Along-track Level-2+ (L2P) Significant Wave Height (SWH) and Wind speed Sentinel-3 Product Handbook

Nomenclature: SALP-MU-S3_COP-OP-17127-CN

Issue: 1 rev 3

Date: February 2021

Chronology Issues:			
Issue:	Date:	Validated by	Reason for change:
1.0	2018/11/05		Creation of the document
1.1	2019/02/19		Taking into account RID from NRT WAVE SRR
1.2	2020/10/16		Addition of L2P Wind speed in L2P WAVE products
1.3	2021/02/22		Precision concerning the S3 L2P Wind speed (Collard based on PLRM input)
1.4	2021/03/08		Taking into account RIDs from ORR (implementation of wind speed in L2P Wind/Wave products)

List of Acronyms:

ATBD	Algorithm Theoretical Baseline Document
ATP	Along Track Product
Aviso+	Archiving, Validation and Interpretation of Satellite Oceanographic data
CLS	Collecte, Localisation, Satellites
CMA	Centre Multimissions Altimetriques
Cnes	Centre National d'Etudes Spatiales
ECMWF	European Centre for Medium-range Weather Forecasting
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GDR	Geophysical Data Record(s)
GOT	Global Ocean Tides
IB	Inverse Barometer
IGDR	Interim Geophysical Data Record(s)
LRM	Low Resolution Mode
LWE	Large Wavelength Error
L2P	Level-2+ product: global 1 Hz along-track data over marine surfaces based on Level-2 products
MSS	Mean Sea Surface
MWR	Microwave Radiometer
Nasa	National Aeronautics and Space Administration
NRT	Near Real Time
NTC	Non Time Critical
OER	Orbit Error Reduction
OSDR	Operational Sensor Data Records
POE	Precise Orbit Ephemeris
RD	Reference Document
SAR	Synthetic Aperture Radar
Ssalto	Segment Sol multimissions d'ALTimétrie, d'Orbitographie et de localisation précise.
SLA	Sea Level Anomaly
SSB	Sea State Bias
SSH	Sea Surface Height
STC	Short Time Critical
TAI	IAT - International Atomic Time
T/P	Topex/Poseidon
UTC	Universal Time Coordinated

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Applicable documents / reference documents

RD 1: Sentinel-3 Marine Altimetry L2P/L3 Service: Product Format Specification.
Reference: SALP-BC-S3_COP-OP-16778-CN

Bibliography

Abdalla, S., Ku-band radar altimeter surface wind speed algorithm, European Space Agency, (Special
Publication) ESA SP, 2007.

Collard, F., 2005, Algorithmes de vent et periode moyenne des vagues JASON a base de reseaux de neurons, BO-021-CLS-0407-RF, Boost Technologies, 33pp.

Gourrion, J., D. Vandemark, S. Bailey, B. Chapron, G. P. Gommenginger, P. G. Challenor, and M. A. Srokosz, 2002. A two-parameter wind speed algorithm for Ku-Band altimeters, J. Atmos. and Oceanic Tech., 19, 2030-2048.

Sepulveda H. H., Queffeulou P. and Ardhuin F. (2015): Assessment of SARAL AltiKa wave height measurements relative to buoy, Jason-2 and Cryosat-2 data. Marine Geodesy, 38 (S1),449-465, doi: 10.1080/01490419.2014.1000470.

Queffeulou P. (2016): Validation of Jason-3 altimeter wave height measurements (poster). OSTST meeting, November 1-4, 2016, La Rochelle, France.

Queffeulou P. and Croizé-Fillon D. (2017): Global Altimeter SWH Data Set, version 11.4, February 2017. Technical report Ifremer. ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves/documentation/altimeter_wave_merge__11.4.pdf

Ray, C., C. Martin-Puig, M. P. Clarizia, G. Ruffini, S. Dinardo, C. Gommenginger, and J. Benveniste, 2015. SAR altimeter backscattered waveform model. IEEE Trans. Geosci. Rem. Sens, 53, 911-919.

(b) Ray, C., M. Roca, C. Martin-Puig, R. Escola, and A. Garcia, 2015. Amplitude and dilation compensation of the SAR altimeter backscattered power. IEEE Geosci. Rem. Sens, Lett. 12(12), 2473-2476.

Tolman et al. (2008): Altimeter wave data, Deep ocean and coastal use and issues. First Coastal Altimetry Workshop, Silver Spring, Maryland, USA, February 5-7, 2008. http://cioss.coas.oregonstate.edu/CIOSS/workshops/Altimeter_workshop_08/Coastal_Alt_Presentations/18_Tolman_Sig_Wave_Ht.pdf

Contents

1. Introduction

The purpose of this document is to describe products generated by the 1Hz monomission along-track altimeter data processing segment for Sentinel-3A and Sentinel-3B missions, named along-track L2P Significant Wave Height (SWH) and Wind Speed products.

The generation of those products is part of the EUMETSAT Sentinel-3 Marine Altimetry L2P/L3 Service. The dissemination of those products is part of the Cnes AVISO-SALP (Service d'Altimétrie et Localisation Précise).

After a description of the input data, a short overview of the processing steps is presented. Then complete information about user products is provided, giving nomenclature, format description, and software routines.

2. Overview

2.1. ABC of the altimeter-derived SWH and wind speed measurements

The altimeter sends a spherical radar signal in the direction of the nadir. This signal is reflected by the sea surface and goes back to the satellite. The analysis of the returned signal allows the calculation of the time needed by the signal to go and come back, i.e. the distance satellite-sea surface. The sea state surface elevation distribution impacts the speed at which the return signal is fully returned to the satellite. Hence, the Significant Wave Height (SWH) over ocean surfaces is determined from the slope of the front in the radar altimeter wave form. The higher the waves, the more the returned signal is spread in time. Hence, a long delay between the first returns and a full signal return will result in a long shadow in the wave form, which then indicates a high sea state (Figure 1 and Figure 2).

The term Significant Wave Height (SWH or H_s) refers to the mean wave height of the highest third of the waves (also sometimes denoted $H_{1/3}$).

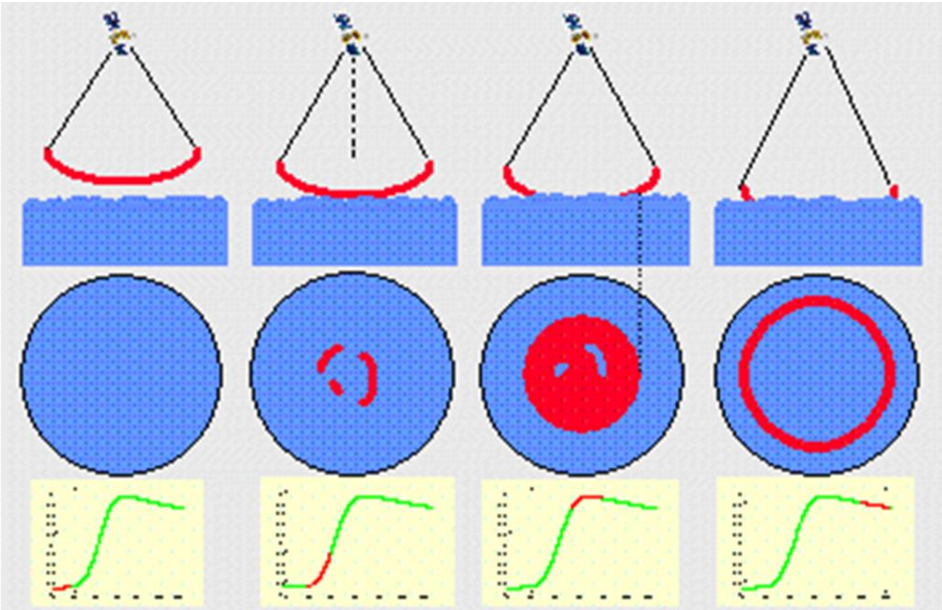


Figure 1: Formation of an echo over a sea surface with waves for conventional altimetry

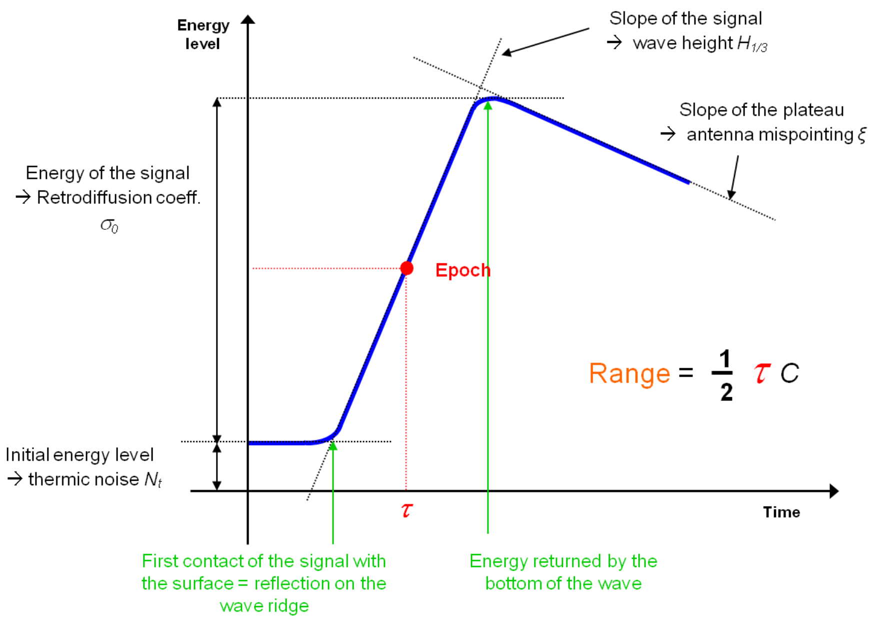


Figure 2: The altimeter waveform

Altimeter wind speeds (defined as the wind speed at a height of 10 m above the mean sea surface) are empirically retrieved by using either 1-parameter algorithm using only the backscattering coefficient (σ_0 in Figure 2) [Abdalla, 2007] or from 2-parameter algorithms using both σ0 and SWH parameters (such as Gourrion et al.[2002] or Collard [2005]).

2.2. Sentinel-3 operating mode

In the Sentinel-3 SRAL mission, there are two main modes of operation:

- High Resolution Mode, also known as Synthetic Aperture Radar mode (SAR)
- Low Resolution Mode (LRM)

The SRAL mission will normally be operated at High Resolution Mode (commonly called SAR mode). Low Resolution Mode (LRM) will be a back-up mode only.

SAR mode is designed to achieve high along-track resolution over relatively flat surfaces. This property can be exploited to increase the number of independent measurements over a given area and is a prerequisite for sea-ice thickness measurements, coastal waters, ice sheet margins, land and inland waters. The scientific justification of High Resolution Mode 100% coverage over the Earth is also applicable to open ocean surfaces because studies have shown that the best performance of this mode is over open ocean surfaces where topography is homogeneous (areas at least as large as the antenna footprint).

