CalVal Jason-3

Jason-3 validation and cross calibration activities (Annual report 2017)

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Glossary

AMR Advanced Microwave Radiometer

CLS Collecte Localisation Satellites

CNES Centre National d'Etudes Spatiales

CNG Consigne Numerique de Gain (= Automatic Gain Control)

DEM Digital Elevation Model

DIODE Détermination Immédiate d'Orbite par Doris Embarqué

ECMWF European Centre for Medium-range Weather Forecasting

GDR Geophysical Data Record

GIM Global Ionosphere Maps

GOT Global Ocean Tide

IGDR Interim Geophysical Data Record

JPL Jet Propulsion Laboratory (Nasa)

MLE Maximum Likelyhood Estimator

MOE Medium Orbit Ephemeris

MQE Mean Quadratic Error

MSS Mean Sea Surface

PLTM PayLoad TeleMetry

POE Precise Orbit Ephemeris

OGDR Operational Geophysical Data Record

SALP Service d'Altimétrie et de Localisation Précise

SSH Sea Surface Height

SLA Sea Level Anomaly

SLR Satellite Laser Ranging

SSB Sea State Bias

SWH Significant Wave Height

TM TeleMetry

1. Introduction

This document presents the synthesis report concerning validation activities of Jason-3 data (Geophysical Data Records (GDRs), as well as Interim and Operational Data Records (O/IGDR)) under SALP contract (N° 160182/Lot 1.6.3) supported by CNES at the CLS Space Oceanography Division.

History
Jason-3 satellite was successfully launched on the 17th of January 2016. Since February 12th, Jason-3 is on its operational orbit to continue the long term climate data record on the primary TOPEX, Jason-1, and OSTM/Jason-2 ground track. Until October 2nd, 2016, Jason-3 and Jason-2 were in tandem flight, with only 80 seconds delay, before Jason-2 was moved to the same interleaved orbit that was used by TOPEX from 2002-2005 and Jason-1 from 2009-2012. After tandem phase with Jason-2, Jason-3 has become the reference misison in DUACS system from mid-september 2016 onwards.

CalVal activities
Since the beginning of the mission, Jason-3 data have been analyzed and monitored in order to assess the quality of Jason-3 products. Cycle per cycle reports summarizing mission performance are generated and made available through the AVISO web page [1]. This encompasses several points, which are either part of Cal/Val routine activities or following mission events:

- mono-mission validation and monitoring,
- Jason-3/Jason-2 cross-calibration,
- accuracy and stability of SLA measurements check,
- specific studies and investigations.

Overview
The present document assesses Jason-3 data quality and mission performance. Anfter an executive summary, dedicated sections of this report deal with:

- description of data processing,
- data coverage / availability,
- monitoring of rejected spurious data,
- analysis of relevant parameters derived from instrumental measurements and geophysical corrections.
- system performance via analyses at crossover points,
- system performance via along-track Sea Level Anomalies monitoring,
- long-term monitoring and contribution to climat surveys.

[1] http://www.aviso.altimetry.fr/en/data/calval/systematic-calval/validation-reports.html

Over all these parts , the document also focuses on Jason-3/Jason-2 cross-calibration:

– During the tandem flight (February, 12^{th} to October 2^{nd} 2016) both satellites were on the same ground track, which is a unique opportunity to precisely assess parameter discrepancies between both missions and detect geographically correlated biases, jumps or drifts.

– But even after Jason-2 move to interleaved orbit (formation flight phase, after the end of the tandem phase and until move to LRO), and also during Jason-2 flight on LRO, comparisons were still possible while Jason-2 data are available.

– The difference at crossovers, SLA performances and consistency with Jason-2 are described.

2017 executive summary on Jason-3

By succeeding to TOPEX/Poseidon, Jason-1 and Jason-2 on their primary ground track, Jason-3 has extended the high-precision ocean altimetry data record [1]. It was launched on January 17th 2016. During the tandem phase with Jason-2 (February 12th to October 2nd 2016), both satellites were on the same ground-track (with only 80 seconds delay), which is a unique opportunity to precisely assess parameter discrepancies between both missions and detect geographically correlated biases, jumps or drifts. OGDR and IGDR products have been publicly available since June 30th 2016. OGDRs were generated in version "T" until cycle 18/pass 137, and then turned into "D" version. Concerning IGDRs, they turned from "T" to "D" version at cycle 14/pass 143 on June 27th. GDR products have been available in version "T" on [2] or via [3] since early October 2016 (more details on products versions on Jason-3 handbook [4]). During each cycle, missing measurements were monitored, spurious data were edited and relevant parameters derived from instrumental measurements and geophysical corrections were analysed for OGDR, IGDR and GDR.
Jason-3 can use two on-board tracking modes: Diode/DEM (open loop) and median tracker (more details in complete annual report). In addition, a tracking automatic transition is possible, which means that when authorized: acquisition mode switches automatically from autonomous DIODE acquisition mode over land to Diode/DEM over ocean and referenced inland water. During 2017, an update of DEM (Digital Elevation Model) was uploaded on August (cycle 057). It aims at adding new hydrologic targets such as rivers and lakes: 110 lakes and more than 2700 virtual stations over lakes and rivers have been added (from 1644 virtual stations up to 4366).

Data availability

Data availability is excellent for Jason-3. Jason-3 presents 100% of data availability over ocean after removing specific events (99.96% for Jason-2, see figure 1). Such events occured twice over Jason-3 full period:

- during cycle 3, where 21.02% of measurements are missing due to the GPS platform upload,
- during cycle 57, where 1.76% of measurements are missing due to the DEM-onboard upload.

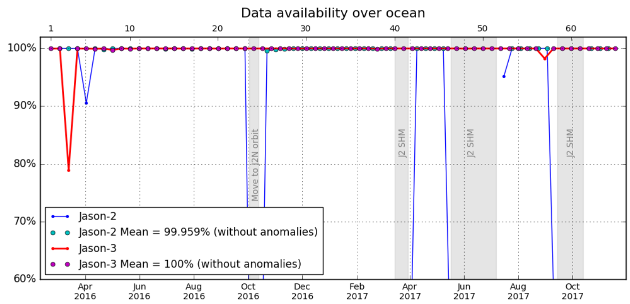


Figure 1 – Jason-2 and Jason-3 GDR data availability over ocean (per cycle)

[1] https://www.aviso.altimetry.fr/?id=601&L=0
[2] ftp://ftp.jason3.oceanobs.com
[3] http://www.class.noaa.gov
[4] https://www.aviso.altimetry.fr/fileadmin/documents/data/tools/hdbk_j3.pdf

Sea Level Anomalies

Over the tandem phase, mean SLA differences between Jason-2 and Jason-3 data is stable in time with variations close to 1 mm rms (left of figure 2) and shows no drift. It presents only a weak hemispheric bias as both satellites measure the same oceanic features only 1'20" apart (figure 2) that corresponds to orbital signatures observed on sea surface height. The global average SSH bias is close to 2.98 cm using SSH corrections (2.84 cm when using ECMWF instead of radiometer wet troposphere correction) and 2.23 cm without.

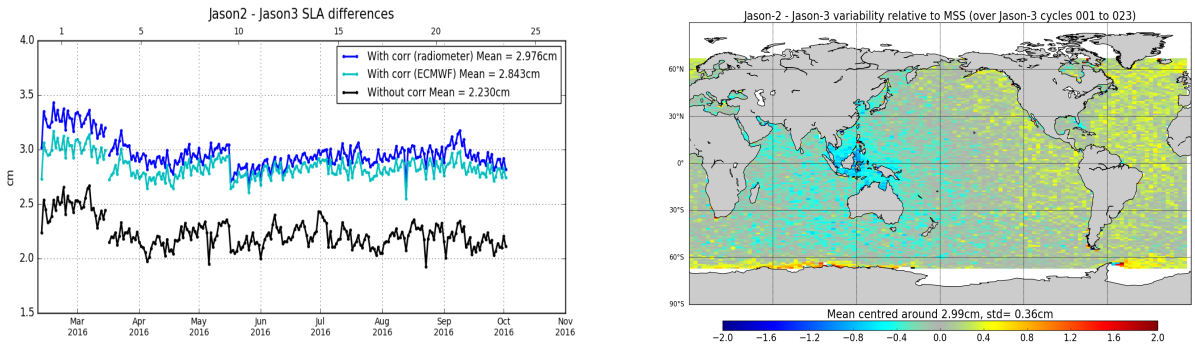


Figure 2 – Jason-3/Jason-2 tandem phase: until 02-10-2016. ***Left:*** *Daily monitoring of SSH bias between Jason-2 and Jason-3 before Jason-2 moved to interleaved ground-track in October 2016: SSH bias without applying geophysical corrections (**black**) and with corrections using radiometer wet troposphere correction (**blue**) or using ECMWF model wet troposphere correction (**cyan**).* ***Right:*** *Map of SLA difference between Jason-2 and Jason-3 over tandem phase*

During the formation flight (i.e. over cycles 25 to 46 from 12-10-2016 to 17-05-2017) and over Jason-2 LRO phase (until Jason-3 cycle 58, on 14-09-2017), average difference of gridded SLA for Jason-2 and Jason-3 shows high variability regions as Gulf Stream and Antarctic circumpolar currents are visible (figure 3). This difference is quite noisy as both satellites are shifted in time and sea state changes especially in regions of high ocean variability.

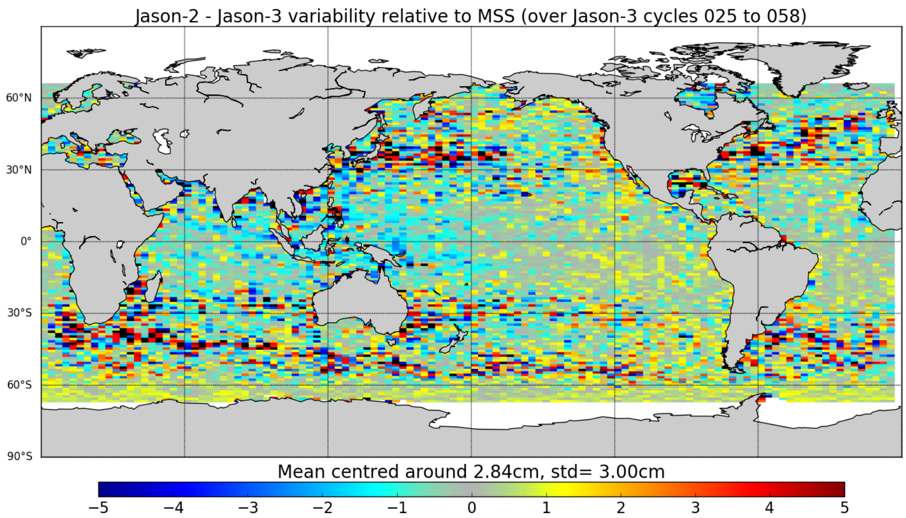


Figure 3 – GDR data. Map of Jason-2 and Jason-3 SLA differences for Jason-3 cycles 025 to 058

Performances at crossover points

Looking at SSH difference at crossovers (figure 4), a 120 day signal is visible on the mean for Jason-3 GDR data. Concerning SSH standard deviation at crossover points, both missions show very good and stable performances: 4.95 cm for Jason-3, 4.91cm for Jason-2.

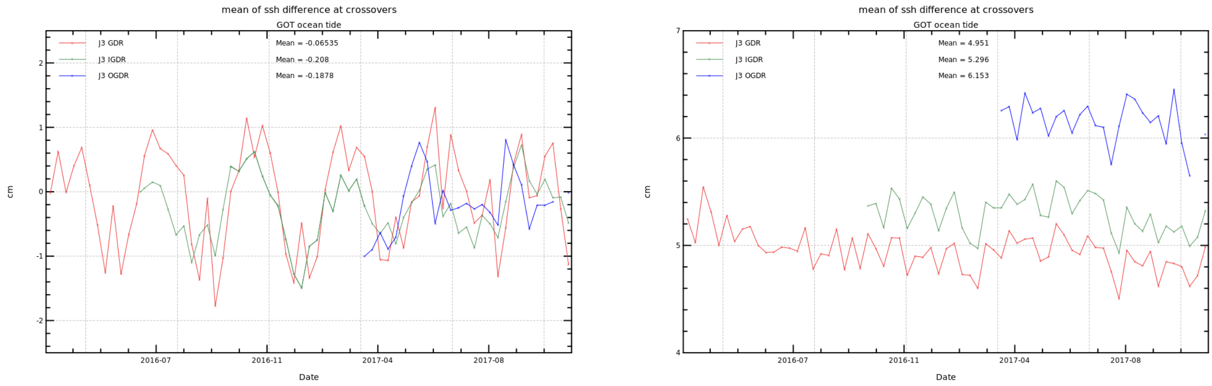


*Figure 4 – Monitoring of SSH difference at crossovers for Jason-2 and Jason-3. Mean (**left**) and standard deviation (**right**) for IGDR and GDR. Only data with |latitude| < 50°, bathymetry < -1000m and low oceanic variability were selected.*

Mean SSH differences at Jason 3/Jason 2 crossovers is quite stable and around 3cm in average (figure 5, left). The geographical pattern indicates some hemispheric biases: positive to the west, negative to the east (figure 5, right). It corresponds to orbital signatures observed on sea surface height.

