Product User Guide

version 1.0, 17 January 2020

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Issue	Date	Comments
0.9	19/09/2019	Full draft submitted for ESA comment
1.0	17/01/2020	Addition of release notes, list of acronyms, other minor updates. Formal submission for ESA approval.

Contents

List of Acronyms

CCI	Climate Change Initiative
CMEMS	Copernicus Marine Environment Monitoring Service
CPU	Central Processing Unit
ECV	Essential Climate Variable
ESA	European Space Agency
FAQ	Frequently Asked Questions
FTP	File Transfer Protocol
GDR	Geophysical Data Record
HPC	High Performance Computing
IPF	Input Processor Function?
L1A	Level 1A
L1B	Level 1B
L2P	Level 2 Preprocessed
L3	Level 3
L4	Level 4
LRM	Low Rate Measurement
PUG	Product User Guide
RA	Radar Altimeters
RR	Round Robin
S3A	Sentinel-3A
S3B	Sentinel-3B
SAR	Synthetic Aperture Radar
SSH	Secure Shell / Sea Surface Height
SWH	Significant Wave Height
WV	Wave (mode for SAR)

1. Introduction

1.1 Purpose and structure of document

This document presents the Product User Guide (PUG) for **Sea_State_cci**. This first version is prepared as a guide to the version 1.1 sea state products that have been made available in July 2019, updating and extending products from the GlobWave project. An updated version of this document, supporting further versions of products, will be produced upon each update of the data products. This is anticipated in 2020 and 2021.

The remainder of this Product User Guide is structured as follows. It includes a general description of the version 1 products and provides the specific variable content of the datasets. Annexes describe the calibration and validation of the data:

- Section 2: Quick start and FAQ
- Section 3: General products description
- Section 4: Version 1 dataset content
- Section 5: Differences from GlobWave L2P products
- Section 6: L2P editing criteria
- Annex A: Calibration of Jason-1, Jason-3, Saral and Cryosat-2 missions
- Annex B: Validation of Sea State CCI dataset v1

1.2 Release notes for Sea State data version 1.0 (20th June 2019)

This dataset is the first version (version 1) of CCI Sea State products, built upon the heritage of ESA GlobWave project. It extends and improves the GlobWave altimeter time series, based on a post-processing of existing L2 altimeter agency products (GDRs) with updated editing, cross-altimeter intercalibration, uncertainties and additional variables, including a denoised Hs using an EMD based filter.

Three products are delivered:

- L2P : Along-track products separated into satellite directories, including all measurements with flags, corrections and extra parameters from other sources. These are expert products with rich content and no data loss.
- L3 : Edited merged daily products retaining only quality-checked measurements from all altimeters over one day (one daily file), with simplified content (only a few key parameters). This is close to what is delivered in NRT by CMEMS project.
- L4 : Monthly gridded products averaging quality_checked measurements from all available altimeters over a fixed resolution grid (1°x1°). These products are meant for statistics and visualization through CCI toolbox.

Known issues

Some issues remain in the provided time series that will be addressed in upcoming new versions.

- the time series starts in 1991 with ERS-1 and stops in December 2018. Previous or newer missions (like GeoSat, SRAL altimeters onboard Sentinel-3A & 3B) will be added later.

- the processing of some missions may relies on older GDR versions. New offers (like Envisat v3.0 dataset, ERS-1 and ERS-2 REAPER datasets) still need to be investigated and may replace later the currently used input GDR products.
- some model variables (from ERA5 reanalysis) are not yet filled in (sea surface temperature and total liquid water content) or still missing over some time periods (before 2000): this is due to missing input ERA5 data at the time of this release's processing and it will be completed soon.
- improvements in the editing of L2 measurements are still under investigation, in particular over sea ice areas, slicks and strong wind areas
- estimate of the mean square slope will be added in future release
- intercalibration of the sigma0 will be carried out for all altimeters and calculation of a cross calibrated wind speed based on a bivariate (Hs and sigma0) analysis will be added in future release.

1.3 Release notes for Sea State data version 1.1 (5th July 2019)

Main changes include:

- updated Hs corrections (intercalibration) for Cryosat-2, Jason-1 and AltiKa
- updated Hs uncertainties (for denoised Hs)
- fixed sum variables in L4 product (previous version should not be used)

2. Quick Start and FAQ

Where do I get the data?
Simple registration at https://forms.ifremer.fr/lops-siam/access-to-esa-cci-sea-state-data/ gives immediate access to ftp account details. See section 3.4.

What are the data products?
There are three types of data product based on measurements of significant wave height from satellite altimeters. These are L2P, L3 and L4. See section 3.1.

What is the data format?
NetCDF4 Classic format. See section 3.3

What is the coverage?
The data are global, mostly up to max 81.5° latitude, with best coverage up to 66° latitude.

What is the time span?
Data span August 1991 to December 2018.

What is the spatial resolution?
The L2P and L3 products are along-track with narrow swath and resolution of 7km. The L4 gridded products have a spatial resolution of 1°.

I am interested in obtaining all the wave height measurements for a particular region and perhaps doing my own quality control, which product should I use?
The L2P product contains the most information. See section 4.1.

I am interested in obtaining all the best quality wave height measurements for a particular region and am not concerned about quality control or which satellite the measurements are from.
The L3 product contains all the significant wave height measurements that are considered good quality, merged from the different instruments. See section 4.2.

I am interested in obtaining quick statistics for large areas.
The L4 product contains a statistical summary of the wave height measurements at a spatial resolution of 1° and temporal resolution of 1 month. See section 4.3.

What about wave period and direction?
This information is derived from satellites carrying a Sythethic Aperture Radar instrument and will be included in future releases of the Sea State data.

Who do I contact for further information?
For general data enquiries contact the Ifremer data team: cersat@ifremer.fr
For application and science issues contact Guillaume Dodet: guillaume.dodet@ifremer.fr

3. General Products Description

3.1 Products overview

The first version (version 1) of CCI Sea State products is inherited from the GlobWave project building on experience and existing outputs. It extends and improves the GlobWave products which were a post-processing over existing L2 altimeter agency products with additional filtering, corrections and variables.

Three kinds of products are delivered:

- L2P : Along-track products separated per satellite and pass, including all measurements with flags, corrections and extra parameters from other sources. These are expert products with rich content and no data loss.
- L3 : Edited merged daily products retaining all valid and good quality measurements from all altimeters over one day (one daily file), with simplified content (only a few key parameters). This is close to what is delivered in NRT by CMEMS project.
- L4 : Gridded products averaging valid and good measurements from all available altimeters over a fixed resolution grid (1°x1°) on a monthly basis. These products are meant for statistics and visualization through CCI toolbox.

3.2 Altimeter missions

Data from the following satellite altimeter missions, spanning from 1991 to 2018, are included in the version 1 data:

Mission	Altimeter	Selected band	Source product
GFO	GFO-RA	Ku	GDR/POE [NOAA]
TOPEX/Poseidon	TOPEX, POSEIDON-1	Ku	MGDR [CNES]
ERS-1	RA	Ku	OPR [ESA/F-PAF]
ERS-2	RA	Ku	OPR [ESA/F-PAF]
Envisat	RA-2	Ku	GDR v2.1 [ESA/F-PAC]
Jason-1	POSEIDON-2	Ku	GDR version E (MLE4 retracker for SWH, MLE3 for sigma0) [Aviso]
Jason-2	POSEIDON-3	Ku	GDR version D (MLE4 retracker for

			SWH, MLE3 for sigma0) [Aviso]
Jason-3	POSEIDON-3B	Ku	GDR version D (MLE4 retracker for SWH, MLE3 for sigma0) [Aviso]
Cryosat-2	SIRAL	Ku	IGDR [NOAA]
SARAL	AltiKa	Ka	GDR [Aviso]

3.3 Format

All products are in NetCDF4 Classic format. They comply to the CCI Data Standard 2.0 (See http://cci.esa.int/working-groups) and follow the CF 1.7 and ACDD conventions

The detailed format of each product is described in the following sections.

3.4 Data access, organisation and file naming

The data can be obtained from Ifremer FTP server: ftp://eftp.ifremer.fr. The login and password can be obtained upon filling the registration form at :

https://forms.ifremer.fr/lops-siam/access-to-esa-cci-sea-state-data/

The common directory structure is based on CCI recommendations and is arranged as follows:

/products/<cci_project>/<type>/<version>/<mission>/<date>/

Where:

- **<cci_project>** : seastate
- **<type>** : will be different for each ECV, but needs to be defined, and consistent within an ECV, here l2 for along-track altimeter data, l3 for edited merged products and l4 for monthly averaged gridded products)
- **<version>** is the dataset version (currently 1.1)
- **<mission>** : satellite mission (for L2P products only)
- **<date>** : <year as YYYY>/<day in the year as DDD>

The file nomenclature is based on form 2 of CCI recommendations :

ESACCI-<CCI Project>-<Processing Level>-<Data Type>-<Product String>[-<Additional Segregator>]-<IndicativeDate>[<Indicative Time>]-fv<File version>.nc

Where:

- **<CCI Project>** : SEASTATE
- **<Processing Level>** : here L2P for along-track altimeter data, L3 for edited merged product and L4 for monthly averages
- **<Data Type>** : SWH for Significant Wave Height
- **<Product String>** :
- **<Additional Segregator>** :
- **<Indicative Date>[<Indicative Time>] :** The identifying date for this data set. Format is YYYYMMDDTHHMMSS, where YYYY is the four digit year, MM is the two digit month from 01 to 12 and DD is the two digit day of the month from 01 to 31. The date used should best represent the observation date for the data set. For along-track data it will be the time of the first measurement in the file.
- **<File version>** : File version number in the form n{1,}[.n{1,}] (That is 1 or more digits followed by optional . and another 1 or more digits.)

Examples:

L2P product:
ESACCI-SEASTATE-L2P-SWH-JASON2-20170130T145103-fv01.nc

L3 product:
ESACCI-SEASTATE-L3-SWH-MULTI_1D-20170130-fv01.nc

L4 product:
ESACCI-SEASTATE-L4-SWH-MULTI_1M-201701-fv01.nc

4. Version 1 Dataset Content

4.1 L2P

The L2P products are along-track files, usually corresponding to a satellite pass, processed from each mission data provider's L2 product (usually using the GDR type of product for altimeter for best quality). All measurements from the source product are kept but only a few variables from this product are copied into the L2P. Additional processing is performed, like quality control, adjustment of significant wave height and sigma0 to a common reference, uncertainty estimation, etc… and complementary variables are also computed or added from other sources. The content is fully consistent and standardized for each mission included in this dataset.

For altimeters, only the Ku band measurements are considered, when available (the only current exception being Saral for which only Ka band is provided).

This section describes in detail the specific content of the version 1 L2P for Sea State CCI.

4.1.1 Content overview

The following table provides the list of variables included in the L2P product.

	coordinate variables
time	time (in seconds since 1985-01-01)
lat	latitude
lon	longitude
	instrumental variables for 1st band altimeter (usually Ku)
sigma0	Ku band backscatter coefficient, as in source product from mission provider
sigma0_adjusted	Ku band adjusted backscatter coefficient. The adjustment is based on Queffeulou et al., 2017.[ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves/documentation/altimeter_wave_merge__11.4.pdf]
sigma0_rms	RMS of the Ku band backscatter coefficient (from unadjusted 20 Hz measurements), as in source product from mission provider
sigma0_num_valid	number of valid points used to compute Ku band backscatter coefficient, as in source product from mission provider
	environmental variables for 1st band altimeter (usually Ku)
swh	significant wave height, taken from the source product from mission provider

swh_adjusted	adjusted significant wave height. The adjustment is based on Queffeulou et al., 2017 [ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves/documentation/altimeter_wave_merge__11.4.pdf] for missions up to Jason-2 and uses new estimates by CCI Sea State project for the latest missions (Jason-3, Saral, CryoSat-2).
swh_denoised	EMD-filtered significant wave height, an adjusted and denoised significant wave height estimated by CCI Sea State project and based on Quilfen and Chapron (2019) [Quilfen, Y., and B. Chapron (2019). On denoising satellite altimeter measurements for geophysical signals analysis. Advances in Space Research. Submitted]
swh_noise	High frequency noise on significant wave height, estimated by CCI Sea State project and based on Quilfen and Chapron (2019) [Quilfen, Y., and B. Chapron (2019). On denoising satellite altimeter measurements for geophysical signals analysis. Advances in Space Research. Submitted]
swh_quality	quality level if significant wave height measurements, as estimated using the editing criteria from Queffeulou et al., 2017 [ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves/documentation/altimeter_wave_merge__11.4.pdf]
swh_uncertainty	best estimate of significant wave height standard error, as estimated by CCI Sea State project for each mission
swh_rms	RMS of significant wave height (from unadjusted 20 Hz measurements), taken from the source product from mission provider
swh_num_valid	number of valid points used to compute significant wave height (from unadjusted 20 Hz measurements), taken from the source product from mission provider
swh_rejection_flag	flag specifying the editing criteria on which a measurement was rejected (meaning its quality level is not set to “good”).
	auxiliary variables
auxiliary measurements	
corssh	sea surface height, as taken from CCI Sea Level products
sea_ice_concentration	sea ice concentration, as taken from CCI Sea Ice products
total_column_liquid_water_content_rad	Total column cloud liquid water content from onboard radiometer, when available in source product.
topography	
bathymetry	ocean depth
distance_to_coast	distance to nearest coast

model auxiliary data	
wind_speed_model_u	U component of the model wind vector, taken from ERA5 reanalysis
wind_speed_model_v	V component of the model wind vector, taken from ERA5 reanalysis
sea_surface_temperature	sea surface temperature, taken from ERA5 reanalysis
surface_air_temperature	surface air temperature, taken from ERA5 reanalysis
surface_air_pressure	surface air pressure, taken from ERA5 reanalysis
total_column_liquid_water_content	Total column cloud liquid water content, taken from ERA5 reanalysis