The detailed information can be found in Sentinel-3 User Handbook:

- Sentinel-3 SRAL Marine User Handbook (EUM/OPS-SEN3/MAN/17/920901)

Note that compared to LRM (on current altimetry missions such as SARAL/AltiKa, Envisat, Jason-1/2/3, ERS-1/2), the antenna footprint is reduced with the SAR technology and the noise on the measurement is reduced.

For altimeters operating in SAR mode (Sentinel-3), both the leading edge and the trailing edge of the waveform are affected by changes in SWH, with the SAMOSA 2.5 model using both these parts of the waveform to determine the SWH value (Ray and al. 2015, Ray and al. 2015b).

When functioning in SAR mode, Pseudo Low Resolution Mod (PLRM) estimates can be derived too. This allows to consider the backscattered radar signal in a circular footprint as in conventional altimetry (rather than within stripes in SAR mode). PLRM estimates are not provided in the L2P/L3 products, they were only used for the initial phase of the calibration process on the reference mission (details in Appendix 8.1.1.1), **except for the L2P wind speed which is computed with PLRM backscattering coefficient and PLRM significant wave height.**

2.3. Orbits, Passes and Repeat cycle

'Orbit' is one revolution around the Earth by the satellite.

A satellite **'Pass' or 'Track'** is half a revolution of the Earth by the satellite from one extreme latitude to the opposite extreme latitude. Passes with odd numbers correspond to ascending orbits, from minimum to maximum latitude; passes with even numbers correspond to descending orbits, from maximum to minimum latitude.

'Repeat Cycle' is the time period that elapses until the satellite flies over the same location again. Every "pass file" of a given cycle (identified by its track number) flies over the same path as the pass file of every other cycle in the same repeat-cycle phase, and covers oceans basins continuously.

For Sentinel-3A and Sentinel-3B:

- the inclination is 98.65 deg;
- the passes are numbered from 1 to 770 representing a full repeat cycle ground track for the repetitive orbit;
- the repeat cycle is 27 days.

2.4. Production centre description for the version covered by this document

The system's primary objective is to provide operational products of calibrated wind speed and calibrated significant wave height (SWH) data for Sentinel-3A and Sentinel-3B missions. The processing sequence can be divided into 4 main steps, illustrated in Figure 3 and described in the next Sub-sections:

- Acquisition;
- Data editing;
- Calibration; and
- Product generation.

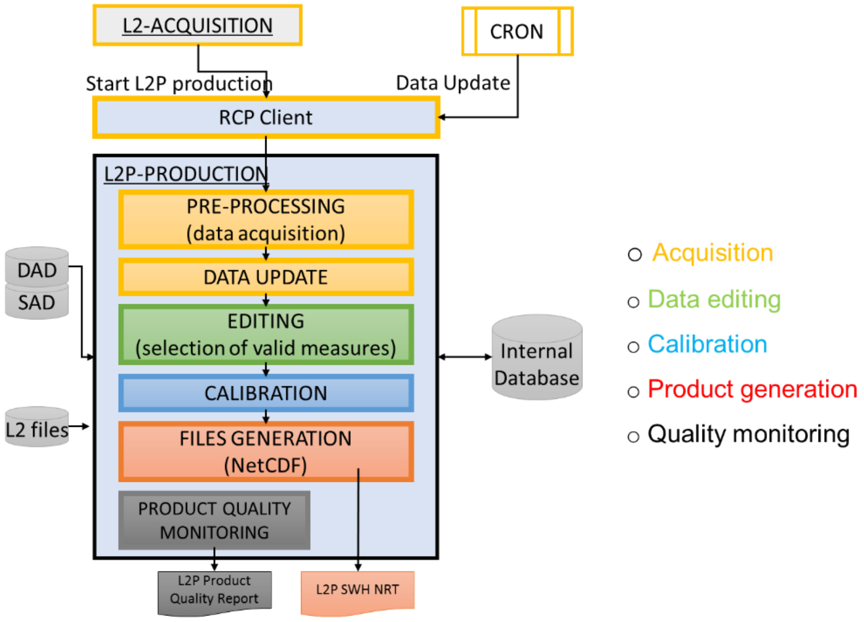


Figure 3: L2P Alti wind and waves production component

2.4.1. Acquisition

The altimeter measurements used in the system consist in Near-Real-Time (OGDR or NRT) Level 2 products from different missions. The Jason-3 mission is also taken into account as a cross calibration is performed between Jason-3 and Sentinel-3A and Jason-3 and Sentinel-3B. The data sources and delays are summarised in Table 1. Mission characteristics are presented in Table 2.

Mission	Type of product	Source	Availability delay
Sentinel-3A	NRT	EUMETSAT	~3h
Sentinel-3B	NRT	EUMETSAT	~3h
Jason-3	OGDR	EUMETSAT/NOAA	~3h

Table 1: Source, delay and period of availability of the L2 altimeter data

Mission	Cycle duration (days)	Latitude range (°N/S)	Number of tracks per cycle	Inter-track distance at equator (km)	Sun-synchronous	Technology
Sentinel-3A	27	±81.5	770	~100	Yes	SAR + PLRM
Sentinel-3B	27	±81.5	770	~100	Yes	SAR + PLRM
Jason-3	10	±66	254	~315	No	LRM

Table 2: Altimeter mission characteristics (for Sentinel-3, only SAR is used)

The acquisition processing has two main functions: acquisition and synchronization of dataflow as illustrated in Figure 4.

File acquisition

The purpose of the acquisition is to acquire new L2 files and new ancillary data (AUX files) needed to compute the products (orbit file, external corrections, etc.) for each data source.

Data synchronization

The synchronization function is synchronizing L2 data with all ancillary data (AUX files) needed to process L2P Wave data. Once the L2 data and all the associated ancillary data are available, they can be used for L2P production.

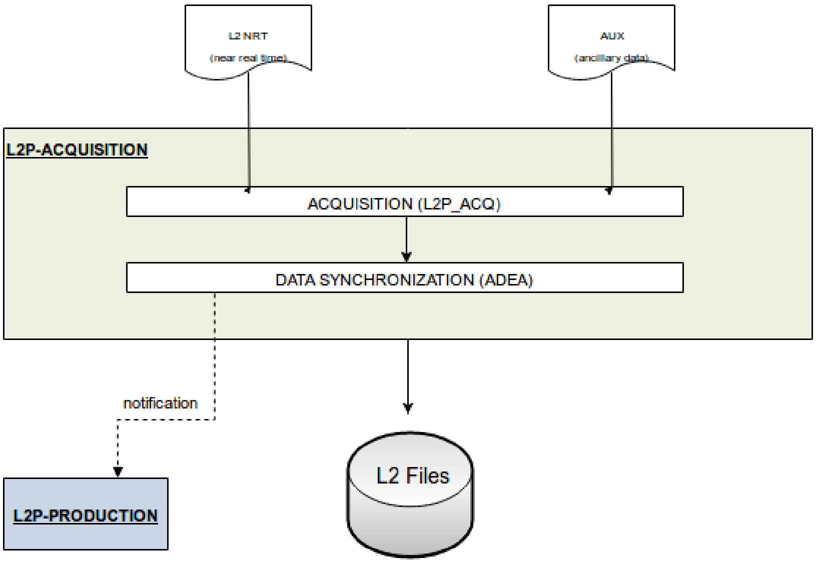


Figure 4: L2 acquisition processing

2.4.2. Data editing

2.4.2.1. Editing criteria

Quality Control on the input L2 data is a critical process applied to guarantee that the system uses only the most reliable altimeter data. The system is supplied with L2 products that contain data directly derived from altimeter measurements (e.g. range, sigma0, swh etc.) as well as geophysical data (e.g. dry and wet tropospheric correction, ionospheric correction, etc) and flags (e.g. surface type, ice presence, etc.). These values are provided at high (20 Hz for Jason-3 and Sentinel-3A & B) and low (1 Hz) frequency. Only the 1 Hz data are used in the L2P altimetry wind/wave system.

Data are selected as valid or invalid using a combination of various criteria such as quality flags and parameter thresholds (see table below**Erreur ! Source du renvoi introuvable.** for details). These criteria are adapted from the ones used for the Sea Level Anomaly (e.g. Aviso/SALP 2016). Only criteria related to retracking derived values were selected. Geophysical parameters (e.g. tropospheric corrections) do not intervene in the SWH and wind speed estimation and therefore are not used in the wind/wave products generation. Consequently, no editing criterion was set for these parameters in the L2P wind/wave chain. For Sentinel-3A and Sentinel-3B, the criteria on the off-nadir angle is not activated since this value is not derived from the retracking in SAR mode and therefore its value does not provide information about data quality. Two separate editings are performed for wind speed and SWH. Specification are mandated in the last column of the Table 3**Erreur ! Source du renvoi introuvable.**.

Parameter	Method	Jason-3	Sentinel-3A and Sentinel-3B criterion	Wind Speed/ SWH editings
Ice Flag	Flag value	Valid value: 0	Valid value: 0 or 5	Same for both

Surface type Flag	Flag value	Valid value: 0 or 1 (Caspian Sea only)	Valid value: 0 or 1 (Caspian Sea only)	Same for both
Swh [m]	Threshold	Min: 0 max: 30	Min: 0 Max: 30	WS: PLRM SWH: SAR
Sigma0 [dB]	Threshold	Min: 9.38 max: 32.38	Min: 5 Max: 28	WS: PLRM SWH: SAR
Square off-nadir angle	Threshold	Min: -0.2 max: 0.64	N/A	Same for both
Wind speed [m/s]	Threshold	Min: 0 Max: 30	Min: 0 Max: 30	WS: Collard PLRM SWH: Abdalla SAR
Orbit - range [m]	Threshold	Min: -130 Max: 100	Min: -130 Max: 100	Same for both
Sigma0 standard deviation [dB]	Threshold	Min: 0 Max: if distance to shoreline <50 km: 2.5 else: 1	Min: 0 Max: 0.7	WS: PLRM SWH: SAR
Range standard deviation [m]	Threshold	Min: 0 Max: 0.0115*swh+0.2	Min: 0 Max: 0.02*swh+0.12	WS: SWH PLRM SWH: SWH SAR
swh_numval_ku	Threshold	Min: 10	Min: 18	WS: PLRM SWH: SAR
swh_RMS_ku	Threshold	Min: 0 Max: Threshold(swh) as detailed below	Min: 0 Max: Threshold(swh) as detailed below	WS: SAR SWH: SAR

Table 3: Editing criteria

The method to compute the threshold on swh_RMS_ku is described in Queffeulou 2016. It consists in determining a threshold on the 20Hz SWH standard dispersion. Such threshold is defined as the sum of the mean value and three times the standard deviation of the gaussian fitting the ln(SWH_STD) (e-base logarithm) distribution for each SWH bin (Figure 5). The curve representing the thresholds as a function of SWH is then filtered (red line in Figure 6). Values for which 5m<SWH<9m are used to determine a linear fit used for SWH>5m. Finally the threshold on ln(SWD_STD) is converted back into a threshold on SWH_STD (Figure 7). This threshold depends on SWH and potentially on the processing baseline. It is recomputed when processing baseline evolutions impact the swh estimates.