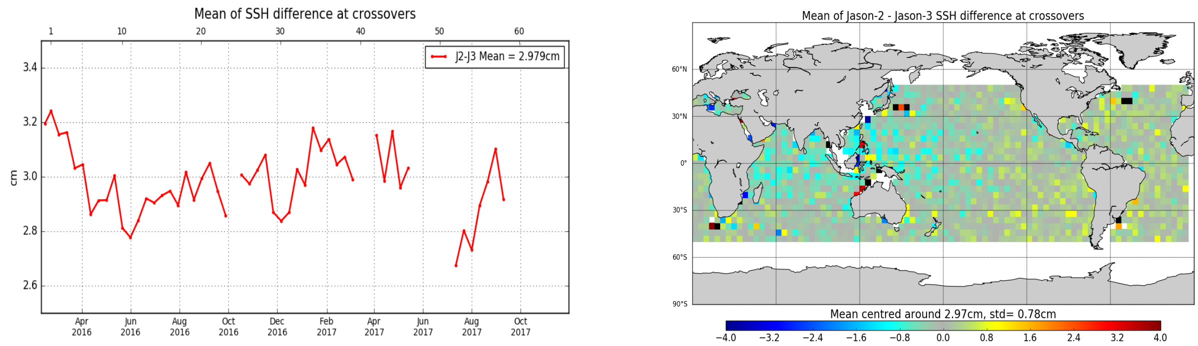


Figure 5 – Cyclic monitoring of Jason-2 - Jason-3 SSH crossover differences mean (left) and map over cycle 1 to 58 (right). Only data with |latitude| < 50°, bathymetry < -1000m and low oceanic variability were selected.

Contribution to Global Mean Sea Level

Since May 2016 (Jason-3 cycle 11), Jason-3 has been the reference altimetry mission to estimate the Global Mean Sea Level (GMSL), replacing Jason-2. Regional and global biases between missions have to be precisely estimated in order to ensure the quality of the reference GMSL serie. For more precisions, see the dedicated section on AVISO+ website [5].

[5] https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level.html

2. Processing status

2.1. List of events

The following table shows the major events during the Jason-3 mission.

Start time → End time	Cycle	Event
15/02/2016 08:00:00 → 18:04:28	0	First calibration in DIODE + DEM mode
16/02/2016 16:07:00 → 16:38:59	0	Poseidon3B instrument CNG calibration
08/03/2016 20:00:00 → 09/03/2016 00:00:01	3	Gyro calibration
11/03/2016 05:14:00 → 05:34:00	3	AMR Cold Sky calibration maneuver
15/03/2016 → 17/03/2016	3	Platform GPS upload
25/03/2016 09:30:15	4	AMR OFF / ON
06/04/2016 06:05:00 → 06:36:59	5	Poseidon3B instrument CNG calibration
07/04/2016 00:21:27 → 22:19:56	6	DIODE DEM mode
08/04/2016 04:44:30 → 05:00:46 05:11:00 → 05:28:21	6	Poseidon3B instrument CAL2 calibration
27/04/2016 11:38:21 → 12:05:55	8	OPS error
02/05/2016 14:34:23 → 14:37:28	8	DEM patch upload.
06/05/2016 18:16:59 → 16/05/2016 16:15:29	9	DIODE DEM mode
12/05/2016 22:44:59 → 22:52:23	9	AMR Cold Sky calibration maneuver
16/05/2016 10:00:00 → 10:16:15	9	Poseidon3B instrument CAL2 calibration
		.../...

Start time → End time	Cycle	Event
17/05/2016 02:34:00 → 19/05/2016 03:34:16	10	Poseidon3B instrument CAL2 calibration (5 sequences)
25/06/2016 08:09:39 → 05/07/2016 06:08:10	14	DIODE DEM mode
07/07/2016 15:04:44 → 15:11:15	15	AMR internal error
12/07/2016 04:26:36 → 04:34:00	15	AMR Cold Sky calibration maneuver
05/09/2016 04:24:44 → 04:32:08	21	AMR Cold Sky calibration maneuver
10/2016	24	OSTM/Jason 2 moved to the interleaved orbit, end of the verification phase for Jason 3
07/11/2016 22:21:30 → 22:28:54	27	AMR Cold Sky calibration maneuver
27/11/2016 06:15:00 → 06:46:59	29	Poseidon3B instrument CNG calibration
08/12/2016 04:36:34 → 09/12/2016 12:58:47	30	AMR anomaly
10/01/2017 16:37:35 → 16:44:59	34	AMR Cold Sky calibration maneuver
23/02/2017 11:35:00 → 12:06:59	38	Poseidon3B instrument CNG calibration
26/02/2017 17:13:07 → 17:20:31	38	AMR Cold Sky calibration maneuver
27/04/2017 04:13:16 → 04:20:40	44	AMR Cold Sky calibration maneuver
03/06/2017 15:46:00 → 16:17:59	48	Poseidon3B instrument CNG calibration
28/06/2017 05:10:04 → 05:17:28	51	AMR Cold Sky calibration maneuver
14/08/2017 05:57:05 → 06:04:29	55	AMR Cold Sky calibration maneuver
29/08/2017 13:41:14 → 31/08/2017 16:24:07	57	DEM onboard upload
		.../...

Start time → End time	Cycle	Event
31/08/2017 21:33:00 → 22:04:59	57	Poseidon3B instrument CNG calibration
04/09/2017 17:32:09 → 17:39:33	58	AMR Cold Sky calibration maneuver
14/09/2017 16:54:56 → 17:52:18	59	Gyro calibration
14/10/2017 15:30:11 → 15:37:35	62	AMR Cold Sky calibration maneuver
02/11/2017 02:05:23 → 02:12:47	63	AMR Cold Sky calibration maneuver
02/12/2017 02:30:00 → 03:01:59	66	Poseidon3B instrument CNG calibration

Table 1 – Events on Jason-3 mission

2.2. Tracking and acquisition mode

Jason-3 can use two on-board tracking modes: Diode/DEM (open loop) and median tracker. In addition, a tracking automatic transition is possible, which means that when authorized: acquisition mode switches automatically from autonomous DIODE acquisition mode over land to Diode/DEM over ocean and referenced inland water. The status of tracking and acquisition modes are detailed in table 2.

Cycle	Acquisition Mode over land	Acquisition Mode over ocean and all referenced inland waters	Comment
Cycle 000	Median tracker + autonomous acquisition / tracking + DEM	Median tracker + autonomous acquisition / tracking + DEM	tracking automatic transition inhibited except for 7 passes
Cycles 001 to 005	Median tracker	Median tracker	tracking automatic transition inhibited.
Cycles 006	see dedicated point below	see dedicated point below	
Cycles 007	Median tracker	Median tracker	tracking automatic transition inhibited everywhere.
			.../...

Cycle	Acquisition Mode over land	Acquisition Mode over ocean and all referenced inland waters	Comment
Cycles 008	mainly Median tracker	mainly Median tracker	autonomous acquisition / tracking for passes 144 to 148 (DEM patch upload on 2016-05-02) . tracking automatic transition inhibited everywhere.
Cycle 009 Pass 001 to mid-248	Median tracker	DEM	mid-pass 248 = CAL2 event on 2016-05-16 10:00)
Cycle 009 Pass mid-248 to 254	Median tracker	Median tracker	mid-pass 248 = CAL2 event on 2016-05-16 10:00)
Cycle 010	Median tracker	Median tracker	tracking automatic transition inhibited
Cycles 011 to 019	Median tracker	DEM	tracking automatic transition authorized
Cycle 020	Median tracker	Median tracker	tracking automatic transition inhibited
Cycles 021 to 056	Median tracker	DEM	tracking automatic transition authorized
Cycle 057			DEM upload
Cycles 058 onwards	Median tracker	DEM	tracking automatic transition authorized

Table 2 – Acquisition mode

- About cycle 006: Altimeter state flag for tracking mode is set to 1 by three times (=0 everywhere else):
  - for passes 018 to 029 from 2016-04-07 16:32:57 to 2016-04-08 03:13:59 : ¿ DIODE Acquisition/Autonomous mode (Altimeter state flag for acquisition mode is set to 9) due to operation error after transponder calibration : back to DIODE DEM mode after the next routine calibration.
  - for passes 065 to 070, from 2016-04-09 12:46:05 to 2016-04-09 17:25:10 : ¿ Auto Acquisition/Autonomous tracking mode (Altimeter state flag for acquisition mode is set to 8) due to automatic reintialisation in POS3B default mode, triggered on-board by GPS reinit : back to DIODE DEM mode after the next routine calibration
  - for passes 113 to 116, from 2016-04-11 10:03:37 to 2016-04-11 12:20:28 : ¿ Auto Acquisition/Autonomous tracking mode (Altimeter state flag for acquisition mode is set to 8) due to automatic reintialisation in POS3B default mode, triggered on-board by GPS OFF-ON : back to DIODE DEM mode after the next routine calibration

- From cycle 21 onwards, except during DEM upload on cycle 057 (see figure 63), tracking automatic transition is activated.

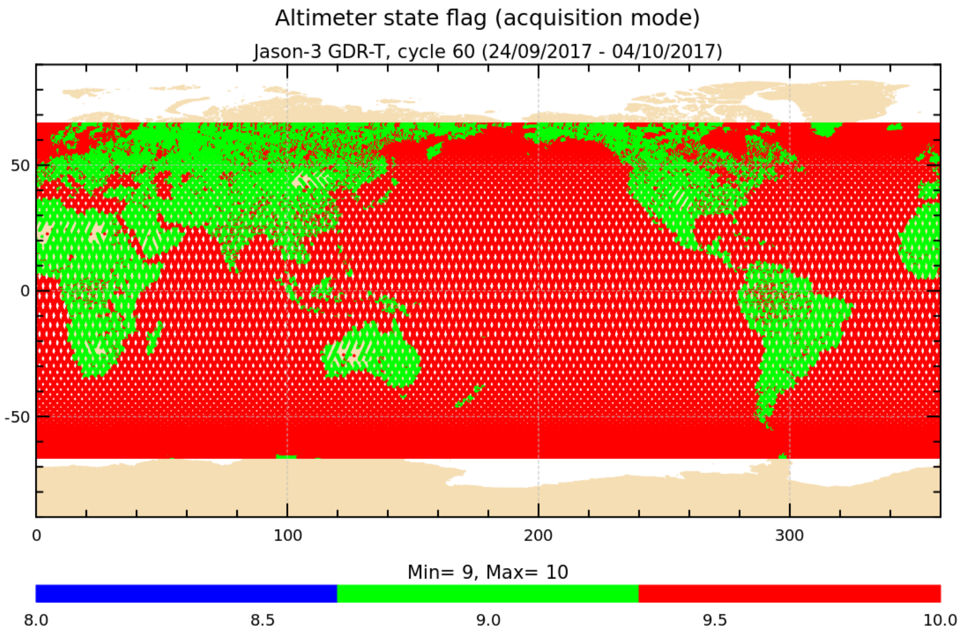


Figure 1 – Acquisition mode for cycle 060 (identical to acquisition mode automatic switch for cycles 6, 9, 11-19, 21-56,58-65). 8 = autonomous acquisition / tracking, 9 = autonomous DIODE acquisition / tracking, 10 = DIODE + Digital Elevation Model tracking

- About cycle 057, some passes are entirely autonomous acquisition / tracking, and some passes entirely median tracker. DEM upload during this cycle is detailed in 8.2.

2.3. Models and standards

The standards used for version “D” are listed in Table 3.
The main differences between the O/IGDRs versions “T” and “D” are summarized hereafter:

- CAL-2 calibration processing are based on typical ocean AGC values, correcting the negative squared-attitude values that were observed from the start of the mission.

- Backscatter (sigma-0) values are adjusted internally during ground processing. A calibration bias of +0.14 dB and +0.109 dB is added to the measured (and reported) MLE-4 and MLE-3 Ku-band sigma-0, respectively, prior to wind speed computation; a calibration bias of -0.231 dB and -0.012 dB is added to the measured (and reported) MLE-3 Ku- and C-band sigma-0, respectively, prior to rain flag computation and rain flag values. This ensure that they are properly aligned with the adopted algorithms, so that rain flagging and wind speed values are in-line with those from Jason-2.

