEEE Trans. on Geoscience and Remote Sensing*, 10.1109/TGRS.2017.2658672 , VOL 55, 5, May 2017

[3] C. Tourain, F. Piras, A. Olivier, JC. Poisson, F. Boy, P. Thibaut, L. Hermozo, D. Hauser, C. Tison, "CFOSAT SWIM ADAPTIVE retracking: description and validation", submitted

2. CONTEXT

2.1. CFOSAT MISSION

The CFOSAT program is carried out through cooperation between French and Chinese Space Agencies (CNES and CNSA respectively).

The CFOSAT satellite carries two radar instruments un Ku Band: SCAT, a wind scatterometer, and SWIM, a wave scatterometer. Figure 1 shows an artist view of the instrument implementation on the platform.

CFOSAT aims at characterizing the ocean surfaces to better model and predict the ocean states and improve the knowledge in ocean/atmosphere exchanges, contributing to marine and weather forecast and to the monitoring of climate essential variables.

CFOSAT observations may also be used for applications on continental surfaces and for the cryosphere, through the use of the normalized radar cross-sections.

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).

2.2. SWIM INSTRUMENT

The SWIM (Surface Wave Investigation and Monitoring) instrument delivered by CNES is dedicated to the measurement of the surface ocean waves directional spectrum (density spectrum of wave slopes as a function of direction and wavenumber of the waves) and associated wave parameters.

SWIM is a Ku-band (13.575 GHz) real aperture radar which illuminates the surface sequentially with six incidence angles around 0°, 2°, 4°, 6°, 8° and 10° with an antenna aperture of 1.5° to 1.8° . 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.

The data are processed in Near-Real time conditions (i.e. in less than three hours from the acquisition) so as to be provided to operational users (meteorology agencies mainly) in nearly real time) for operational use. They are made available to the scientific community in less than 4 days on the Aviso website (http://www.aviso.altimetry.fr/en/home.html).

2.2.1. 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.

The radar backscattered signal is sampled with a high horizontal resolution of only a few meters in the range direction but integrated over a large footprint (several kilometers) in the perpendicular direction. Hence, waves with a significant component in the azimuth direction are averaged over many wavelengths and therefore contribute little to the radar signal , whereas long waves travelling in the range direction will be seen because of the sensitivity of the radar backscatter to the local tilting of the surface. Wave propagation direction is determined from the known pointing direction of the antenna.

Table 1 summarizes the main parameters of SWIM. The six beams are illuminated sequentially with different PRF values for each incidence angle. The PRF is adapted 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, slightly varying along the orbit to account for altitude variation
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 HH polarization

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 2).

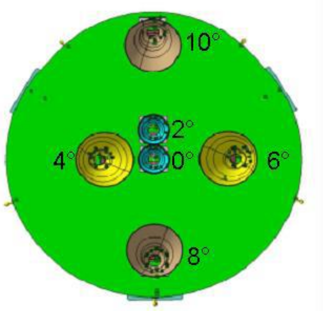


Fig.2 SWIM horns accommodation on baseplate.

Figure 3 illustrates the geometry of the SWIM acquisition.

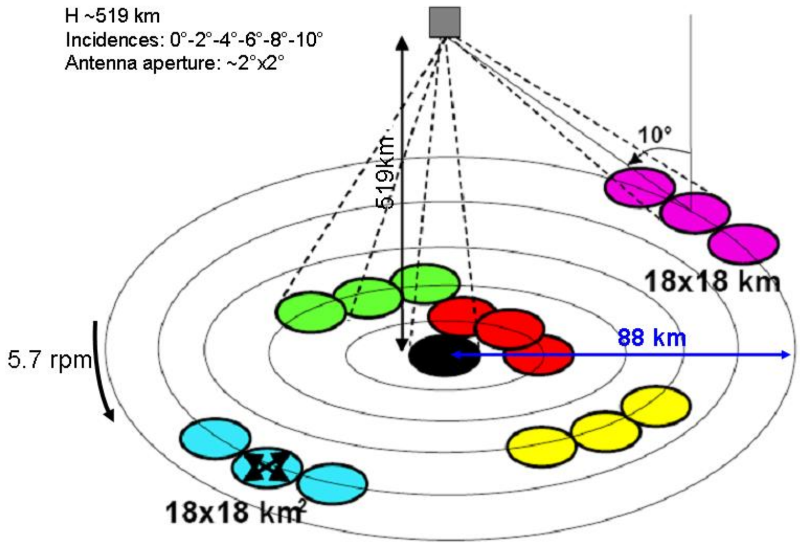


Figure 3. SWIM illumination pattern. Each coloured circle represents the footprint for a single antenna beam (about 18 km in diameter) and a single cycle of measurement. The sampling is illustrated for 3 successive macrocycles composed of a sequence using beams at 0, 2, 4, 6, 8, and 10° incidence.

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 sequence of the repeated successive cycles. The nominal macro-cycle is composed of six cycles sampling successively all the incidence beams (0°, 2°, 4°, 6°, 8°, 10°). Alternative macro-cycles may be chosen by a command sent to the on-board processor 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.

2.2.2. On-board processing

Because of the limitations on the telemetry rate and the important data amount acquired by SWIM, an on-board processing is necessary. This on-board processing is designed to sample the radar echoes in regular range gates, and to reduce the overall data rate.

This includes numerical range compression, combined with range registration. This is based on a convolution of the received signal with a replica of the transmitted signal while compensating from one pulse to the other for the effects of geometrical migration, due to satellite displacement and antenna rotation. (see [2] for details). The output is a radar echo oversampled by a factor 1.25 with respect to the original resolution of 0.47 m.

In addition, an incoherent summation of the signals is carried out over time and range, with number of averaged samples defined as shown in Table 3 (first two lines). Finally, a selection of the swath is carried out with a number of points selected as presented in Table 3 (last line)

For each cycle, only one averaged waveform (also called “echo”) is downloaded.

	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}).

3. CFOSAT GROUND SEGMENT

TBC

4. 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 [1].

The products are generated for each download to one of the receiving station. 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.

File nomenclature:

SWIM product form L1A to L2 provided to users are named as follow:

CFO_OPER_ TTTTTTTTTT _<G>_<observation_start_time>_<observation_end_time>

With:

- TTTTTTTTTT: File Type
    - L1A product: SWI_L1A___
    - L1B product: SWI_L1B___
    - L2 product: SWI_L2____
    - Auxiliary meteo product: AUX_METEO_

- <G>: Ground mission center country where the product is generated
  F or C

- <observation_start_time> : time of the first observation in the file
  Format: AAAAMMDDTHHMMSS

- <observation_end_time> : time of the last observation in the file
  Format: AAAAMMDDTHHMMSS

Example:

CFO_OPER_SWI_L2_____F_20200120T102427_20200120T115712.nc

4.1. MAIN PRODUCTS

The SWIM data are inversed to retrieve three main kinds of geophysical products which are provide in the Level 2 products (Figure):

- 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.

In addition, the L1a products contain, among other parameters, the Normalized Radar Cross-Section (NRCS) with same range and time sampling as in the downloaded product, with associated values of the local incidence and geolocalization parameters. Details on L1a and L1b products may be found in [1].

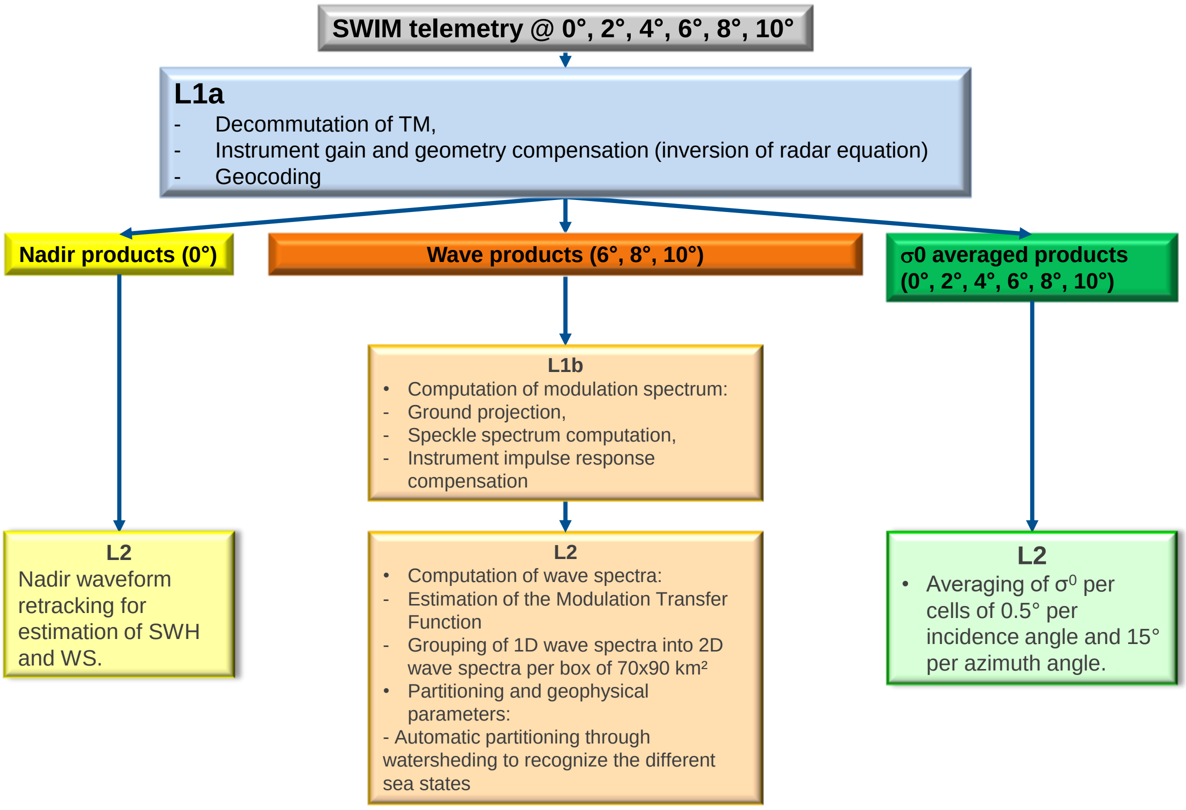


Figure 4. Overview of the main physical parameters estimated from the SWIM data.

Six kinds of files are made available to the users per download (Table 4). The exact content of these files is described in [1].

File Name	File Type	File Description	Update frequency
SWI_L1A___	L1a product	Contains calibrated and geocoded waveform, i.e, NRCS as a function of range or local incidence for each cycle/macrocycle, with associated time and latitude/longitude	15 files per day
SWI_L1B___	L1b product	Contains the modulation of the signal (in the 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 the wave parameters estimated from the spectra and their partitions (L2SPEC).	15 files per day
SWI_AUX_METEO	ECMWF Meteorogical products sampled on SWIM data locations	Contains some meteorological variables from the ECMWF forecasted fields sampled at the location of SWIM acquisitions.	15 files per day

Table 4. Available files on AVISO 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.

5. SWIM PRODUCTS GUIDE

Important note:

For most of the Jupiter notebook provided with this handbook, the cartopy package is needed.

5.1. MAIN REMINDERS

5.1.1. SWIM measurements organisation

SWIM instrument is composed of 6 incidence beams, from nadir to 10 degrees. The acquisition is performed sequentially one beam after another.

The terminology for this specific acquisition is the following:

- **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**:
  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°).
  The duration of this nominal macrocycle is 220ms

  L1a and L1B products contain variables provided with a time sampling which follows the cycles and macrocycles sequences.