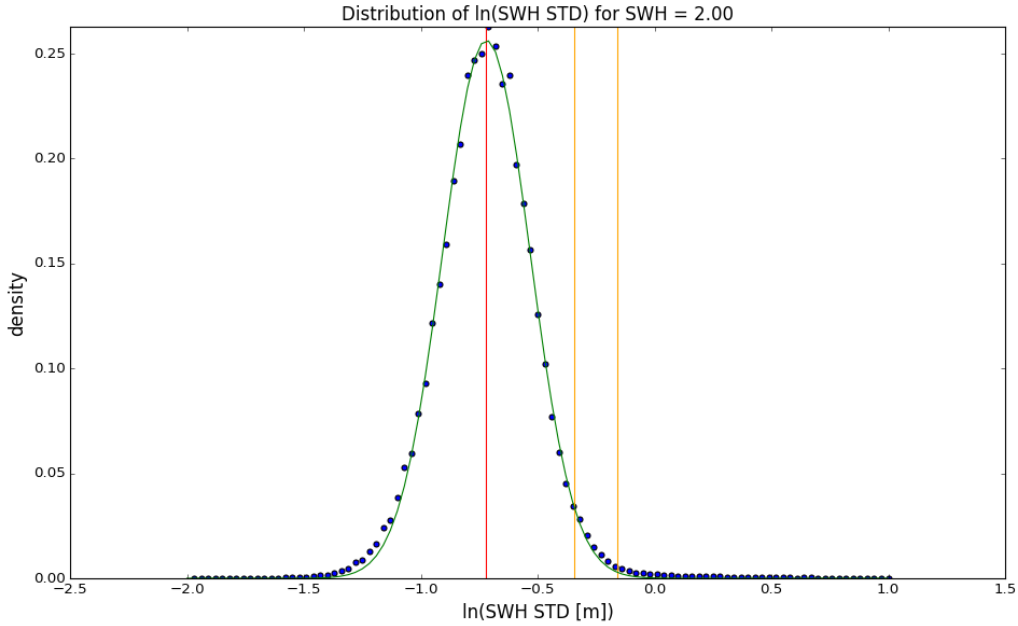


Figure 5: Distribution of ln(SWH_STD) for SWH between 2m and 2.1m (Jason-3 between 2017 july 11th and 2018 september 10th). The green line represents the gaussian fitting the distribution. The red line is the fitting gaussian mean, the orange lines represent mean + 2sigma and mean + 3 sigma.

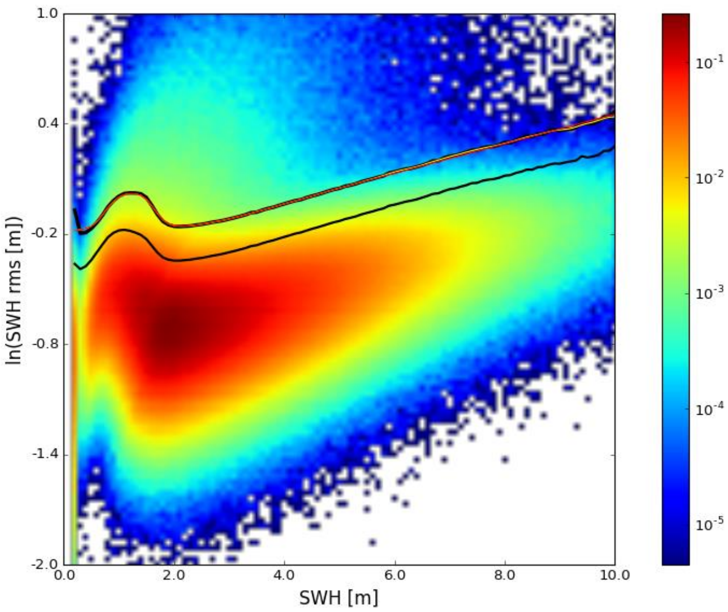


Figure 6: Density plot of SWH / ln(SWH_STD). The colour scales logarithmically. The black lines represent the mean+2sigma and mean +3sigma, computed for each swh bin as described in Figure 5. The red line represents the smoothed mean+3sigma curve for SWH<5m and consists in an affine function at higher SWH values.

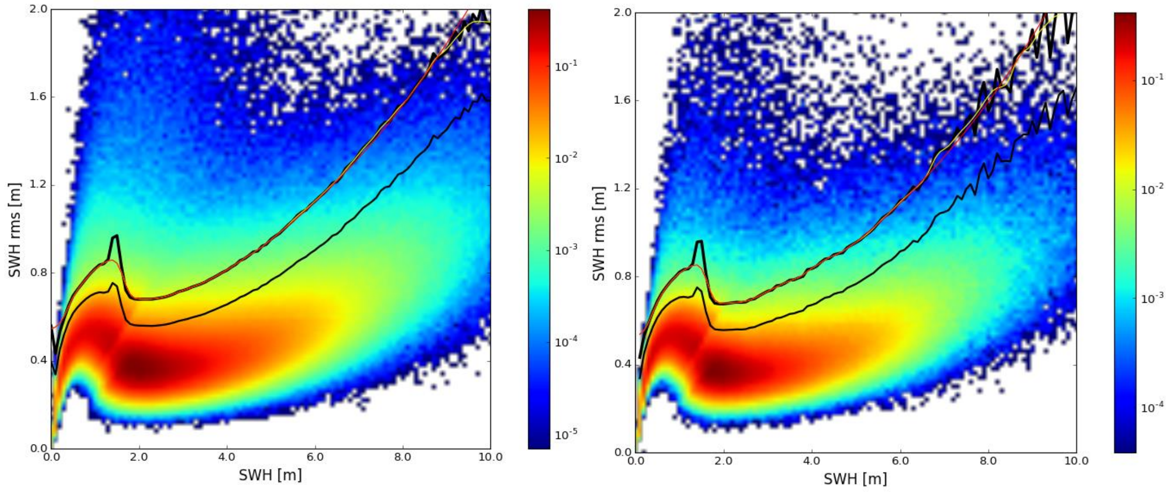


Figure 7: Density plots and computed thresholds. Left: S3A (2018 january 1st to 2018 november 6th to only account for data derived from L2 Baseline Collection 003 processing), Right: S3B (28 days of data between 2018 july 19th and 2018 october 1st). Density scales logarithmically.

2.4.3. Wind speed computation

Actually, Sentinel-3 wind speed estimations in L2 products are computed with the 1D Abdalla's model [Abdalla, 2007] following the Envisat strategy whereas all missions in the Jason series (from Jason-1 to Sentinel-6/Jason-CS) use the 2D Collard's model [Collard, 2005; Gourrion et al, 2002]. As reported by Tolman in his 2008 presentation [Tolman et al, 2008], the 2D model version better reduces the wave field impact in the altimeter retrieved wind speed (see Figure 8 which copied his slide) than the 1D version. For the Sentinel-3 L2P product, the wind speed estimations are updated to be in-line with Sentinel-6 choice.

Therefore, the L2P wind speed estimations come now from the Collard's model using PLRM input. Details are provided in appendix.

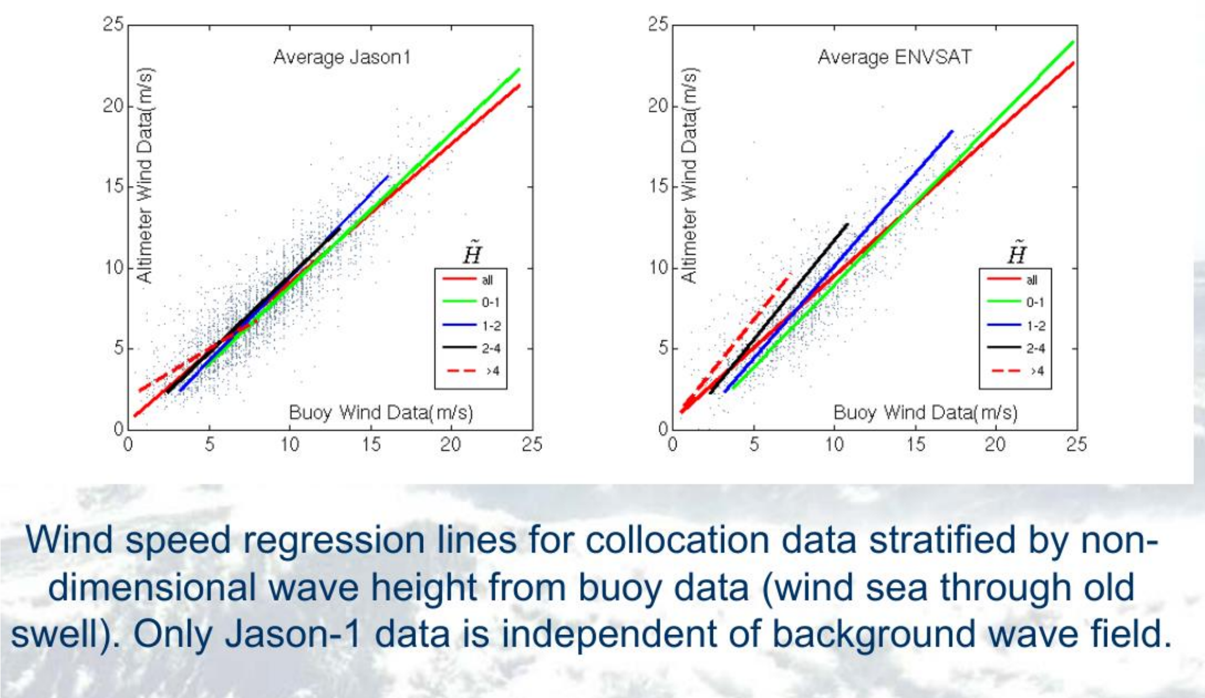


Figure 8: From Tolman et al, 2008.

2.4.4. SWH and wind speed Calibration

Calibration is divided in two main steps (see Figure 9): cross-calibration on the reference mission and absolute calibration on in-situ data. The first step consists in homogenising the data from the different missions. Significant wave height and wind speed measurements of every single mission are calibrated on those of a reference mission (Jason-3). The second step consists in applying a correction computed between the reference mission and in-situ measurements provided by buoys. The second step is only performed for SWH calibration.

Finally, another calibration step can be added in the process when L2 upstream products evolve for a mission already implemented in the L2P altimetry wave chain (see Figure 9, L2 version upgrade in yellow). A new calibration for the physical variables of interest is determined between the current and the upcoming L2 version and is added to the existing calibration of this mission in the L2P altimetry wave chain.

The next sub-sections describe the computation of the two main calibrations: cross-calibration and absolute calibration.