Model	Product version "D"
Orbit	Based on Doris onboard navigator solution for OGDRs. DORIS tracking data for IGDRs (orbit standard GRD-E). DORIS and/or GPS tracking data for GDRs (orbit standard GRD-E).
Altimeter Retracking	OceanMLE4 retracking: MLE4 fit from 2nd order Brown model: MLE4 simultaneously retrieves the following 4 parameters from the altimeter waveforms: • Epoch (tracker range offset) → altimeter range • Composite Sigma → SWH • Amplitude → Sigma0 • Trailing Edge slope → Square of mispointing angle (Ku band only, a null value is used in input of the C band retracking algorithm) OceanMLE3 retracking: MLE3 fit from first orderBrown analytical model: MLE3 simultaneously retrieves the 3 parameters that can be inverted from the altimeter waveforms: • Epoch (tracker range offset) → altimeter range • Composite Sigma → SWH • Amplitude → Sigma0 "Ice" retracking: Geometrical analysis of the altimeter waveforms, which retrieves the following parameters: • Epoch (tracker range offset) → altimeter range • Amplitude → Sigma0
Altimeter Instrument Corrections	Two sets: one set consistent with MLE4 retracking and one set consistent with MLE3 retracking
Jason3 Advanced Microwave Radiometer (AMR) Parameters	Using parameters derived from long term calibration tool developed and operated by NASA/JPL
Dry Troposphere Range Correction	From ECMWF atmospheric pressures and model for S1 and S2 atmospheric tides
Wet Troposphere Range Correction from Model	From ECMWF model
Ionosphere correction from model	Based on Global Ionosphere TEC Maps from JPL
	.../...

Model	Product version "D"
Sea State Bias Model	Two empirical models: • MLE4 version derived from 1 year of MLE4 Jason-2 altimeter data with version "D" geophysical models • MLE3 version derived from 1 year of MLE3 Jason-2 altimeter data with version "D" geophysical models
Mean Sea Surface Model	MSS_CNES-CLS11 (reference 7 years)
Mean Dynamic Topography Model	MDT_CNES-CLS09
Geoid	EGM96
Bathymetry Model	DTM2000.1
Inverse Barometer Correction	Computed from ECMWF atmospheric pressures after removing S1 and S2 atmospheric tides
Non-tidal High-frequency De-aliasing Correction	Mog2D high resolution ocean model on I/GDRs. None on OGDRs. Ocean model forced by ECMWF atmospheric pressures after removing S1 and S2 atmospheric tides.
Tide Solution 1	GOT4.8 + S1 ocean tide. S1 load tide ignored
Tide Solution 2	FES2004 + S1 and M4 ocean tides. S1 and M4 load tides ignored
Equilibrium long-period ocean tide model.	From Cartwright and Taylor tidal potential.
Non-equilibrium long-period ocean tide model.	Mm, Mf, Mtm, and Msqm from FES2004
Solid Earth Tide Model	From Cartwright and Taylor tidal potential.
Pole Tide Model	Equilibrium model
Wind Speed from Model	ECMWF model
Rain Flag	Derived from comparisons to thresholds of the radiometer-derived integrated liquid water content and of the difference between the measured and the expected Ku-band backscatter coefficient
Ice Flag	Derived from comparison of the model wet tropospheric correction to a dual-frequency wet tropospheric correction retrieved from radiometer brightness temperatures, with a default value issued from a climatology table

Table 3 – List of GDR version "D" standard

2.4. Processing

OGDR and IGDR products are publicly available since June 30th 2016. OGDRs were generated in version "T" until cycle 18/pass 137, and then turned in "D" version.
→ The first OGDR "D" file is: JA3_OPN_2PdS018_137_20160809_080914_20160809_100739.nc

Concerning IGDRs, they turned from "T" to "D" version a few days before OGDRs on June 27th(cycle 14/pass 143).
→ The first IGDR "D" file is: JA3_IPN_2PdP014_043_20160626_233040_20160627_002653.nc

GDRs were generated in version "T" until cycle 021/pass 254, and then turned in "D" version.
→ The first GDR "D" file is: JA3_GPN_2PdP022_001_20160912_155750_20160912_165403.nc

2.5. Data Used

Metrics provided in this document are based on Jason-3 dataset from cycle 0 to 65 for GDR products (corresponding to February 12th 2016 to November 22th 2017). This period extends until cycle 68 (December 22th 2017) when IGDR data are considered. Cycle 0 is not included in many statistics because of its available data covering only 5 days.
Note that from cycle 1 to 41, IGDR products were analysed without update.
After tandem phase with Jason-2, Jason-3 has become the reference misison in *DUACS* system from mid-september 2016 onwards. Note that in order to improve their product quality (and also to use as possible same corrections for multimission products), *DUACS* system applies some updates to IGDR data. If no precision is done, IGDR results that are presented in this document contains *DUACS* updates (also called here IGDR-L2P).

3. Data coverage and edited measurements

3.1. Missing measurements

3.1.1. Over land and ocean

Determination of missing measurements relative to the theoretically expected orbit ground pattern is an essential tool to detect missing telemetry or satellite events for instance. Applying the same procedure for Jason-2 and Jason-3, the comparison of the percentage of missing measurements has been performed.

Figure 2 shows the percentage of available measurements for Jason-3 and Jason-2 for all kind of surfaces observed, computed with respect to a theoretical possible number of measurements. In average Jason-3 provides 98.57% of measurements over 65 cycles (without taking into accounts cycles with explained anomalies), which shows an improvement compared to Jason-2 tracking capabilities.

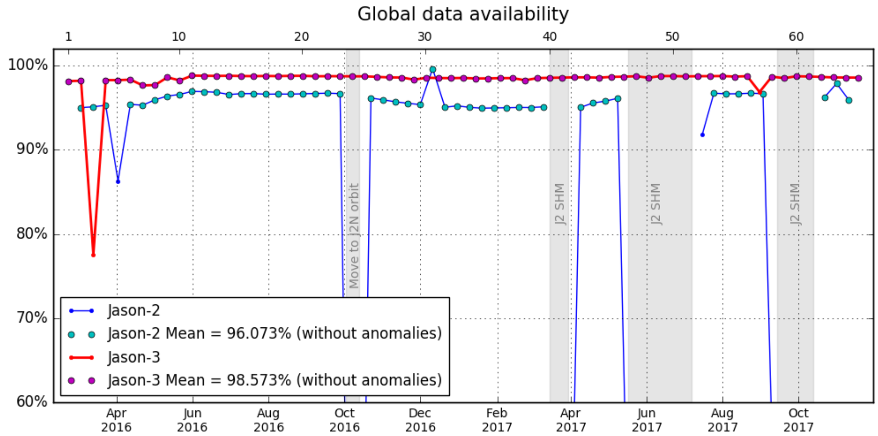


Figure 2 – Global GDRs data availability per cycle

For almost all cycles, available data percentage is greater for Jason-3 than for Jason-2. This is due to differences in tracking and acquisition modes (Jason-3 uses DEM mode and Jason-2 uses median tracker): Jason-3 data coverage over land surface can be slightly different regarding to Jason-2 (as shown on top of figure 3).

– Jason-3 Cycle 3: GPS platform upload interrupted the data production for two days.

– Jason-3 Cycle 57: DEM onboard upload interrupted the data production for few passes.

– In April 2016: note that data are missing on Jason-2 cycle 285 between April, 5 at 13:35:10 and April, 6 at 12:02:40. No scientific products have been processed during this period to allow the upload of new GPS On Board software.

– Available data percentage is greater for Jason-3 than for Jason-2 even over cycles where median tracker is used on Jason-2 (all except Jason-2 cycle 311) and only median tracker is used on Jason-3 (cycles 1 to 5, 7-8, 10 and 20: see 2.2.). This difference is probably due to a limitation imposed on Jason-2 tracking to avoid ghost echoes.

– Note that Jason-2 cycle 311 (partly over Jason-3 cycles 30 and 31) is in DEM mode, so that availability of measurements over this cycle is quite 100% (but more data are rejected). Bottom part of figure 3 shows that these additional measurements for Jason-2 (right) compared to Jason-3 (left) are mainly located over Asia.

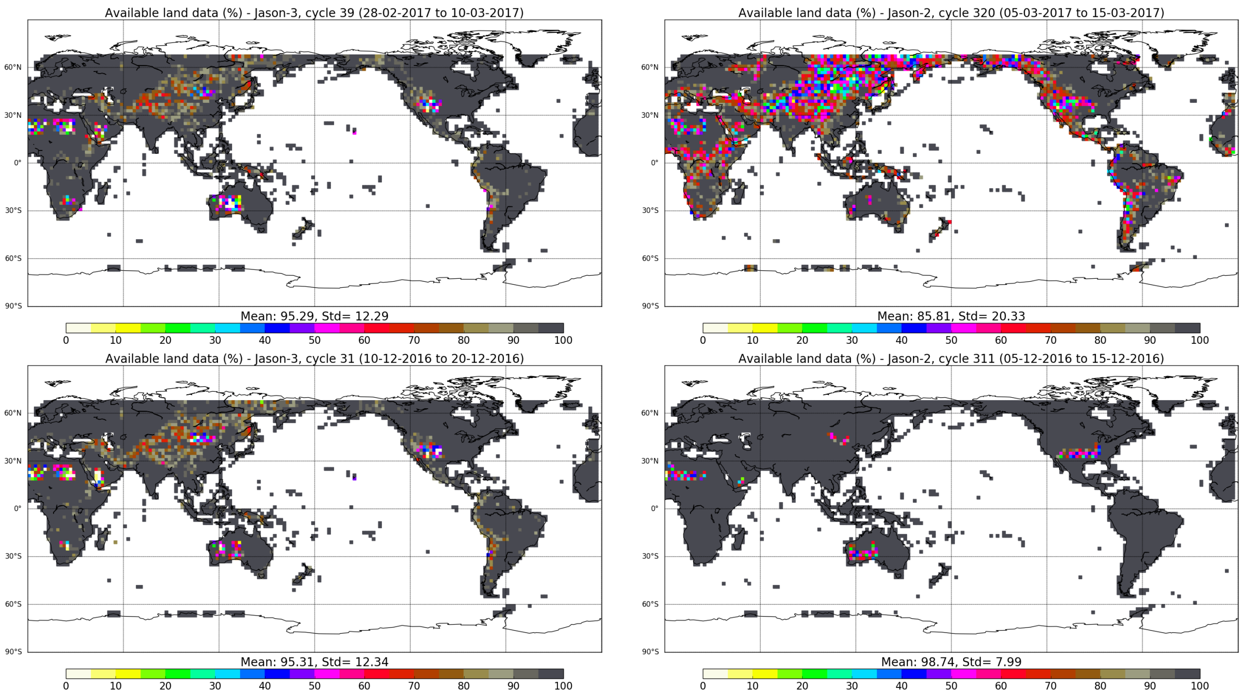


Figure 3 – Map of percentage of available measurements over land for Jason-3 (left) and for Jason-2 (right). ***Top:*** *Jason-3 cycle 039 in DEM mode and Jason-2 cycle 320 in median mode.* ***Bottom:*** *Jason-3 cycle 031 in DEM mode and Jason-2 cycle 311 in DEM mode*

Table 4 gives an overview of missing passes and reasons for Jason-3.

Date	Jason-3 Cycle/Pass	Reason
Before 12/02/2016 01:11:09	C000 / P001-116	Final ground-track reached on 12-02-2016 01:11:09
	C000 / P201, 203, 236	Due to calibration events, passes 201 (∼10%), 203 (∼12%) and 236 (∼8%) partly missing
08/03/2016 20:00:00 → 09/03/2016 00:00:01	C003	Due to Gyro calibration , data gap on pass 018.
11/03/2016 05:14:00 → 05:34:00	C003	AMR Cold Sky calibration maneuver
		.../...

Date	Jason-3 Cycle/Pass	Reason
15/03/2016 07:15:04 to 17/03/2016 08:06:13	C003 / P181-233	Due to platform GPS software upload, passes 182 to 232 are entirely missing, as well as part of passes 181 and 233
06/04/2016 06:05:00 → 06:36:59	C005 / P235	Due to Poseidon3B instrument CNG calibration, data gap on pass 235, that mainly concerns land data acquisition and a portion of Red Sea.
26/04/2016 20:18:29 → 2016-05-06 18:16:59	C008	Due to Poseidon3B instrument CAL2 calibrations , data gaps over land on passes 55, 53, 27, 5, 38, 12 and 29
27/04/2016 11:38:11 to 12:05:55	C008 / P017	Due to OPS error, pass 017 has 49.39% of missing measurements (42.44% over ocean)
08/04/2016 04:44:30 → 05:00:46 05:11:00 → 05:28:21	C006	Due to Poseidon3B instrument CAL2 calibration, data gaps over land
02/05/2016 10:17:04 to 10:28:14 and 14:34:22 to 14:37:28	C008 / P144,148	Due to DEM upload: • Pass 144 has 20.33% of missing measurements (13.27% over ocean, Norwegian Sea) • Pass 148 has 6.60% of missing measurements over ocean (western african coast)
12/05/2016 22:44:59 → 22:52:23	C009	AMR Cold Sky calibration maneuver
16/05/2016 10:00:00 → 10:16:15	C009	Due to Poseidon3B instrument CAL2 calibration, data gap over land on pass 248
17/05/2016 02:34:00 → 19/05/2016 03:34:16	C010	Due to Poseidon3B instrument CAL2 calibration (5 sequences), data gaps over land on passes 31, 64, 38, 12, and 44
12/07/2016 04:26:36 → 04:34:00	C015	AMR Cold Sky calibration maneuver
05/09/2016 04:24:44 → 04:32:08	C021	AMR Cold Sky calibration maneuver
07/11/2016 22:21:30 → 22:28:54	C027	AMR Cold Sky calibration maneuver
		.../...