4.1.2 Processing details

4.1.2.1 Variables from L2

Some variables are directly copied from the source L2 GDR product without any modification or editing, including:

- the coordinate variables: lat, lon, time
- the 1 Hz calculated significant wave height value in Ku band (Ka for AltiKa), and the number and RMS of the 20Hz measurements averaged to get this 1 Hz value
- the 1Hz radar backscatter (sigma0) in Ku band (Ka for AltiKa), and number of valid 20Hz measurements averaged to get this 1 Hz value

time

```
int64 time(time) ;
        time:_FillValue = 9.96921e+36f ;
        time:long_name = "time of measurement" ;
        time:standard_name = "time" ;
        time:units = "seconds since 1985-01-01 00:00:00.0" ;
        time:calendar = "gregorian" ;
        time:axis = "T" ;
         time:coverage_content_type = "coordinate" ;
```

Latitude [lat]

```
double lat(time) ;
        lat:_FillValue =9.96921e+36f ;
        lat:long_name = "latitude" ;
        lat:standard_name = "latitude" ;
        lat:units = "degrees_north" ;
         lat:axis = "Y" ;
         lat:valid_range = -90, 90 ;
        lat:comment = "Positive latitude is North latitude, negative latitude is South latitude" ;
```

```
        lat:coverage_content_type = "coordinate" ;
```

Longitude [lon]

```
double lon(time) ;
        lon:_FillValue = 9.96921e+36f ;
        lon:long_name = "longitude" ;
        lon:standard_name = "longitude" ;
        lon:units = "degrees_east" ;
        lon:axis = "X" ;
        lon:valid_range = -180, 180 ;
        lon:comment = "East longitude relative to Greenwich meridian" ;
        lon:coverage_content_type = "coordinate" ;
```

Significant wave height [swh]
Hs as provided by the original data producer [no calibration, no editing].

```
double swh(time) ;
        swh:_FillValue = 9.96921e+36f ;
        swh:long_name = "Ku band significant wave height" ;
        swh:standard_name = "sea_surface_wave_significant_height" ;
        swh:units = "m" ;
        swh:ancillary_variables = "swh_quality rejection_flag" ;
        swh:coordinates = "time lon lat" ;
        swh:comment = "All instrumental corrections included. As available in source GDR product and unedited" ;
        swh:band = "Ku" ;
        swh:coverage_content_type = "physicalMeasurement" ;
```

significant wave height rms [swh_rms]

```
double swh_rms(time) ;
        swh_rms:_FillValue = 9.96921e+36f  ;
        swh_rms:long_name = "RMS of the Ku band significant wave height (from 20 Hz measurements)" ;
        swh_rms:units = "m" ;
        swh_rms:coordinates = "time lon lat" ;
        swh_rms:band = "Ku" ;
        swh_rms:coverage_content_type = "auxiliaryInformation" ;
```

number of valid points used to compute 1st band significant wave height [swh_num_valid]

```
byte swh_num_valid(time) ;
        swh_num_valid:_FillValue = 127b ;
        swh_num_valid:long_name = "number of 20 Hz valid points used to compute Ku band significant wave height" ;
        swh_num_valid:units = "1" ;
        swh_num_valid:coordinates = "time lon lat" ;
        swh_num_valid:coverage_content_type = "auxiliaryInformation" ;
```

sigma0 [sigma0]
`` double sigma0(time) ;   sigma0:_FillValue = 9.96921e+36f ;   sigma0:long_name = "Ku band backscatter coefficient" ;   sigma0:band = "Ku" ;   sigma0:units = "dB" ;   sigma0:quality_flag = "sigma0_quality" ;   sigma0:coordinates = "time lon lat" ;   sigma0:comment = "All instrumental corrections included. Unadjusted" ;   sigma0:coverage_content_type = "physicalMeasurement" ; ```

sigma0 [sigma0]

```
double sigma0(time) ;
        sigma0:_FillValue = 9.96921e+36f ;
        sigma0:long_name = "Ku band backscatter coefficient" ;
         sigma0:band = "Ku" ;
        sigma0:units = "dB" ;
        sigma0:quality_flag = "sigma0_quality" ;
        sigma0:coordinates = "time lon lat" ;
        sigma0:comment = "All instrumental corrections included. Unadjusted" ;
         sigma0:coverage_content_type = "physicalMeasurement" ;
```

sigma0 RMS [sigma0_rms]

```
double sigma0_rms(time) ;
        sigma0_rms:_FillValue =9.96921e+36f ;
        sigma0_rms:long_name = "RMS of the Ku band backscatter coefficient" ;
         sigma0_rms:band = "Ku" ;
        sigma0_rms:units = "dB" ;
        sigma0_rms:coordinates = "time lon lat" ;
         sigma0_rms:coverage_content_type = "auxiliaryInformation" ;
```

number of valid points used to compute backscatter coefficient [sigma0_num_valid]

```
byte sigma0_num_valid(time) ;
        sigma0_num_valid:_FillValue = 127b ;
        sigma0_num_valid:long_name = "number of valid points used to compute Ku
band backscatter coefficient" ;
         sigma0_num_valid:band = "Ku" ;
        sigma0_num_valid:units = "1" ;
        sigma0_num_valid:valid_range = 0b, 10b ;
        sigma0_num_valid:coordinates = "time lon lat" ;
         sigma0_rms:coverage_content_type = "auxiliaryInformation" ;
```

4.1.2.2 SWH quality level and rejection flags

Quality control of individual altimeter measurements is undertaken with checks on instrument flags and ancillary variables. As a result, the SWH comes with a quality level provided in the *swh_quality*variable. Its meaning is defined as follows:

value	meaning	description
0	undefined	the measurement value is not defined or relevant (missing value, etc…), no quality check was applied.
1	bad	the measurement was qualified as not usable after quality check.

2	acceptable	the measurement may be usable for specific applications only or the quality check could not fully assess if it is a bad or good value (suspect).
3	good	the measurement is usable.

significant wave height quality [swh_quality]

```
byte swh_quality(time) ;
        swh_quality:valid_min = 0b ;
        swh_quality:valid_max = 2b ;
        swh_quality:long_name = "quality of Ku band significant wave height
measurement" ;
        swh_quality:flag_values = 0b, 1b, 2b, 3b ;
        swh_quality:flag_meanings = "undefined bad acceptable good" ;
         swh_quality:coverage_content_type = "qualityInformation" ;
```

When SWH measurements were rejected as **bad**, the reason (quality test) for which they were rejected is reported in the related *swh_rejection_flags* variable. The following table provides the meaning of each flag possibly raised. Depending on the mission, the criteria used to set these flags may be different and are detailed in the related section.

flag	**criteria**
not_water	the surface type is not water. It may be land, continental ice,.... We try to keep lake and inner seas measurements (when the discrimination is possible from the GDR information)
sea_ice	the measurement has possible ice contamination. The sea ice fraction is taken from an external source (such as the CCI Sea Ice microwave based daily maps). Sea ice contamination is defined as areas where the sea ice fraction is greater than a minimal threshold (corresponding to 10% of ice in the current configuration).
swh_validity	the SWH measurements were considered as invalid (for instance because out of the possible range).
sigma0_validity	the sigma0 measurements were considered as invalid for water surface type.
waveform_validity	the measurements were considered as invalid as there are indications of unsuitable waveforms for a proper SWH calculation.
ssh_validity	the SWH measurements were considered as invalid as there were issues on SSH which was considered as an indication of problematic quality for SWH too.
swh_rms_outlier	the measurements were considered as invalid when the RMS of the SWH measurements used to estimate each 1 Hz SWH measurement was beyond the acceptable threshold for a given range of SWH.

swh_outlier	the measurements were considered as invalid when performing the SWH outlier test, based on the neighbouring measurements within a 100 km window.

The editing criteria which leads to setting the SWH quality level and rejection flags are specific to each mission and are detailed in annex 1.

Rejection flags [rejection_flags]

```
uint8 swh_rejection_flag(time) ;
        rejection_flag:long_name = "consolidated instrument and ice flags" ;
        rejection_flag:flag_masks = 0b, 1b, 2b, 4b, 8b, 16b, 32b, 64b ;
        rejection_flag:flag_meanings = "not_water sea_ice swh_validity
sigma0_validity waveform_validity ssh_validity swh_rms_outlier swh_outlier”;
         rejection_flag:coverage_content_type = "qualityInformation" ;
```

4.1.2.3 Adjusted SWH

The table below provides the calibration table for SWH used in CCI Sea State products. They are inherited from the work of Queffeulou (2017) within GlobWave. New calibration coefficients have been calculated by CCI Sea State project for the latest missions: Jason-3, AltiKa and Cryosat-2. These coefficients were computed from inter-calibration at crossover measurements, using Jason-2 as reference.

The calibration source and formulae is traced in the variable attributes of *swh_adjusted* variable.

References:

Queffeulou, Pierre - ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves/documentation/altimeter_wave_merge__11.4.pdf, February 2017

Calibration derived from GlobWave error analysis [Ash E R & Carter D J T, September 2010, Satellite wave data quality report, GlobWave Deliverable D.16] http://globwave.ifremer.fr/download/GlobWave_D.16_SWDQR.pdf

GlobWave Product User Guide Phase 3, Deliverable D.7

Satellite	Adjustment formulae	Reference
ERS-1 *OPR*	swh_adjusted = 1.1259 x swh + 0.1854	Queffeulou et al.,2017
ERS-2 *OPR*	swh_adjusted =1.0541 x swh + 0.0391	Queffeulou et al.,2017

Envisat *Version 2.1 [2010]*	[swh > 3.41m] swh_adjusted = 1.0095 x swh + 0.0192 [swh < 3.41m] swh_adjusted = -0.021 x swh^3 + 0.1650 x swh^2 + 0.5693 x swh + 0.4358	Queffeulou et al.,2017
AltiKa *GDR*	swh_adjusted = swh * 0.9881 + 0.0555	Dodet et al.,2019 [CCI Sea State projet]
GFO *Version b*	swh_adjusted = 1.0625 x swh + 0.0754	Queffeulou et al.,2017
Jason-1 *Version E*	swh_adjusted = 1.0125 x swh + 0.0461	Dodet et al.,2019 [CCI Sea State project]
Jason-2 *Version T & D*	swh_adjusted = 1.0149 x swh + 0.0277	Queffeulou et al.,2017
Jason-3	swh_adjusted = swh * 1.0086 + 0.0503	Dodet et al.,2019 [CCI Sea State projet]
CryoSat-2	swh < 7.67: swh_adjusted = 0.1446 + 0.8858 swh + 0.0124swh^2 swh >= 7.67: no adjustment applied.	Dodet et al.,2019 [CCI Sea State projet]
Topex	**Side A (up to cycle 235):** swh_adjusted = 1.0539 x swh - 0.0766 + dh with: ● dh = 0 for cycle < 98 ● dh = poly3(98) - poly3(cycle) for 98 <= cycle <= 235 with ○ a0 = 0.0864 ○ a1= -6.0426 x 10-4 ○ a2 = -7.7894 x 10-6 ○ a3 = 6.9624 x 10-8 **Side B (from cycle 236):** swh_adjusted = 1.0237 x swh - 0.0476	Queffeulou et al.,2017

adjusted significant wave height [swh_adjusted]

```
double swh_adjusted(time) ;
        swh_adjusted:_FillValue = 9.96921e+36f  ;
        swh_adjusted:long_name = "Ku band adjusted significant wave height" ;
        swh_adjusted:standard_name = "sea_surface_wave_significant_height" ;
        swh_adjusted:units = "m" ;
        swh_adjusted:calibration_formula = "1.0149*swh + 0.0277" ;
        swh_adjusted:calibration_reference = "Ash E R & Carter D J T, September 2010, Satellite wave data quality report, GlobWave Deliverable D.16" ;
        swh_adjusted:ancillary_variables = "swh_quality swh_uncertainty rejection_flag" ;
        swh_adjusted:coordinates = "time lon lat" ;
        swh_adjusted:comment = "All instrumental corrections included. adjusted and unedited" ;
        swh_adjusted:band = "Ku" ;
        swh_adjusted:coverage_content_type = "physicalMeasurement" ;
```