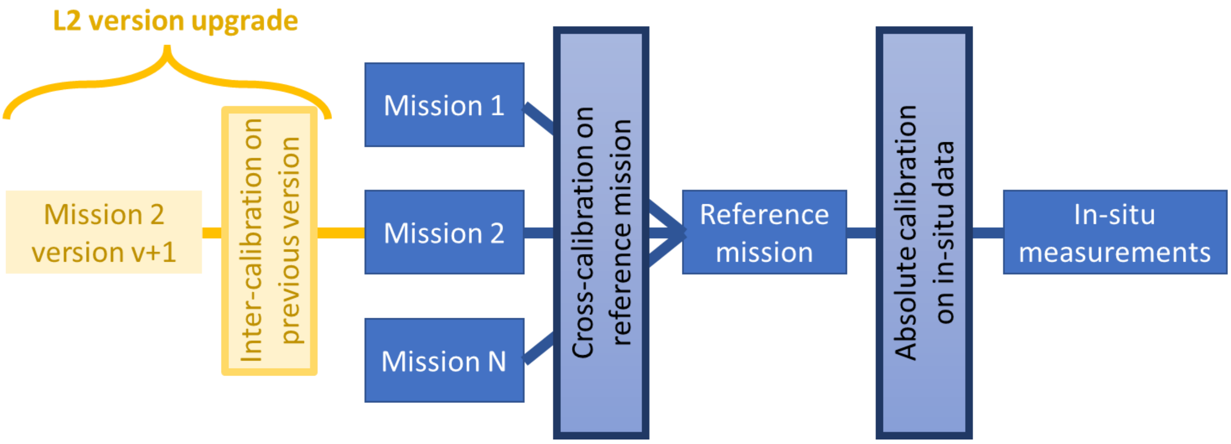


Figure 9: Description of the calibration process

2.4.4.1. Cross-calibration

Cross-calibration consists in determining the relation between the significant wave height or wind speed measurements provided by two different missions. This relation is determined on a representative number of collocated measurements and then used in the operational system to homogenise the missions with respect to the reference one. Such a relation is expected to remain valid as long as instrumental drifts are not detected or ground segment evolutions do not affect the L2 products in input of the operational system. Should one of these evolve, another cross-calibration relation should be computed and implemented into the operational system.

Jason-3 is used as the reference mission as it is a conventional altimeter mission, expected to show robust results for SWH and wind speed measurements.

Two different methods of collocation can be considered, depending on the orbit of the mission to be calibrated with respect to the orbit of the reference mission.

The first one is applied during the “tandem phase”, if it exists, between two missions: both satellites are on the same orbit separated by a few minutes. A very large number of spatially collocated measurements are therefore available for cross-calibration.

The second method is employed when the two missions are on different orbits or no validation phase is available. Crossover points between the two orbits are determined. For SWH measurements calibration, only crossover points with a time difference lower than 3 hours are considered. This short delay ensures that both missions observe a scene that did not significantly evolve (when a longer dataset archive is available, this time difference can be lowered to 1 hour). The 1 Hz along track data for each mission is then interpolated at the selected crossover points. The interpolation technique consists in spline approximation and accounts for the average noise associated with SWH measurements: 12 cm rms for Jason-3 and 9 cm rms for Sentinel-3A and Sentinel-3B. Such values correspond to the uncertainty on the 1 Hz significant wave height values computed from the high frequency values (20 Hz).

Once the two missions’ measurements are collocated, the differences between the reference mission and the secondary mission significant wave heights are computed. The bias is plotted as a function of the secondary mission wave height in order to provide a height-dependent bias correction. The next step consists in fitting a polynomial function to the distribution of this bias. This function is stored in an abacus file used as an input in the L2P wind and waves processing chain.

2.4.4.2. Absolute calibration

Once inter-mission biases are removed, using the cross-calibration corrections described in the previous section, an absolute calibration correction is applied to all missions. This absolute calibration aims at correcting the biases between in-situ measurements and satellite altimetry. All the missions are cross-calibrated on the reference mission Jason-3. Therefore, the absolute calibration is computed from the comparison of Jason-3 significant wave heights to buoy measurements at collocated points. This absolute calibration is not performed for wind speed variable.

Details on the calibration relations are provided in appendix.

3. Product Presentation

3.1. Temporal availability

Mission	Begin date	End date	Characteristics
NRT Sentinel-3A	21-02-2019	Ongoing	27-day cycles
NRT Sentinel-3B	21-02-2019	Ongoing	27-day cycles

Table 4. Temporal availability of LP2 Sentinel-3A and Sentinel-3B products.

3.2. Nomenclature

This is the generic model of L2P filename is:

**global_swh_l2p_<data_type>_<mission>_<cycle>_<pass>_<begin_date>_
<end_date>_<production_date>.nc**

The L2P products name components are:

- The type of data (nrt): <data_type>
- The mission (s3a/s3b): <mission>
- The cycle/pass considered: <cycle>_<pass>
- The begin and end dates of the data: <begin_date>_<end_date>
- The production date: <production_date>

This is a filename example:
global_swh_l2p_nrt_s3a_C0036_P0664_20181010T035011_20181010T035634_20181010T120644.nc

4. Data Format

This chapter presents the data storage format and convention used for S3 L2P Wind and Waves products. All products are distributed in NetCDF-4 with norm CF.

NetCDF (Network Common Data Form) is an open source, generic and multi-platform format developed by Unidata. An exhaustive presentation of NetCDF and additional conventions is available on the following web site:

http://www.unidata.ucar.edu/packages/netcdf/index.html.

All basic NetCDF conventions are applied to files.

Additionally the files are based on the attribute data tags defined by the Cooperative Ocean/Atmopshere Reasearch Data Service (COARDS) and Climate Forecast (CF) metadata conventions. The CF convention generalises and extends the COARDS convention but relaxes the COARDS constraints on dimension and order and specifies methods for reducing the size of datasets. A wide range of software is available to write or read NetCDf/CF files. API made available by UNIDATA (http://www.unidata.ucar.edu/software/netcdf):

- C/C++/Fortran
- Java
- MATLAB, Objective-C, Perl, Python, R, Ruby, Tcl/Tk.

4.1. L2P Wave Product Format

4.1.1. Dimensions

1 Dimension is defined:

- **time:** number of data in current file, sampled at 1Hz.

4.1.2. Data Handling Variables

You will find hereafter the definitions of the variables defined in the product:

Name of variable	Type	Content	Unit
time	double	Time of measurements	seconds since 2000-01-01 00:00:00 UTC
latitude	int	Latitude value of measurements	degrees_north
longitude	int	Longitude value of measurements	degrees_east
swh	short	Significant Wave Hight	meters
validation_flag	byte	Flag indicating if Significant Wave Height is valid (validation_flag=0) or not (validation_flag=1)	none
applied_bias	short	Significant Wave Height bias correction on main altimeter frequency band	meters
wind_speed	short	L2P wind speed	meters per second
applied_change_on_wind_speed	int	Difference between L2 and L2P wind speed	meters per second
validation_flag_wind	byte	Flag indicating if wind speed is valid (validation_flag=0) or not (validation_flag=1)	none
sigma0	short	backscattering coefficient used for wind speed computation	dB

Table 5. Overview of data handling variables in L2P Wind/Wave NetCDF file.

The mapping between variables of L2 products and variables of L2P products is available in Table 6.

4.1.2.1. Attributes

Additional attributes may be available in L2P Wave files. They are providing information about the type of product or the processing and parameter used.

4.1.2.2. Example of L2P Wave/Wind file

```
netcdf
global_swh_l2p_nrt_s3a_C0069_P0357_20210308T091139_20210308T095834_20210308T133121 {
dimensions:
        time = 2642 ;
variables:
        double time(time) ;
                time:long_name = "time (sec. since 2000-01-01)" ;
                time:standard_name = "time" ;
                time:units = "seconds since 2000-01-01 00:00:00.0" ;
                time:calendar = "gregorian" ;
                time:axis = "T" ;
        int latitude(time) ;
                latitude:scale_factor = 1.e-06 ;
                latitude:valid_min = -90000000 ;
                latitude:comments = "Positive latitude is North latitude, negative latitude is South
latitude." ;
                latitude:long_name = "latitude" ;
                latitude:standard_name = "latitude" ;
                latitude:units = "degrees_north" ;
                latitude:valid_max = 90000000 ;
        int longitude(time) ;
                longitude:scale_factor = 1.e-06 ;
                longitude:valid_min = 0 ;
                longitude:comments = "East longitude relative to Greenwich meridian" ;
                longitude:long_name = "longitude" ;
                longitude:standard_name = "longitude" ;
                longitude:units = "degrees_east" ;
                longitude:valid_max = 360000000 ;
        short swh(time) ;
                swh:_FillValue = -32767s ;
                swh:quality_flag = "validation_flag" ;
                swh:comment = "Bias corrected. Calibration relative to buoys [Sepulveda et al, 2015].
Initial L2 swh values can be recomputed using swh + applied_bias." ;
                swh:scale_factor = 0.001 ;
                swh:valid_min = 0s ;
                swh:coordinates = "longitude latitude" ;
                swh:long_name = "Significant Wave Height on main altimeter frequency band" ;
                swh:standard_name = "sea_surface_wave_significant_height" ;
                swh:units = "m" ;
                swh:valid_max = 32767s ;
        short applied_bias(time) ;
                applied_bias:_FillValue = -32767s ;
                applied_bias:comment = "bias correction for calibration relative to the reference
mission and buoys [Sepulveda et al, 2015]. This bias is already taken into account in the swh variable."
;
                applied_bias:scale_factor = 0.001 ;
                applied_bias:coordinates = "longitude latitude" ;
                applied_bias:long_name = "Significant Wave Height bias correction on main altimeter
frequency band" ;
                applied_bias:valid_min = -30000s ;
                applied_bias:units = "m" ;
                applied_bias:valid_max = 30000s ;
        short wind_speed(time) ;
                wind_speed:_FillValue = -32767s ;
```

```
		wind_speed:quality_flag = "validation_flag_wind" ;
		wind_speed:comment = "L2P wind speed." ;
		wind_speed:scale_factor = 0.001 ;
		wind_speed:valid_min = 0s ;
		wind_speed:coordinates = "longitude latitude" ;
		wind_speed:long_name = "Equivalent 10-m wind speed derived from altimeter measurements" ;
		wind_speed:standard_name = "wind_speed" ;
		wind_speed:units = "m s-1" ;
		wind_speed:valid_max = 32767s ;
	byte validation_flag(time) ;
		validation_flag:_FillValue = -127b ;
		validation_flag:flag_meanings = "valid_data_over_ocean rejected_data" ;
		validation_flag:long_name = "validation flag" ;
		validation_flag:coordinates = "longitude latitude" ;
		validation_flag:flag_values = 0b, 1b ;
	byte validation_flag_wind(time) ;
		validation_flag_wind:_FillValue = -127b ;
		validation_flag_wind:flag_meanings = "valid_data_over_ocean rejected_data" ;
		validation_flag_wind:long_name = "validation flag wind" ;
		validation_flag_wind:coordinates = "longitude latitude" ;
		validation_flag_wind:flag_values = 0b, 1b ;
	short sigma0(time) ;
		sigma0:_FillValue = -32767s ;
		sigma0:comment = "backscatter coefficient used for wind speed computation." ;
		sigma0:scale_factor = 0.01 ;
		sigma0:valid_min = 0s ;
		sigma0:coordinates = "longitude latitude" ;
		sigma0:long_name = "backscatter coefficient" ;
		sigma0:standard_name = "surface_backwards_scattering_coefficient_of_radar_wave" ;
		sigma0:units = "dB" ;
		sigma0:valid_max = 32767s ;
	int applied_change_on_wind_speed(time) ;
		applied_change_on_wind_speed:_FillValue = -2147483647 ;
		applied_change_on_wind_speed:comment = "Initial L2 wind speed values can be recomputed using wind_speed + applied_change_on_wind_speed." ;
		applied_change_on_wind_speed:scale_factor = 0.001 ;
		applied_change_on_wind_speed:coordinates = "longitude latitude" ;
		applied_change_on_wind_speed:long_name = "Difference between L2 and L2P wind speed" ;
		applied_change_on_wind_speed:valid_min = -30000 ;
		applied_change_on_wind_speed:units = "m s-1" ;
		applied_change_on_wind_speed:valid_max = 30000 ;

// global attributes:
		:Conventions = "CF-1.6" ;
		:cycle_number = 69 ;
		:pass_number = 357 ;
		:absolute_pass_number = 52717 ;
		:first_meas_time = "2021-03-08 09:11:39" ;
		:last_meas_time = "2021-03-08 09:58:34" ;
		:comment = "Significant Wave Height and Wind Speed measured by altimetry" ;
		:creator_email = "aviso@altimetry.fr" ;
		:cdm_data_type = "swath" ;
		:references = "https://aviso.altimetry.fr" ;
		:platform = "Sentinel-3A" ;
		:Metadata_Conventions = "Unidata Dataset Discovery v1.0" ;
```

```
		:keywords = "Oceans > Ocean Topography > Significant Wave Height, Oceans > Ocean Winds > Surface Winds" ;
		:institution = "CLS, CNES, EUMETSAT" ;
		:creator_name = "AVISO" ;
		:license = "https://www.aviso.altimetry.fr/fileadmin/documents/data/License_Aviso.pdf" ;
		:title = "NRT Sentinel-3A Global Ocean Along track significant wave height and wind speed L2P product" ;
		:standard_name_vocabulary = "NetCDF Climate and Forecast (CF) Metadata Convention Standard Name Table v37" ;
		:project = "EUMETSAT Sentinel-3 L2P/L3 marine altimetry service" ;
		:keywords_vocabulary = "NetCDF COARDS Climate and Forecast Standard Names" ;
		:contact = "aviso@altimetry.fr" ;
		:source = "Sentinel-3A measurements" ;
		:based_on = "Sentinel-3A NRT" ;
		:creator_url = "https://aviso.altimetry.fr" ;
		:processing_level = "L2P" ;
		:equator_time = "2021-03-08T09:33:22.174000" ;
		:equator_longitude = 186.7 ;
		:creation_date = "2021-03-08T13:31:21" ;
		:product_version = "2_0" ;
		:software_version = "L2PRT_SWH: 3.6.2; OCTANT: 13.3.0-20200605" ;
		:applied_bias_on_L2_sigma0 = "2.85" ;
}
```