Date	Jason-3 Cycle/Pass	Reason
27/11/2016 06:15:00 to 06:46:58	C029 / P159, 160	Due to CNG calibration, parts of passes 159 and 160 are missing (mostly over land). Pass 159 has 54.73% of missing measurements (10.54% over ocean).
10/01/2017 16:37:35 → 16:44:59	C034	AMR Cold Sky calibration maneuver
23/02/2017 11:35:00 → 12:06:59	C038	Poseidon3B instrument CNG calibration
26/02/2017 17:13:07 → 17:20:31	C038	AMR Cold Sky calibration maneuver
27/04/2017 04:13:16 → 04:20:40	C044	AMR Cold Sky calibration maneuver
03/06/2017 from 15:46:00 to 16:17:59	C048 / P159	Due to CNG calibration, pass 159 has 56.55% of missing data mostly over land (10.54% over ocean)
28/06/2017 05:10:04 → 05:17:28	C051	AMR Cold Sky calibration maneuver
14/08/2017 05:57:05 → 06:04:29	C055	AMR Cold Sky calibration maneuver
30/08/2017 12:07:15 to 14:10:33	C057 / P123-125	Due to DEM upload: • Pass 123 has 23.91% of missing measurement (15.44% over ocean). • Pass 124 is missing • Pass 125 has 96.16% of missing measurement (100% over ocean).
31/08/2017 14:22:58 to 16:26:10	C057 / P151-153	Due to DEM upload: • Pass 151 has 12.40% of missing measurement (8.57% over ocean). • Pass 152 has 100% of missing measurement over ocean • Pass 153 has 98.40% of missing measurement (100% over ocean).
		.../...

Date	Jason-3 Cycle/Pass	Reason
31/08/2017 21:33:00 to 22:04:59	C057 / P159	Due to CNG calibration, pass 159 has 56.17% of missing measurement (10.54% over ocean).
04/09/2017 17:32:09 → 17:39:33	C058	AMR Cold Sky calibration maneuver
14/09/2017 from 16:54:56 to 17:52:18	C059 / P005	Due to Gyro calibration, pass 5 has 47.22% of missing measurements (0.07% over ocean)
14/10/2017 15:30:11 → 15:37:35	C062	AMR Cold Sky calibration maneuver
02/11/2017 02:05:23 → 02:12:47	C063	AMR Cold Sky calibration maneuver
02/12/2017 02:30:00 → 03:01:59	C066	Poseidon3B instrument CNG calibration

Table 4 – List of missing Jason-3 passes

3.1.2. Over ocean

Looking at data over ocean, Jason-3 has in average 99.61% of available measurements per cycle when taking into account missing data during anomalies (ocean is fully covered out of specific events). There is 21.02% of missing measurements due to GPS platform upload during cycle 3 and 1.76% of missing measurements due to the DEM-onboard upload during cycle 57.

Jason-2 missing measurements reason is detailed in Jason-2 2017 Annual report [113].
During this time period, the behaviour of Jason-3 over ocean is excellent and conform to what is observed with Jason-2 on the same ground track, with 80 seconds of difference, and after on interleaved groundtrack.

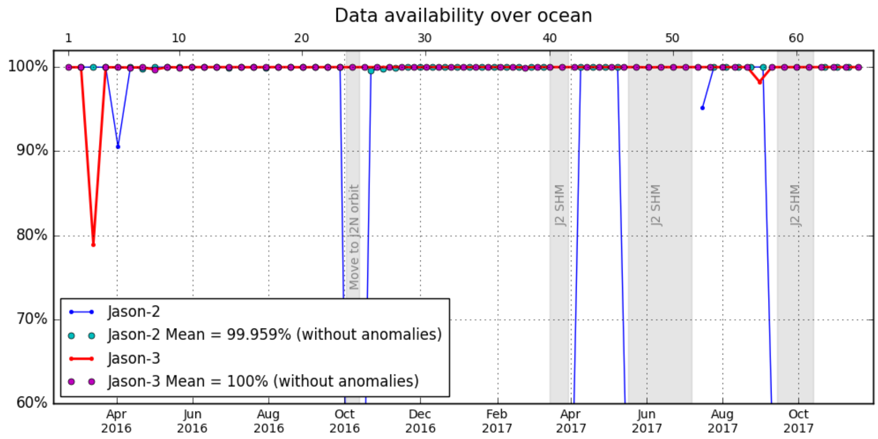


Figure 4 – Jason-2 and Jason-3 GDR data availability over ocean (per cycle)

3.2. Edited measurements

Editing criteria allow to select only measurements considered as valid over ocean. This editing process is structured in 4 main steps:

1. Measurements over land are removed, only measurements over ocean and lakes are kept
2. Measurements over ice are removed
3. Threshold criteria are applied on altimeter, radiometer and geophysical parameters as described in the following table 5. Except for the dual frequency ionosphere correction, only Ku-band measurements are used in this editing procedure, as they mainly represent the end user dataset.
4. A spline criterion is applied to remove the remaining spurious data.

3.2.1. Global editing

The percentage of total edited measurements is monitored on a cyclic basis. The average of total edited measurements is 37.76% (see Figure 5). A small annual cycle is visible due to ice coverage signal (see dedicated part 3.2.2.): the total percentage is a little lower during March/April/May (30-35%), then increasing during May to July and remains around 38-42%, and start to slowly decrease in mid-September. This expected behaviour is related to sea ice coverage, and was already observed on previous altimetry missions such as OSTM/Jason 2. The peak detected on cycle 30 is due to an AMR anomaly that occured from 08/12/2016 04:36:34 to 09/12/2016 12:58:47.

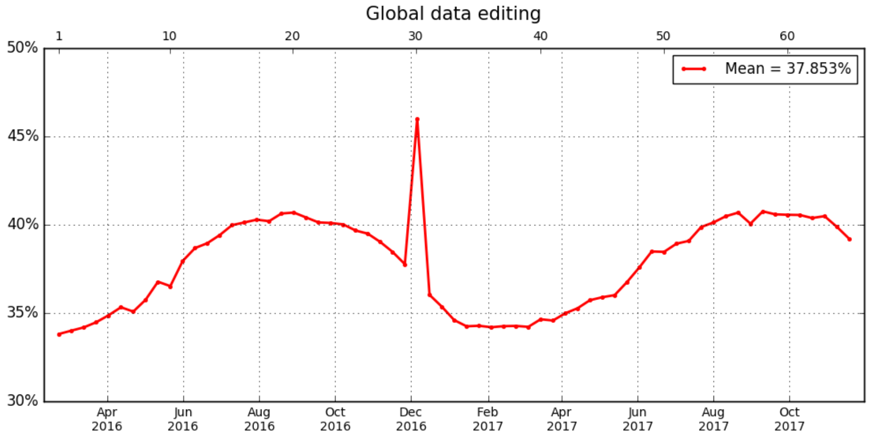


Figure 5 – Jason-3 data editing average by cycle.

3.2.2. Flagging quality criterion: Ice flag

The ice flag (from official product) is used to remove the ice and sea ice data. Figure 6 shows cycle per cycle percentage of measurements edited by this criterion in comparison with Jason-2 (only ocean and big lakes measurements are kept). Jason-2 and Jason-3 ice flag show similar features while on repetitive orbit. A small bias is visible since Jason-2 has been on its drifting orbit (it might be due to the way land/sea mask is applied and is under investigation).

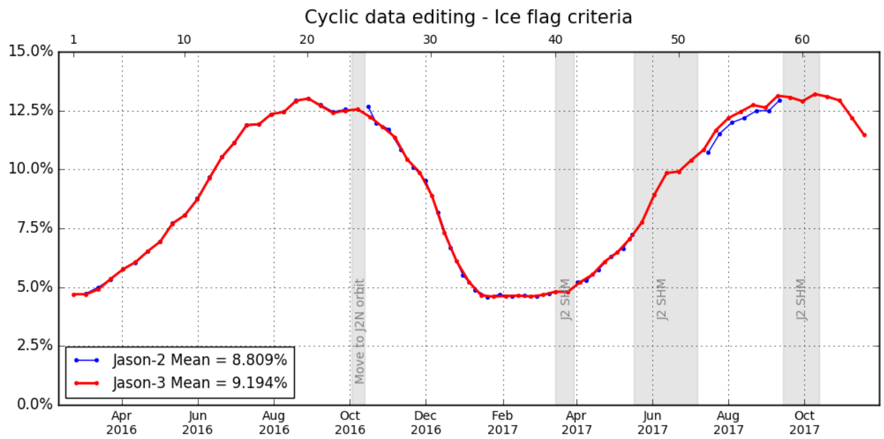


Figure 6 – Cycle per cycle monitoring of the percentage of edited measurements by ice flag criterion.

Over the shown period, no anomalous trend is detected but the nominal annual cycle is visible. Indeed, the maximum number of points over ice is reached during the southern winter (i.e. July - September). As Jason-3 takes measurements between 66° north and south, it does not detect thawing of sea ice (due to global warming), which takes place especially in northern hemisphere over 66°N.

3.2.3. Flagging quality criterion: Rain flag

Though the altimeter rain flag is available in GDR, it is not used hereafter during the editing procedure. The percentage of measurements where rain flag is set to 1 is plotted in figure 7 top pannel. Using the altimeter rain flag would lead to edit 6.5% of additional measurements (see figure 7 bottom pannels for comparison).

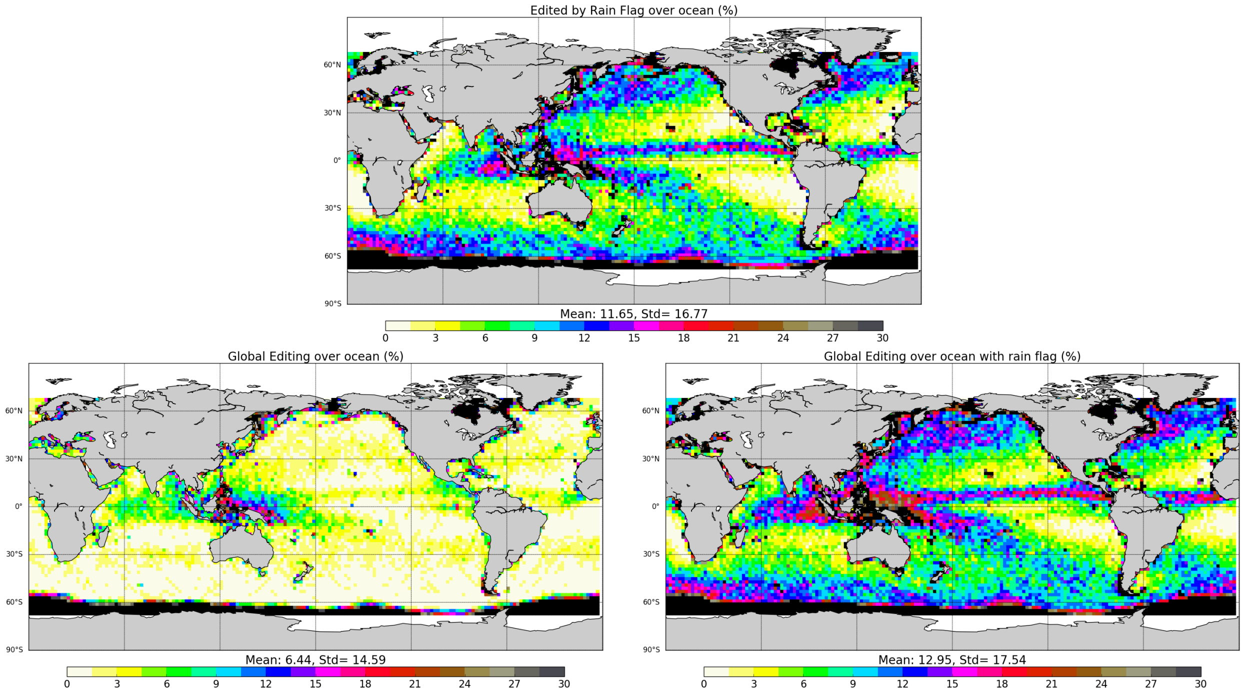


Figure 7 – Top: Percentage of edited measurements by altimeter rain flag criterion. Bottom left: Map of global edited measurements without considering the rain flag. Bottom right: Map of global edited measurements using all criteria and considering the rain flag. All figures are computed over ocean and from cycle 1 to 65.