4.1.2.4 SWH uncertainties

The uncertainties on adjusted significant wave height (*swh_uncertainties* variable) have been estimated by the CCI Sea State project team using altimeter/buoy match-ups. The methodology used to estimate uncertainties is the one implemented during the Globwave project (Ash, 2012). The estimated uncertainty can be expressed as a function of significant wave height as follows:

for SWH > 1m:

SWH uncertainty = 1.96 x (STD_ERR_P1 x swh + STD_ERR_P0)

for SWH <= 1m:

SWH uncertainty = 1.96 x (STD_ERR_P1 + STD_ERR_P0)

The STD_ERR_P0 and STD_ERR_P1 coefficients, estimated over the match-ups for each mission independently are listed in the following table:

Mission	STD_ERR_P0	STD_ERR_P1
ERS-1	0.123	0.004
ERS-2	0.081	0.020
TOPEX	0.023	0.034
Envisat	0.024	0.053
Jason-1	0.038	0.027
Jason-2	0.050	0.021

Jason-3	0.042	0.020
GFO	0.069	0.023
SARAL	0.074	0.012
Cryosat-2	0.035	0.021

References:

Ellis Ash, 2012. GlobWave Annual Quality Control Report, Phase 2, pp. 43.

significant wave height uncertainty [swh_uncertainty]

```
double swh_uncertainty(time) ;
        swh_uncertainty:_FillValue = 9.96921e+36f  ;
        swh_uncertainty:long_name = "best estimate of significant wave height
standard error" ;
        swh_uncertainty:units = "m" ;
        swh_uncertainty:source = "GlobWave Wave Data Quality Report" ;
        swh_uncertainty:coordinates = "time lon lat" ;
        swh_uncertainty:comment = "Standard error calculated from buoy
colocations" ;
         swh_uncertainty:coverage_content_type = "qualityInformation" ;
```

4.1.2.5 Denoised SWH

A non-parametric denoising method based on Empirical Mode Decomposition (EMD, Huang et al., 1998) and inspired by wavelet thresholding is applied to the parameter swh_adjusted (see Kopsinis and McLaughlin, 2009, Quilfen et al., 2018 and Quilfen and Chapron, 2019ab). A detailed description of the method can be found in Quilfen and Chapron, 2019b.

References:

Huang, N.E., Shen, Z., Long, S.R., Wu, M.C., Shih, H.H., Zheng, Q., Yen, N.-C., Tung, C.C., Liu, H.H., 1998. The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis. Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences 454, 903–995. https://doi.org/10.1098/rspa.1998.0193

Kopsinis, Y., McLaughlin, S., 2009. Development of EMD-Based Denoising Methods Inspired by Wavelet Thresholding. IEEE Transactions on Signal Processing 57, 1351–1362. https://doi.org/10.1109/TSP.2009.2013885

Quilfen, Y., Yurovskaya, M., Chapron, B., Ardhuin, F., 2018. Storm waves focusing and steepening in the Agulhas current: Satellite observations and modeling. Remote Sensing Of Environment 216, 561–571. https://doi.org/10.1016/j.rse.2018.07.020

Quilfen, Y., and Chapron, B., 2019. Ocean Surface Wave-Current Signatures From Satellite Altimeter Measurements. Geophysical Research Letters 46, 253–261. https://doi.org/10.1029/2018GL081029

Quilfen, Y., and Chapron, B., 2019. On denoising satellite altimeter measurements for geophysical signals analysis. Advances in Space Research. Submitted

Denoised significant wave height [swh_denoised]

```
double swh_denoisedd(time) ;
        swh_denoised:_FillValue = 9.96921e+36f ;
        swh_denoised:long_name = "Ku band denoised significant wave height" ;
        swh_denoised:standard_name = "sea_surface_wave_significant_height" ;
        swh_denoised:units = "m" ;
        swh_denoised:coordinates = "time lon lat" ;
        swh_denoised:comment = "All instrumental corrections included. adjusted,
denoised with EMD and unedited" ;
        swh_denoised:band = "Ku" ;
        swh_denoised:coverage_content_type = "physicalMeasurement" ;
```

4.1.2.6 Adjusted Sigma0

The next table gives details of the calibrations applied to the sigma0 measurements, as defined in Queffeulou et al., 2017. The content is subject to change with time.

A first calibration is obtained from information published by the agencies or by people involved in the monitoring of this measurements – sources are indicated for each altimeter.

A second calibration is obtained from comparison with the ENVISAT sigma0, which seems to be stable with time: for each altimeter, a bias was estimated relative to ENVISAT, comparing mean values of sigma0, over the global oceans, between 66.15° S and 66.15° N, and over the common time period with ENVISAT, for TOPEX, ERS-2, Jason-1 & 2 and GFO. ERS-1 was adjusted indirectly by a first comparison with ERS-2, itself adjusted relatively to ENVISAT.

These two calibration values are applied to the GDR sigma0, resulting in the adjusted sigma0 parameter given in the data set.

References:
Queffeulou et al.,2017
[ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves/documentation/altimeter_wave_merge__9.0__annexe_II.pdf]

satellite	Sigma0 calibration	Comment

ERS-1	+0.0976 dB +0.0465 + 0.0511 [ENVISAT]	adjusted sigma0 Ku-band and adjusted wind speed set to NaN before 01-Aug-1991 02:15:18
ERS-2	+0.15 dB from January 16 to February 7, 2000 +0.35 dB from February 10 to March 2, 2000 +0.25 dB from 3 Mar 2000 to 7 Oct 2000 +0.35 dB from 8 Oct 2000 (anomaly occurs) to 5 Feb 2001 +0.45 dB from 6 Feb 2001 (Extra backup mode starts) to 29 Apr 2001 +0.25 dB since 30 Apr 2001 (Zero Gyro mode implemented) +0.0511 dB [ENVISAT]	calibrations were obtained from Dorandeu et al. 2000, and Scharroo, personal communication. Extra Backup Mode (extended further...): do not use sigma0 ERS-2 from 17 Jan 2001 to 31 March 2001, included; calibrated sigma0 Ku-band and adjusted wind speed set to NaN over this time period
Envisat	+0. dB [ENVISAT]	*Version 2.1 [2010]*
AltiKa	TBD	Not estimated
GFO	+0.32 dB from 11 January 2000 to 6 December 2000 (included) -0.4322 dB [ENVISAT]	Do not use sigma0 GFO after 2 Aug 2006. Calibrated sigma0 Ku-band and adjusted wind speed set to NaN over this time period.
Jason-2 *Version T & D*	-2.7668] + 0.2024 (version D) dB [ENVISAT	
Jason-3	TBD	Not estimated
CryoSat-2	none	

Topex-Poseidon/Topex Side A (up to cycle 235):	correction as a function of cycle number: for side-A:	Do not use the 10 first TOPEX cycles, date lower than or equal to 31 Dec 1992.

	• table 2-b for cycle numbers lower than 133 • table 2-a for cycle 133 and greater, from Hayne and Hancock, July 1999. -0.4739 dB [ENVISAT]	Do not use TOPEX miss-pointing cycles 433-437 included, i.e. data between June 15, 2004 and August 2, 2004, included. Calibrated sigma0 Ku-band and adjusted wind speed set to NaN over this time periods.
Side B (from cycle 236):	for side-B : Table G-1 of Lockwood et al., July 2006. -0.4739 dB [ENVISAT]	

adjusted sigma0 [sigma0]

```
double sigma0_adjusted(time) ;
        sigma0_adjusted:_FillValue = 9.96921e+36f ;
        sigma0_adjusted:long_name = "Ku band adjusted backscatter coefficient" ;
         sigma0_adjusted:band = "Ku" ;
        sigma0_adjusted:units = "dB" ;
        sigma0_adjusted:quality_flag = "sigma0_quality" ;
        sigma0_adjusted:coordinates = "time lon lat" ;
        sigma0_adjusted:comment = "All instrumental corrections included.
Adjusted." ;
         sigma0_adjusted:coverage_content_type = "physicalMeasurement" ;
```

4.1.2.7 Wind speed

The provided altimeter wind speed is taken from the source product without any adjustment or correction.

4.1.2.8 Model data

The selected source for model is the ERA5 reanalysis (https://climate.copernicus.eu/climate-reanalysis) : currently it is only filled in from 2000 to 2018, but it is being extended backward in a later version. The parameters currently extracted are:

- U and V wind components at 10m
- air temperature at 2m
- sea level surface pressure

Sea surface temperature and total liquid water content are currently missing and will be added in a later version.

Model wind speed zonal component [wind_speed_model_u]

```
double wind_speed_model_u(time) ;
        wind_speed_model_u:_FillValue = 9.96921e+36f  ;
        wind_speed_model_u:long_name = "U component of the model wind vector" ;
        wind_speed_model_u:standard_name = "eastward_wind" ;
        wind_speed_model_u:units = "m s-1" ;
        wind_speed_model_u:source = "atmospheric model ERA5" ;
        wind_speed_model_u:institution = "ECMWF" ;
        wind_speed_model_u:coordinates = "time lon lat" ;
         wind_speed_model_u:coverage_content_type = "modelResult" ;
```

Model wind speed meridional component [wind_speed_model_v]

```
double wind_speed_model_v(time) ;
        wind_speed_model_v:_FillValue = 9.96921e+36f  ;
        wind_speed_model_v:long_name = "V component of the model wind vector" ;
        wind_speed_model_v:standard_name = "northward_wind" ;
        wind_speed_model_v:units = "m s-1" ;
        wind_speed_model_v:source = "atmospheric model ERA5" ;
        wind_speed_model_v:institution = "ECMWF" ;
        wind_speed_model_v:coordinates = "time lon lat" ;
         wind_speed_model_v:coverage_content_type = "modelResult" ;
```

Sea surface temperature [sea_surface_temperature]

```
double sea_surface_temperature(time) ;
        sea_surface_temperature:_FillValue = 32767s ;
        sea_surface_temperature:long_name = "sea surface temperature" ;
        sea_surface_temperature:standard_name = "sea_surface_temperature" ;
        sea_surface_temperature:units = "K" ;
        sea_surface_temperature:source = "atmospheric model ERA5" ;
        sea_surface_temperature:institution = "ECMWF" ;
        sea_surface_temperature:coordinates = "time lon lat" ;
         sea_surface_temperature:coverage_content_type = "modelResult" ;
```

Surface air temperature [surface_air_temperature]

```
double surface_air_temperature(time) ;
        surface_air_temperature:_FillValue = 32767s ;
        surface_air_temperature:long_name = "surface air temperature" ;
        surface_air_temperature:standard_name = "air_temperature" ;
        surface_air_temperature:units = "K" ;
        surface_air_temperature:source = "atmospheric model ERA5" ;
        surface_air_temperature:institution = "ECMWF" ;
        surface_air_temperature:coordinates = "time lon lat" ;
         surface_air_temperature:coverage_content_type = "modelResult" ;
```

Surface air pressure [surface_air_pressure]

```
double surface_air_pressure(time) ;
        surface_air_pressure:_FillValue = 32767s ;
        surface_air_pressure:long_name = "surface air pressure" ;
        surface_air_pressure:standard_name = "air_pressure_at_mean_sea_level" ;
        surface_air_pressure:units = "Pa" ;
        surface_air_pressure:source = "atmospheric model ERA5" ;
        surface_air_pressure:institution = "ECMWF" ;
        surface_air_pressure:coordinates = "time lon lat" ;
         wind_speed_model_u:coverage_content_type = "modelResult" ;
```

Total column liquid water [total_column_liquid_water_content]

```
double total_liquid_water_content(time) ;
        total_liquid_water_content:_FillValue = 32767s ;
        total_liquid_water_content:long_name = "total column liquid water" ;
        total_liquid_water_content:standard_name =
"atmosphere_cloud_liquid_water_content" ;
        total_liquid_water_content:units = "kg m-2" ;
        total_liquid_water_content:source = "atmospheric model ERA5" ;
        total_liquid_water_content:institution = "ECMWF" ;
        total_liquid_water_content:coordinates = "time lon lat" ;
         total_liquid_water_content:coverage_content_type = "modelResult" ;
```

4.1.2.9 Sea Surface Height

The sea surface height is taken from the ESA CCI Sea Level datasets, available for ERS-1, ERS-2, Envisat, GFO, Topex-Poseidon, Jason-1, Jason-2, CryoSat-2 and Altika, up to February 2016. As a consequence:

- no sea level information is provided for the latest altimeters: Jason-3, Sentinel-3A,...
- no sea level information is filled in beyond February 2016 for any altimeter

The CCI sea level dataset is strongly edited, retaining only the good quality measurements: we use _FillValue wherever no sea level measurements is provided in the CCI Sea Level dataset or could be matched to the L2P measurements for some reason.

4.1.2.10 Sea ice concentration

Note that in this editing, we use an external sea ice concentration product to discard possibly ice contaminated pixels. Because no products provides a complete temporal coverage (missed acquisitions, discontinuities between different microwave radiometer missions, infrequent updates of some datasets), we had to use three different sources, which are in order of priority:

1. CCI Sea Ice Concentration from AMSR, v2.1 (2002-2017)
2. CCI Sea ice Concentration from SSMI, v1.11 (-2017)
3. OSI SAF Sea Ice Concentration reprocessing v1p2 (2017-2019)
4. OSI SAF Sea Ice Concentration reprocessing v2p0 (1979-2015)

For each source, we use the closest in time concentration map, up to three days old, before switching to the next source in line.