4.2. Mapping between L2 and L2P variables

Hereafter the mapping between variables of L2 and L2P products is listed (in the case that L2P product contain the same content as L2 products):

Name of L2P variable	Name of L2 variable	Comment
time	time_01	
latitude	lat_01	
longitude	lon_01	
swh		Note that in the L2P the provided swh value is based on L2 variable swh_ocean_01_ku , but calibrated on buoys
validation_flag		
applied_bias		Adding this value to swh allows recovering the original L2 swh value
wind_speed		The L2P wind speed is recomputed using the Gourrion algorithm with the Collard table with PLRM Sigma0 (+ bias) and SWH input. It is than cross-calibrated on the reference mission wind speed.
applied_change_on_wind_speed		Difference between L2 (wind_speed_alt_01_ku) and L2P wind speed
validation_flag_wind		
sigma0		Backscattering coefficient used for the wind speed computation. It corresponds to L2

		(sig0_ocean_01_plrm_ku), but with a bias applied (2.85 dB for S3A and 2.80 dB for S3B)

Table 6. Mapping between variables in L2 and L2P files

5. Products accessibility

The Sentinel-3A and Sentinel-3B L2P products are available via **authenticated** servers.

- On authenticated **Aviso+ FTP (online products)**:
    - You first need to register via the Aviso+ web portal and sign the License Agreement: http://www.aviso.altimetry.fr/en/en/data/data-access/registration-form.html. and select the product **"Wave Along-track Level-2+ (L2P) Sentinel-3"**

  The information to access the data will be sent by email.

    - Once you are registered, the access to the products is given in your personal MY AVISO+ account in the 'product page' available on:

      https://www.aviso.altimetry.fr/no_cache/en/my-aviso-plus.html

- On the authenticated **Aviso+ CNES Data Center (archived products)**:

  Register and download on https://aviso-data-center.cnes.fr/

Citation:

Please refer to the licence agreement to mention credits explicitly in function of your use (section 13. Licence specific to Sentinel-3 L2P products).

6. News, updates and reprocessing

6.1. Operational news

To be kept informed about events occurring on the satellites and on the potential services interruption, see the [Duacs] operational news on the Aviso+ website:

http://www.aviso.altimetry.fr/en/data/operational-news/index.html.

6.2. Updates and reprocessing

Information about updates and reprocessing are described in

https://www.aviso.altimetry.fr/en/data/product-information/updates-and-reprocessing/monomission-data-updates.html

7. Contacts

For more information, please contact:

Aviso+ User Services
CLS
11 rue Hermès
Parc Technologique du canal
F-31520 Ramonville Cedex
France
Tél: (+33) (0) 561 394 780
Fax: (+33) (0) 561 393 782
E-mail: aviso@altimetry.fr
On Internet: https://www.aviso.altimetry.fr/

The user service is also interested in user feedbacks; questions, comments, proposals, requests are much welcome.

8. Appendix

8.1. SWH Calibration information

8.1.1. Intercalibration phase

8.1.1.1. Sentinel-3A SAR cross-calibration with Jason-3

Sentinel-3A crossover points with Jason-3 were computed on a 138-day period (November 23th, 2016 to April 9th, 2017). The starting date corresponds to the beginning of the production of Sentinel-3A product with the Samosa 2.3 ocean retracking used to determine the wave height from the waveform. Figure 10 presents the spatial distribution of the valid crossover points after editing. The number of points is larger at high latitudes in the southern hemisphere, allowing sampling higher waves associated with extra-tropical storms.

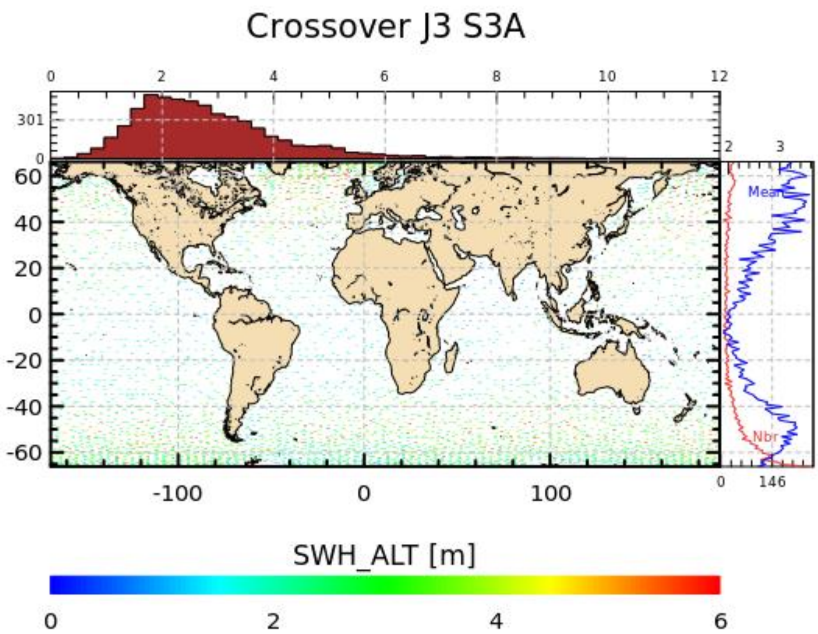


Figure 10: Spatial distribution of Sentinel-3A and Jason-3 crossover points. Only valid points after editing are displayed. Top: histogram of the selected points. Right: Number of points and mean SWH valid values as a function of latitude.

The representativeness of the crossover points with respect to the ensemble of valid along-track points is checked by comparing the Jason-3 SWH distribution for the two ensembles of points (Figure 11). The distribution at the crossover points is skewed towards larger SWH values due to the larger density of crossover points at high latitudes where the mean SWH is larger than in the inter-tropical band. Despite these distribution differences, crossover points sample all range of significant wave height values from 0.5 to 6 m. Outside this interval, the population in each bin of 10-cm width is smaller than 10 points and the cross-calibration fit is likely to be less reliable.

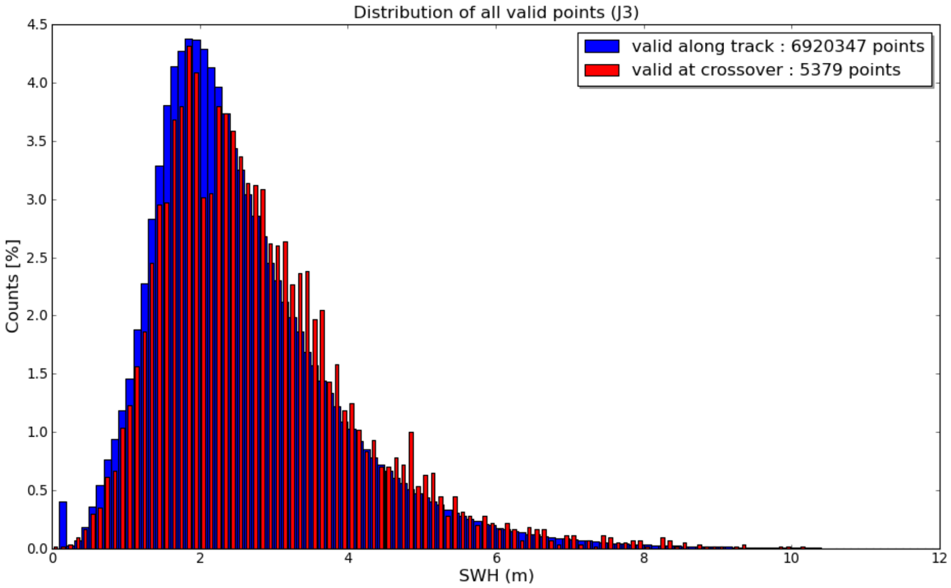


Figure 11: Valid Jason-3 points distribution over the cross-calibration period with S3-A

First, we compute the linear fit between S3-A PLRM and J3 measured wave heights at crossover points (Figure 12). Although the dispersion remains important due to the poor statistics at large SWH values, the mean bias is of the order of +/-3 cm. Both fits on the [0-6 m] or [0-12 m] ranges (orange and green curves respectively) are in good agreement. We select the linear correction function computed over the [0-6 m] range, where most of the wave population lies:

$$Corr(S3A_{PLRM}/J3) = 0.0265\ H - 0.109$$

Equation 1: Linear correction for cross-calibration of S3A PLRM and J3 LRM significant wave height