3.2.4. Editing on thresholds criteria

After quality flag analysis, instrumental parameters have also been analyzed from comparison with thresholds. The average of total edited measurements following threshold criterion is around 3.4% (Figure 8). For each criterion, cycle percentage of edited measurements is monitored (detailed from part 3.2.4.1. to 3.2.4.11.). This allows detection of anomalies in the number of removed data, which could have instrumental, geophysical or algorithmic origins. In particular, note that no measurement is edited by the following corrections (these parameters are only verified in order to detect data at default values, which might happen during a processing anomaly):

- dry troposphere correction,
- inverted barometer correction (including DAC),
- equilibrium tide,
- earth tide,
- pole tide.

Threshold criteria applied on altimeter, radiometer and geophysical parameters are described in the following table 5. The last column represents the mean of rejected data on each criterion over GDR cycles 1 to 65.

Parameter	Min thresholds	Max thresholds	Mean edited
Sea surface height	$-130\ m$	$100\ m$	0.77%
Sea level anomaly	$-2.0\ m$	$2.0\ m$	1.05%
Number measurements of range	10	$Not\ applicable$	1.02%
Standard deviation of range	0	$0.2\ m$	1.34%
Squared off-nadir angle	$-0.2\ deg^2$	$0.64\ deg^2$	0.58%
Dry troposphere correction	$-2.5\ m$	$-1.9\ m$	0.00%
Inverted barometer correction	$-2.0\ m$	$2.0\ m$	0.00%
AMR wet troposphere correction	$-0.5m$	$-0.001\ m$	0.31%
Ionosphere correction	$-0.4\ m$	$0.04\ m$	1.15%
Significant wave height	$0.0\ m$	$11.0\ m$	0.57%
Sea State Bias	$-0.5\ m$	$0.0\ m$	0.51%
Number measurements of Ku-band Sigma0	10	$Not\ applicable$	1.03%
			.../...

Parameter	Min thresholds	Max thresholds	Mean edited
Standard deviation of Ku-band Sigma0	0	$1.0\,dB$	2.08%
Ku-band Sigma0 [2]	$7.0\,dB$	$30.0\,dB$	0.54%
Ocean tide	$-5.0\,m$	$5.0\,m$	0.01%
Equilibrium tide	$-0.5\,m$	$0.5\,m$	0.00%
Earth tide	$-1.0\,m$	$1.0\,m$	0.00%
Pole tide	$-15.0\,m$	$15.0\,m$	0.00%
Altimeter wind speed	$0\,m.s^{-1}$	$30.0\,m.s^{-1}$	1.04%
All together	-	-	3.38%

Table 5 – Editing criteria over cycles 1 to 65

The peak detected on cycle 30 (Figure 8) is due to an AMR anomaly that occured from 08/12/2016 04:36:34 to 09/12/2016 12:58:47. Except this anomaly, the rate of rejected by thresholds data is quite stable.

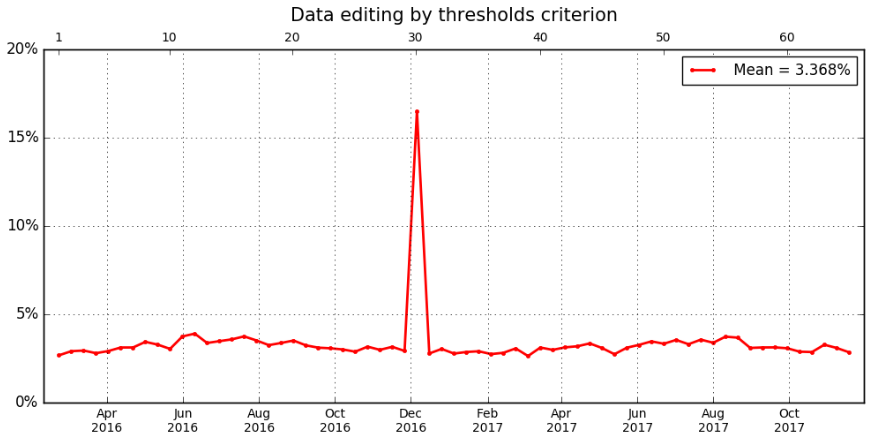


Figure 8 – Jason-3 data editing by threholds average by cycle.

[2] A bias of -2.38 dB is substracting in order to be in agreement with TOPEX thresholds.

3.2.4.1. Threshold criteria: 20-Hz range measurements number and standard deviation

Range measurements computed with less than 10 full resolutions (20Hz, 20 measurements/seconds) are removed. Indeed they are considered as not consistent to compute 1Hz resolution range. Such situation usually occurs in regions with disturbed sea state or heavy rain, as shown on Figure 9 top right. Indeed waveforms are distorted by rain cells, which makes them often meaningless for SSH calculation. As a consequence, edited measurements due to several altimetric criteria are often correlated with wet areas.

For Jason-3, the average percentage of removed measurements using this criterion is 1.02% whereas it is 1.04% for Jason-2. The two missions provide very closed values (Figure 9 top right).

Using the threshold editing on 20Hz measurements standard deviation (Figure 9 bottom), 1.34% of data are removed in average for Jason-3, which is very close to Jason-2 (1.40%). An annual signal appears here for both missions. As for 20Hz range measurements number, edited measurements are correlated with wet areas.

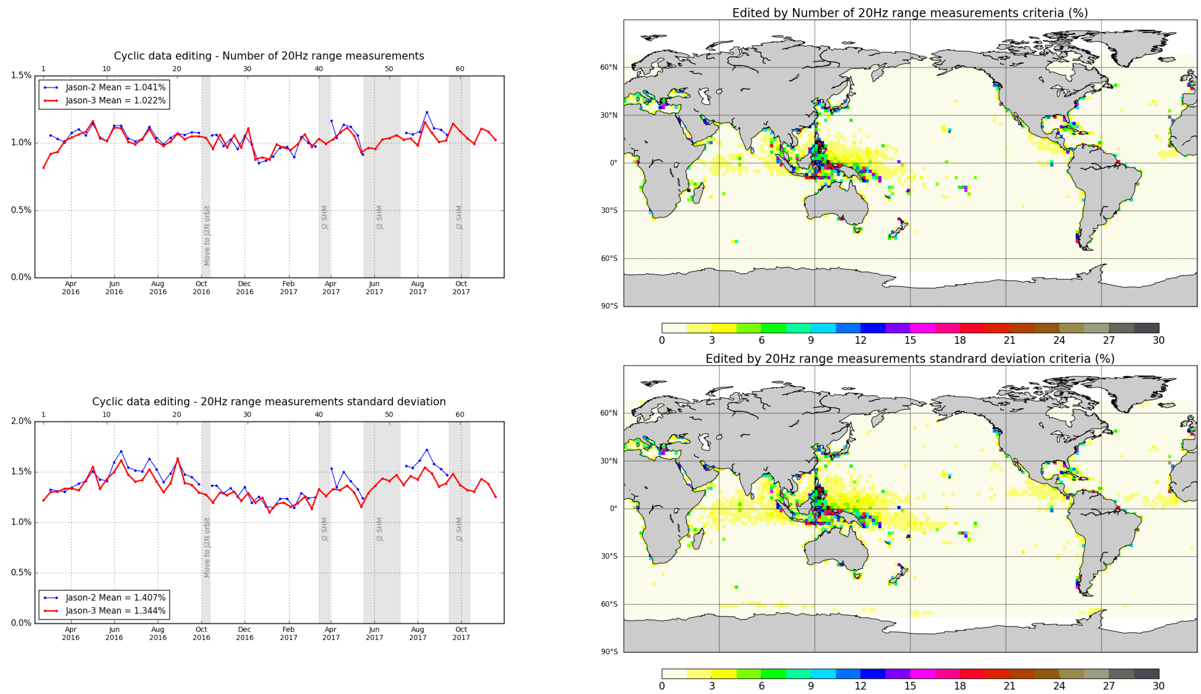


Figure 9 – Percentage of edited measurements by 20Hz range measurements threshold criterion (top) and by 20Hz range measurements standard deviation threshold criteria (bottom). Cycle per cycle monitoring compared with Jason-2 (left) and Jason-3 averaged map from cycle 1 to 65 (right).

3.2.4.2. Threshold criteria: Significant wave height (swh)

The percentage of edited measurements due to significant wave heights criterion is represented on Figure 10, and is about 0.57%. They are mostly due to set to default values data, and are located near coasts, in the equatorial regions and in circumpolar areas. Compared to Jason-2, the former remove globally more SWH data (0.64%), which seems to be linked to acquisition modes (under investigation):

- For Jason-3 cycles 1 to 5, 7-8, 10, and 20, both missions are using median tracker: rejected data rate on this criterion are equivalent for both missions.
- For almost all cycles, Jason-2 uses meadian tracker and Jason-3 uses Diode/DEM automatic switch: there are less data removed for Jason-3 than for Jason-2.
- For Jason-2 cycle 311 (over Jason-3 cycles 30 and 31), both missions are in Diode/DEM mode: there are quite equivalent, with slightly less data removed on Jason-2.

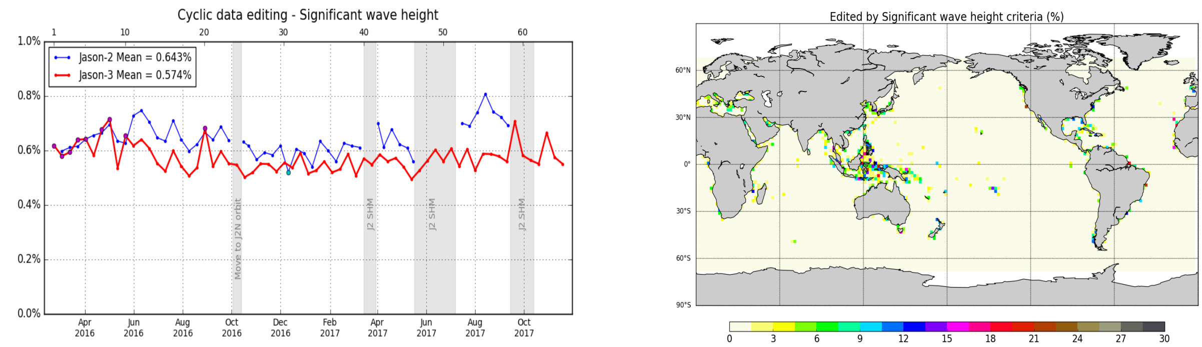


Figure 10 – Percentage of edited measurements by SWH threshold criterion. Left: Cycle per cycle monitoring compared with Jason-2 (Jason-2 DEM cycle in cyan. Jason-3 median tracker cycles in purple.) Right: Map over Jason-3 period.

3.2.4.3. Threshold criteria: Backscatter coefficient (sigma0)

The percentage of edited measurements due to backscatter coefficient criterion is represented on top of Figure 11. It is about 0.55%, compared to 0.61% for Jason-2. The bottom part of Figure 11 shows again close values between the two missions for the 20Hz sigma0 standard deviation criterion. However, there are slightly more rejected measurements with this criterion on Jason-3 (2.08%) than Jason-2 (1.95%). Edited measurements are especially found in regions with disturbed waveforms, as shown on the maps. As for SWH criterion (3.2.4.2.), differences seem to be linked to acquisition modes (under investigation):

- For Jason-3 cycles 1 to 5, 7-8, 10, and 20, both missions are using median tracker: rejected data rate on this criterion are equivalent for both missions.
- For almost all cycles, Jason-2 uses meadian tracker and Jason-3 uses Diode/DEM automatic switch: there are less data removed for Jason-2 than for Jason-3.
- For Jason-2 cycle 311 (over Jason-3 cycles 30 and 31), both missions are in Diode/DEM mode: there are quite equivalent.

Note that a change of behaviour appears after DEM upload on cycle 057. Sigma0 standard deviation on 20Hz measurements slightly drop (see special investigation part 8.2.), and rejected measurements due to this criterion is nearest the Jason-2 rate (caution as only two Jason-2 cycles are available for this comparison). This is linked to a better way to center waveform echo.