  Figure 5 shows the acquisition geometry for 3 successive macrocycles

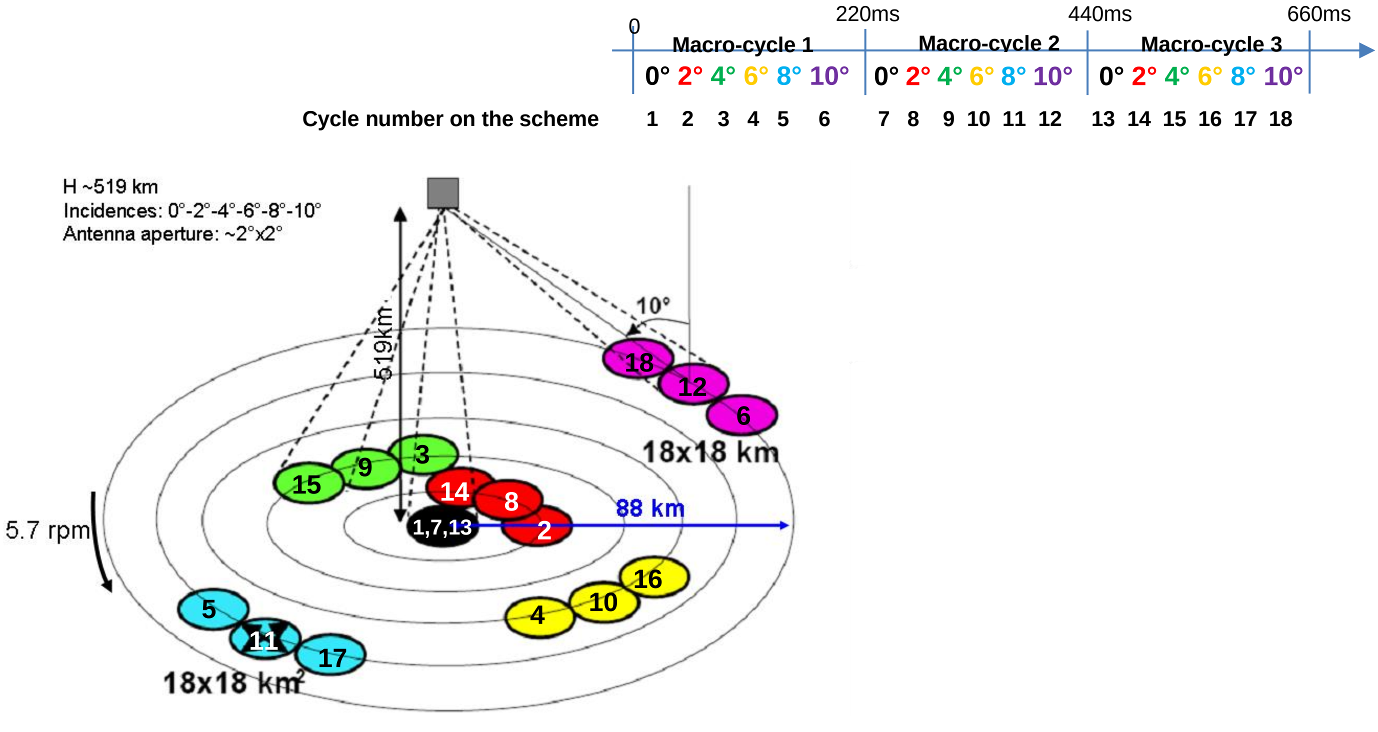


Figure 5 acquisition geometry for 3 successive SWIM macrocycles

- **Box**:
  In order to construct the SWIM 2D observations, we define product cells called boxes.
  These boxes are illustrated in Figure 6 as shaded blue areas. They are defined as the areas on the left and the right sides of the nadir track (blue dots in Figure 6) which covers complete azimuthal scans over 180°. The boxes cover areas of about 70 km x 90 km.

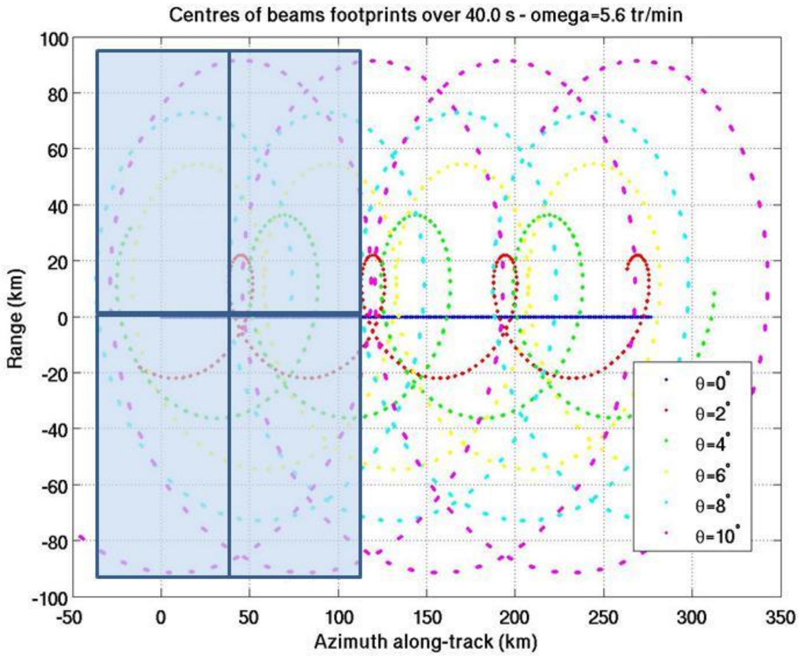


Figure 6. Horizontal sampling of SWIM data. The coloured dots indicate the centre of each antenna footprint according to the radar geometry and followed by the Level 1a data. The shaded light blue boxes illustrate the area of the "product cells" (boxes) used to generate the Level 2 products.

Most of the parameters of the L2 products are provided with a sampling which follows the box sampling (except for nadir variables, see below).

Several geophysical parameters are provided over these boxes:

- σ_0 profiles with incidence,
- SWH and WS from nadir retracking,
- 2D wave spectra
- Wave parameters on the wave spectra
  - Direction
  - Wavelength
  - Significant Wave Height
- Wave parameters of up to three partitions of the wave spectra
  - Direction
  - Wavelength
  - Significant Wave Height

Note that when the antenna rotation mode is off, the L2 products contain only nadir data.

5.2. L1A PRODUCT

5.2.1. Normalized radar cross-section (sigma0) first access guide

The normalized radar cross-section (also noted sigma0 or $\sigma 0$) are provided in the level 1A products in natural units

(W) and as profiles (in W) along the swath, for each beam and each macrocycle (see section 5.1.1 to get the definition of the macrocycle dimension). We recall that the swath length, corresponding to the number of gates within the swath retained after on-board and ground-processing, varies according to each beam.

Mean sigma0 mean "mini-profiles" provided as a function of incidence are also available and provided in the level 2 products (see section 5.3.2).

5.2.1.1. L1A-product Sigma0 profiles main parameters

The level 1A sigma0 profiles are given for each beam, as one parameter per beam in the macrocycle configuration. To distinguish each beam, the parameter is named ***echo_l1a_x***, x corresponding to the absolute number of the beam in the macrocycle configuration.

For instance, if the current macrocycle configuration is {0°,2°,4°,6°,8°,10°}, sigma0 profiles for each beam will correspond to the level 1A variables:

- **echo_l1a_0**
- **echo_l1a_1**
- **echo_l1a_2**
- **echo_l1a_3**
- **echo_l1a_4**
- **echo_l1a_5**

The variable echo_l1a_x is defined for all macrocycles, and for each gate along the swath axis, for beam number x of the macrocycle configuration. It is given in natural units, with eventually punctually negative values obtained after thermal noise floor subtraction applied in the Level1a processing.

Dimensions of echo_l1a_x are:
n_mcycles, n_swath

- n_mcycles: corresponds to the macrocycle in the studied L1A file
- n_swath: corresponds to the number of the gate in the swath

Each gate in the swath is defined according to various parameters provided in the level 1A products, for each macrocycle in the studied file. The parameters are the following:

- incidence_x:
  The incidence angle value (at the surface) for each macrocycle and for each gate in the swath, for beam number x
  Values are given in rad
  Dimensions : n_mcycles, n_swath
    - n_mcycles: corresponds to the macrocycle in the studied L1A file
    - n_swath: corresponds to the number of the gate in the swath

- elevation_x:
  The elevation angle value (at the satellite level) at each macrocycle and for each gate of the swath, for beam number x
  Values are given in rad
  Dimensions : n_mcycles, n_swath
    - n_mcycles: corresponds to the macrocycle in the studied L1A file
    - n_swath: corresponds to the number of the gate in the swath

- radar_range_x:
  The radar range values associated to each gate of the swath (distance satellite-radar gate in radar geometry), for each macrocycle, for beam number x
  Values are given in m
  Dimensions : n_mcycles, n_swath
    - n_mcycles: corresponds to the macrocycle in the studied L1A file
    - n_swath: corresponds to the number of the gate in the swath

- ground_range_x:
  The ground range values associated to each gate of the swath (distance satellite-radar gate projected on ground), for each macrocycle, for beam number x
  Values are given in m

Dimensions : n_mcycles, n_swath
  - n_mcycles: corresponds to the macrocycle in the studied L1A file
  - n_swath: corresponds to the number of the gate in the swath

Each macrocycle in the studied L1A file is localized and timed via the following parameters:

- time_nr:
  Time of each Near Range measurement, for each macrocycle and each gate of the swath, relative to the reference time
  Dimensions : n_mcycles, n_beam, n_tim
  - n_mcycles: corresponds to the macrocycle in the studied L1A file
  - n_beam: corresponds to the number of the beam
  - n_tim: corresponds to time components:
    - 0: seconds relative to reference time
    - 1: microseconds in the second

- lon_l1a_x:
  Longitude of each macrocycle and each gate in the swath, for beam number x in the macrocycle configuration
  Dimensions : n_mcycles, n_swath
  - n_mcycles: corresponds to the macrocycle in the studied L1A file
  - n_swath: corresponds to the number of the gate in the swath

- lat_l1a_x:
  Latitude of each macrocycle and each gate in the swath, for beam number x in the macrocycle configuration
  Dimensions : n_mcycles, n_swath
  - n_mcycles: corresponds to the macrocycle in the studied L1A file
  - n_swath: corresponds to the number of the gate in the swath

When visualizing and analysing the sigma0 profiles in the level 1A products, it is recommended to select the sigma0 profiles over the reliable part of the swath. This reliable swath subset corresponds to a reduced part of the n_swath gates. It is beam dependant, but does not depend on the macrocycle. Such swath gates are selected using the following flag in the level 1A products:

- ***reliable_swath_x***
  Value (0 or 1) describing if the gate is part of the reliable swath or not :
  - 0: gate is out of the reliable part of the swath
  - 1: gate is within the reliable part of the swath
  Dimensions: n_swath
  - n_swath: corresponds to the number of the gate in the swath

5.2.1.2. L1A-product Sigma0 profiles analysis tools

The Jupiter notebook sigma0_visu.ipynb allows to visualize the sigma0 profiles for a given macrocycle and beam(s).

Before activation, some parameters have to be specified in the arguments initialization part

- The full path of the directory where is placed the SWIM L1A NetCDF file

  SWIM_L1A_NC_file_path='<*full path*>'

- The name of the SWIM L1A NetCDF file

  SWIM_L1A_NC_file_name='<*SWIM L1a Net CDF file name*>'

- The number of the macrocycle for visualization:

  num_mcycle=<macrocycle *number for visualization*>

- The beam(s) to visualize: 0=> beam 0°; 1=> beam 2°; 2=> beam 4° ; 3=> beam 6° ; 4=> beam 8° ; 5=> beam 10°

  beam = [<beam(s) to visalize>]

- The axis used for the swath gates:
  - 1 => incidence values in deg
  - 2 => elevation values in deg

- 3 => radar range values in m
- 4 => ground range values in m

x_axis = <number of corresponding axis for the swath gates>

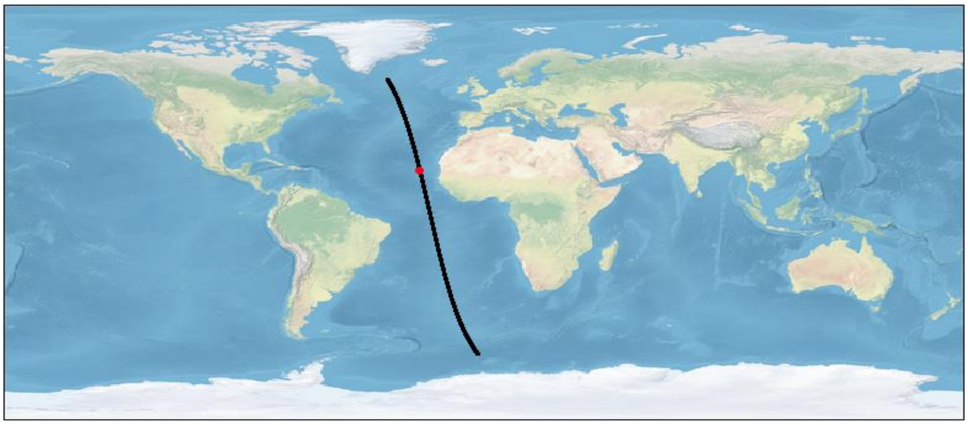
- The unit of sigma0 visualisation, in dB or in natural values (W):
  - dB
  - W