4.1.2.11 Bathymetry

The same bathymetry source was used for all mission to get the ocean sea floor depth. We selected the 30 second arc General Bathymetric Chart of the Oceans (GEBCO), 2014 [doi:10.1002/2015EA000107], available at:

https://www.gebco.net/data_and_products/gridded_bathymetry_data/gebco_30_second_grid

Ocean depth [bathymetry]

```
double bathymetry(time) ;
        bathymetry:_FillValue = 32767s ;
        bathymetry:long_name = "ocean depth" ;
        bathymetry:units = "m" ;
        bathymetry:source = "The GEBCO_2014 Grid, version 20150318,
www.gebco.net,  doi:10.1002/2015EA000107" ;
        bathymetry:institution = "IOC/IHO" ;
        bathymetry:coordinates = "time lon lat" ;
        bathymetry:coverage_content_type = "auxiliaryInformation" ;
```

4.1.2.12 Distance to coast

The distance to the nearest coastline for each ocean measurement was extracted from the Distance to Nearest Coastline grid at 0.01 degree resolution, provided by the NASA Goddard Space Flight Center (GSFC) Ocean Color Group and available at:

http://www.pacioos.hawaii.edu/metadata/dist2coast_1deg.html

Distance to nearest coast [distance_to_coast]

```
double distance_to_coast(time) ;
        distance_to_coast:_FillValue = 1.e+20 ;
        distance_to_coast:long_name = "distance to nearest coast" ;
        distance_to_coast:authority = "CF-1.7" ;
        distance_to_coast:units = "m" ;
        distance_to_coast:source = "Distance to Nearest Coastline: 0.01-Degree
Grid, by NASA Goddard Space Flight Center (GSFC) Ocean Color Group" ;
        distance_to_coast:coverage_content_type = "auxiliaryInformation" ;
        distance_to_coast:institution = "NASA/GFSC" ;
        distance_to_coast:coordinates = "time lon lat" ;
```

4.1.3 Global attributes

Global Attribute	Example content

title	ESA CCI Sea State L2P derived from Jason-2 GDR
institution	Institut Francais de Recherche pour l'Exploitation de la mer / CERSAT, European Space Agency
institution_abbreviation	Ifremer/Cersat, ESA
source	CCI Sea State Jason-2 GDR to L2P Processor 1.0
history	2018-06-18T14:17:10 UTC -- Creation from processor version v1.0
references	http://cci.esa.int/seastate
Conventions	CF-1.6, ACDD-1.3, ISO 8601
product_version	1.0
summary	This dataset contains along-track significant wave height measurements from Jason-2 altimeter, cross-calibrated with other altimetry missions and reference in situ measurements.
keywords	satellite,observation,ocean
id	ESACCI-SEASTATE-L2P-SWH-JASON2-20170130T145103-fv01.nc
naming authority	fr.ifremer.cersat
keywords_vocabulary	NASA Global Change Master Directory (GCMD) Science Keywords
cdm_data_type	trajectory
featureType	trajectory
comment	These data were produced at ESACCI as part of the ESA SST CCI project.
date_created	20120131T120000Z
date_modified	20160111T181628Z
creator_name	Ifremer / Cersat
creator_url	http://cersat.ifremer.fr
creator_email	cersat@ifremer.fr
creator_institution	Ifremer / Cersat
project	Climate Change Initiative - European Space Agency
geospatial_lat_min	-80
geospatial_lat_max	80

geospatial_lat_units	degrees_north
geospatial_lon_min	-180
geospatial_lon_max	180
geospatial_lon_units	degrees_east
time_coverage_start	20170130T145103Z
time_coverage_end	20170130T154708Z
time_coverage_duration	PT1H2M5S
time_coverage_resolution	PT1S
geospatial_bounds	POLYGON ((-180. -90., -180. 90., 180. 90., 180. -90., -180. -90.))
standard_name_vocabulary	NetCDF Climate and Forecast (CF) Metadata Convention version 1.6
license	ESA CCI Data Policy: free and open access
platform	Jason-2
platform_vocabulary	CEOS
sensor	POSEIDON-3
instrument	POSEIDON-3
instrument_vocabulary	CEOS
spatial_resolution	11.2 km x 5.1 km
cycle_number	316
pass_number	157
equator_crossing_time	2017-01-30T15:19:10.105000 UTC
equator_crossing_longitude	47.48
netcdf_version_id	4.3.0 of Jul 8 2013 12:17:12 $
metadata_link	
acknowledgement	Please acknowledge the use of these data with the following statement: these data were obtained from the ESA CCI Sea State project
format_version	Data Standards Requirements for CCI Data Producers, v2.0, 17 Septembre 2018
processing_software	Jason-2 GDR to L2P Processor 1.0
processing_level	L2P

uuid	57822220-4F3C-11E8-B351-0024E836CC1A
publisher_name	Ifremer/Cersat
publisher_url	cersat.ifremer.fr
publisher_email	cersat@ifremer.fr
publisher_institution	Ifremer/Cersat
scientific_support_contact	Guillaume.Dodet@ifremer.fr
technical_support_contact	cersat@ifremer.fr

4.1.4 Planned improvements

New releases may be published in the coming months, including the following improvements:

- extending the time series beyond 2018
- adding SRAL altimeters onboard Sentinel-3A & 3B
- using newest source L2 for some missions such as the Envisat v3.0 dataset, ERS-1 and ERS-2 REAPER datasets
- completing the ERA5 model variables before 2000 and adding sea surface temperature and total liquid water content
- improving the editing of SWH data, in particular over sea ice areas, slicks and strong wind areas
- adding the mean square slope
- revising the adjustment of sigma0
- adding an adjusted altimeter wind speed

4.2 Version 1 dataset: L3

This section describes the specific variables contained in the version 1 L3 for Sea State CCI. A full description of the coordinates and variables is given in Annex A.

	coordinate variables
time	time (in seconds since 1985-01-01)
lat	latitude
lon	longitude
	instrumental variables for 1st band altimeter (usually Ku)
sigma0	Ku band backscatter coefficient (raw)
sigma0_calibrated	Ku band calibrated backscatter coefficient
	environmental variables for 1st band altimeter (usually Ku)
swh	significant wave height (as available in source GDR product)
swh_adjusted	significant wave height (adjusted)
swh_denoised	significant wave height (adjusted and denoised)
swh_uncertainty	best estimate of significant wave height standard error
	auxiliary variables
topography	
bathymetry	ocean depth
distance_to_coast	distance to nearest coast
	source
satellite	identifier of the satellite from which the measurement comes from
relative_pass_number	relative pass number in the satellite history, from which the measurement comes from
cycle	cycle in the satellite history, from which the measurement comes from

4.3 Version 1 dataset: L4

This section describes the specific variables contained in the version 1 L4 for Sea State CCI. L4 is a monthly gridded product with a spatial resolution of 1°. Statistics are based on the median SWH value from transects over each 1° square, provided there are at least 5 valid measurements (at 1Hz) along the transect.

	coordinate variables
time	time (in seconds since 1985-01-01)
lat	latitude
lon	longitude
	environmental variables for 1st band altimeter (usually Ku)
swh_mean	mean of median significant wave height values
swh_rms	rms of median significant wave height values
swh_num	number of median significant wave height values
swh_sum	total of median significant wave height values
swh_squared_sum	total of median significant wave height squared values
swh_log_sum	total of median significant wave height log values
swh_log_squared_sum	total of median significant wave height log squared values
swh_num_gt0050	number of median significant wave height values greater than 0.5m
swh_num_gt0100	number of median significant wave height values greater than 1.0m
swh_num_gt0150	number of median significant wave height values greater than 1.5m
swh_num_gt0200	number of median significant wave height values greater than 2.0m
swh_num_gt0250	number of median significant wave height values greater than 2.5m
swh_num_gt0300	number of median significant wave height values greater than 3.0m
swh_num_gt0350	number of median significant wave height values greater than 3.5m
swh_num_gt0400	number of median significant wave height values greater than 4.0m

swh_num_gt0500	number of median significant wave height values greater than 5.0m
swh_num_gt0600	number of median significant wave height values greater than 6.0m
swh_num_gt0800	number of median significant wave height values greater than 8.0m
swh_num_gt1000	number of median significant wave height values greater than 10.0m
swh_max	maximum median significant wave height value

5. Differences with GlobWave L2P products

The following table summarizes the differences between GlobWave and CCI L2P products : in black: common variables between GlobWave and CCI, in red: removed wrt GlobWave, in green: additions to GlobWave.

	coordinate variables
time	time (in seconds since 1985-01-01)
lat	latitude
lon	longitude
	sensor variables for each altimeter band
1st band backscatter	
sigma0	Ku band backscatter coefficient (1st band)
sigma0_rms	RMS of the Ku band backscatter coefficient
sigma0_num_valid	number of valid points used to compute Ku band backscatter coefficient
mss	Mean square slope
2nd band backscatter	
sigma0_2nd	C-band backscatter coefficient (2nd band)
sigma0_rms_2nd	RMS of the C band backscatter coefficient
sigma0_num_valid_2nd	number of valid points used to compute C band backscatter coefficient
	environmental variables for each altimeter band (usually: 1st band = Ku, 2nd band = C or S)
1st band wave variables	
swh	significant wave height (1st band, uncalibrated)
swh_corrected	significant wave height (1st band, calibrated)
swh_denoised	significant wave height (1st band, calibrated, denoised)
swh_quality	quality level significant wave height measurement (1st band)
swh_standard_error	best estimate of significant wave height standard error

swh_rms	RMS of significant wave height (1st band)
swh_num_valid	number of valid points used to compute significant wave height (1st band)
swh_rejection_flags	consolidated instrument and ice flags
2nd band wave variables	
swh_2nd	corrected significant wave height (2ns band, uncalibrated)
swh_rms_2nd	RMS of significant wave height (2nd band)
swh_num_valid_2nd	number of valid points used to compute significant wave height (2nd band)
swh_2nd_quality	quality level significant wave height measurement (2nd band)
	auxiliary variables
instrument/platform	
off_nadir_angle_wf	square of the off nadir angle computed from waveforms
off_nadir_angle_pf	Off nadir angle from platform
Auxiliary measurements	
wind_speed_alt	altimeter wind speed
wind_speed_alt_calibrated	Calibrated Altimeter wind speed.
wind_speed_rad	radiometer wind speed
sea_surface_height	sea level
range_rms	RMS of the Ku band range
range_rms_2nd	RMS of the C band range
topography	
bathymetry	ocean depth
distance_to_coast	distance to nearest coast
Model auxiliary data	

wind_speed_model_u	U component of the model wind vector
wind_speed_model_v	V component of the model wind vector
sea_surface_temperature	sea surface temperature
surface_air_temperature	surface air temperature
surface_air_temperature	surface air pressure
total_column_liquid_water_content	Total column cloud liquid water content

6. L2P editing criteria

Editing is applied to original L2 data in order to qualify measurements (in L2P) and retain only good measurements (in L3). The used criteria are specific to each mission and are detailed in the following sections for each of them.

6.1 Topex

6.1.1 sanity checks

Measurements are classified as **undefined** if swh or swh rms (Ku band) was not calculated in the source GDR product (fill value).

Measurements are classified as **bad** if one of the following sanity tests fails:

- GDR geo_bad1 bit1 = 0 [land]
- GDR geo_bad1 bit3 = 0 [ice]
- GDR swh_ku > 0
- GDR swh_numval_ku = 8
- GDR agc_numval = 16

6.1.2 SWH outlier test

Last, an iterative filtering of outliers is performed over a window of 100 km around each 1 Hz measurement (at least 4 valid measurements are required within the window): measurements which deviation to the mean swh within the window is beyond 5 standard deviation or 5m are classified as **bad**.

6.1.3 sea-ice test

The sea ice fraction used here comes from the products by the CCI Sea-Ice project.

Among the remaining **good** measurements, measurements for which sea ice fraction is greater than 0. but lower than 0.1 are classified as **acceptable**. If the sea ice fraction is greater than 0.1, measurements are classified as **bad**.

6.1.4 SWH rejection flag

The SWH rejection flags are set as follows:

flag	criteria for which the flag is set
not_water	GDR geo_bad1 bit1 = 1 [land] GDR geo_bad1 bit3 = 1 [ice]
sea_ice	CCI sea ice fraction >= 0.1

swh_validity	GDR swh_ku <= 0 or undefined
sigma0_validity	GDR sigma0_ku <= 0 or undefined GDR agc_numval = 16
ssh_validity	unused (always 0)
waveform_validity	GDR swh_numval_ku != 8
swh_rms_outlier	GDR swh_rms_ku <= 0 or undefined
swh_outlier	measurements classified as bad when performing the SWH outlier test

6.2 ERS-1

6.2.1 sanity checks

Measurements are classified as **undefined** if swh and swh rms (Ku band) was not calculated in the source GDR product (fill value).