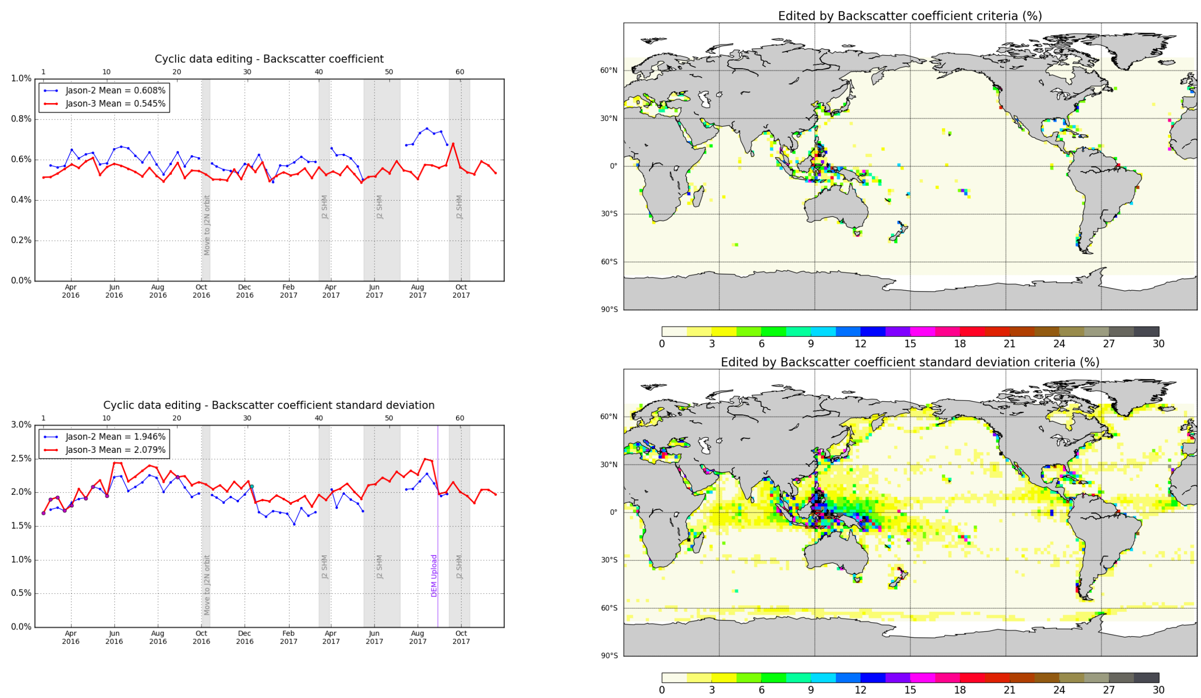
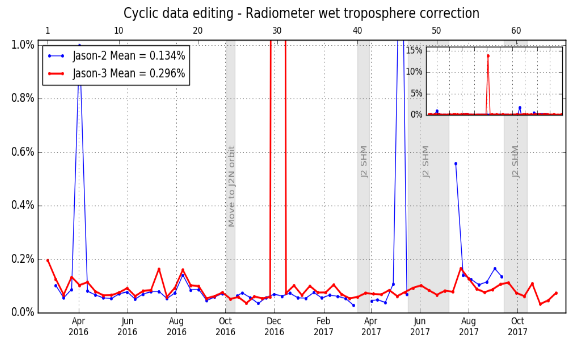


Figure 11 – Percentage of edited measurements by backscatter coefficient threshold criterion (top) and by 20Hz backscatter coefficient standard deviation threshold criteria (bottom). Cycle per cycle monitoring compared with Jason-2 (left, Jason-2 DEM cycle in cyan. Jason-3 median tracker cycles in purple) and Jason-3 averaged map from cycle 1 to 65 (right).

3.2.4.4. Threshold criteria: Radiometer wet troposphere correction

The percentage of edited measurements due to radiometer wet troposphere correction criterion is represented in figure 12. It is about 0.30%. When removing cycles which experienced problems, percentage of edited measurements drops to 0.09%. For some cycles, the percentage of edited measurements is higher than usual. For cycle 30, this unusual value (13.85%) is due to an AMR anomaly. Compared to Jason-2 values, they are within the same order of magnitude, except specific events or anomalies (Jason-2 AMR anomalies during cycle 285 and cycle 326, that correspond respectively to Jason-3 cycle 5 and cycle 45 datation).



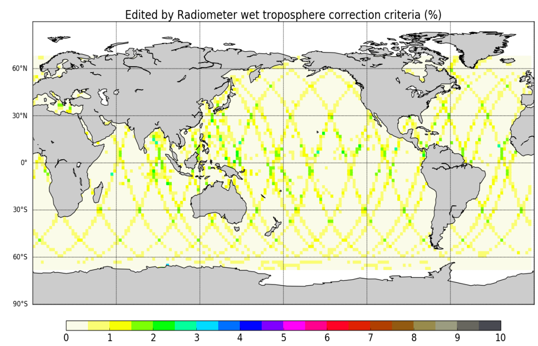
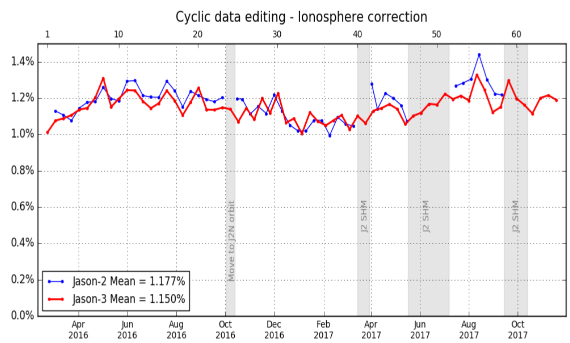


Figure 12 – Percentage of edited measurements by radiometer wet troposphere correction threshold criterion. Left: Cycle per cycle monitoring compared with Jason-2. Right: Jason-3 averaged map from cycle 1 to 65.

3.2.4.5. Threshold criteria: Ionospheric correction

The mean percentage of edited data by threshold criterion on ionospheric correction is 1.15% and is very close to Jason-2 mean (1.15%). The map on figure 13 shows that measurements edited by dual frequency ionosphere correction are mostly found in equatorial regions.



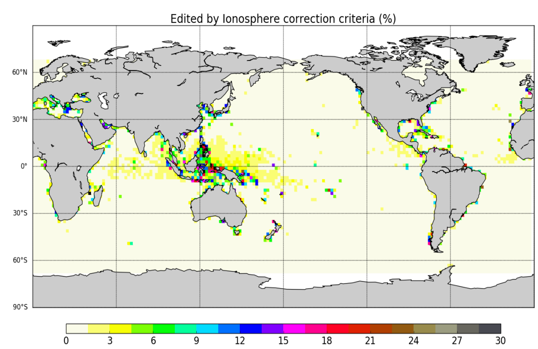


Figure 13 – Percentage of edited measurements by ionospheric correction threshold criterion. Left: Cycle per cycle monitoring compared with Jason-2. Right: Jason-3 averaged map from cycle 1 to 65.

3.2.4.6. Threshold criteria: Altimeter wind speed

The percentage of edited measurements due to altimeter wind speed criterion is represented in figure 14. It is about 1.04%, and in accordance with Jason-2 (1.04%). Measurements are usually edited because of default values. This is the case when sigma0 itself is at default value, or when it shows very high values (higher than 25 dB), which occurs during sigma bloom situations and also over sea ice. Indeed, the wind speed algorithm (which uses backscatter coefficient and significant wave height) can not retrieve values for sigma0 higher than 25 dB.
Wind speed is also edited when it includes negative values, which can occur in GDR products. Nevertheless, sea state bias is available even for negative wind speed values. Therefore, the percentage of edited altimeter wind speed data is higher than the percentage of edited sea state bias data.
The map 14 showing percentage of measurements edited by altimeter wind speed criterion is correlated with maps 10 and 15.

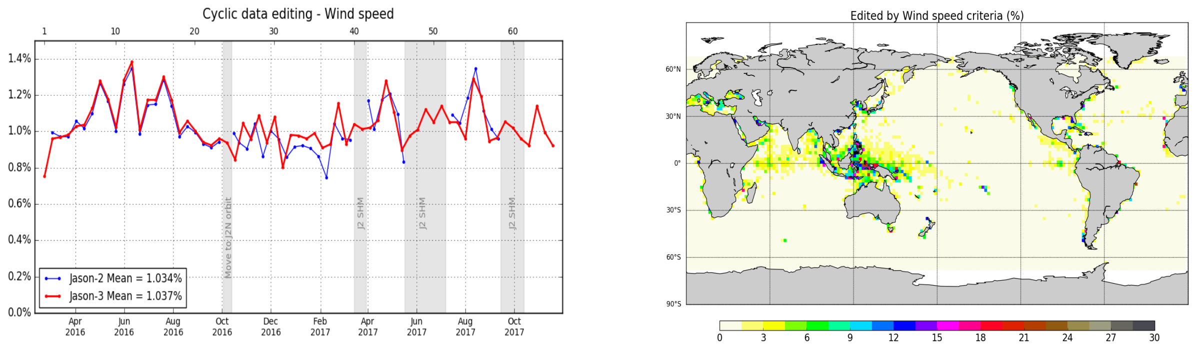


Figure 14 – Percentage of edited measurements by wind speed threshold criterion. Left: Cycle per cycle monitoring compared with Jason-2. Right: Jason-3 averaged map from cycle 1 to 65.

3.2.4.7. Threshold criteria: Sea State Bias

Regarding the sea state bias criterion, the percentage of Jason-3 edited measurements is about 0.51% and 0.62% for Jason-2. The difference can also be observed on the sigma0 (0.06%) and the significant wave height (0.07%) threshold criteria (which are both used for SSB computation).

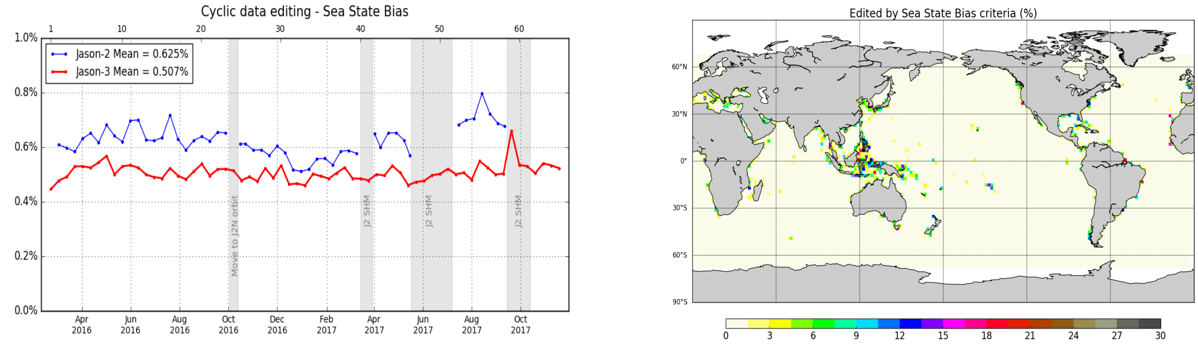


Figure 15 – Percentage of edited measurements by sea state bias threshold criterion. Left: Cycle per cycle monitoring compared with Jason-2. Right: Jason-3 averaged map from cycle 1 to 65.

3.2.4.8. Threshold criteria: Ocean tide

The percentage of edited measurements due to ocean tide is 0.01% for both missions. The ocean tide correction is a model output, there should therefore be no edited measurement. Indeed there are no measurements edited in open ocean areas, but only very few near coasts (Alaska, Kamchatka, Labrador). These measurements are mostly at default values. The level of edited measurements decreases or increases with move of orbit for Jason-2 : this is related to the new ground track, which no longer overflows the same areas.

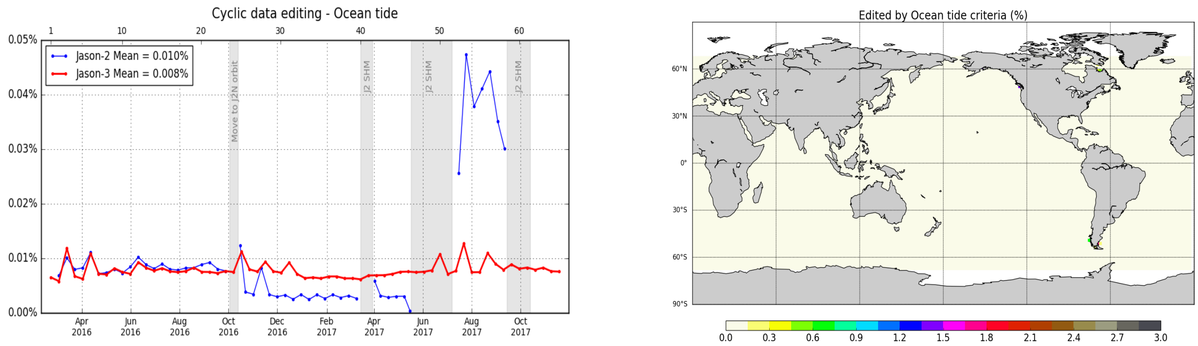


Figure 16 – Percentage of edited measurements by ocean tide threshold criterion. Left: Cycle per cycle monitoring compared with Jason-2. Right: Jason-3 averaged map from cycle 1 to 65.

3.2.4.9. Threshold criteria: Square off nadir angle

The percentage of edited data for both missions is almost similar (about 0.58%). An increase in Jason-2 edited measurements is observed from July 2017 after Jason-2 move to drifting orbit.

The map 17 shows that edited measurements are mostly found in coastal regions and regions with disturbed waveforms.