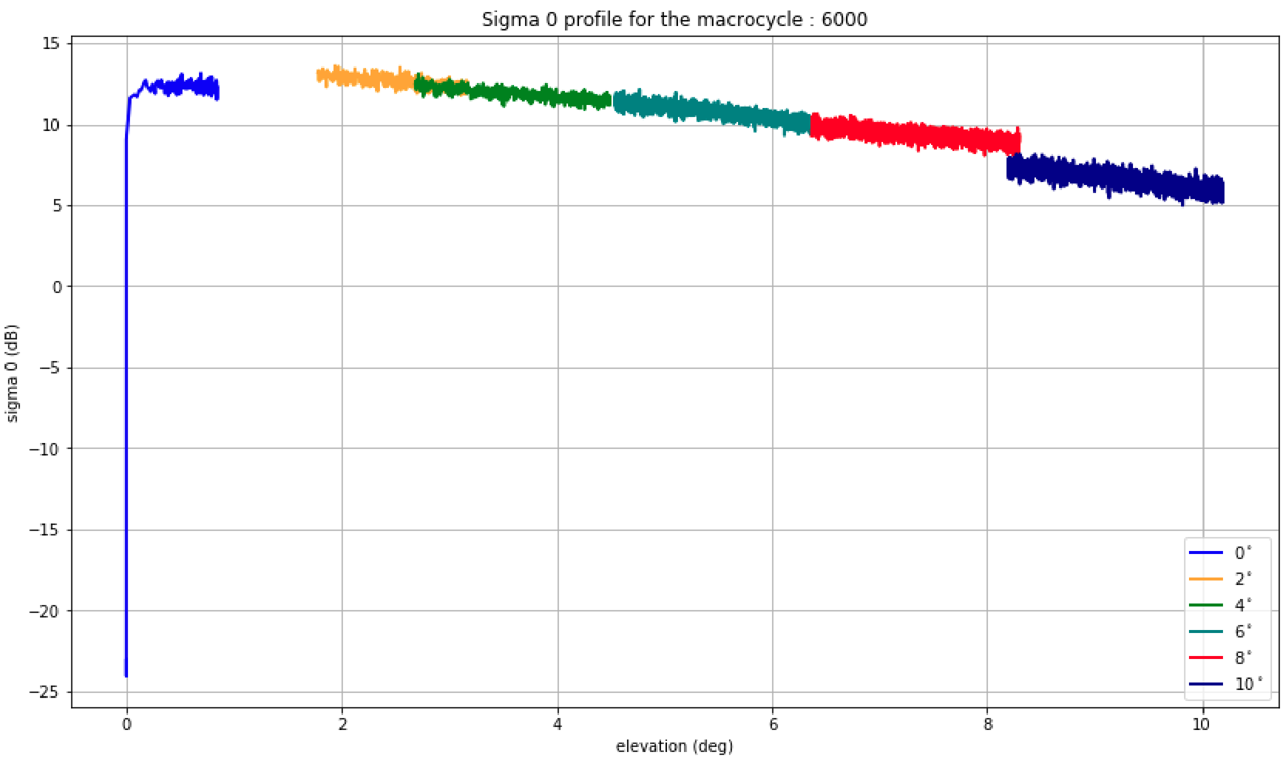
  unit_sigma0 : '<unit of sigma0>'

- If the visalization of the sigma0 profile(s) is done over the reliable part of the swath only (True) or over the full swath (False)

  Reliable_swath=<True or False>

When activated, the notebook gives the visualization of the macrocycle localization (for the nadir beam) along the satellite track over a global map, and the corresponding sigma0 profile for this macrocycle:





where each beam is plotted with a different color in the sigma0 profile figure.

5.3. L2 PRODUCT

5.3.1. Nadir data first access guide

The nadir processing of ocean and sea-ice surfaces is based on the so called ADAPTIVE retracking algorithm described in [3]. Two others algorithms are applied on all surfaces. They are described in [1].

5.3.1.1. Defintions

CWWIC L2 product contains many parameters derived from the processing of nadir measurements.

We focus here only on parameters for ocean observation. For ice and land surface useful parameters, please report to [1].

The three main parameters that can be used the same way as for conventional altimeter data are:

- Significant Wave Height (SWH)
- Sigma naught (Sigma0)
- Wind Speed (WS)

Note that there is no range information available in the product (no radiometer, no precise orbit determination).

3 classes of parameters are provided at different sampling rates corresponding to different averages:

- **native**: Parameters derived from each individual echo processing
  - **nadir_swh_native**: significant wave height
  - **nadir_sigma0_native:** sigma naught
  - **nadir_wind_native :** Wind speed

  Rate: every macrocycle (approximatively 220ms)
  The dimension of these parameters is:
  n_mcycles: corresponds to the number of macrocycle of the nadir measurements (index starting at 0 for each file)

  These parameters are timed and localized through 3 other parameters:

  - time_nadir_native :
    time of the nadir native parameters
    Dimensions : n_mcycles, n_tim
    - n_ mcycles: corresponds to the macrocycle number
    - n_tim : corresponds to time components:
      - 0: seconds relative to reference time
      - 1: microseconds in the second
  - lon_l2anad:
    Longitude of nadir beam parameters
    Dimensions : n_mcycles
    - n_ mcycles: corresponds to the macrocycle number
  - lat_l2anad :
    Latitude of nadir beam parameters
    Dimensions : n_mcycles
    - n_ mcycles: corresponds to the macrocycle number

  There are other auxiliary variables associated to these native parameters which can be used for quality control (see [1] for details) :
  For SWH: **nadir_swh_native_validity**
  For sigma naught: **nadir_sigma0_native_validity**
  For WS: **flag_valid_wind_native**
  Others : **nadir_Wf_native_validity, nadir_native_MQE, Nadir_native_retracking_validity**

- **nsec:** Parameters resulting from the compression (editing, smoothing, average) of 19 to 20 native parameters (over 4.5 seconds)
  - **nadir_swh_nsec:** significant wave height
  - **nadir_ sigma0_nsec:** sigma naught

- **nadir_ wind_nsec:** wind speed

  Rate: every 220ms
  These parameters are given at the same rate than native data,
  The dimension of these parameters is:
  n_mcycles: corresponds to the macrocycle where the average value is associated

  These parameters are timed and localized through 3 other parameters:

  - time_nadir_native:
    time of the nadir native parameters, significant for nsec values (same rate)
    Dimensions : n_mcycles, n_tim
    - n_ mcycles: corresponds to the macrocycle number
    - n_tim : corresponds to time components:
      - 0: seconds relative to reference time
      - 1: microseconds in the second

  - lon_l2anad:
    Longitude of nadir beam parameters
    Dimensions : n_mcycles
    - n_ mcycles: corresponds to the macrocycle number

  - lat_l2anad :
    Latitude of nadir beam parameters
    Dimensions : n_mcycles
    - n_ mcycles: corresponds to the macrocycle number

There are also auxiliary variables associated to these native parameters which can be used for quality control (see [1] for details) :
For SWH: **nadir_swh_nsec_std, nadir_swh_nsec_used_native, flag_valid_swh_nsec**
For sigma naught:**nadir_sigma0_nsec_std, nadir_sigma0_nsec_used_native, flag_valid_sigma0_nsec**
For WS: **flag_valid_wind_nsec**

- **box:** Parameters resulting from the compression (editing, averaging) of 45 to 50 native parameters, contained in the SWIM box
  - **nadir_swh_box:** significant wave height
  - **nadir_sigma0_box:** sigma naught
  - **nadir_wind_box:** wind speed

  Rate: box rate (approximatively every 10s)
  The dimension of these parameters is:
  n_box: corresponds to the box where the average value is associated

  these parameters are timed and localized through 3 other parameters:

  - time_nadir_l2:
    Mean time of nadir beam in each box
    Dimensions : n_box, n_tim
    - n_ box: corresponds to the box number
    - n_tim : corresponds to time components:
      - 0: seconds relative to reference time
      - 1: microseconds in the second

  - lon_nadir_l2:
    Mean longitude of nadir beam in each box
    Dimensions : n_box
    - n_ box: corresponds to the box number

  - lat_nadir_l2 :
    Mean latitude of nadir beam in each box
    Dimensions : n_box
    - n_ box: corresponds to the box number

There are also auxiliary variables associated to these native parameters which can be used for quality control with the same time sampling and localization (see [1] for details)
• For SWH: **nadir_swh_box_std , nadir_swh_box_used_native, flag_valid_ swh_box**
• For Sigma naught: **nadir_sigma0_box_std , nadir_sigma0_box_used_native , flag_valid_ sigma0_box**
• For WS: **flag_valid_ wind_box**
The dimension of these parameters is: n_box (see above).

5.3.1.2. Visualization tool : CFO_SWIM_visu_nadir.ipynb

The Jupiter notebook CFO_SWIM_visu_nadir.ipynb allows to visualize the nadir main parameters.

Before activation, some parameters have to be specified in the arguments initialization part

- The full path of the directory where is placed the SWIM L2 NetCDF file

  SWIM_L2_NC_file_path='<*full path*>'

- The name of the SWIM L2 NetCDF file

  SWIM_L2_NC_file_name='<*SWIM L2 Net CDF file name*>'

- The rate of parameter to visualize (0: native data; 1: 1Hz compressed data; 2: nsec compressed data; 3: data compressed over one box:

  Param_rate= *<0, 1, 2 or 3>*

- The activation of data filtering on validity flag (0: no filtering , 1: filtering)

  val_filter = < 0 or 1 >

- The activation of comparison with ECMWF data

  ecmwf_comp = < 0 or 1 >

  If the comparison with ECMWF data is activated (ecmwf_comp = 1), the following parameters have to be specificed

  - The full path of the directory where is placed the SWIM AUX_METEO NetCDF file

    SWIM_AUX_MET_NC_file_path='<*full path*>'

  - The name of the SWIM AUX_METEO NetCDF file

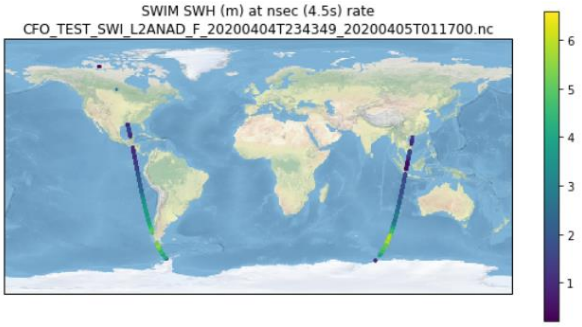
    SWIM_AUX_MET_NC_file_name='<*SWIM* AUX_METEO *Net CDF file name*>'

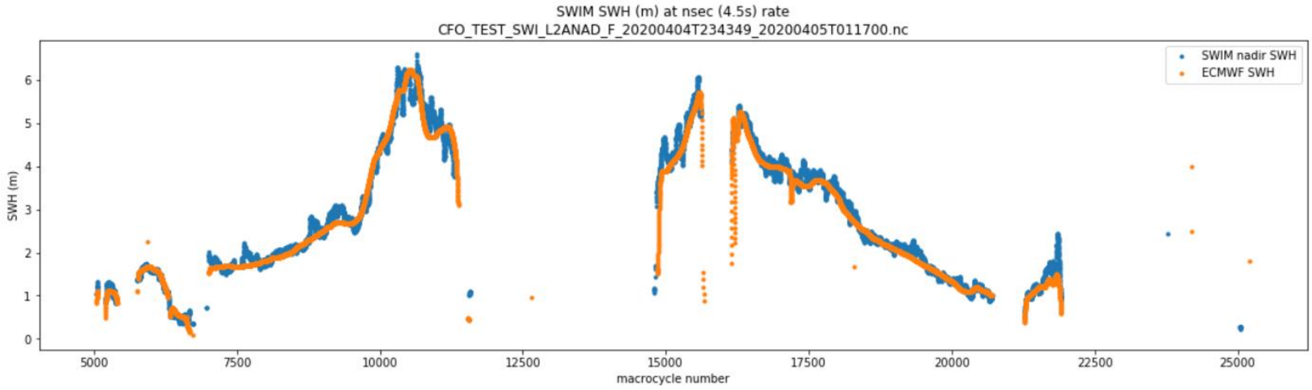
When activated, the notebook gives the visualization of each geophysical parameters SWH, sigma0 and wind speed through:

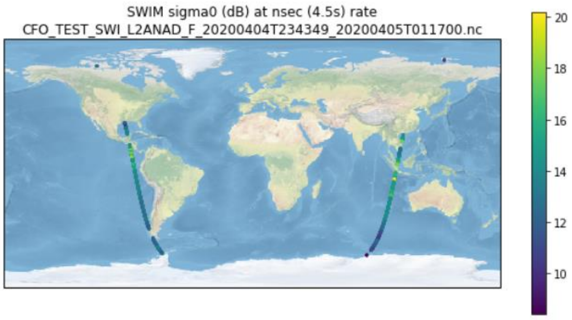
- a cartography with a colour bar
- a plot of the values function of samples

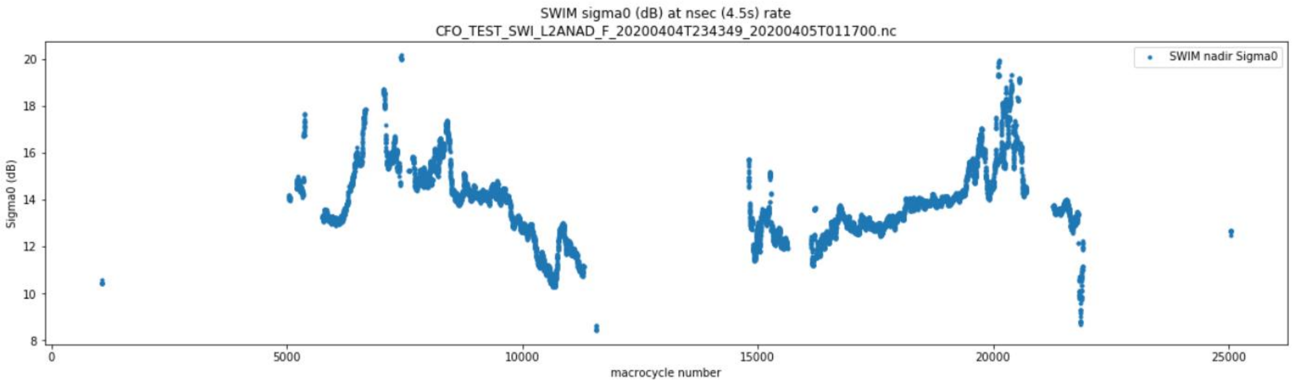
For native and nsec rate parameters, when the comparison to ECMWF is activated, ECMWF values are also plotte. Complementary scatter plots giving SWIM results versus ECMWF data are also given for SWH and Wind speed.