Measurements are classified as **bad** if one of the following sanity tests fails:

- GDR mcd bit0 = 0 [record is invalid]
- GDR mcd bit7 = 0 [swh quality]
- GDR mcd bit8 = 0 [sigma0 quality]
- GDR swh_numval_ku > 16
- GDR sigma0_ku defined
- GDR swh_ku > 0

6.2.2 SWH outlier test

Last, an iterative filtering of outliers is performed over a window of 100 km around each 1 Hz measurement (at least 4 valid measurements are required within the window): measurements which deviation to the mean swh within the window is beyond 5 standard deviation or 5m are classified as **bad**.

6.2.3 sea-ice test

The sea ice fraction used here comes from the products by the CCI Sea-Ice project.

Among the remaining **good** measurements, measurements for which sea ice fraction is greater than 0. but lower than 0.1 are classified as **acceptable**. If the sea ice fraction is greater than 0.1, measurements are classified as **bad**.

6.2.4 SWH rejection flag

The SWH rejection flags are set as follows:

flag	criteria for which the flag is set
not_water	GDR mcd bit0 = 1 [invalid product]
sea_ice	CCI sea ice fraction >= 0.1
swh_validity	GDR swh_ku <= 0 or undefined GDR mcd bit7 = 1 [swh quality]
sigma0_validity	GDR sigma0_ku <= 0 or undefined GDR mcd bit8 = 1 [sigma0 quality]
ssh_validity	unused (always 0)
waveform_validity	GDR swh_numval_ku <= 16
swh_rms_outlier	GDR swh_rms_ku <= 0 or undefined
swh_outlier	measurements classified as bad when performing the SWH outlier test

6.3 ERS-2

6.3.1 sanity checks

Measurements are classified as **undefined** if swh and swh rms (Ku band) was not calculated in the source GDR product (fill value).

Measurements are classified as **bad** if one of the following sanity tests fails:

- GDR mcd bit0 = 0 [record is invalid]
- GDR mcd bit7 = 0 [swh quality]
- GDR mcd bit8 = 0 [sigma0 quality]
- GDR swh_numval_ku > 16
- GDR sigma0_ku defined
- GDR swh_ku > 0

6.3.2 SWH outlier test

Last, an iterative filtering of outliers is performed over a window of 100 km around each 1 Hz measurement (at least 4 valid measurements are required within the window): measurements which deviation to the mean swh within the window is beyond 5 standard deviation or 5m are classified as **bad**.

6.3.3 sea-ice test

The sea ice fraction used here comes from the products by the CCI Sea-Ice project.

Among the remaining **good** measurements, measurements for which sea ice fraction is greater than 0. but lower than 0.1 are classified as **acceptable**. If the sea ice fraction is greater than 0.1, measurements are classified as **bad**.

6.3.4 SWH rejection flag

The SWH rejection flags are set as follows:

flag	criteria for which the flag is set
not_water	GDR mcd bit0 = 1 [invalid product]
sea_ice	CCI sea ice fraction >= 0.1
swh_validity	GDR swh_ku <= 0 or undefined GDR mcd bit7 = 1 [swh quality]
sigma0_validity	GDR sigma0_ku <= 0 or undefined GDR mcd bit8 = 1 [sigma0 quality]
ssh_validity	unused (always 0)
waveform_validity	GDR swh_numval_ku <= 16
swh_rms_outlier	GDR swh_rms_ku <= 0 or undefined
swh_outlier	measurements classified as bad when performing the SWH outlier test

6.4 GFO

6.4.1 sanity checks

Measurements are classified as **undefined** if swh and swh rms (Ku band) was not calculated in the source GDR product (fill value).

Measurements are classified as **bad** if one of the following sanity tests fails:

- GDR bit02 of quality_word_1 = 0 [record is zero filled]
- GDR bit03 of quality_word_1 = 0 [A not in fine track]
- GDR bit07 of quality_word_1 = 0 [no smoothed VATT]
- GDR bit10 of quality_word_1 = 0 [SWH bounds error]
- GDR bit11 of quality_word_2 = 0 [land contamination]
- GDR surface_type != 3 [ocean like]
- GDR swh_numval_ku = 10
- GDR swh_rms_ku / swh_ku < 0.2
- GDR sigma0_ku defined
- GDR swh_ku > 0

6.4.2 SWH outlier test

Last, an iterative filtering of outliers is performed over a window of 100 km around each 1 Hz measurement (at least 4 valid measurements are required within the window): measurements which deviation to the mean swh within the window is beyond 5 standard deviation or 5m are classified as **bad**.

6.4.3 sea-ice test

The sea ice fraction used here comes from the products by the CCI Sea-Ice project.

Among the remaining **good** measurements, measurements for which sea ice fraction is greater than 0. but lower than 0.1 are classified as **acceptable**. If the sea ice fraction is greater than 0.1, measurements are classified as **bad**.

6.4.4 SWH rejection flag

The SWH rejection flags are set as follows:

flag	**criteria for which the flag is set**
not_water	GDR surface_type == 3 GDR bit11 of quality_word_2 = 1 [land contamination]
sea_ice	CCI sea ice fraction >= 0.1
swh_validity	GDR swh_ku <= 0 or undefined GDR bit10 of quality_word_1 = 1 [SWH bounds error]
sigma0_validity	GDR sigma0_ku <= 0 or undefined
ssh_validity	unused (always 0)
waveform_validity	GDR swh_numval_ku != 10 GDR bit02 of quality_word_1 = 1 [record is zero filled] GDR bit03 of quality_word_1 = 1 [A not in fine track] GDR bit07 of quality_word_1 = 1 [no smoothed VATT]
swh_rms_outlier	GDR swh_rms_ku <= 0 or undefined GDR swh_rms_ku swh_rms_ku / swh_ku >= 0.2
swh_outlier	measurements classified as bad when performing the SWH outlier test

6.5 Envisat

6.5.1 sanity checks

Measurements are classified as **undefined** if swh was not calculated in the source GDR product (fill value).

Measurements are classified as **bad** if one of the following sanity tests fails:

- GDR mcd bit16 = 0 [retracking Ku]
- GDR mcd bit06 = 0 [wave form samples fault]
- GDR altim_landocean_flag = 0 [ocean like]
- GDR ku_ocean_retrk_qua_flags = 0
- GDR abs(off_nadir_angle_wf) < 0.1
- GDR quality = 0
- GDR sigma0_ku > 0
- GDR swh_rms_ku > 0
- GDR swh_ku > 0

6.5.2 SWH rms test

Besides, a test on swh rms (as provided in GDR for 1 Hz measurements) is performed, checking it is below an altimeter and swh dependant threshold. Measurements for which the swh rms is beyond this threshold are classified as **bad**. The threshold is defined following recommendations in "Global altimeter SWH dataset, P.Queffeulou, 2017":

- a polynomial fit:

$$P(swh) = 0.0384\ swh^2 - 0.0500\ swh + 0.8457$$

6.5.3 SWH outlier test

Last, an iterative filtering of outliers is performed over a window of 100 km around each 1 Hz measurement (at least 4 valid measurements are required within the window): measurements which deviation to the mean swh within the window is beyond 5 standard deviation or 5m are classified as **bad**.

6.5.4 sea-ice test

The sea ice fraction used here comes from the products by the CCI Sea-Ice project.

Among the remaining **good** measurements, measurements for which sea ice fraction is greater than 0. but lower than 0.1 are classified as **acceptable**. If the sea ice fraction is greater than 0.1, measurements are classified as **bad**.

6.5.5 SWH rejection flag

The SWH rejection flags are set as follows:

flag	criteria for which the flag is set
not_water	GDR land != 0
sea_ice	CCI sea ice fraction >= 0.1
swh_validity	GDR swh_ku <= 0 or undefined
sigma0_validity	GDR sigma0_ku <= 0 or undefined
ssh_validity	unused (always 0)
waveform_validity	GDR swh_numval_ku <= 18 GDR abs(off_nadir_angle_wf) >= 0.1 GDR quality != 0 GDR ku_ocean_retrk_qua_flags != 0 GDR MCD bit16 != 0 GDR MCD bit06 != 0
swh_rms_outlier	GDR swh_rms_ku <= 0 or undefined measurements classified as bad when performing the SWH rms outlier test
swh_outlier	measurements classified as bad when performing the SWH outlier test

6.6 Jason-1

6.6.1 sanity checks

Measurements are classified as **undefined** if swh was not calculated in the source GDR product (fill value).

Measurements are classified as **bad** if one of the following sanity tests fails:

- GDR surface_type < 2 [open oceans or semi-enclosed seas, enclosed seas or lakes]
- GDR qual_alt_1hz_swh_ku = 0 [ocean like]
- GDR swh_numval_ku > 18
- GDR swh_rms_ku > 0
- GDR swh_ku > 0

6.6.2 SWH rms test

Besides, a test on swh rms (as provided in GDR for 1 Hz measurements) is performed, checking it is below an altimeter and swh dependant threshold. Measurements for which the swh rms is beyond this threshold are classified as **bad**. The threshold is defined following recommendations in “Global altimeter SWH dataset, P.Queffeulou, 2017”:

- a look-up table is used for swh in the [0, 5m] range
- a polynomial fit for the [5m, 8m] range:

$$P(swh) = 0.0138\ swh^3 - 0.1864\ swh^2 + 1.0491\ swh - 1.0052$$

- P(8m) is used for swh values beyond 8 meters

6.6.3 SWH outlier test

Last, an iterative filtering of outliers is performed over a window of 100 km around each 1 Hz measurement (at least 4 valid measurements are required within the window): measurements which deviation to the mean swh within the window is beyond 5 standard deviation or 5m are classified as **bad**.

6.6.4 sea-ice test

The sea ice fraction used here comes from the AMSR L4 products by the CCI Sea-Ice project.

Among the remaining **good** measurements, measurements for which sea ice fraction is greater than 0. but lower than 0.1 are classified as **acceptable**. If the sea ice fraction is greater than 0.1, measurements are classified as **bad**.

6.6.5 SWH rejection flag

The SWH rejection flags are set as follows:

flag	criteria for which the flag is set
not_water	GDR surface_type >= 2 qual_alt_1hz_swh_ku != 0
sea_ice	CCI sea ice fraction >= 0.1
swh_validity	GDR swh_ku <= 0 or undefined
ssh_validity	unused (always 0)
sigma0_validity	GDR sig0_ku_mle3 defined
waveform_validity	GDR swh_numval_ku <= 18
swh_rms_outlier	GDR swh_rms_ku <= 0 or undefined measurements classified as bad when performing the SWH rms outlier test
swh_outlier	measurements classified as bad when performing the SWH outlier test

6.7 Jason-2

6.7.1 sanity checks

Measurements are classified as **undefined** if swh was not calculated in the source GDR product (fill value).

Measurements are classified as **bad** if one of the following sanity tests fails:

- GDR surface_type < 2 [open oceans or semi-enclosed seas, enclosed seas or lakes]
- GDR swh_ku > 0
- GDR swh_numval_ku > 10
- GDR swh_rms_ku defined
- GDR sig0_ku_mle3 >= 5.

6.7.2 SWH rms test

Besides, a test on swh rms (as provided in GDR for 1 Hz measurements) is performed, checking it is below an altimeter and swh dependant threshold. Measurements for which the swh rms is beyond this threshold are classified as **bad**. The threshold is defined following recommendations in “Global altimeter SWH dataset, P.Queffeulou, 2017”:

- a look-up table is used for swh in the [0, 4.5m] range
- a polynomial fit for the [4.5m, 8m] range:

$$P(swh) = 0.00854127\, swh^4 - 0.16602944\, swh^3 - 1.21803198\, swh^2 - 3.73409038\, swh + 5.00280091$$

- P(8m)= 3.06 is used for swh values beyond 8m

6.7.3 SWH outlier test

Last, an iterative filtering of outliers is performed over a window of 100 km around each 1 Hz measurement (at least 4 valid measurements are required within the window): measurements which deviation to the mean swh within the window is beyond 5 standard deviation or greater than 5 meters are classified as **bad**.

6.7.4 sea-ice test

The sea ice fraction used here comes from the AMSR L4 products by the CCI Sea-Ice project.

Among the remaining **good** measurements, measurements for which sea ice fraction is greater than 0. but lower than 0.1 are classified as **acceptable**. If the sea ice fraction is greater than 0.1, measurements are classified as **bad**.

6.7.5 SWH rejection flag

The SWH rejection flags are set as follows:

flag	criteria for which the flag is set
not_water	GDR surface_type >= 2
sea_ice	CCI sea ice fraction >= 0.1
swh_validity	swh_ku <= 0
ssh_validity	unused (always 0)
sigma0_validity	GDR sig0_ku_mle3 < 5. or undefined
waveform_validity	GDR swh_numval_ku <= 10
swh_rms_outlier	GDR swh_rms_ku undefined measurements classified as bad when performing the SWH rms outlier test
swh_outlier	measurements classified as bad when performing the SWH outlier test

6.8 Jason-3

6.8.1 sanity checks

Measurements are classified as **undefined** if swh was not calculated in the source GDR product (fill value).