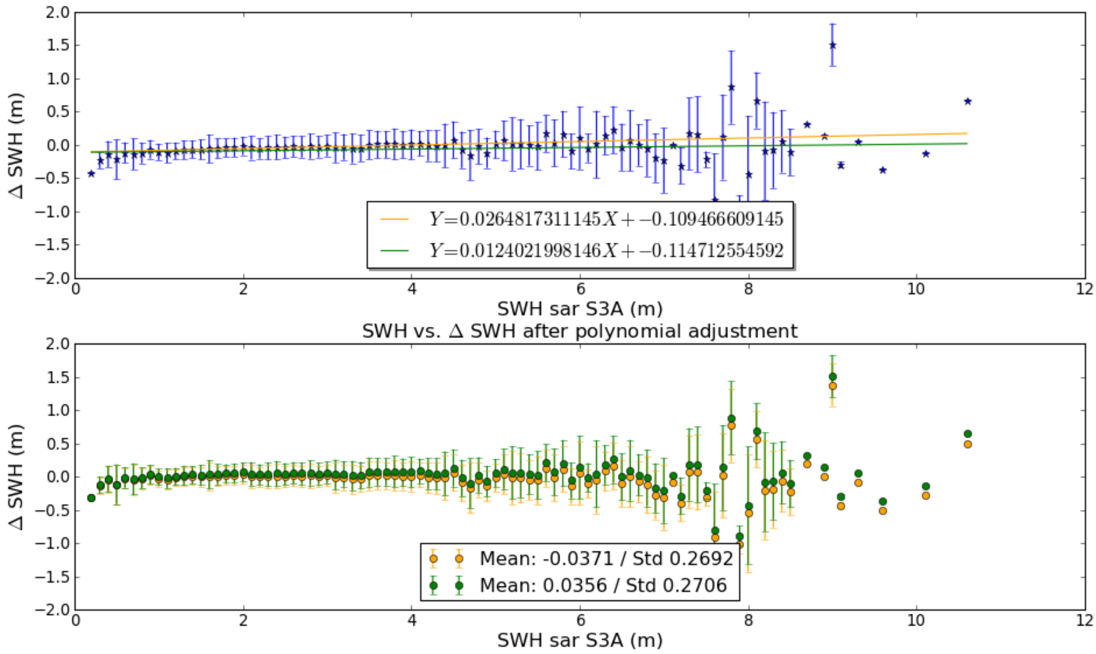


Figure 12: Top: Median of the difference between S3-A PLRM and J3 SWH values per 10 cm bin. Error bars represent the standard deviation of the difference inside each bin. The orange and green curves represent respectively the linear fits over the [0-6 m] and [0-12 m] ranges. Bottom: Residuals between the median and the fits. The mean bias is of the order of 3 cm.

Secondly, using the simultaneously valid PLRM and SAR S3-A measurements over the same period (about 7 million points), the SAR vs PLRM bias fitting function can therefore be accurately computed for wave heights larger than 6 m (Figure 13). Regarding the wave heights larger than 12 m, not enough measurements are available to correctly compute the fitting function. We also discard wave heights smaller than 1 m, as they present a behaviour different from the rest of the distribution. Therefore, the cross-calibration correction for S3A SAR vs PLRM is computed over the [1-12 m] range and is assumed to remain constant and is extrapolated for values outside this range:

$$Corr(S3A_{SAR}/S3A_{PLRM}) = -0.0105\ H^2 + 0.122\ H - 0.0225$$

Equation 2: 2nd-order correction for cross-calibration of S3A SAR and PLRM significant wave height

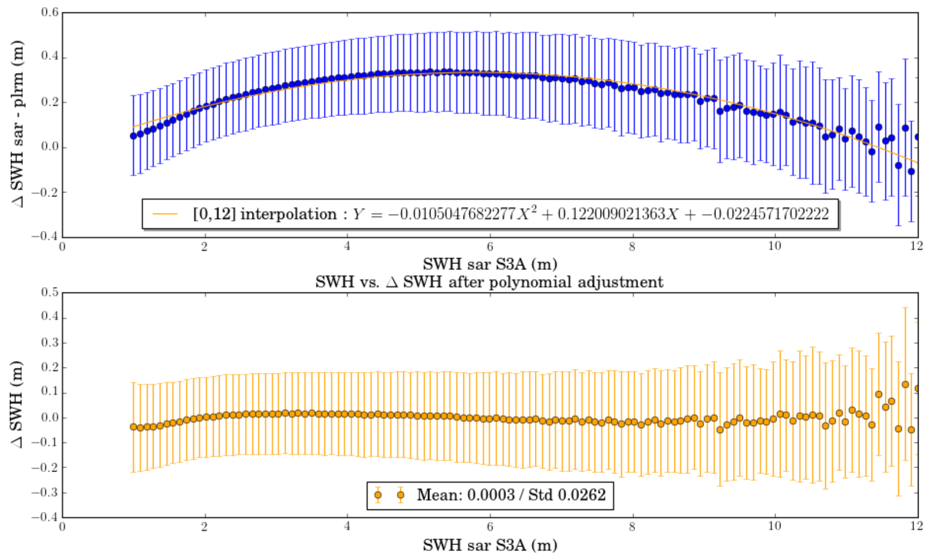


Figure 13: Top: Median of the difference between S3-A SAR and PLRM SWH values per 10 cm bin. Error bars represent the standard deviation of the difference inside each bin. The orange curve represents the second order fitting polynomial. Bottom: Residuals between the median and the fit. The mean over the [1-12 m] range shows that the residuals are unbiased. The dispersion is of the order of 3 cm.

Finally, combining the S3-A SAR vs PLRM and S3-A PLRM vs J3 bias corrections, a global fitting function allows to cross-calibrate S3-A SAR on J3 SWH.

The ‘L2 version upgrade’ module presented in Figure 9 allows to account for L2 products evolutions that would affect the calibration (e.g. L2 retracking algorithm evolution). Since the Sentinel-3A / Jason-3 intercalibration was performed using Sentinel-3A L2 data (IPF 6.07, baseline collection 002) generated with the Samosa 2.3 retracking, the intercalibration abaque has been updated to account for Samosa update in the version of the Sentinel-3A L2 production chain (IPF 6.10, baseline collection 003) operated at EUMETSAT since December 13th, 2017. The 6.10 version presents a modification in the SAMOSA retracking with respect to v6.07, impacting the SAR significant wave height. Consequently, the calibration correction embedded in the wave chain was updated to account for this IPF version change.

Valid SWH values from both IPF versions were compared during a 20-day period. As all points from IPF v6.10 and IPF v6.07 are collocated, a 20-day period is long enough to perform the cross-calibration. The significant wave height bias between the two L2 versions is presented on Figure 14. A second-order polynomial function is fitted to this bias and added to the existing Sentinel-3A calibration correction abaque as described in Figure 9.

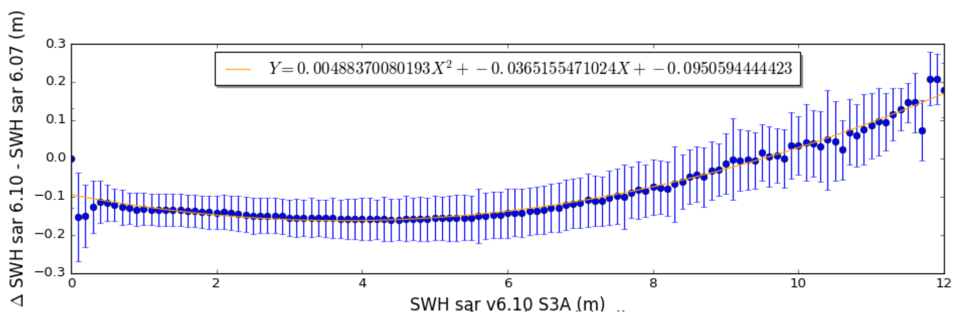


Figure 14: Differences between the IPF versions v6.10 and v6.07 of L2 S3A SAR significant wave height before polynomial adjustment

8.1.1.2. Sentinel-3B SAR cross-calibration with Jason-3

A comparison between Sentinel-3B and Sentinel-3A significant wave heights was performed over the tandem phase of the two satellites. This was done over 13 days in S3B cycle 13 in which both SRAL instruments were using the close loop acquisition mode. This corresponds to the planned operational behavior over oceanic surfaces.

The significant wave height differences between Sentinel-3B and Sentinel-3A are represented as a function of Sentinel-3B swh values in Figure 15Figure 12. The fitting curve is combined with the S3A to J3 intercalibration formula and stored in an abacus to be used in the processing chain.

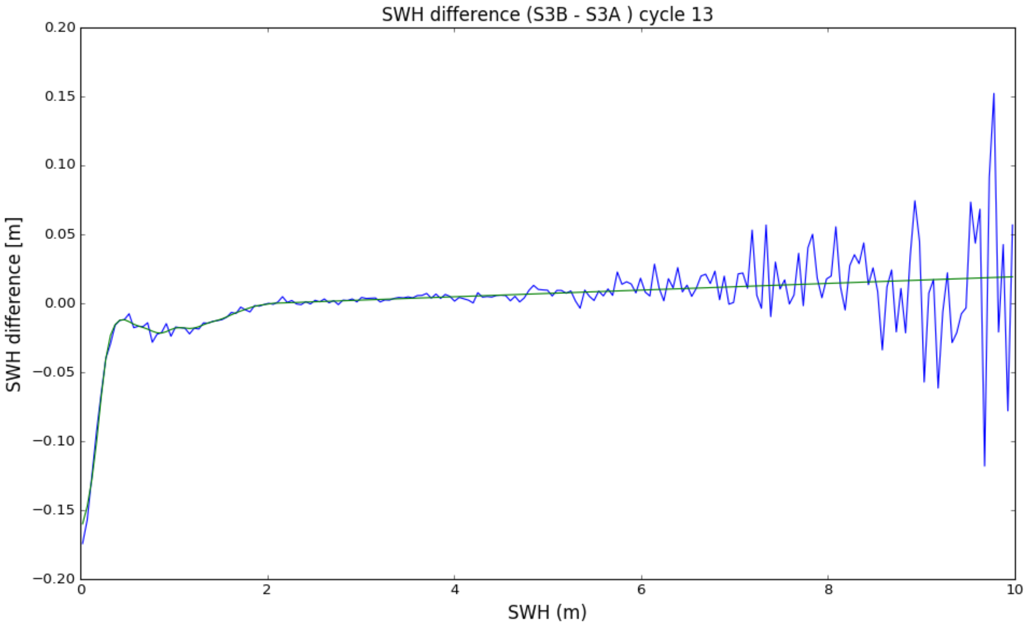


Figure 15: SWH difference as a function of S3B SWH values. The green curve represents the fitting formula.