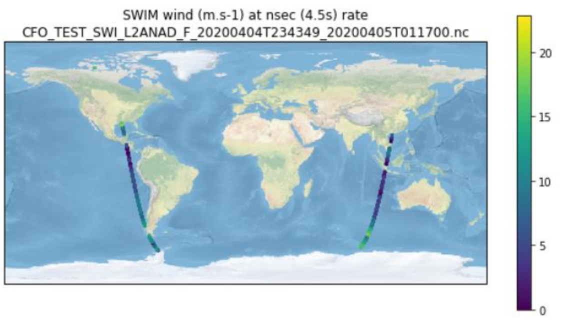
Here is given an example for nadir nsec parameters :

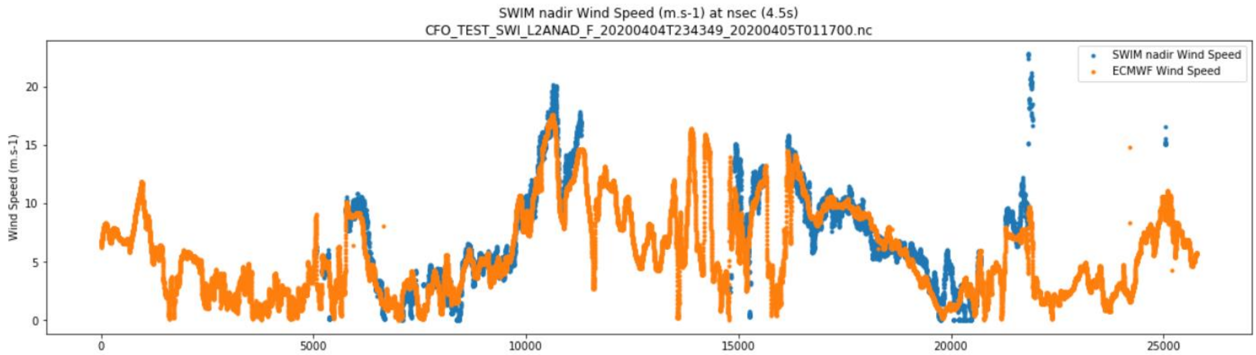

SWIM SWH (m) at nsec (4.5s) rate
CFO_TEST_SWI_L2ANAD_F_20200404T234349_20200405T011700.nc
1
2
3
4
5
6

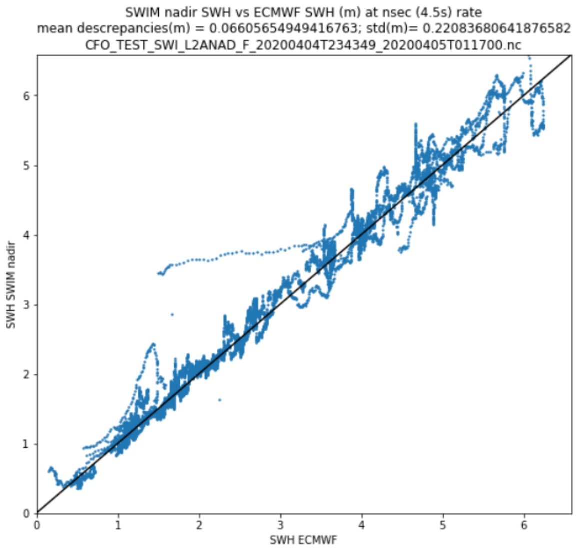

SWIM SWH (m) at nsec (4.5s) rate
CFO_TEST_SWI_L2ANAD_F_20200404T234349_20200405T011700.nc
SWIM nadir SWH
ECMWF SWH
SWH (m)
macrocycle number
5000
7500
10000
12500
15000
17500
20000
22500
25000

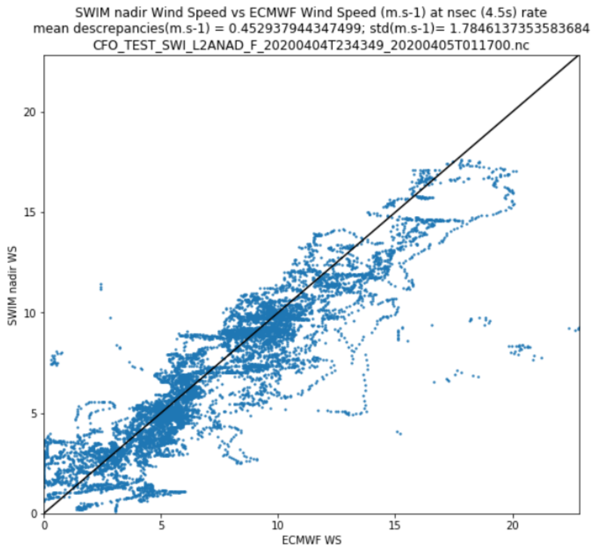

SWIM sigma0 (dB) at nsec (4.5s) rate
CFO_TEST_SWI_L2ANAD_F_20200404T234349_20200405T011700.nc
10
12
14
16
18
20


SWIM sigma0 (dB) at nsec (4.5s) rate
CFO_TEST_SWI_L2ANAD_F_20200404T234349_20200405T011700.nc
SWIM nadir Sigma0
Sigma0 (dB)
macrocycle number
0
5000
10000
15000
20000
25000









5.3.2. Mean normalized radar cross-section (sigma0) profiles first access guide

Mean normalized radar cross-sections (also noted sigma0 or σ_0) are provided in the level 2 products as "mini-profiles" as a function of incidence angles or as a function of both incidence and azimuth angles. They are given by box (see section 5.1.1 to get the definition of the box dimension), for each beam. Sigma0 mini-profiles are computed by averaging L1A sigma0 profiles contained in each box. They are provided in dB for up to 9 bins of incidence angles ranging within +/-2° on both sides on the central incidence angle of each beam. In the L2 processing, the individual $\sigma 0$ values are corrected for atmospheric attenuation (excluding rain effect) and averaged in natural units before conversion to dB of the mean values.

5.3.2.1. L2-product Sigma0 mini-profiles main parameters

The level 2 sigma0 mini-profile parameters are given by box (cf §4.1.1). The spatial distribution of these boxes is illustrated in the figure from section 5.2.3.1.

In each L2 Product file, there are at least n_box * n_posneg * n_beam_sig0 sigma0 mini-profiles of size n_theta_mini, where n_box is the number of box slices along the orbit track, n_posneg is the number of sides considered on each side of the nadir track (2 in the standard processing mode, with posneg=0 for the right-hand side and posneg=1 for the left-hand side of the nadir track), n_beam_sig0 is the number of beams for which the parameter is available (all beams in the current macrocycle configuration) and n_theta_mini is usually equal to 9.

There are 5 different variables for sigma0 mini-profiles:

- **sigma0_mini_profile_all_azim_cor**: sigma0 mini-profiles averaged over all azimuths, in a given box, for a given beam,
- **sigma0_std_mini_profile_all_azim_cor**: their corresponding standard deviation over all measurements in the box, at a given beam,
- **sigma0_mini_profile**: sigma0 mini-profiles for each azimuth bin, in a given box, for a given beam,
- **sigma0std_mini_profile**: their corresponding standard deviation over all measurements in the box, at a given azimuth bin and a given beam
- **sigma0N_mini_profile**: the corresponding number of measurements taken to compute the sigma0 mini-profiles, in a given box, at a given azimuth bin and a given beam inside each theta bin.

All the variables are given by box (cf §4.1.1), which are localized and timed via the following parameters :

- time_l2:
  Mean time of box area used to compute sigma0 mini-profiles and 2D spectrum (i.e. center of the box)
  ⇨ time in seconds and microseconds relative to reference time
  Dimensions: n_posneg, n_box, n_tim
    - n_posneg: corresponds to side of the box
    - n_box: corresponds to box sampling along track
    - n_tim: corresponds to time components:
      - 0: seconds relative to reference time
      - 1: microseconds in the second

- lon_l2:
  Mean longitude of box used to compute sigma0 mini-profiles and 2D spectrum
  Dimensions : n_posneg, n_box
    - n_posneg: corresponds to side of the box
    - n_box: corresponds to the box number along track

- lat_l2:
  Mean latitude of box used to compute sigma0 mini-profiles and 2D spectrum
  Dimensions : n_posneg, n_box
    - n_posneg: corresponds to side of the box
    - n_box: corresponds to box sampling along track

In addition to this dimension, variables **sigma0_mini_profile**, **sigma0std_mini_profile** and **sigma0N_mini_profile** are given by azimuth bins. There are 12 azimuth bins ranging from 0° to 180° every step of 7.5°.

Finally, all variables are given for incidence angles within +/-2° around the central incidence angle, of each beam every 0.5°, corresponding to the incidence step.

Hereafter, are described the main variables for a first access to SWIM sigma0 mini-profiles.

5.3.2.2. Sigma0 mini-profiles averaged over all azimuths

5.3.2.2.1. Definitions:

For each box and each beam, a sigma0 mini-profile is given as the mean backscattering power profile as a function of incidence angle. Incidence angles range within +/-2° around the central incidence angle of each beam.

Mean sigma0 are computed by averaging all L1A sigma0 values (expressed in natural units) contained in a given box, all azimuths confounded, after correcting individual values for atmospheric effects (except rain).

This variable is given in dB, with its corresponding standard deviation. Description and dimensions of both variables are given hereafter:

- **sigma0_mini_profile_all_azim_cor:**
  ⇨ gives the mean sigma0 mini-profile for each beam of the macrocycle configuration and each box.
  Values are averaged over all azimuths in a given box.
  The dimensions of this parameter are:

n_theta_mini, n_posneg, n_box, n_beam_sig0

- n_theta_mini: corresponds to the number of incidence bins of each mini_profiles (usually 9)
- n_posneg: corresponds to the side of the box
- n_box: corresponds to the box sampling along track
- n_beam_sig0: corresponds to the beam in the macrocycle configuration

  For instance, for a nominal macrocycle configuration:
  - 0: 0° beam
  - 1: 2° beam
  - 2: 4° beam
  - 3: 6° beam
  - 4: 8° beam
  - 5: 10° beam

  for a specific {0°, 2°, 8°, 10°} macrocycle configuration:
  - 0: 0° beam
  - 1: 2° beam
  - 2: 8° beam
  - 3: 10° beam

- **sigma0_std_mini_profile_all_azim_cor:**

  ⇨ gives the corresponding mean sigma0 mini-profile's standard deviation for each beam of the macrocycle. Variability is given over all azimuths in a given box.

  The dimensions of this parameter are:

  n_theta_mini, n_posneg, n_box, n_beam_sig0
  - n_theta_mini: corresponds to the number of incidence bins of each mini_profiles (usually 9)
  - n_posneg: corresponds to side of the box
  - n_box: corresponds to box sampling along track
  - n_beam_sig0: corresponds to the beam in the macrocycle configuration.

5.3.2.2.2. Visualization tool: visu_mini_prof_sigma0.ipynb

The Jupiter notebook visu_mini_prof_sigma0.ipynb allows to visualize the mean and standard deviation sigma0 mini-profiles for each beam of a nominal macrocycle configuration and a given box.