Measurements are classified as **bad** if one of the following sanity tests fails:

- GDR surface_type < 2 [open oceans or semi-enclosed seas, enclosed seas or lakes]
- GDR swh_ku > 0
- GDR swh_numval_ku > 10
- GDR swh_rms_ku defined
- GDR sig0_ku_mle3 >= 5.

6.8.2 SWH rms test

Besides, a test on swh rms (as provided in GDR for 1 Hz measurements) is performed, checking it is below an altimeter and swh dependant threshold. Measurements for which the swh rms is beyond this threshold are classified as **bad**. The threshold is defined following recommendations in “Global altimeter SWH dataset, P.Queffeulou, 2017”:

- a look-up table is used for swh in the [0, 4.5m] range
- a polynomial fit for the [4.5m, 8m] range:

$P(swh) = 0.00245436\, swh^4 - 0.04199479\, swh^3 + 0.28811371\, swh^2 - 0.77121584\, swh + 1.66388247$

- P(8m)= 2.4851 is used for swh values beyond 8m

6.8.3 SWH outlier test

Last, an iterative filtering of outliers is performed over a window of 100 km around each 1 Hz measurement (at least 4 valid measurements are required within the window): measurements which deviation to the mean swh within the window is beyond 5 standard deviation or greater than 5 meters are classified as **bad**.

6.8.4 sea-ice test

The sea ice fraction used here comes from the AMSR L4 products by the CCI Sea-Ice project.

Among the remaining **good** measurements, measurements for which sea ice fraction is greater than 0. but lower than 0.1 are classified as **acceptable**. If the sea ice fraction is greater than 0.1, measurements are classified as **bad**.

6.8.5 SWH rejection flag

The SWH rejection flags are set as follows:

flag	**criteria for which the flag is set**
not_water	GDR surface_type >= 2
sea_ice	CCI sea ice fraction >= 0.1
swh_validity	swh_ku <= 0
ssh_validity	unused (always 0)
sigma0_validity	GDR sig0_ku_mle3 < 5. or undefined
waveform_validity	GDR swh_numval_ku <= 10
swh_rms_outlier	GDR swh_rms_ku undefined measurements classified as bad when performing the SWH rms outlier test
swh_outlier	measurements classified as bad when performing the SWH outlier test

6.9 Cryosat-2

6.9.1 sanity checks

Measurements are classified as **undefined** if swh was not calculated in the source GDR product (fill value).

Measurements are classified as **bad** if one of the following sanity tests fails:

- GDR 'alt_land' flag not set
- GDR 'range_suspect' flag not set
- GDR 'hardware_bad' flag not set [not in SAR mode]
- GDR 'swh_suspect' flag not set
- GDR 'backscatter_suspect' flag not set
- GDR swh_rms_ku defined
- GDR swh_ku > 0

6.9.2 SWH rms test

Besides, a test on swh rms (as provided in GDR for 1 Hz measurements) is performed, checking it is below an altimeter and swh dependant threshold. Measurements for which the swh rms is beyond this threshold are classified as **bad**. The threshold is defined following recommendations in “Global altimeter SWH dataset, P.Queffeulou, 2017”:

- a look-up table is used for swh in the [-1, 4.5m] range
- a polynomial fit for the [4.5m, 8m] range:

$$P(swh) = 0.003712808782105\ swh^3 - 0.022959435041166\ swh^2 + 0.155517950243010\ swh + 0.484687460175769$$

- $P(8m) = 2.1604$ is used for swh values beyond 8 meters

6.9.3 SWH outlier test

Last, an iterative filtering of outliers is performed over a window of 100 km around each 1 Hz measurement (at least 4 valid measurements are required within the window): measurements which deviation to the mean swh within the window is beyond 3.9 standard deviation or greater than 5 meters are classified as **bad**.

6.9.4 sea-ice test

The sea ice fraction used here comes from the AMSR L4 products by the CCI Sea-Ice project.

Among the remaining **good** measurements, measurements for which sea ice fraction is greater than 0. but lower than 0.1 are classified as **acceptable**. If the sea ice fraction is greater than 0.1, measurements are classified as **bad**.

6.9.5 SWH rejection flag

The SWH rejection flags are set as follows:

flag	criteria for which the flag is set
not_water	GDR 'alt_land' flag is set
sea_ice	CCI sea ice fraction >= 0.1
swh_validity	GDR swh_ku <= 0 or undefined GDR 'swh_suspect' flag is set
sigma0_validity	GDR 'backscatter_suspect' flag is set
ssh_validity	GDR 'range_suspect' flag is set GDR 'hardware_bad' flag is set
waveform_validity	not used (always set to 0)
swh_rms_outlier	GDR swh_rms_ku undefined measurements classified as bad when performing the SWH rms outlier test
swh_outlier	measurements classified as bad when performing the SWH outlier test

6.10 AltiKa

Measurements are classified as **undefined** if swh was not calculated in the source GDR product (fill value).

Measurements are classified as **bad** if one of the following sanity tests fails:

- GDR surface_type < 2
- GDR ice_flag = 0
- sigma0 >= 5.
- sea ice fraction < 0.1

The sea ice fraction used here comes from the AMSR L4 products by the CCI Sea-Ice project.

Besides, a test on swh rms (as provided in GDR for 1 Hz measurements) is performed, checking it is below an altimeter and swh dependant threshold. Measurements for which the swh rms is beyond this threshold are classified as **bad**. The threshold is defined following recommendations in “Global altimeter SWH dataset, P.Queffeulou, 2017”:

- a look-up table is used for swh in the [0, 2.5m] range
- a polynomial fit for the [2.5m, 12m] range:

$$P(swh) = 0.00122599\ swh^3 - 0.01741631\ swh^2 + 0.17180005\ swh + 0.17894723$$

- P(12m) is used for swh values beyond 12m

Last, an iterative filtering of outliers is performed over a window of 100km around each 1 Hz measurement (at least 4 valid measurements are required within the window): measurements which deviation to the mean swh within the window is beyond 5 standard deviation or 5m are classified as **bad**.

Among the remaining **good** measurements, measurements for which sea ice fraction is between 0. and 0.1 are classified as **acceptable**.

6.9.4 sea-ice test

The sea ice fraction used here comes from the AMSR L4 products by the CCI Sea-Ice project.

Among the remaining **good** measurements, measurements for which sea ice fraction is greater than 0. but lower than 0.1 are classified as **acceptable**. If the sea ice fraction is greater than 0.1, measurements are classified as **bad**.

6.9.5 SWH rejection flag

The SWH rejection flags are set as follows:

flag	criteria for which the flag is set
not_water	GDR surface_type >= 2 GDR ice_flag != 0
sea_ice	CCI sea ice fraction >= 0.1
swh_validity	not used (always set to 0)
sigma0_validity	GDR sigma0 < 5. or undefined
ssh_validity	not used (always set to 0)
waveform_validity	not used (always set to 0)
swh_rms_outlier	GDR swh_rms_ku undefined measurements classified as bad when performing the SWH rms outlier test
swh_outlier	measurements classified as bad when performing the SWH outlier test

Annex A: Calibration of Jason-1, Jason-3, Saral and Cryosat-2 missions

This annex describes the methodology used to calibrate the significant wave height (swh) estimated from Jason-1, Jason-3, Cryosat-2 and Saral. For the other missions of the Sea State CCI data set V1, the calibration formula obtained during the GlobWave project were maintained (see Section 4.1.2.3). Note that the calibration formula derived for Jason-1 during the GlobWave project has been updated since the new version (version E) of the Jason-1 Geophysicial Data Record is provided by AVISO (using MLE4 retracker for SWH and MLE3 retracker for sigma0) is used in the Sea State CCI project.

The calibrations of missions Jason-1, Jason-3, Cryosat-2 and Saral are performed against the Jason-2 data, as calibrated by Queffeulou et al. (2017). According to the GlobWave Annual Quality Control Report (AQCR), there was no specific quality problem in Jason-2 and the variability in terms of data quality was lower than for Jason-1 and Envisat (see Fig 2.3 and p10 in AQCR). During the GlobWave project, the Jason-2 swh data was calibrated based on GlobWave error analysis (1.041 x swh - 0.042). This calibrated Jason-2 swh data is considered as our reference data set for calibration. Note that this choice is likely to evolve in the future version of the Sea State CCI dataset.

Altimeter swh calibration is carried out by comparing swh measurements at cross-over locations between the altimeter to be calibrated and the reference altimeter (Jason-2 in our case). A cross-over data pair is defined each time the two satellite ground tracks intersect within a 60-min time window (Figure 1). In order to attenuate the impact of along-track noise (instrumental and retracking-induced noise) in the comparison, swh is averaged along n (7-9 depending on altimeter orbital velocity) consecutive measurements 25-km apart of the intersection points. swh at cross-over locations are then compared to estimate the calibration formula.

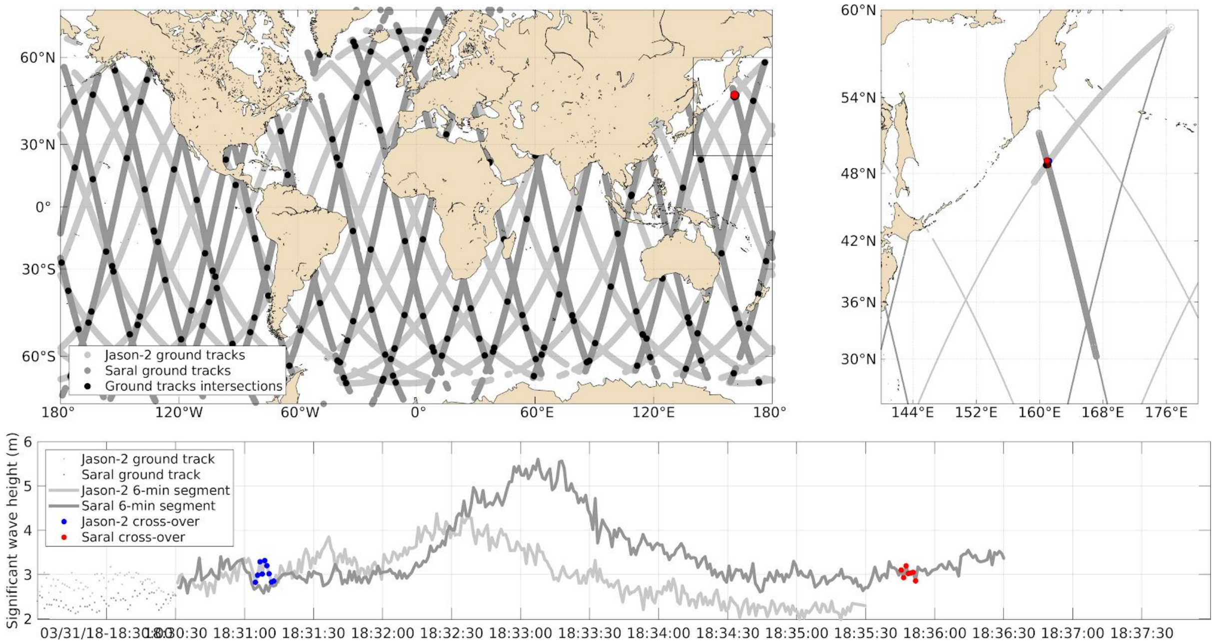

Figure 1. Top-left panel. Jason-2 (light grey) and Saral (dark grey) ground tracks on March 31 2018 with ground track intersection shown with black circles. Top right panel. Zoom on a ground track cross-over occurring within 1

hour. Bottom panel. Time-series of the along-track significant wave height corresponding to the ground tracks shown in the top right panel.

Visual assessment of Jason-1, Jason-3 and Saral swh measurements against Jason-2 calibrated swh measurements indicate a linear relationship between these missions (Figure 2, 3 and 4). Linear calibration formula for Jason-1, Jason-3 and Saral are obtained by fitting a least-square regression line through the Jason-2 against Saral and Jason-3 swh data. Note that the fitting was only applied for swh values larger than 1 m since altimeter measurements become very noisy at low sea states.