8.1.2. Absolute calibration

Once inter-mission biases are removed, using the cross-calibration corrections described in the previous section, an absolute calibration correction is applied to all missions. This absolute calibration aims at correcting the biases between in-situ measurements and satellite altimetry. All the missions are cross-calibrated on the reference mission Jason-3. Therefore, the absolute calibration is computed from the comparison of Jason-3 significant wave heights to buoy measurements at collocated points.

According to results from Queffeulou [2016], performances for Jason-3 are very similar to those given by Jason-2 and can thus be applied to compensate for systematic errors. The linear correction is given below [Queffeulou and Croizé-Fillon 2017]:

$$Corr(J2/buoys) = -1.0149H + 0.0277$$

Equation 3: Linear correction for absolute calibration of Jason-2 SWH with respect to buoy measurements

Comparisons between Jason-3 and Jason-2 along-track 1 Hz collocated measurements during Jason-3 commissioning (same track, 80 s difference between the two altimeters), were performed to compare sea state sensed by the two altimeters at the same geographical location (**Figure 16**). The left plot shows 1 Hz collocated SWH for Jason-3 and Jason-2, which show remarkable agreement. The regression line is very close to the unity. The bias is less than 2 mm and the RMSD is about 19 cm. The right plot shows a symmetrical distribution of the SWH RMS which indicates similar precisions.

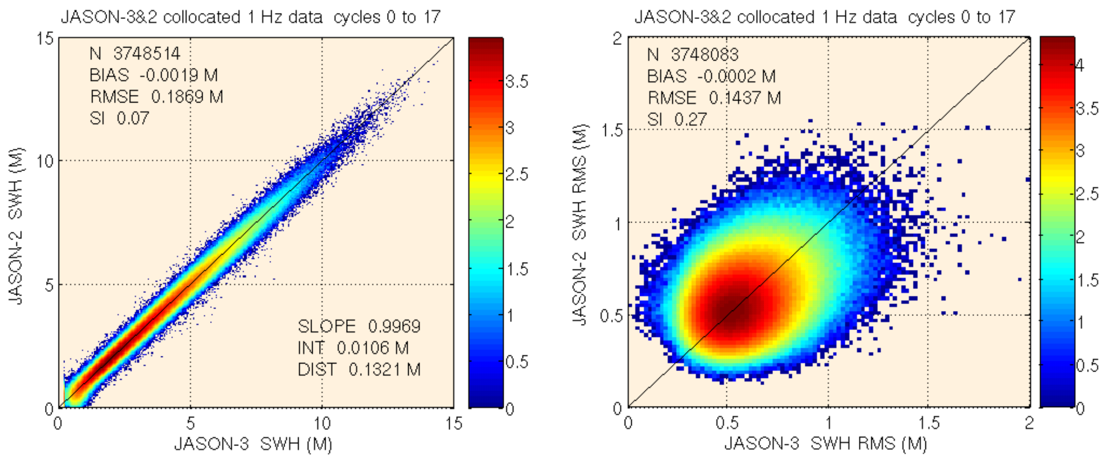
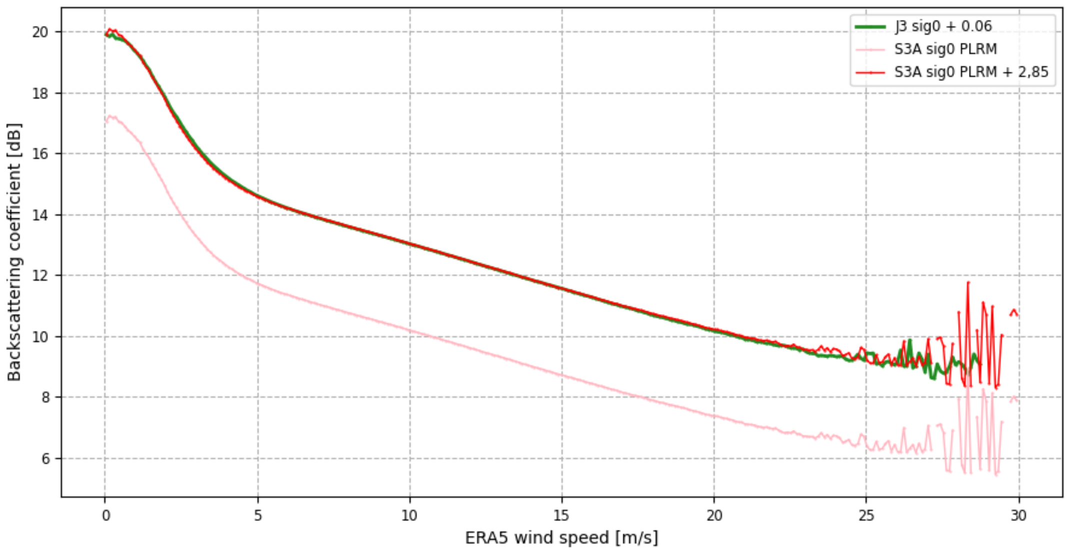


Figure 16: JASON-3 and JASON-2 1-Hz collocated SWH (left) and SWH RMS (right) (SWH RMS filtering applied). Extracted from Queffeulou [2016].

8.2. L2P wind speed information

8.2.1. Computing two-parameter wind speed (Gourion algorithm with Collard table)

In order to apply the Collard's model (which was developed from Jason-1 data based on collocations with QuikSCAT scatterometer data) to data from other altimeter missions, a simple approach consisting in the application of a bias shift on backscattering coefficient looks efficient. This approach is already used in Jason-3 ground segment to generate the GDR-F products (a bias of 0.06 dB is applied to nominal Ku-band (MLE4) backscattering coefficient before wind speed calculation). Figure 17 shows the backscattering coefficient of Sentinel-3A (PLRM data) and Jason-3 as a function of ERA5 wind speed, used as an external data source to better evaluate the needed sigma0 bias. The use of the ERA-5 reference allows the determination of a global bias between the data from the two missions. One year of data (mid 2016 to mid 2017) was used for this analysis with Sentinel-3A data from Baseline Collection 004 reprocessing and Jason-3 GDR-F data (nominal and shifted curves are shown). Applying a bias of 2.85 dB to S3A PLRM backscattering coefficient shows that the sigma0 curve as a function of ERA5 wind speed becomes very close to the Jason-3 GDR-F one (except for high backscattering coefficients values which are quite noisy for Sentinel-3A).



	nbr	min	mean	med	max	std
J3 sig0 + 0.06	287	8.595	12.26	11.73	19.91	2.856
S3A sig0 PLRM	294	5.45	9.408	8.817	17.23	2.799
S3A sig0 PLRM + 2,85	294	8.3	12.26	11.67	20.08	2.799

Figure 17: Backscattering coefficient in function of ERA5 wind speed for S3A L2 PLRM sigma0 (light pink), S3A PLRM sigma0 with 2.85dB bias applied (red), and Jason-3 L2 GdrF sigma0 with 0.06 dB bias applied (as it is done in Jason-3 ground segment prior wind speed computation). Only valid backscattering coefficient data are used.

Currently a one-year period common between Jason-3 Gdr-F and Sentinel-3B Baseline Collection 004 is not yet available, as the operational switch to Jason-3 Gdr-F standard took place end of October 2020, the reprocessing of Jason-3 in standard Gdr-F has just started and Sentinel-3B starts after the study year available of Jason-3 in standard F (mid-2016 mid-2017).

Therefore the sigma0 distribution of Sentinel-3B was fitted over Sentinel-3A (+ sigma0 Sentinel-3A bias: 2.85 dB) distribution which is already fitted on Jason-3 F sigma0 distribution (Figure 18). This gives a bias of 2.80 to be applied on Sentinel-3B PLRM sigma0 before Collard wind speed computation.

	nbr	min	mean	med	max	std
s3b sigma0_PLRM + 2.80	19043369	-15.66	13.88	13.68	44.13	2.454
s3a sigma0_PLRM + 2.85	19004212	-15.04	13.89	13.7	43.48	2.439

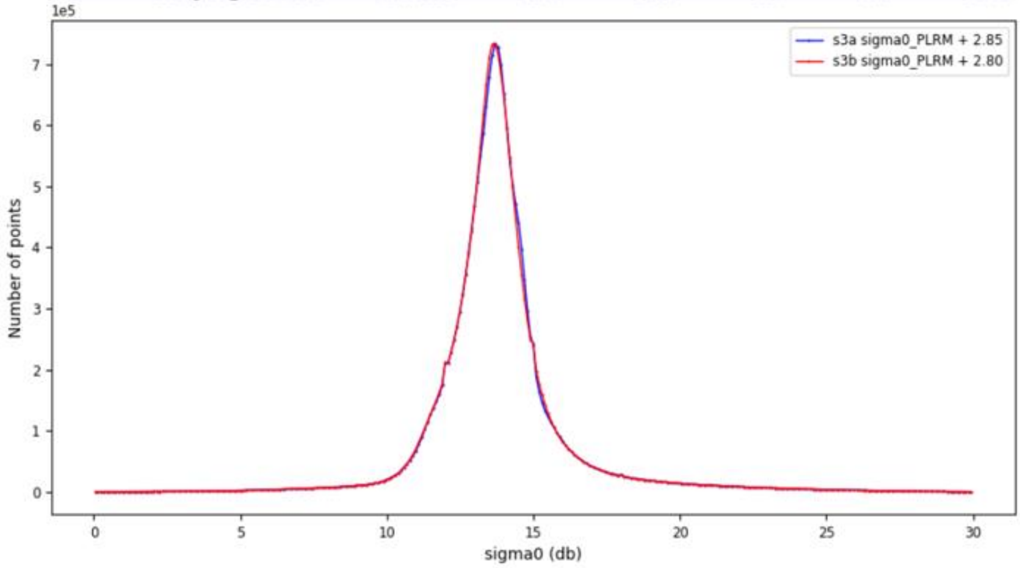


Figure 18: Sigma0 distribution of S3A (+ 2.85 dB) (blue line) and S3B (+2.80 dB) (red line) over the period mid-2018 mid-2019.

When using the Collard wind speed (left side of Figure 19) the wind speed is much more independent of significant wave height classes than when using the wind speed from L2 products (right side of Figure 19).

As seen in Figure 19 (left panel), the use of the Collard's model helps to reduce significantly the SWH impact on S3A retrieved wind speed estimations when one compares with the plot based on L2 products (right panel of Figure 19). The SWH dependency cannot be totally removed because the

Collard's model was fitting based on MLE3 retracked data. The Samosa retracking does not display exactly the same correlations between sigma0 and SWH than one looks at MLE3 data.