Before activation, some parameters have to be specified in the arguments initialization part

- The full path of the directory where is placed the SWIM L2 NetCDF file

  SWIM_L2_NC_file_path='<*full path*>'

- The name of the SWIM L2 NetCDF file

  SWIM_L2_NC_file_name='<*SWIM L2 Net CDF file name*>'

- The number of the box for visualization:

  num_box=<*box number for visualization*>

- The side of the nadir track to analyse (0: right side ; 1 :left side) which correspond to n_posneg

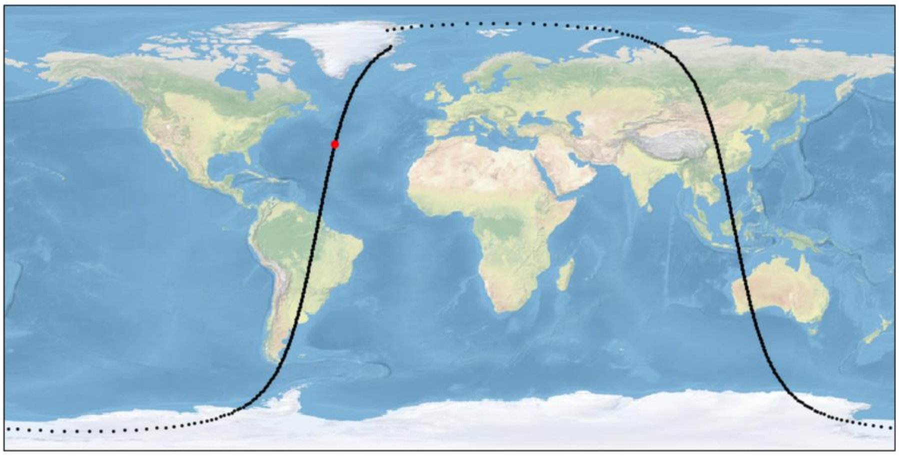
  nadir_side=< *0 or 1* >

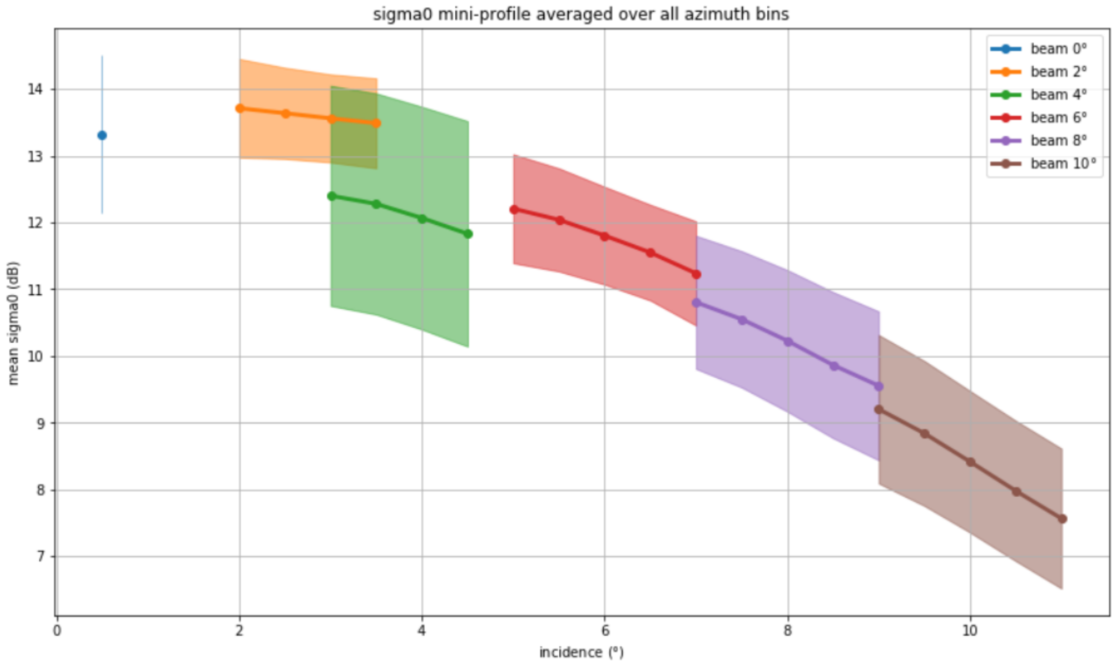
When activated, the notebook gives the visualization of the box localization and a second plot showing for this box:

- the mean sigma0 mini-profiles (thick continuous lines)
- and the corresponding standard deviation (shaded areas)

as a function of incidence. Note that incidence array of each mini-profile is built by adding to the "theta_ticks_mini_profile" vector (extracted from global attributes) the value of the beam incidence angle.

Colours distinguish each beam.





5.3.2.3. Sigma0 mini-profiles for each azimuth bin

5.3.2.3.1. Definitions:

For each box, each beam, and each azimuth angle bin, a sigma0 mini-profile is given as the mean sigma0 (normalized radar cross-section) profile as a function of incidence angle. Incidence angles range within +/-2° around the central incidence angle for each beam.

The mean noramlized radar cross-section is computed by averaging all L1A sigma0 values (in natural units) contained in a given box and in a given azimuth binn after correcting individual values for atmospheric effects (except rain).

This variable is given in dB. It is available with its corresponding standard deviation and the number of measurements, at the macrocycle scale, included in a given box, and used to compute the averaging and standard deviation of the simga0-mini-profiles.

Description and dimensions of both variables are given hereafter:

- **sigma0_mini_profile:**
  ⇨ gives the mean sigma0 mini-profile for each beam of the macrocycle configuration and each box. Values are given for each azimuth bin in a given box.

  The dimensions of this parameter are:
  n_theta_mini, n_phi, n_posneg, n_box, n_beam_sig0

- n_theta_mini: corresponds to the number of incidence bins within the ±2 incidence range
- n_phi: corresponds to the number of azimuth bins
- n_posneg: corresponds to side of the box
- n_box: corresponds to box sampling along track
- n_beam_sig0: corresponds to the beam number in the macrocycle configuration.

- **sigma0std_mini_profile:**
  ⇨ gives the corresponding mean sigma0 mini-profile's standard deviation for each box and each beam of the macrocycle. Variability is given each azimuth bin.

  The dimensions of this parameter are:
  n_theta_mini, n_phi, n_posneg, n_box, n_beam_sig0
  - n_theta_mini: corresponds to the number of incidence bins within the ±2 incidence range
  - n_phi: corresponds to the number of azimuth bins
  - n_posneg: corresponds to the side of the box
  - n_box: corresponds to the box sampling along track
  - n_beam_sig0: corresponds to the beam number in the macrocycle configuration.

- **sigma0N_mini_profile:**
  ⇨ gives the corresponding number of L1A-product sigma0 estimations, at the macrocycle scale, included in each box and each azimuth bin area, and used to compute the averaging and standard deviation of each sigma0 mini-profile.

  The dimensions of this parameter are:
  n_theta_mini, n_phi, n_posneg, n_box, n_beam_sig0
  - n_theta_mini: corresponds to the number of incidence bins within the ±2 incidence range
  - n_phi: corresponds to the number of azimuth bins
  - n_posneg: corresponds to the side of the box
  - n_box: corresponds to the box sampling along track
  - n_beam_sig0: corresponds to the beam in the macrocycle configuration.

5.3.2.3.2. <u>Visualization tool:</u> visu_mini_prof_sigma0.ipynb

The Jupiter notebook visu_mini_prof_sigma0.ipynb allows to visualize the mean and standard deviation sigma0 mini-profiles for each beam of a nominal macrocycle configuration and a given box.

Before activation, some parameters have to be specified in the arguments initialization part

- The full path of the directory where is placed the SWIM L2 NetCDF file

  SWIM_L2_NC_file_path='<*full path*>'

- The name of the SWIM L2 NetCDF file

  SWIM_L2_NC_file_name='<*SWIM L2 Net CDF file name*>'

- The number of the box for visualization:

  num_box=<*box number for visualization*>

- The side of the nadir track to analyse (0: right side ; 1 :left side) which correspond to n_posneg

  nadir_side=< *0 or 1* >

- The azimuth bin number (corresponding to the azimuth angle region) to analyse (number between 0 and 11 included)

  num_azimuth_bin=< *value between 0 and 11 included* >

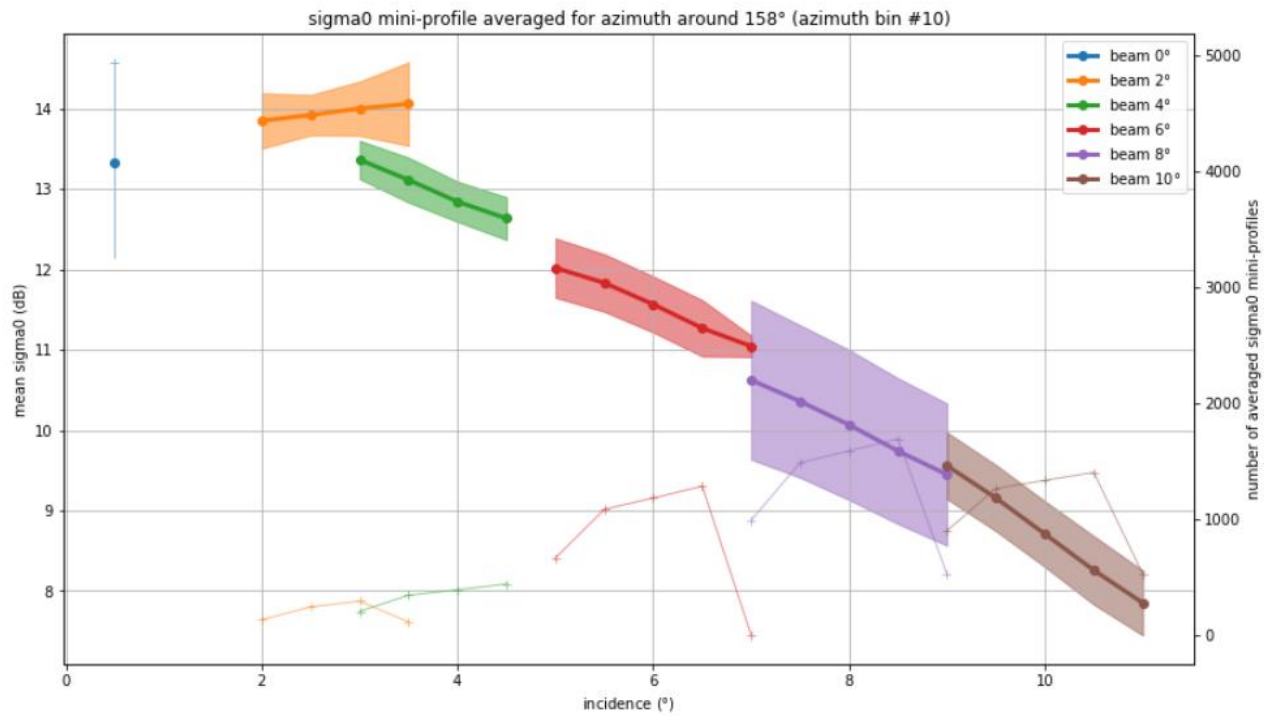
When activated, the notebook gives as a third plot, the visualization for this box of :

- the mean sigma0 mini-profiles (thick continuous lines and y-axis on the left hand side),
- the corresponding standard deviation (shaded areas and y-axis on the left hand side)
- and the number of measurements (at the macrocycle scale) used to compute the averaging and standard deviation of sigma0 mini-profiles (thin continuous lines and y-axis on the right hand side)

as a function of incidence. Note that incidence array of each beam mini-profile is built by adding to the “theta_ticks_mini_profile” vector (extracted from global attributes) the value of the beam incidence angle.

.

Colours distinguish each beam.