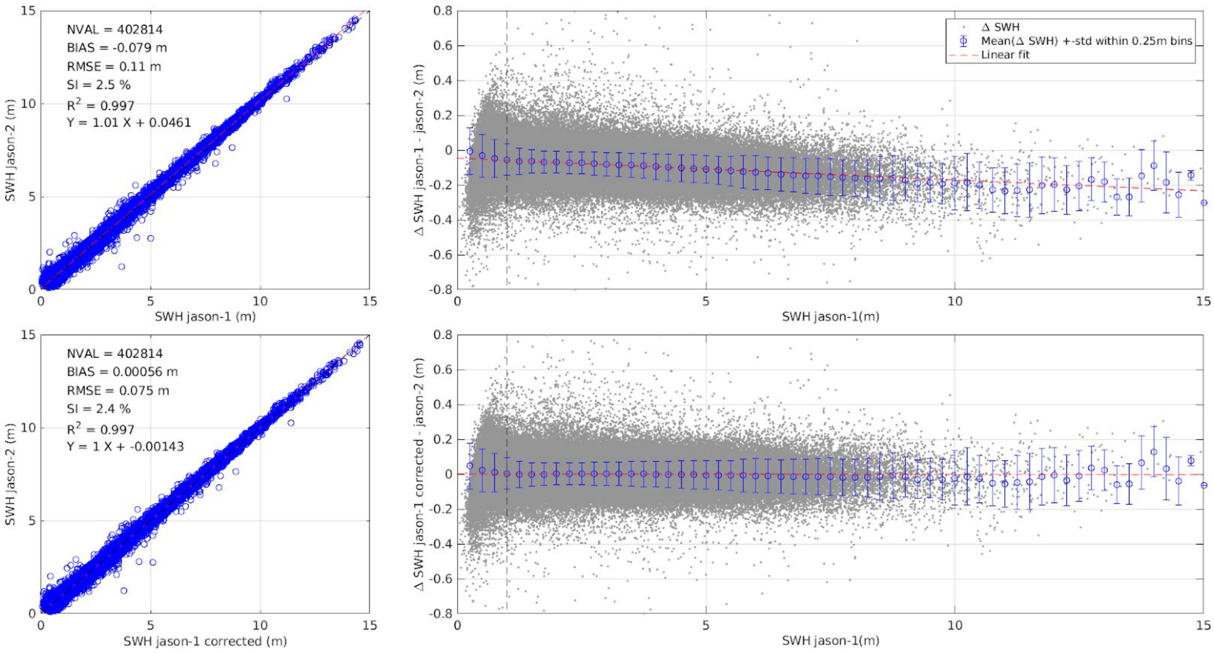

Figure 2. (Left) Scatter diagrams of Jason-2 swh against Jason-1 swh before (top) and after (bottom) calibration. (Right) Residual of Jason-1 swh – Jason-2 swh as a function of Jason-1 swh before (top) and after (bottom) calibration. The red dashed line is a linear fit through the data.

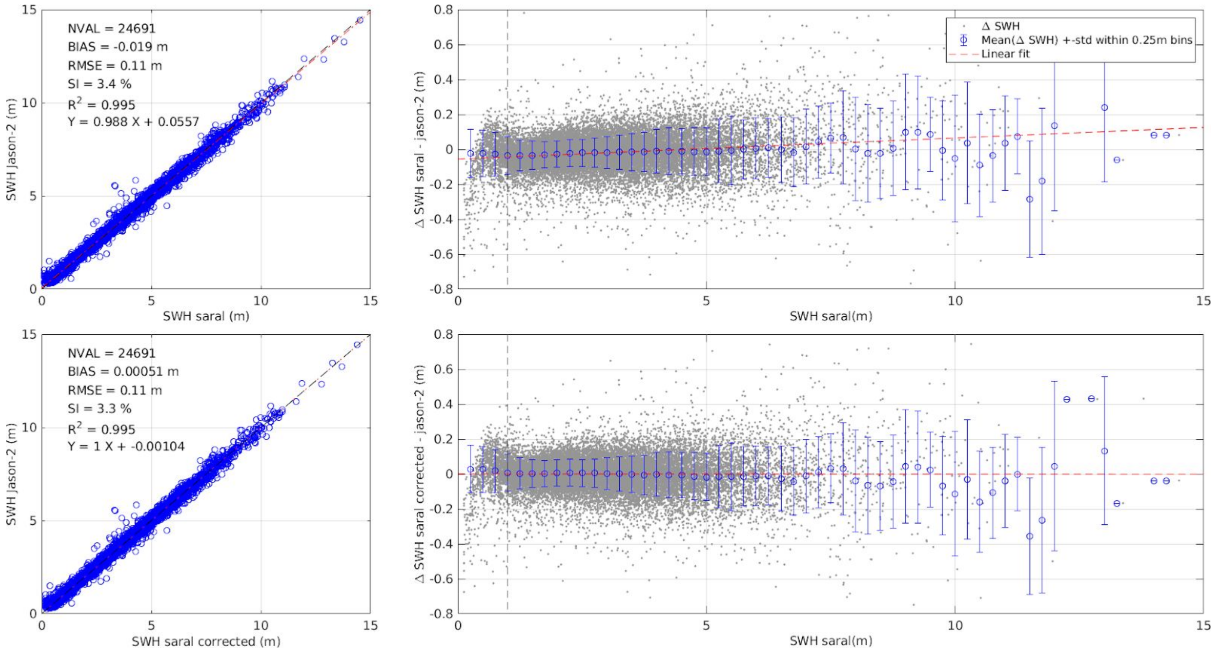

Figure 3. (Left) Scatter diagrams of Jason-2 swh against Saral swh before (top) and after (bottom) calibration. (Right) Residual of Saral swh – Jason-2 swh as a function of Saral swh before (top) and after (bottom) calibration. The red dashed line is a linear fit through the data.

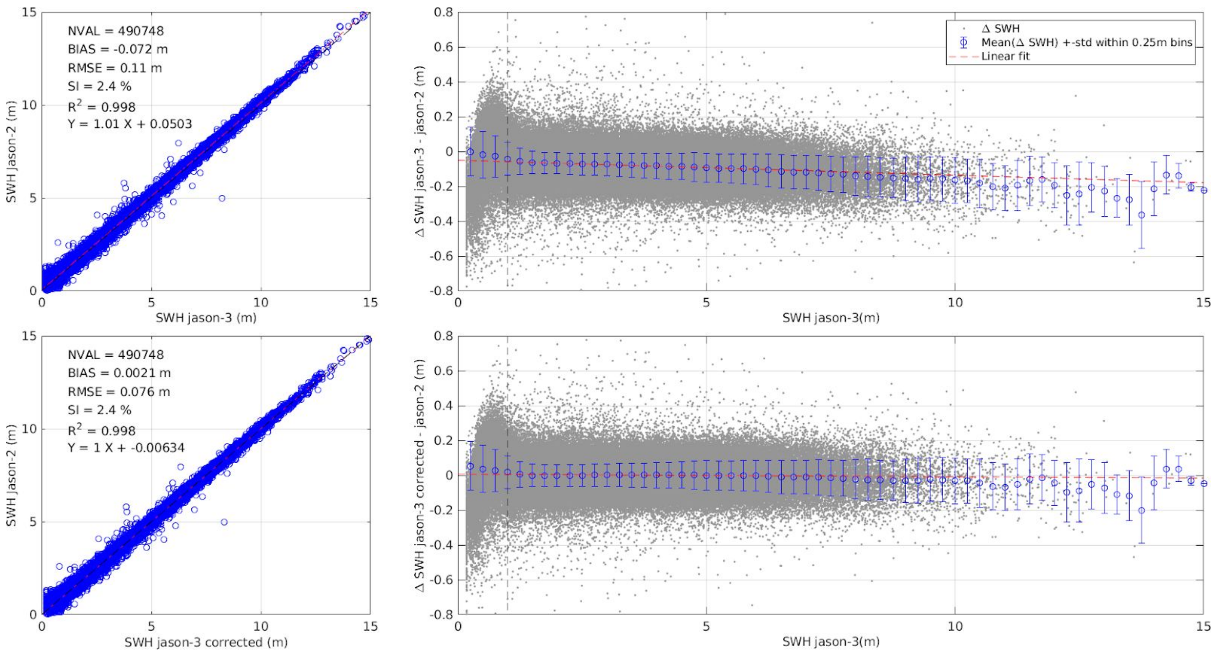

Figure 4. (Left) Scatter diagrams of Jason-2 swh against Jason-3 swh before (top) and after (bottom) calibration. (Right) Residual of Jason-3 swh – Jason-2 swh as a function of Jason-3 swh before (top) and after (bottom) calibration. The red dashed line is a linear fit through the data.

For Cryosat-2 the relationship is no longer linear (Figure 5) and we use a second-order polynomial function to correct this mission. In order to avoid discontinuous and unrealistic corrections at high sea state, we apply this second-order polynomial corrections until an upper threshold, corresponding to the swh values at which the polynom intersects the zero residual y-axis (in this case 7.67 m).

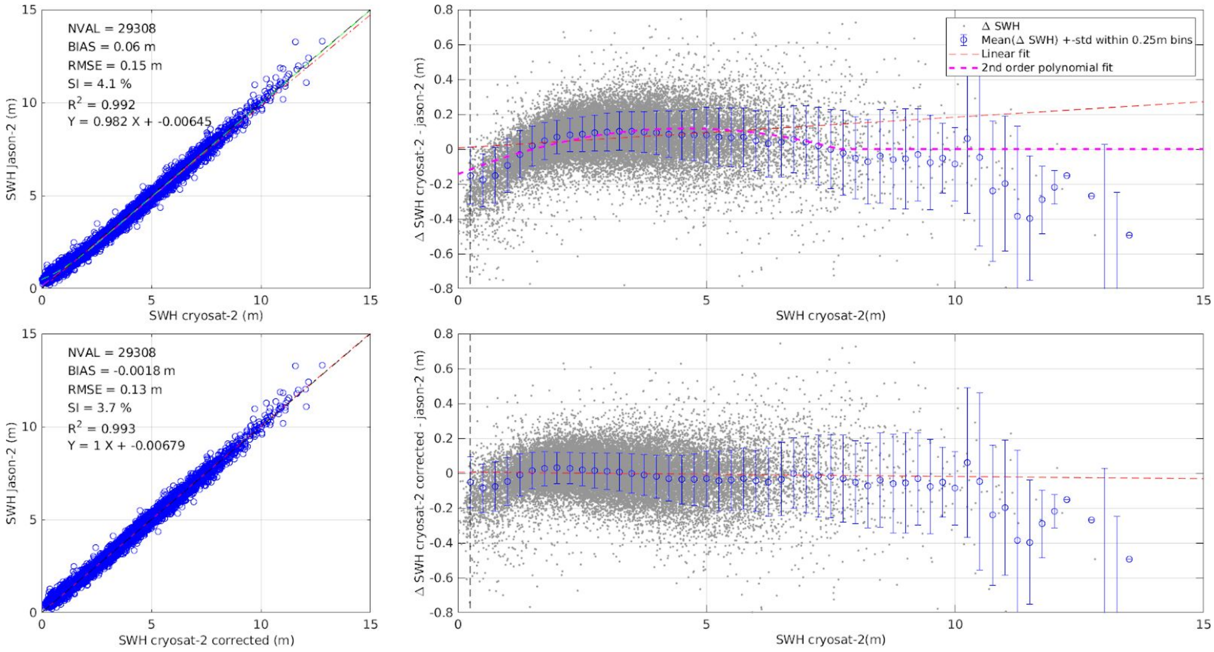

Figure 5. (Left) Scatter diagrams of Jason-2 swh against Cryosat-2 swh before (top) and after (bottom) calibration. (Right) Residual of Jason-3 swh – Jason-2 swh as a function of Cryosat-2 swh before (top) and after (bottom) calibration. The red dashed line is a linear fit through the data. The magenta dashed line is a second-order polynomial corrections applied up to 7.67 m.

In order to ensure that the calibrated altimeter swh are consistent over the whole time period covered by altimeter measurements, we compute the monthly global mean swh for each mission, within 60°S and 60°N. Figure 6 show time-series of global monthly means of un-calibrated and calibrated swh over 1992-2018, revealing how calibration of altimeter swh improves consistency between altimeters over this period.

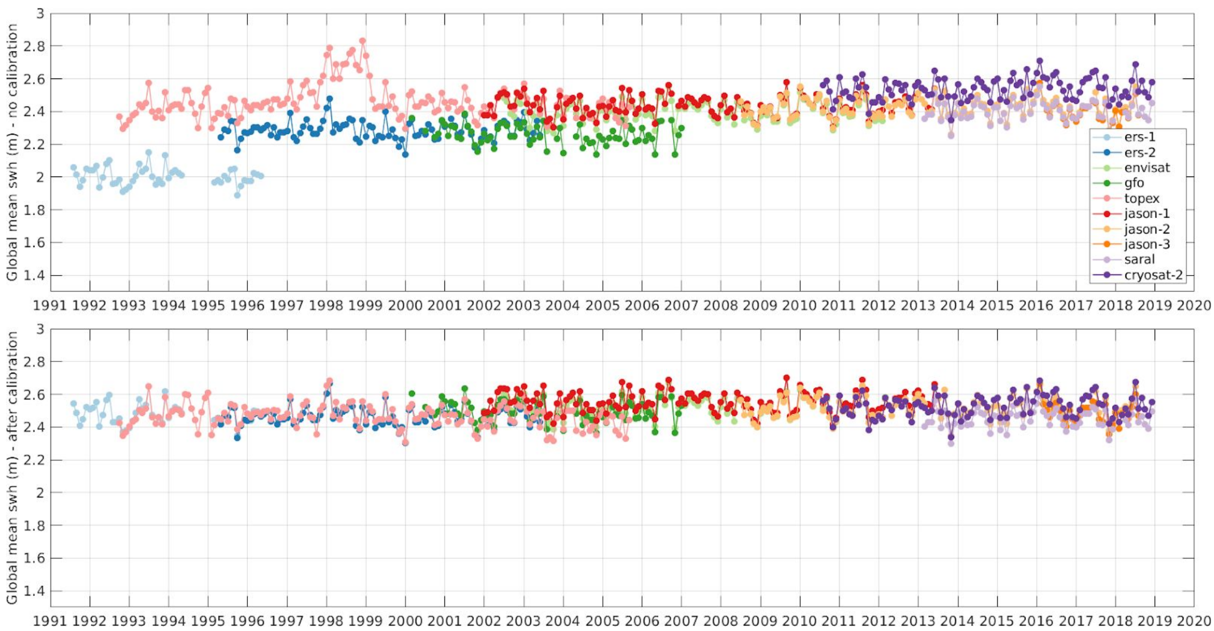

Figure 6. Monthly global mean swh over the period 1992-2018 before (top panel) and after (bottom panel) calibration is applied.