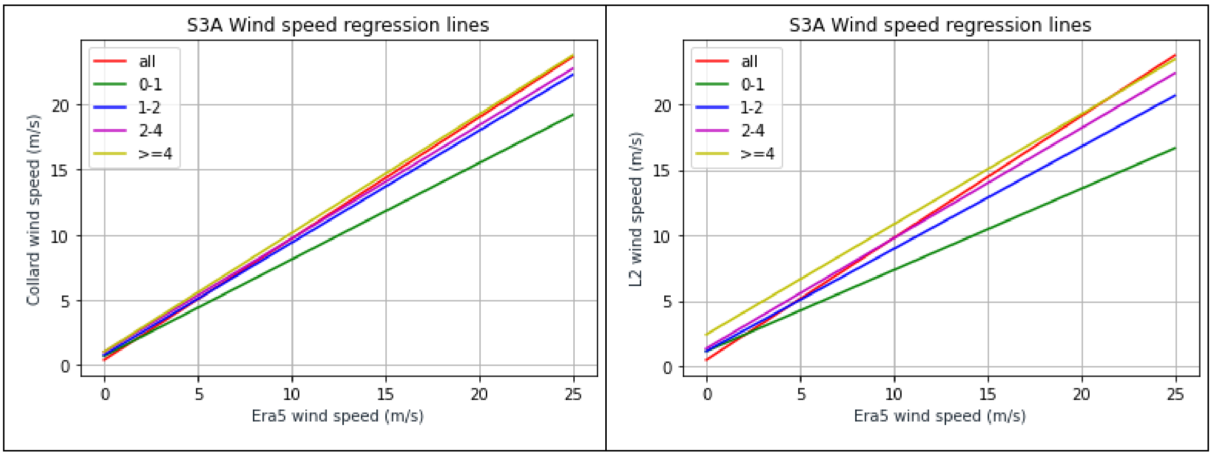


Figure 19: Sentinel-3A altimeter wind speed regression lines in function of ERA wind speed for several significant wave height classes (all classes (red), 0 to 1 m (green), 1 to 2 m (blue), 2 to 4 m (lilac), higher than 4 m (yellow). Left: using Collard wind speed. Right: using L2 (Abdalla) wind speed.

Wind speed Collard used on L2P products is based on sigma0 PLRM (+2.85 dB for S3A and 2.80 dB for S3B) and SWH PLRM data instead of SAR data for several reasons:

- Show better agreements with blended wind speed reference and reduce regional bias
- No correlation with satellite radial velocity
- Impact of both SWH and swell on SAR SWH estimations along with a waveform centering dependency

8.2.2. Intercalibration on reference mission

8.2.2.1. Sentinel-3A

Wind speed abacus is computed for S3A Collard wind speed based on PLRM data (Baseline Collection 004) over the period mid-2016 and mid-2017 based on the section 2.4.4.2. This period has been chosen for wind speed calibration calculation because we need one year in common between J3F and the last baseline of S3A. S3A wind speed calibration abacus is based on J3 F standard. Results of the calibration is show in the Figure 20. Wind speed mean difference at crossover before calibration is about 0.1 m/s between J3F and S3A during the period mid-2016 and mid-2017 (Figure 20 top). Abacus is created using interpolation spline from bin 0 to 18 m/s and linear interpolation is used for bin superior to 18 m/s. In addition, we can say that mean value at crossover between J3F and S3A are really close during this period, which results to small bias correction in abacus (about 0.07 m/s in average). Residual values are show in Figure 20 (bottom) and correspond to the mean wind speed crossover between J3F and S3A after calibration. Residual values are small and about 0.04m/s in average over the period mid-2016 mid-2017. However, we can notice that residual has got higher value for extreme wind speed.

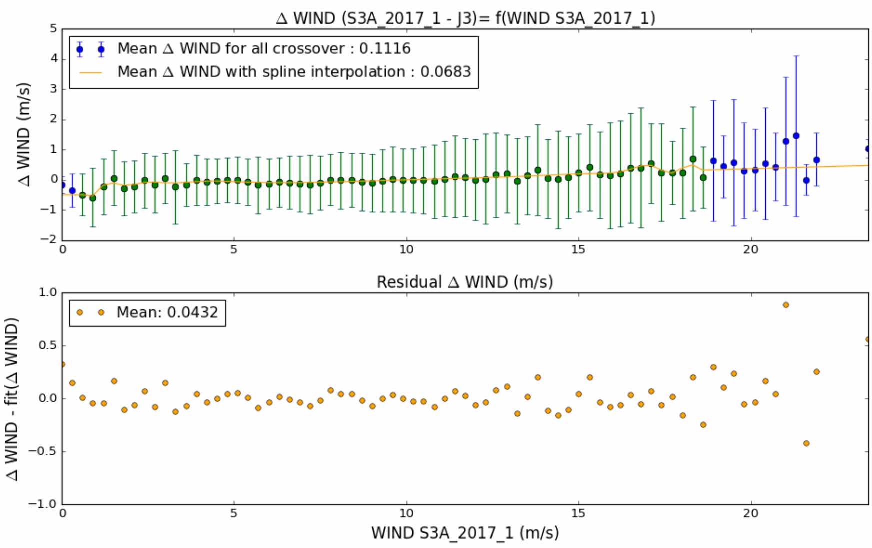


Figure 20: Wind speed calibration between J3 standard F and S3A during the period mid-2016 mid-2017. Top: wind speed mean difference at crossover; green dots correspond to bin with enough values to use for abacus calculation; blue dots correspond to bin with not enough values to use for abacus calculation; yellow line corresponds to the abacus values, bottom: Mean difference at crossover between J3 F standard and S3A after calibration.

This abacus will be used for operational treatment. Figure 21 show mean wind speed at crossover between J3F and S3A before (green line) and after calibration (blue line) between mid-November 2020 to mid-February 2021. We can notice that after calibration (blue line) residual value on mean wind speed difference at crossover remains (about -0.14 m/s in average). From December 2020 we observed a bias of about -0.2 m/s in average for mean wind speed difference at crossover between J3F and S3A. Furthermore, we saw on Figure 20 that correction applied with S3A abacus is small in average (about 0.04 m/s). Therefore, we can not expect to correct this recent bias observed (cf section 2.4.4.1). Creating an abacus for period from mid-November 2020 to mid-February 2021 gives better results after calibration (not shown). However, a three months abacus can not be used for the whole year because an entire year is mandatory to compute calibration abacus to represents all situations. The Figure 21 shows that improvements could be made on intercalibration process by using new methods such as quantile-quantile or artificial intelligence.

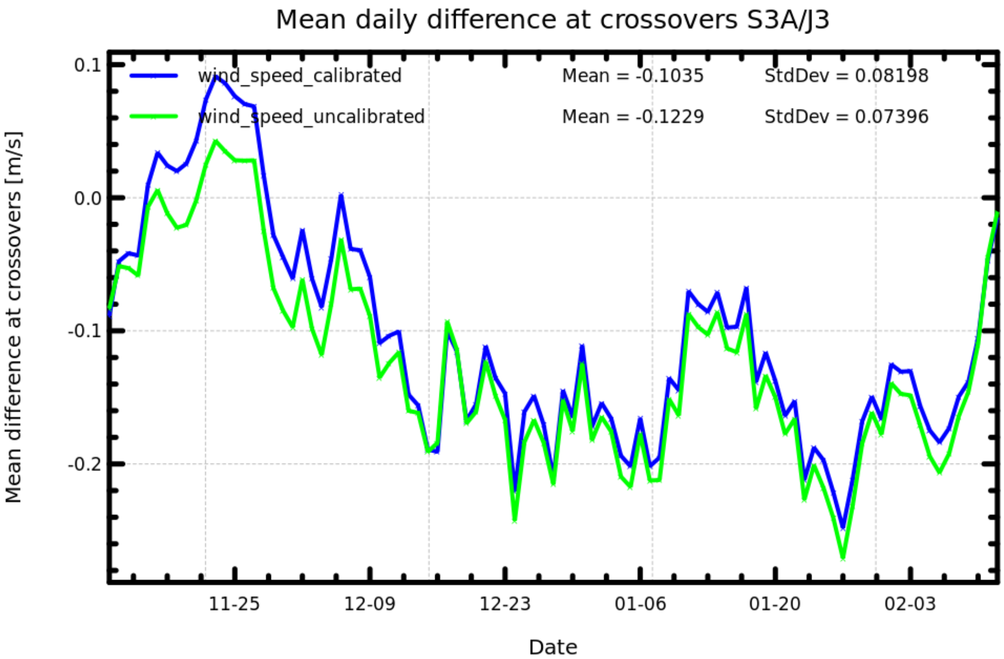


Figure 21: Mean of significant wind speed difference at crossovers (3h constraint). Sentinel-3A / Jason-3 crossovers. The green line represents the daily mean between the valid uncalibrated wind speed values.

8.2.2.2. Sentinel-3B

To create S3B abacus we needed to make it in two steps because as we said we need an entire one-year period in common between J3F and S3B, which is not yet available. Therefore a first calibration between J3 standard D and S3B Baseline Collection 004 products (over the year 2019) is done (this lowers the S3B Collard wind speed by (averaged over windspeed interval of 0 to 17 m/s) 0.29 m/s and in a second step an abacus containing a bias between J3 standard D and J3 standard F is applied (this increases the wind speed by (averaged over windspeed interval of 0 to 17 m/s) 0.36 m/s. The S3B Collard wind speed is therefore in average slightly increased after the intercalibration process. Figure 22 shows the S3B wind speed values before (green line) and after (blue line) calibration. After calibration, the mean average wind speed difference at crossover is closer to 0 than before calibration.

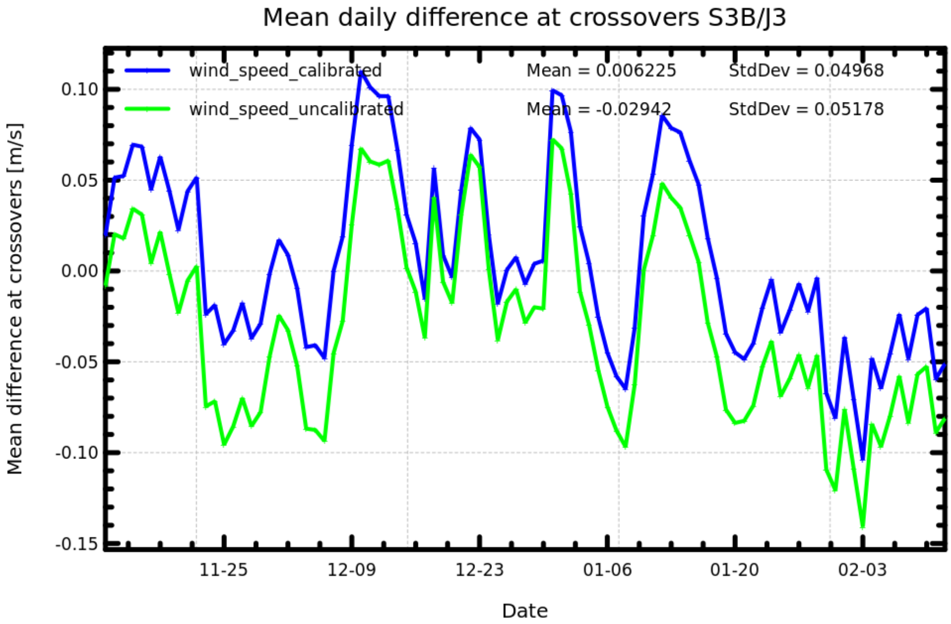


Figure 22: Mean of wind speed difference at crossovers (3h constraint). Sentinel-3B / Jason-3 crossovers. The green line represents the daily mean between the valid uncalibrated wind speed values.