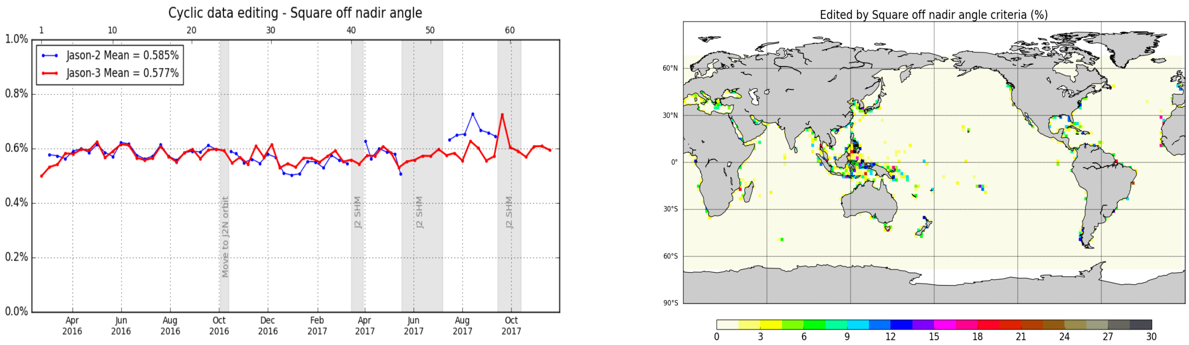


Figure 17 – Percentage of edited measurements by square off nadir angle threshold criterion. Left: Cycle per cycle monitoring compared with Jason-2. Right: Jason-3 averaged map from cycle 1 to 65.

3.2.4.10. Threshold criteria: Sea surface height

Sea surface height represents the difference between the orbit and the altimeter range in Ku band. Figure 18 summarizes the editing resulting from the sea surface height threshold criterion. It removes in average 0.75% of data for Jason 3 whereas it removes 0.77% for Jason 2. The editing is usually due to range measurements at default values near coast in equatorial and mid-latitude regions, as well as regions with low significant wave heights.

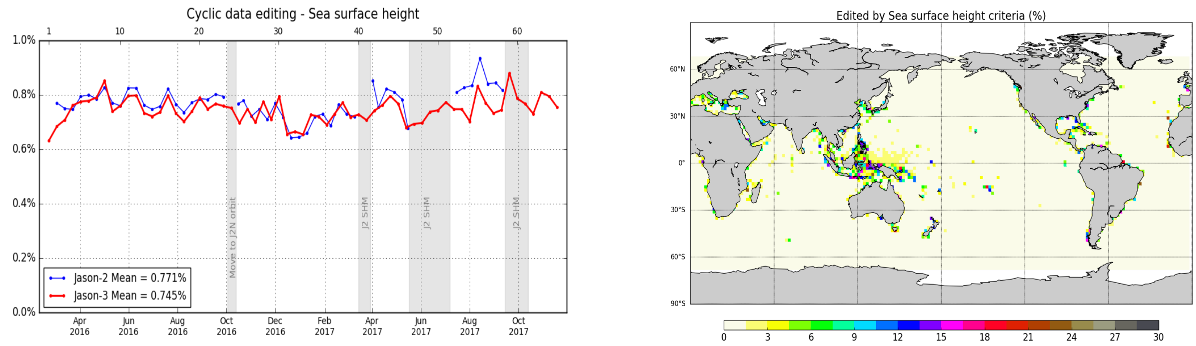
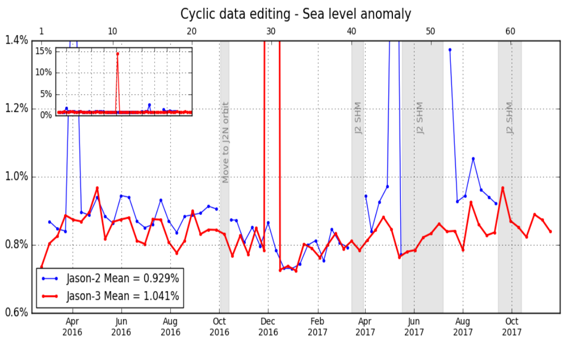


Figure 18 – Percentage of edited measurements by sea surface height threshold criterion. Left: Cycle per cycle monitoring compared with Jason-2. Right: Jason-3 averaged map from cycle 1 to 65.

3.2.4.11. Threshold criteria: Sea level anomaly

The percentage of edited data by threshold criterion is 1.04% for Jason-3. As the wet tropospheric correction is used in the SLA computation, percentage of edited SLA measurement presents the same peak on cycle 30. When removing this cycle, percentage of edited measurements drops to 0.83%. The difference between Jason-3 and Jason-2 (0.93%) is mainly due to Jason-2 wet troposphere contribution, where AMR was unavailable during cycle 285 (Jason-3 cycle 5) and cycle 326 (Jason-3 cycle 45) leading to an increase of the quantity of edited data (point out of plot scale).

Otherwise the overall performance of Jason-3 system is in excellent agreement with Jason-2, and shows very close results in terms of edited data.



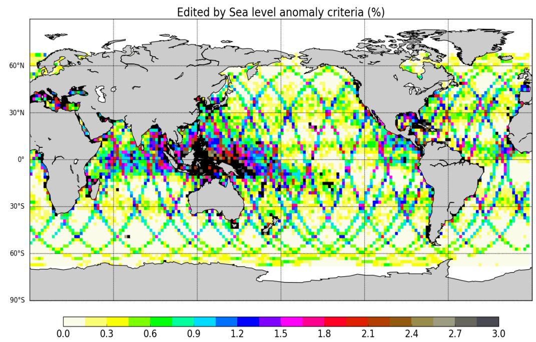


Figure 19 – Percentage of edited measurements by sea level anomaly threshold criterion. Left: Cycle per cycle monitoring compared with Jason-2. Right: Jason-3 averaged map from cycle 1 to 65.

4. Monitoring of altimeter and radiometer parameters

4.1. Methodology

Mean and standard deviation of Jason-3 main parameters have both been monitored since the beginning of the mission. Moreover, a comparison with Jason-2 parameters has been performed: it allows to monitor the bias between the parameters of the 2 missions.

- Till Jason-3 cycle 23, Jason-3 and Jason-2 are on the same ground track and are spaced out about 80 seconds apart (tandem phase), the mean of the Jason-2 - Jason-3 differences can be computed using a point by point repeat track analysis (refered as 'residuals' in plots).
- From Jason-3 cycle 24, a maneuver sequence was conducted (from end of Jason-2 cycle 303) to move Jason-2 to the new formation flight mission orbit. Jason-2 has a repeat groundtrack which is interleaved with Jason-3. It is the same ground-track as already used by Topex/Poseidon during its formation flight phase with Jason-1, and Jason-1 with Jason-2. Because of a time shift of 5 days, geographical variations are then too strong to directly compare Jason-3 and Jason-2 parameters on a point by point basis. Therefore day per day global differences have been carried out to monitor differences between the two missions. A filter over 11 days was applied. Nevertheless the differences are still quite noisy, especially for corrections which vary rapidly in time and space. Therefore occasional small jumps might be covered by the noise of the differences. Nevertheless it should be possible to detect drifts and permanent jumps. Jason-3 and Jason-2 were in this formation flight phase from Jason-3 cycles 25 to 46 (Jason-2 cycles 305 to 327).

In March and May 2017, Jason-2 experienced severals safe holds caused by gyro anomalies. It was decided to move Jason-2 to an End-of-Life (EOL) Long Repeat Orbit (LRO). Jason-2 mission phase is detailed in [113]. Science data on the LRO are available from 11th of July 2017 onwards. Note that the first cycle on the new orbit starts with cycle 500 (this corresponds to mid-Jason-3 cycle 52). As during the formation flight phase, day per day global differences of the parameters have been carried out to monitor differences between the two missions.
Note that differences are done over Jason-3 cycles 1 to 58, corresponding to Jason-2 cycles 281 to 506.

4.2. 20Hz range measurements

The monitoring of the number and standard deviation of 20 Hz elementary range measurements used to derive 1 Hz data is presented here. These two parameters are computed during the altimeter ground processing. For both Jason-2 and Jason-3, before performing a regression to derive the 1 Hz range from 20 Hz data, a MQE (mean quadratic error) criterion is used to select valid 20 Hz measurements. This first step of selection consists in verifying that the 20 Hz waveforms can be approximated by a Brown echo model (Brown, 1977 [47]) (Thibaut et al. 2002 [99]).
Then, through an iterative regression process, elementary ranges too far from the regression line are discarded until convergence is reached. Thus, monitoring the number of 20 Hz range measurements and the standard deviation computed among them is likely to reveal changes at instrumental level.

4.2.1. 20 Hz range measurements number in Ku-Band and C-Band

Jason-3 number of elementary 20 Hz range measurements starts with values slightly higher than Jason-2 until cycle 3. During cycle 3, new calibration (CAL2) filter turned the square off-nadir angle to zero, which implies the absence of waveform mispointing, a higher MQE and a smaller number of elementary measurements. Then from cycle 4 onwards, Jason-3 number of elementary 20 Hz range measurements is very similar to Jason-2 with an average of 19.604 versus 19.607 in Ku-band (left of figure 20) and 19.237 versus 19.246 in C-band (right of figure 20).

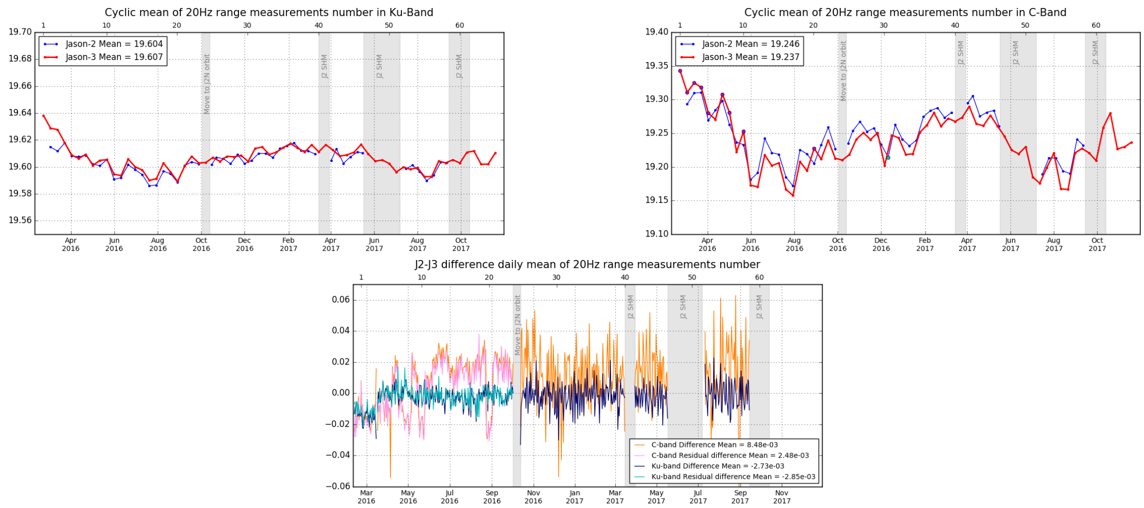


*Figure 20 – **Top:** Cyclic monitoring of number of elementary 20 Hz range measurements for Jason-2 and Jason-2 for Ku-band and C-band. **Bottom:** Jason-2 - Jason3 difference daily monitoring of elementary 20 Hz range measurements number.*

Elementary number of measurements used to compute a 1Hz measurement is correlated to significant wave height (4.5.): figure 21 shows less elementary range measurements around Indonesia, the Mediterranean Sea and close to coasts, which are all regions of low significant wave heights.

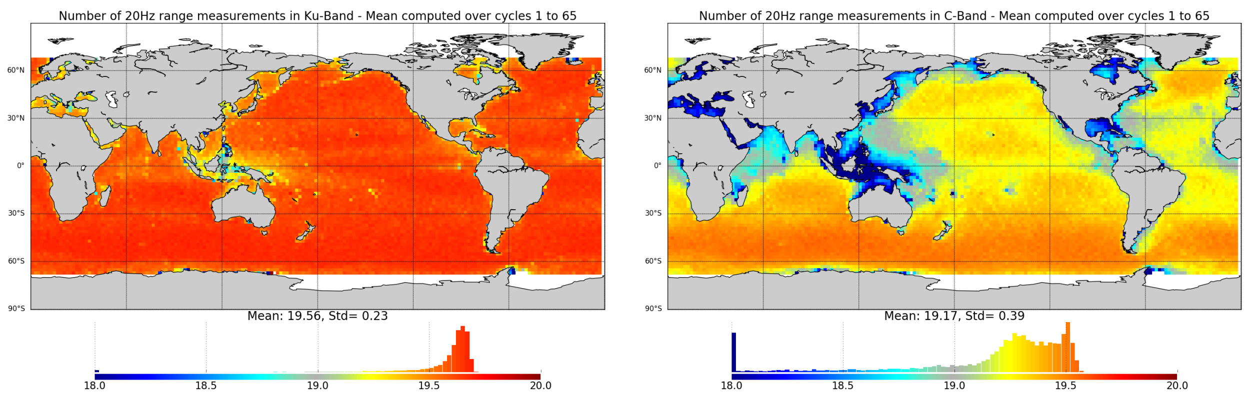


Figure 21 – Map of number of 20 Hz range measurements for Jason-3 averaged over cycles 1 to 65, in Ku-band (left) and in C-band (right).