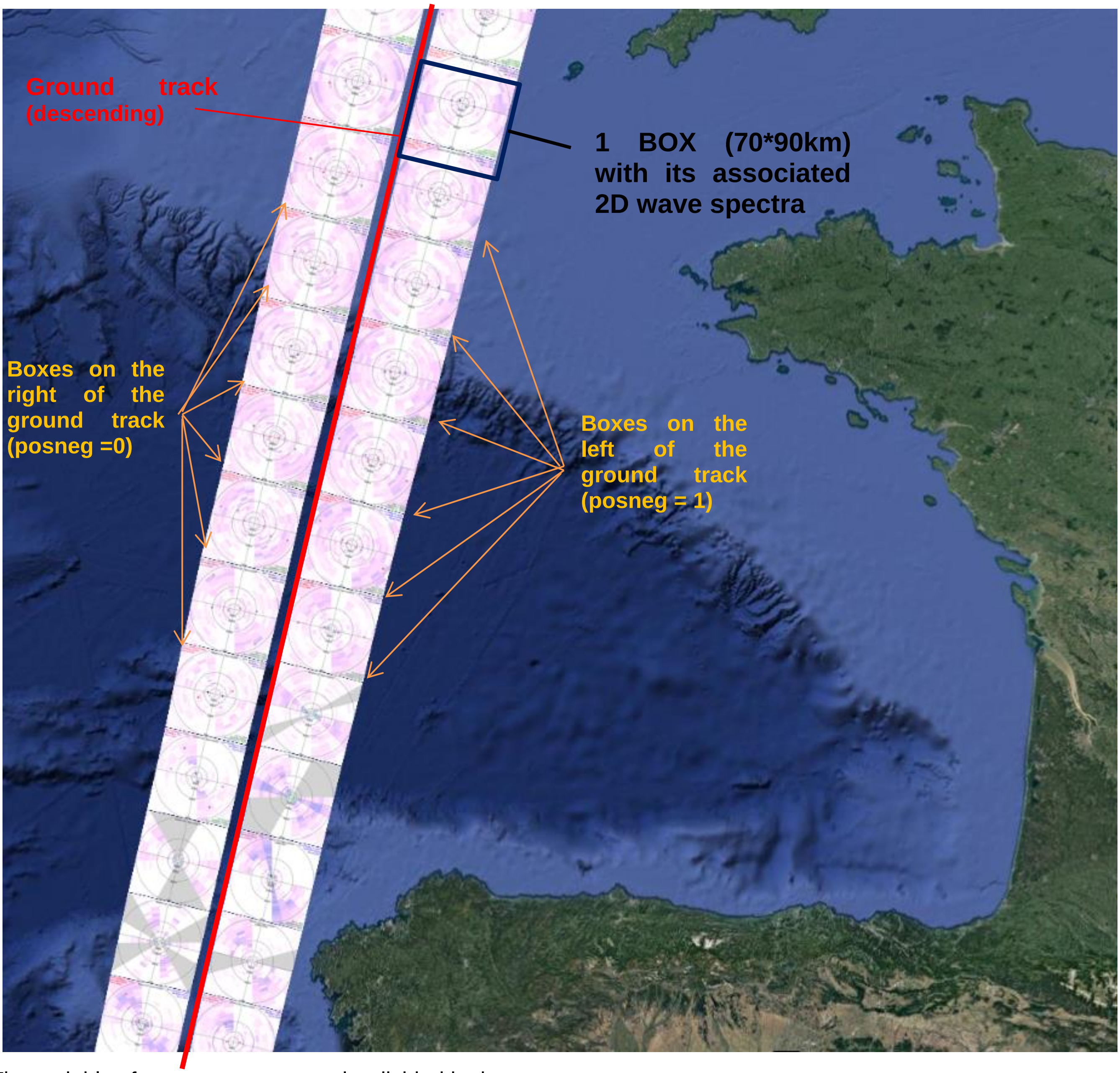


5.3.3. Wave spectra first access guide

5.3.3.1. CWWIC wave spectra main parameters

The wave spectra parameters are given by box (cf §4.1.1). The spatial distribution of these boxes is illustrated on the figure below.

In each L2 Product file there are n_box * n_posneg wave spectra where n_box is the number of box slices along the orbit track, and n_posneg is the number of sides considered to build the wave spectra (2 in the standard processing mode, with posneg=0 for the right-hand side and posneg=1 for the left-hand side of the nadir track)



The variables for wave spectra can be divided in three parts:

- The Omni-directional spectrum,
- the 2D directional wave spectrum and associated partitions,
- wave parameters (integral parameters) of 2D wave spectrum and of associated partitions.

These variables are provided based for each of the **6°, 8° and 10° beams** observations, these beams are called the **spectral beams.**

All the variables are given by box (cf §4.1.1), which are localized and timed via the following parameters :

- time_l2:
  Mean time of box area used to make 2D spectrum (i.e. center of the box)
  ⇨ time in seconds and microseconds relative to reference time
  Dimensions: n_posneg, n_box, n_tim
  - n_posneg: corresponds to side of the box
  - n_box: corresponds to box sampling along track
  - n_tim: corresponds to time components:
    - 0: seconds relative to reference time
    - 1: microseconds in the second

- lon_l2:
  Mean longitude of box used to make 2D spectrum
  Dimensions : n_posneg, n_box
  - n_posneg: corresponds to side of the box
  - n_box: corresponds to the box number along track

- lat_l2:
  Mean latitude of box used to make 2D spectrum
  Dimensions : n_posneg, n_box
    - n_posneg: corresponds to side of the box
    - n_box: corresponds to box sampling along track

Hereafter, are described the main variables for a first access to SWIM wave information, several additional variables that can be used for quality control are described in ANNEX 1

5.3.3.2. Omnidirectional wave slope spectra:

5.3.3.2.1. Definitions:

For each box, the omnidirectional wave spectrum is given as wave slope spectrum as a function of the wave number.

Two type of spectra are available:

- **pp_omni:**
  ⇨ gives the omni-directional slope spectrum for each spectral beam.
  It is the integration of the 2D wave slope spectrum for each spectral beam (**pp_mean**, see 5.3.3.3) over all azimuths

  The dimensions of this parameter are:
  nk, n_posneg, n_box, n_beam_l2
    - nk: corresponds to wave number sampling
    - n_posneg: corresponds to side of the box
    - n_box: corresponds to box sampling along track
    - n_beam_l2: corresponds to spectral beam possible selection:
      0: 6° beam
      1: 8° beam
      2: 10 °beam

- **pp_omni_comb:**

  ⇨ gives the omni-directional slope spectrum obtained from the combined 2D spectra.
  ⇨ It is the integration of the 2D wave slope spectrum combining all spectral beams (**p_combined**, see 5.3.3.3) over all azimuths

  The dimensions of this parameter are:
  nk, n_posneg, n_box,
    - nk: corresponds to wave number sampling
    - n_posneg: corresponds to side of the box
    - n_box: corresponds to box sampling along track

For both cases, the nk values of the wave number vector are given by the variable **k_spectra**:

⇨ It is the 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. The dimension **of k_spectra** is also nk

5.3.3.2.2. <u>Visualization tool: CFO_SWIM_omini-dir_spectrum_visu.ipynb</u>

The Jupiter notebook omini-dir_spectrum_visu.ipynb allows to visualize the omnidirectional wave slope spectrum for a given box.

Before activation, some parameters have to be specified in the arguments initialization part

- The full path of the directory where is placed the SWIM L2 NetCDF file

SWIM_L2_NC_file_path='<*full path*>'

- The name of the SWIM L2 NetCDF file

  SWIM_L2_NC_file_name='<*SWIM L2 Net CDF file name*>'

- The number of the box for visualization:

  num_box=<*box number for visualization*>

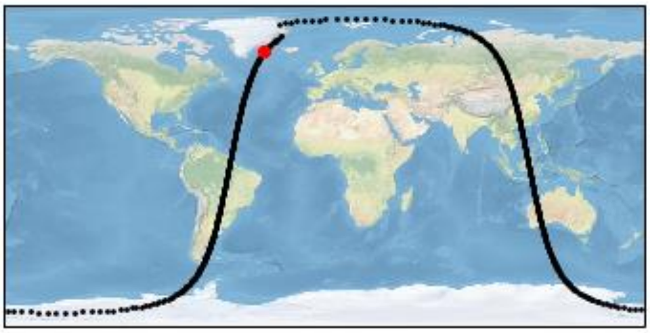
- The side of the nadir track to analyse (0: right side ; 1 :left side) which correspond to n_posneg

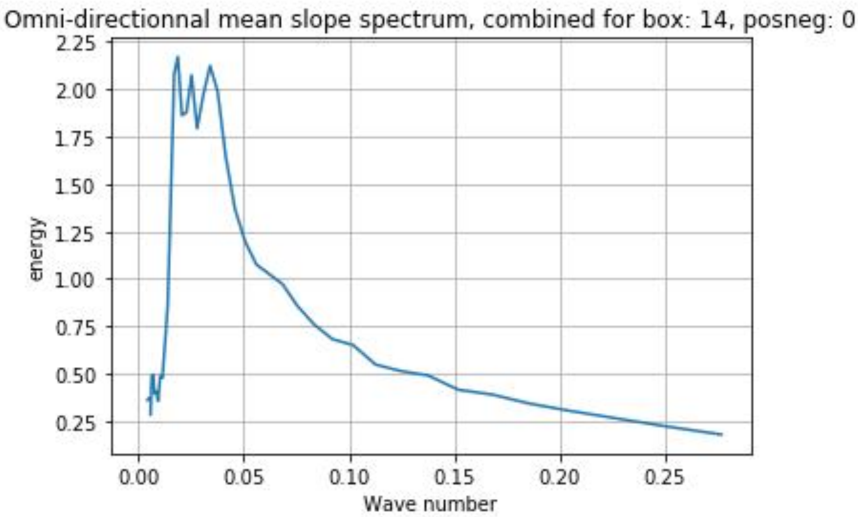
  Nadir_side=< *0 or 1* >

- The spectral beam selected for visualization: 6=> beam 6°; 8=> beam 8°; 10=> beam 10° ; 0 => combined (combination of the 3 beams)

  beam =<*6 or 8 or 10 or 0*>

When activated, the notebook gives the visualization of the box localization and the omnidirectional spectra for this box:





5.3.3.3. 2D wave spectra:

5.3.3.3.1. Definitions:

The wave spectra are given with a polar representation with spectral density of wave slopes expressed as function of wavenumber and direction (azimuth) (wave spectra (energy) = f(wavenumber,azimuth))

In one box, each sample value of wave spectrum is given for one wavenumber and one azimuth.

Two types of spectra are available:

- **pp_mean:**
  ⇨ gives the 2D wave slope spectrum for each spectral beam (6, 8 and 10°).

The dimensions of this parameter are:
nk, n_phi, n_posneg, n_box, n_beam_l2

- nk: corresponds to wave number sampling
- n_phi: correspond to azimuth sampling
- n_posneg: corresponds to side of the box
- n_box: corresponds to box sampling along track
- n_beam_l2: corresponds to spectral beam possible selection:
  - 0: 6° beam
  - 1: 8° beam
  - 2: 10 °beam

- **p_combined:**
  ⇨ gives the Mean slope spectrum obtained by combining all spectral beams:
  It is a weighted average of **pp_mean** values over the 3 spectral beams (6, 8, 10) for each wave number and each azimuth.

  The dimensions of this parameter are:
  nk, n_phi, n_posneg, n_box
  - nk: corresponds to wave number sampling
  - n_phi: correspond to azimuth sampling
  - n_posneg: corresponds to side of the box
  - n_box: corresponds to box sampling along track

For both cases (pp_mean and p_combined),the nk values of the wave number vector are given by the variable **k_spectra**:

⇨ It is the 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. The dimension **of k_spectra** is also nk

The n_phi azimuth samples values are given by the parameter **phi_vector**:

⇨ it is the wave direction vector (centre of azimuth bins and from 0 to 180°) 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 or from South,
  - 90°= from or toward East or frim West.
  - 180°= from or towards South.
  - 270°= from or towards west

On each 2D wave spectrum, a partitioning process has been applied in order to identify different wave systems (see [1] or [2] for details). Up to 3 partitions are determined. The masks of these partitions are given in:

- The parameter **mask**: for partitions obtained with the **pp_mean** wave spectra:
  ⇨ It gives the partitions mask for the different spectral beams wave spectra
  The dimension of this parameter are the same as **pp_mean**:
  nk, n_phi, n_posneg, n_box, n_beam_l2

- The parameter **mask_combined**: for partitions obtained with the **p_combined** wave spectrum:
  ⇨ It gives the partitions mask for the combined wave spectrum
  The dimension of this parameter are the same as **p_combined**:
  nk, n_phi, n_posneg, n_box

5.3.3.3.2. Visualization tool: CFO_SWIM_2D_wave_spectrum_visu.ipynb and plot_spectre_2D.py

The Jupiter notebook 2D_wave_spectrum_visu.ipynb allows to visualize the 2D wave slope spectrum for a given box.

To be activated it needs to have the python script plot_spectre_2D.py in the same directory.