Annex B: Validation of the Sea State CCI dataset V1

Validation of the Sea State CCI dataset V1 is based on comparisons of the altimeter swh data with in-situ buoy data and numerical wave model results. Statistical errors are computed for the significant wave height before calibration (swh), after calibration (swh_adjusted), and after calibration and denoising (swh_denoised).

An altimeter-buoy match-up is defined each time the altimeter ground track is less than 50 km from a buoy location and the buoy measurement is available within 30-min (following Queffeulou et al. 2004). For each match-up, the altimeter swh is averaged over along-track records lying within a 50-km-radius-circle centered on the buoy location and the buoy time-series is smoothed with a one hour (3-point) moving average before the nearest (in time) buoy record is stored for comparisons with the averaged altimeter swh.

Figure 7 shows the comparison between Jason-2 and in-situ buoy swh measurements during year 2017, when all wave buoys are considered (left) and when only offshore wave buoys 200 km away from the coast are considered (right).

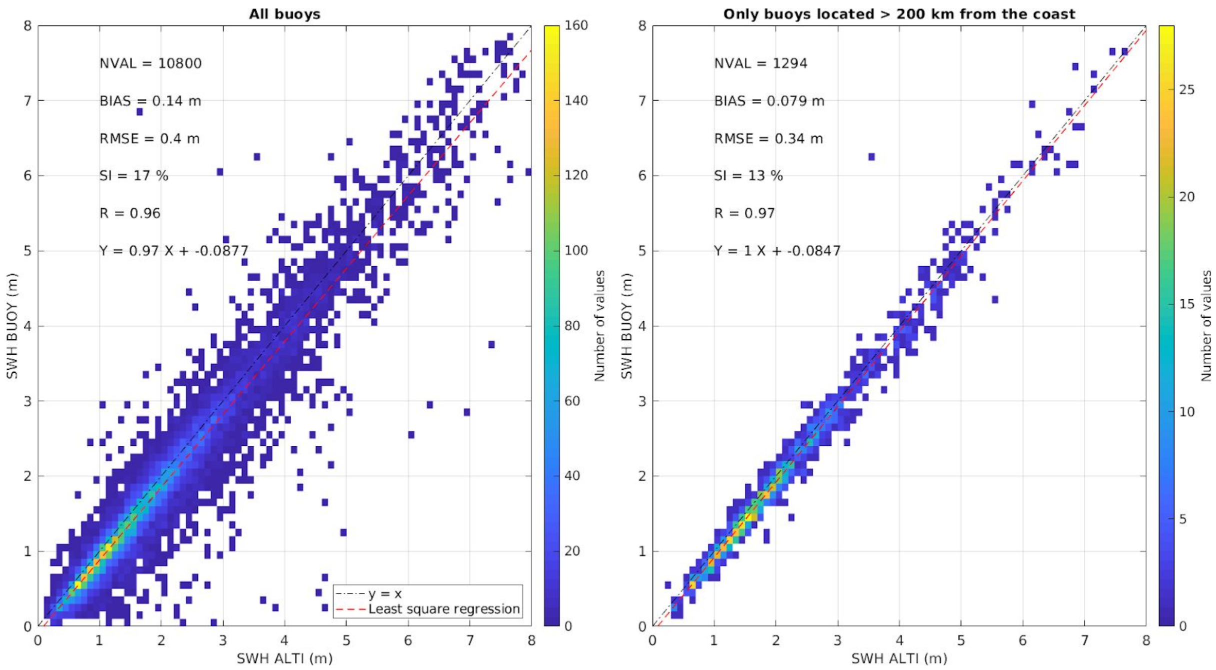

Figure 7. Comparison between Saral and wave buoy swh measurements during year 2014, when all wave buoys are considered (left) and when only wave buoy 200km away from the coast are considered (right).

Bias, root-mean-square error (RMSE) and scatter index (SI) show much better agreement when coastal buoys (<200 km) are discarded from the analysis. Hence, the validation of altimeter swh was performed on a reduced data set including only offshore buoys.

Statistical metrics were computed for each mission, and each year, and the overall scores are provided in Table 1 for calibrated and denoised swh (swh_denoised). With a minimum number of 1018 match-up data for ers-1 and an average number of 6120 match-up data, all the computed values are statistically significant. Except for ers-1 (-7.2 cm), all the mission show a positive bias comprise between 1-10 cm. The root-mean-square error is below 26 cm for all missions, corresponding to a value lower than 11% once normalized by the mean of the observations. The scatter index is lower than 9% and the correlation coefficient higher than 0.98 for all missions.

Mission	year	match-ups	Bias (m)	RMSE (m)	NRMSE (%)	SI (%)	R
ers-1	3	1018	-0.072	0.259	9.946	8.409	0.984
ers-2	17	9207	0.014	0.239	10.408	8.957	0.985
envisat	11	8286	0.044	0.234	10.052	8.582	0.985
gfo	9	5221	0.026	0.264	10.914	9.463	0.982
topex	12	7797	0.014	0.236	9.735	8.388	0.987
jason-1	12	11094	0.010	0.221	9.584	8.310	0.986
jason-2	11	14395	0.069	0.211	9.667	7.857	0.988
jason-3	3	4181	0.097	0.205	9.945	7.481	0.990
saral	6	7876	0.088	0.214	10.141	7.956	0.988
cryosat-2	9	7913	0.069	0.197	9.168	7.462	0.989

Table 1. Statistical metrics for the validation of denoised swh in the Sea State CCI dataset V1 against buoy data

Figure 8 shows the bias and NRMSE for uncalibrated swh (swh), calibrated swh (swh_adjusted) and calibrated and denoised swh (swh_denoised). We can see that the calibration carried out during GlobWave significantly decrease the bias for ers-1, ers-2, envisat, gfo and topex, but increase the bias for Jason-2. As a result, the bias also increases for some of the missions (Jason-3 and Saral) calibrated during this first stage of the Sea State CCI project, using the Jason-2 calibrated swh as a reference. The calibration methodology will therefore require improvements for the future versions of the Sea State CCI dataset.

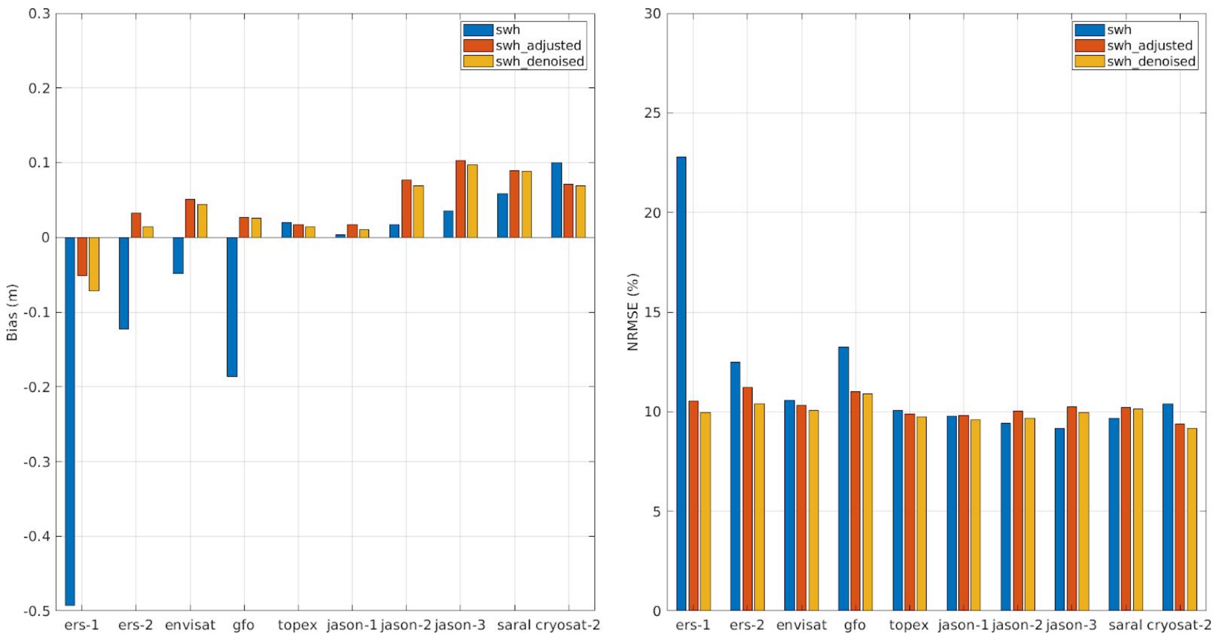

Figure 8. Bias (left) and NRMSE (right) computed from the comparisons between altimeter and in-situ buoy data.

Comparison of the altimeter swh against wave model hindcast was also performed as a complementary validation with another independent data set. Modelled swh values were linearly interpolated along the satellite ground track and errors were computed. The wave hindcasts were produced with the spectral wave model WAVEWATCH-III © in the context of the ERC IOWAGA project directed by Fabrice Ardhuin (LOPS-CNRS). The model is forced by wind fields from the Climate Forecast System Reanalysis (CFSR) for the period 1992-2016 and wind fields from the operational analysis from the Integrated Forecast System provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) for the period 2016-2018. The coverage is over the global grid from 78S to 80N at 0.5deg resolution with 3-hourly output fields. Depending on the year of reprocessing, the version of the model used are the stable releases v4.08, v5.05 and v6.02.

Figure 9 show the globally-averaged bias and normalized root-mean-square error between model and altimeter measurements for each mission of the Sea State CCI dataset V1. The bias is strongly attenuated after the swh measurements are calibrated (compare value for swh and swh_adjusted). The bias between model and altimeter swh_adjusted is lower than 10 cm for ers-1 and lower than 5 cm for all the other missions. The NRMSE for swh_adjusted is lower than 20% for ers-1 and ers-2 and lower than 15% for all other missions. In addition, we see that the denoised swh parameter decrease by up to 20% and by 10% on average the NRMSE between model results and measurements.

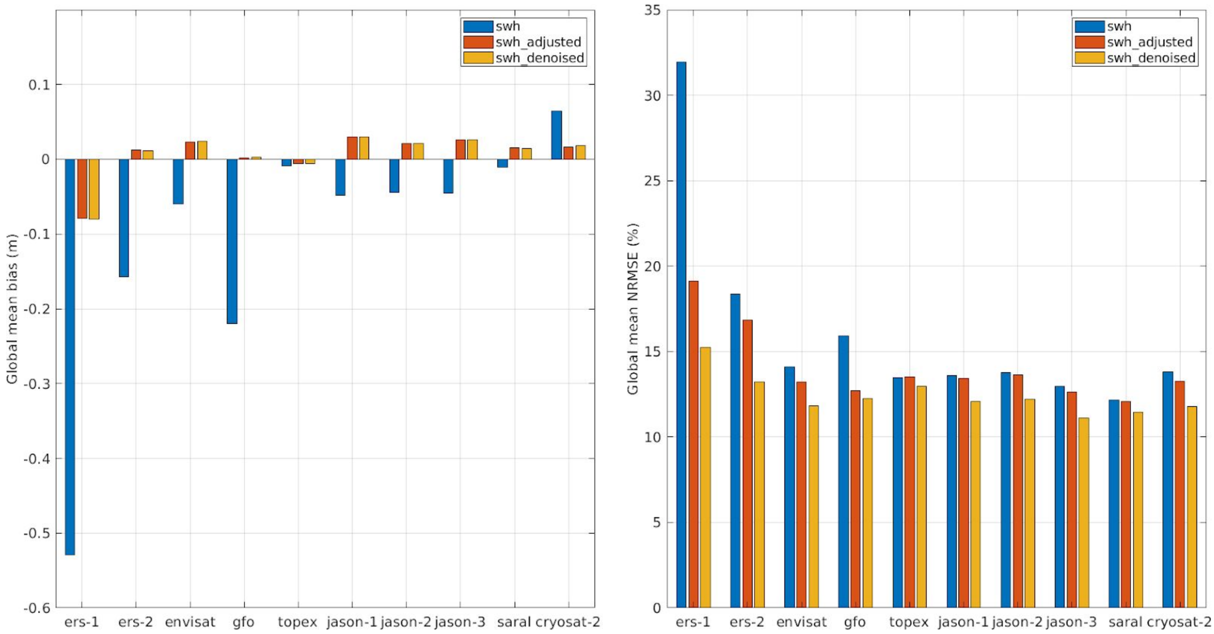

Figure 9. Bias (left) and NRMSE (right) computed from the comparisons between altimeter and wave model hindcast.

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