Before activation, some parameters have to be specified in the arguments initialization part

- The full path of the directory where is placed the SWIM L2 NetCDF file:

SWIM_L2_NC_file_path='<*full path*>'

- The name of the SWIM L2 NetCDF file:

  SWIM_L2_NC_file_name='<*SWIM L2 Net CDF file name*>'

- The box number for visualization:

  num_box=<*box number for visualization*>

- The side of the nadir track to analyse (0: right side ; 1 :left side) which correspond to n_posneg:

  Nadir_side=< *0 or 1* >

- The spectral beam selected for visualization: 6=> beam 6°; 8=> beam 8°; 10=> beam 10° ; 0 => combined (combination of the 3 beams)

  beam =<*6 or 8 or 10 or 0*>

- The activation of partitions visualization: True => partitions visualization; False => no partitions visualization

  partitions =<*True or False*>

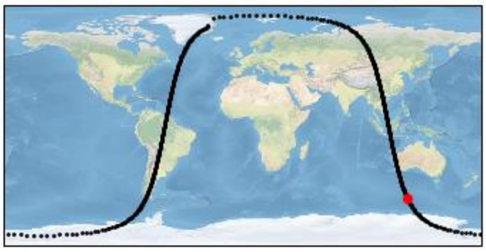
- The Wavelength range for visualization, [minimum wavelength (m); maximum wavelength (m)]

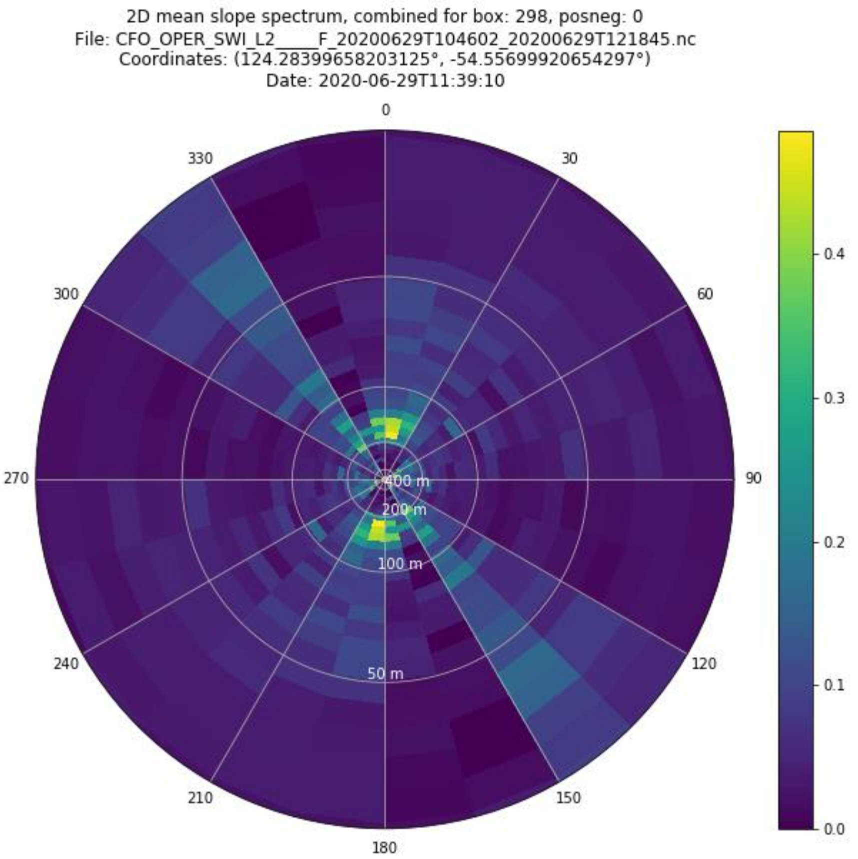
  min_wavelength =<*minimum wavelength for visualization in m*>

  max_wavelength =<*maximum wavelength for visualization in m*>

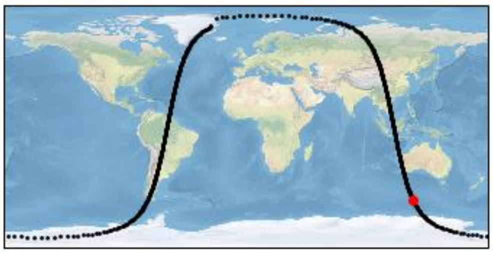
When activated, the notebook gives the visualization of the box localization and the 2D wave slope spectra for this box:

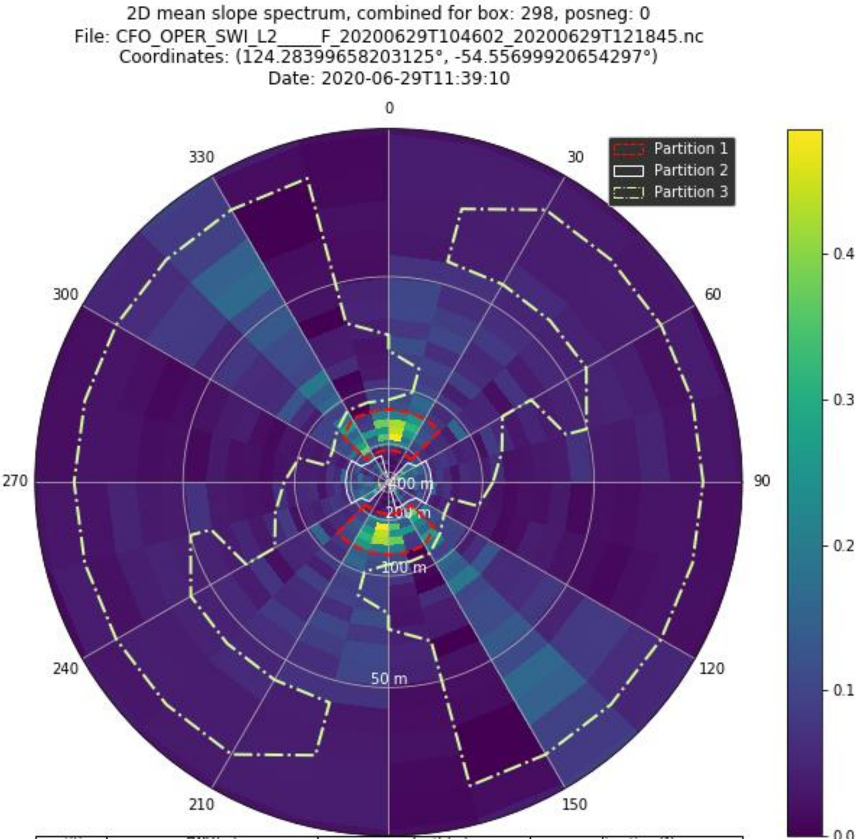
- The box localization and the raw wave slope spectra when partitions visualization is not activated:





- The box localization, the raw wave slope spectra, the partitions and the associated parameters when partitions visualization activated:





partition	SWH(m)	wavelenth(m)	direction (°)
1	1.915	163.904	74.831
2	2.011	331.99	90.56
3	1.558	64.505	123.591

5.3.3.4. Wave parameters:

5.3.3.4.1. Definitions:

3 wave parameters are given for each wave spectrum:

- The Significant Wave Height given, in meter
- The dominant wavelength given, in meter
- The dominant direction given in the meteorological convention with a 180° ambiguity (0°= from or towards North or from South, 90°= from or toward East or frim West, 180°= from or towards South, 270°= from or towards west

Two types of wave parameters are available:

1- <u>Wave parameters derived from the whole spectrum:</u>

- **wave_param:**
  ⇨ gives the wave parameters determined from the whole spectrum **pp_mean**, for each spectral beam (6, 8 and 10°).

  The dimensions of this parameter are:
  nparam, n_posneg, n_box, n_beam_l2
  - nparam: corresponds to the wave parameter
    - 0: Significant Wave Height
    - 1: dominant wavelength
    - 2: dominant direction
  - n_posneg: corresponds to side of the box
  - n_box: corresponds to box sampling along track
  - n_beam_l2: corresponds to spectral beam possible selection:
    - 0: 6° beam
    - 1: 8° beam
    - 2: 10 °beam

- **wave_param_combined:**
  ⇨ gives the wave parameters determined from the whole combined spectrum, **p_combined.**

  The dimensions of this parameter are:
  nparam, n_posneg, n_box
  - nparam: corresponds to the wave parameter
    - 0: Significant Wave Height
    - 1: dominant wavelength
    - 2: dominant direction
  - n_posneg: corresponds to side of the box
  - n_box: corresponds to box sampling along track

2- <u>Wave parameters derived from the partitions identified for each box</u>

- **wave_param_part:**
  ⇨ gives the wave parameters of each partition of the wave spectrum **pp_mean** given, for each spectral beam (6, 8 and 10°).

  The dimensions of this parameter are:
  nparam, npartitions, n_posneg, n_box, n_beam_l2
  - nparam: corresponds to the wave parameter
    - 0: Significant Wave Height
    - 1: dominant wavelength
    - 2: dominant direction
  - npartitions: corresponds to partitions identified for the box
    - 0: first partition
    - 1: second partition
    - 2: third partition

- n_posneg: corresponds to side of the box
- n_box: corresponds to box sampling along track
- n_beam_l2: corresponds to spectral beam possible selection:
  - 0: 6° beam
  - 1: 8° beam
  - 2: 10 °beam

- **wave_param_part_combined:**

⇨ gives the wave parameters of each partition of the combined spectrum **p_combined**.

The dimensions of this parameter are:
nparam, npartitions, n_posneg, n_box

- nparam: corresponds to the wave parameter
  - 0: Significant Wave Height
  - 1: dominant wavelength
  - 2: dominant direction

- npartitions: corresponds to partitions identified for the box
  - 0: first partition
  - 1: second partition
  - 2: third partition

- n_posneg: corresponds to side of the box
- n_box: corresponds to box sampling along track

5.3.3.4.2. Visualization tool: CFO_SWIM_wave_param_visu.ipynb

The Jupiter notebook wave_param_visu.ipynb allows to visualize the wave parameters for a given box.

Before activation, some parameters have to be specified in the arguments initialization part

- The full path of the directory where is placed the SWIM L2 NetCDF file:

  SWIM_L2_NC_file_path='<*full path*>'

- The name of the SWIM L2 NetCDF file:

  SWIM_L2_NC_file_name='<*SWIM L2 Net CDF file name*>'

- The box number for visualization:

  num_box=<*box number for visualization*>

- The side of the nadir track to analyse (0: right side ; 1 :left side) which correspond to n_posneg:

  Nadir_side=< *0 or 1* >

- The spectral beam selected for visualization: 6=> beam 6°; 8=> beam 8°; 10=> beam 10° ; 0 => combined (combination of the 3 beams)

  beam =<*6 or 8 or 10 or 0*>

- The wave parameters'origin for visualization: 0: visualization of parameters from partitions 1: visualization of parameters from the whole spectrum

  spectrum = <*0 or 1*>

- The partition selected for wave parameters visualization (only if spectrum=0) : 0=> wave parameters of all partitions; 1=> wave parameters of first partition ; 2=> wave parameters of second partition; 1=> wave parameters of third partition

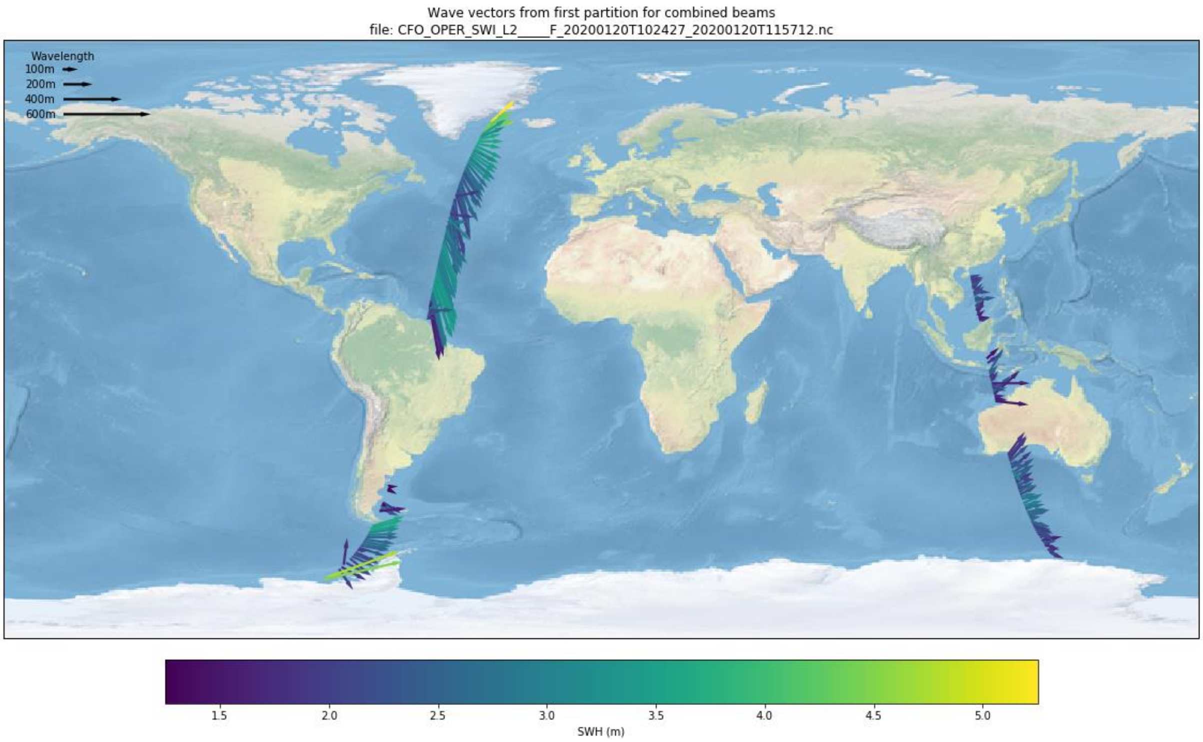
  num_part =<*0, 1, 2 or 3*>

When activated, the notebook gives the visualization of the wave parameters on a map through so called wave vectors defined as follow:

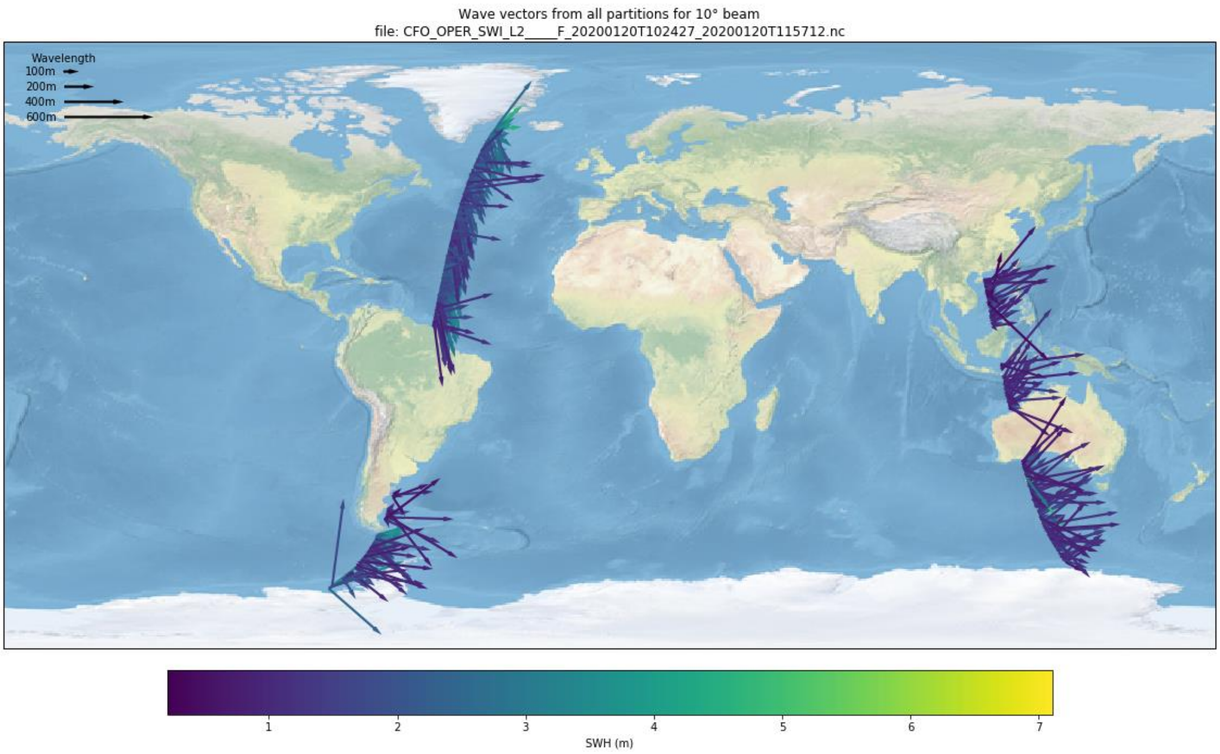
- Direction: dominant direction
- Norm: dominant wavelength (scale given in the left up part of the map)
- Colour: relative to SWH (colorbar value given below the map)

Here are given 3 examples:

1- Wave parameters of the first partition from the combined beams data :
   ⇨ beam = 0; spectrum = 1; num_part=1

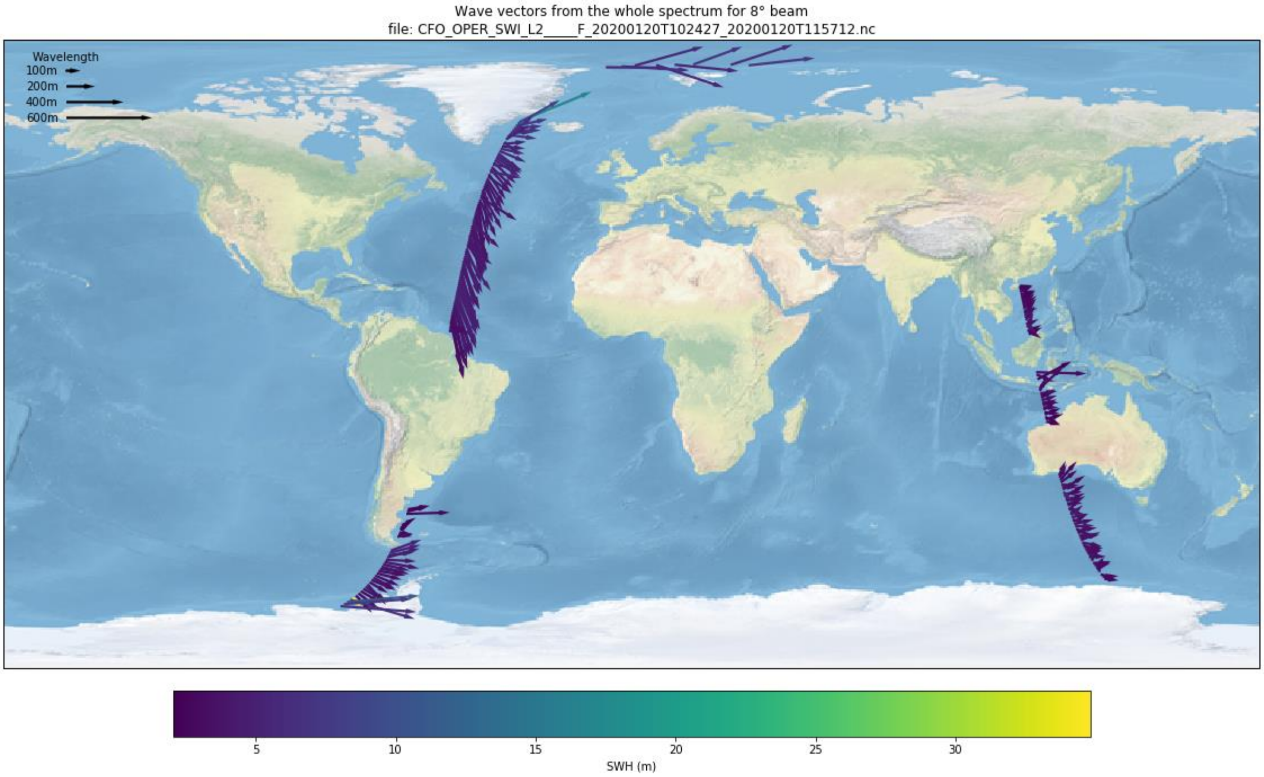


2- Wave parameters of the 3 partitions from the 10° beam data:
   ⇨ beam = 10; spectrum = 1; num_part= 0



3- Wave parameters of the whole wave slope spectrum from the 8° beam data:

⇨ beam = 8; spectrum = 0;



ANNEX 1 ADDITIONAL VARIABLES THAT CAN BE USED FOR QUALITY CONTROL

1- Free/ice-covered ocean

The wave parameters are provided over all ocean surfaces, including marginal ice zones. However, the inversion model may be invalid on ice zones and/or the data quality may be decreased due to the lower signal to noise ratio on ice, at least for the outer beams (8 and 10°).

If the user wishes to select wave data only ocean surfaces free of ice, this can be done by using the variable **sea_ice_coverage_box** or **sea_ice_coverage_combined**

sea_ice_coverage

This parameter gives the percentage of sea-ice flag raised for each spectral beam and in each box (each wave spectrum **pp_mean**). The sea-ice flag comes from the ECMWF model and is raised when sea-ice concentration given by the ECMWF model is greater than a defined threshold (0,5 in the current processing).

To filter out all boxes potentially affected by sea-ice, the user can reject data for which **sea_ice_coverage** is greater than 0%.

The dimensions of **sea_ice_coverage** are: n_posneg, n_box, n_beam_l2

- n_posneg: corresponds to side of the box
- n_box: corresponds to box sampling along track
- n_beam_l2: corresponds to spectral beam possible selection:
  - 0: 6° beam
  - 1: 8° beam
  - 2: 10 °beam

sea_ice_coverage_combined

same as sea_ice_coverage but to be used in association with the combined spectrum p_combined or the associated parameters. The dimensions of **sea_ice_coverage_combined** are reduced to n_box and n_posneg.

2- Coastal zones, small Islands

In the L1 processing, there is land flag based on a land mask provided by the ECMWF and collocated with the centre of the swath of each measurement (each cycle).

As wave spectra can only be estimated on ocean scenes, there is no estimation of the wave spectrum density at level 1b, when the land flag is raised for a given cycle and spectral beam. However, 2D wave spectra may be constructed by using the other macrocycles accumulated in a box, if these are not affected by the land flag.

The variables **land_coverage** (associated to **pp_mean**) and **land_coverage_combined** (associated to **p_combined**) indicate the percentage of cycles in the box which correspond to the cases when the land flag is raised.

If the users wants to filter out spectra (and associated parameters) which may have some directions affected by the presence of land, he can choose to reject data for which **land_coverage** (for **pp_mean** and associated parameters) or **land_coverage_combined** (for **p_combined** or associated parameters) is greater than 0%.

- Variable **land_coverage, land_coverage_combined** :
  Dimensions: n_posneg, n_box, n_beam_l2
  - n_box: corresponds to box sampling along track
  - n_posneg: corresponds to side of the box
  - n_beam_l2: corresponds to spectral beam possible selection:
    - 0: 6° beam
    - 1: 8° beam
    - 2: 10 °beam

3- Products potentially affected by rain or other non-wave related signals

Radar scenes analysed to estimate wave spectra may be affected by rain or other phenomena not related to the ocean waves. A rain flag and a "bloom" flag calculated from the nadir signal is provided in the L2 product at the rate of the cycle (nadir_rain_flag). It is propagated to the L2 products with the variables **nadir_rain_index** and nadir_sigma_bloom_index which give:

nadir_rain_index : it is the occurrence (in %) in each box of nadir flags raised for rain suspicion according to the nadir_rain_flag parameter .

The user may choose to reject wave spectra and wave parameters potentially affected by rain, by filtering out samples for which the associated **nadir_rain_index is larger than 0%.**

nadir_sigma_bloom_index : it is the occurrence (in %) in each box of nadir flags raised for bloom suspicion according to the nadir_rain_flag parameter . This flag is not yet fully validated. It is not recommended to use it for the moment

- Variable **nadir_rain_index, nadir_sigma_bloom_index** :
  Dimensions: n_posneg, n_box
  - n_posneg: corresponds to side of the box
  - n_box: corresponds to box sampling along track

4- Indicators of wave spectrum quality

A variable called snr (Signal to Noise Ratio) is provided in the L2 products to characterize the ratio between the maximum of spectral energy associated to ocean waves and the spectral energy of the background speckle noise . This estimation is provided for the direction of maximum of wave energy. The highest is the snr variable, the highest is the confidence in the retrieved 2D wave spectrum.

- Variable **snr**:
  Dimensions: n_posneg, n_box, n_beam_l2
  - n_box: corresponds to box sampling along track
  - n_posneg: corresponds to side of the box
  - n_beam_l2: corresponds to spectral beam possible selection:
    0: 6° beam
    1: 8° beam
    2: 10 °beam

• Associated to the value of the energy spectrim of the waves , two kinds of variable are provide : the number of degrees of freedom and the confidence interval

- Variables **DOF** and **DOF_combined**:

  Both give the number of degrees of freedom associated to each spectral compnent (see details in [1] **. DOF** is associated to pp_mean whereas **DOF_combined** is associated to **p_combined**

  Dimensions: n_box, n_posneg, nk, n_phi, n_beam_l2
  - n_box: corresponds to box sampling along track
  - n_posneg: corresponds to side of the box
  - nk: corresponds to the number of wavenumber in the polar spectrum
  - n_phi: corresponds to the number of directions in the polar spectrum
  - n_beam_l2: corresponds to spectral beam possible selection:
    0: 6° beam
    1: 8° beam
    2: 10 °beam

- Variables **CI_inf_dir** , **CI_sup_dir**
  Lowest and upper values of the energy density of the 2D spectrum representing the 95% confidence interval

  Dimensions: nk, n_phi, n_posneg, n_box, n_beam_l2
  - nk: corresponds to the number of wavenumber in the polar spectrum
  - n_phi: corresponds to the number of directions in the polar spectrum

- n_posneg: corresponds to side of the box
- n_box: corresponds to box sampling along track
- n_beam_l2: corresponds to spectral beam possible selection:
  - 0: 6° beam
  - 1: 8° beam
  - 2: 10 °beam

- Variables **CI_inf_omni , CI_sup_omni**

  Lowest and upper values of the energy density of the omni-directional spectrum **pp_omni** representing the 95% confidence interval;

  Dimensions: nk, n_posneg, n_box, n_beam_l2

  - nk: corresponds to the number of wavenumber in the polar spectrum
  - n_posneg: corresponds to side of the box
  - n_box: corresponds to box sampling along track
  - n_beam_l2: corresponds to spectral beam possible selection:
    - 0: 6° beam
    - 1: 8° beam
    - 2: 10 °beam

- Variables **CI_inf_omni_combined , CI_sup_omni_combined**

  Lowest and upper values of the energy density of the omni-directional spectrum **pp_omni_combined** representing the 95% confidence interval

  Dimensions: nk, n_posneg, n_box

  - nk: corresponds to the number of wavenumber in the polar spectrum
  - n_posneg: corresponds to side of the box
  - n_box: corresponds to box sampling along track