4.2.2. 20 Hz range measurements standard deviation in Ku-Band and C-Band

Figure 22 shows the monitoring of Jason-3 and Jason-2 20 Hz range measurements standard deviation, in Ku-band (left) and C-band (right). Jason-3 standard deviation of the 20 Hz measurements is 8.0 cm for Ku-Band and 17.6 cm for C-Band. It is very similar to Jason-2 data. 20 Hz range measurements standard deviation is higher on C-band than on Ku-band due to the onboard averaging that is performed over less waveforms (onboard averaging of 90 measurements for each 20Hz Ku-band value, for 15 in case of C-band), which leads to an increased noise.

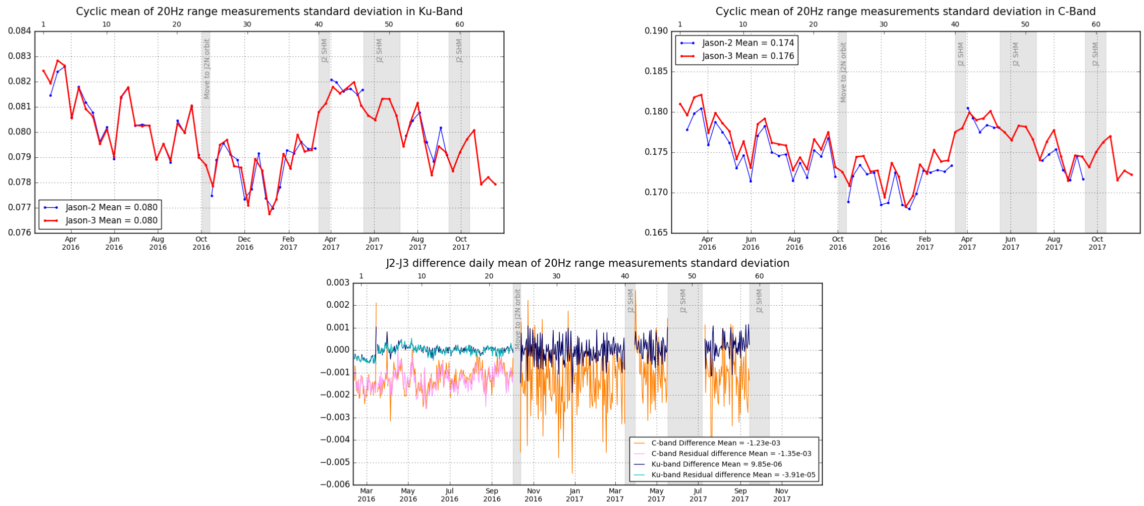


*Figure 22 – **Top:** Cyclic monitoring of elementary 20 Hz range measurements standard deviation for Jason-2 and Jason-3 for Ku-band and C-band. **Bottom:** Jason-2 - Jason3 difference daily monitoring of elementary 20 Hz range measurements standard deviation.*

Standard deviation of measurements is correlated to significant wave height (4.5.).

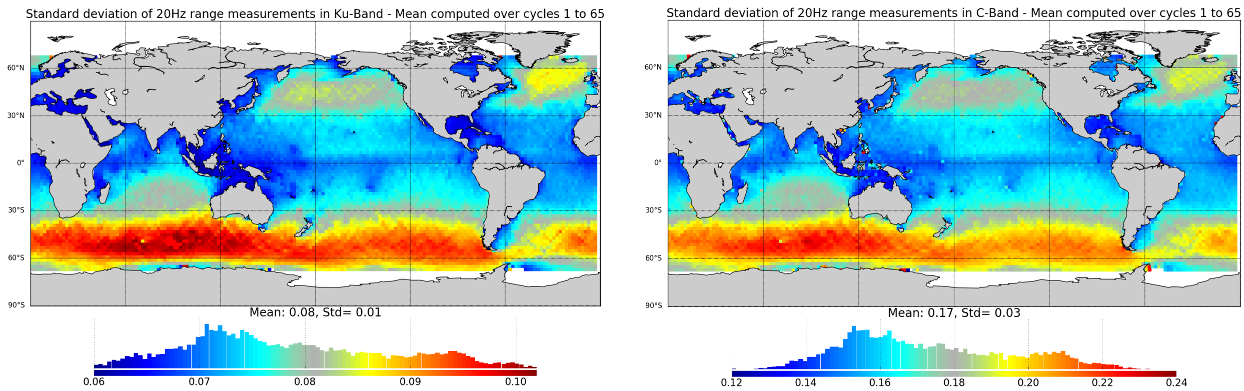


Figure 23 – Map of 20 Hz range measurements standard deviation for Jason-3 averaged over cycles 1 to 65, in Ku-band (left) and in C-band (right).

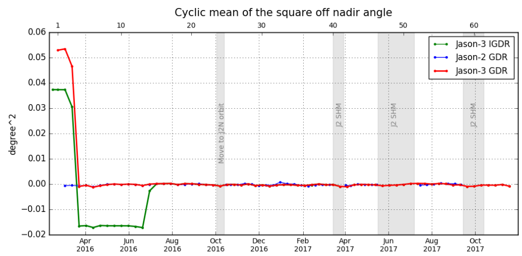
4.3. Off-Nadir Angle from waveforms

The off-nadir angle is estimated from the waveform shape during the altimeter processing. It allows an estimation of Jason-3 mispointing. The square of the off-nadir angle, averaged on a cyclic basis, has been plotted for Jason-3 and Jason-2 on figure 24.

Jason-3 altimeter mispointing was deeply analysed to understand the negative values observed from cycle 3 after GPS upload. Mispointing is actually related to CAL2 filter shapes, which depends on automatic gain control settings for Jason-3.

During the first cycles, the in-flight calibration (CAL2) filters were measured using a different Automatic Gain Control code than the one used during waveform acquisition over ocean, in order to optimize the CAL2 measurement numerical accuracy (quantification optimization). It has however an impact on the filter slope and fully explains the observed mispointing negative values.

The filter slope was modified during cycle 14 (June 26th, 2016) and explains the jump to zero on the IGDR curve. This correction was applied during GDR production, which explains the difference between red and green curves between cycles 4 and 14, so that GDR mispointing has been close to zero from cycle 4.



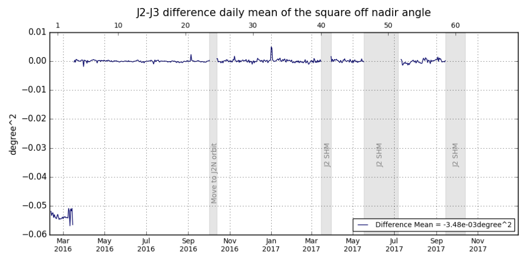


*Figure 24 – **Left:** Cyclic monitoring of the square off-nadir angle for Jason-2 and Jason-3 for GDRs (blue and red curves) and Jason-3 IGDRs (product IGDR for cycles 1 to 41 in light green, and IGDR L2P from cycle 25 to 68 in dark green). **Right:** Jason-2 - Jason3 difference daily monitoring of the square off-nadir angle (GDR data).*

The map of figure 25 is generally slightly negative, except for regions around Indonesia, and close to coasts. The off-nadir angle is derived from the slope of the trailing edge of the waveform during the altimeter processing: it can either be caused by real platform mispointing or by backscattering properties of the surface.

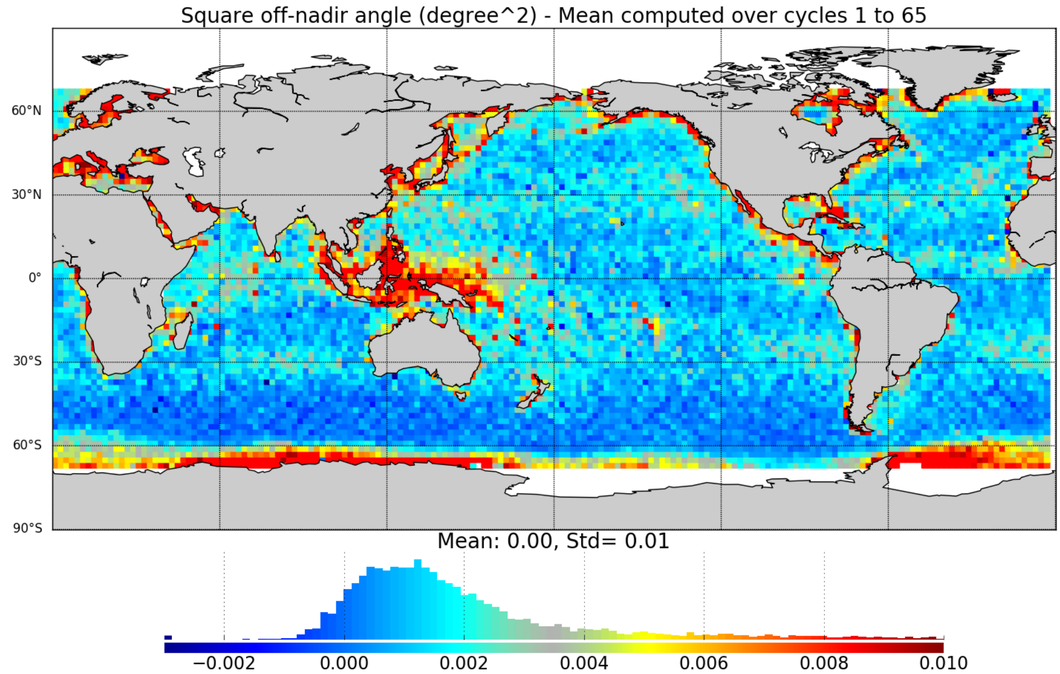


Figure 25 – Map of the square off-nadir angle for Jason-3 averaged over cycles 1 to 65.

4.4. Backscatter coefficient

The Jason-3 Ku-band and C-band backscatter coefficients show good agreement with Jason-2 as visible on cyclic monitoring (figure 26). Jason-3 backscatter coefficient is about 13.76 dB for Ku-band (15.51 dB for C-band) while for Jason-2 it is about 13.51 dB (15.41 dB). The difference between the two missions is about -0.25 dB (-0.1 dB) and present a good stability. However, this was different from cycle 0 to cycle 4, where slight mispointing on Jason-3 caused higher differences of sigma0 between missions.

During the tandem flight, Jason-3 sigma0 was modified with a new altimeter characterization file, an update of the look up tables (Patch 6) and a new CAL2 filter (cycle 14, June 26th , 2016). All of them where applied on all GDR cycles.

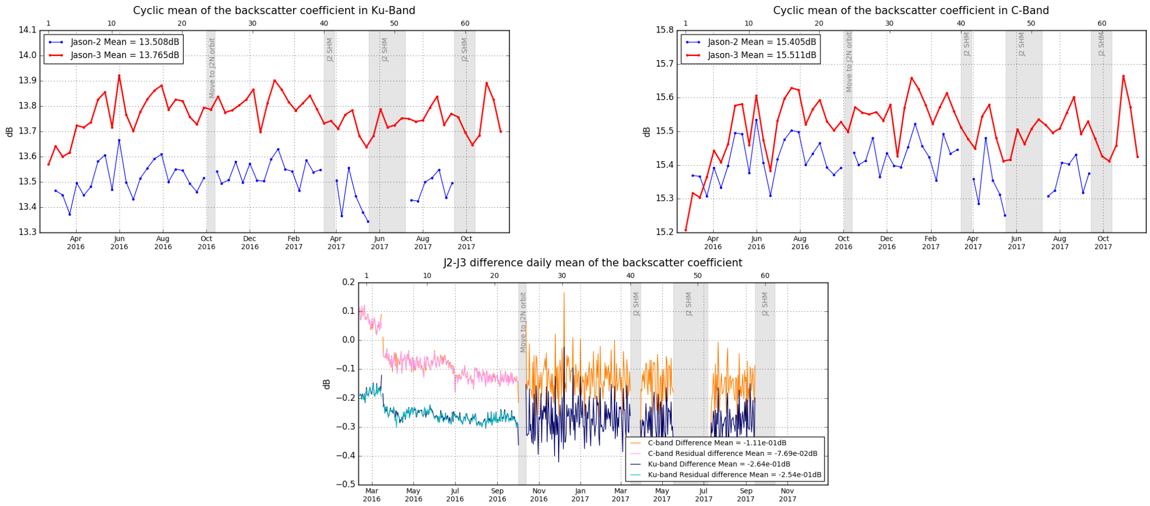


*Figure 26 – **Top:** Cyclic monitoring of backscatter coefficient for Jason-2 and Jason-3 for Ku-band (left) C-band (right). **Bottom:** daily monitoring of Jason-2 - Jason3 GDR difference of the backscatter coefficient.*

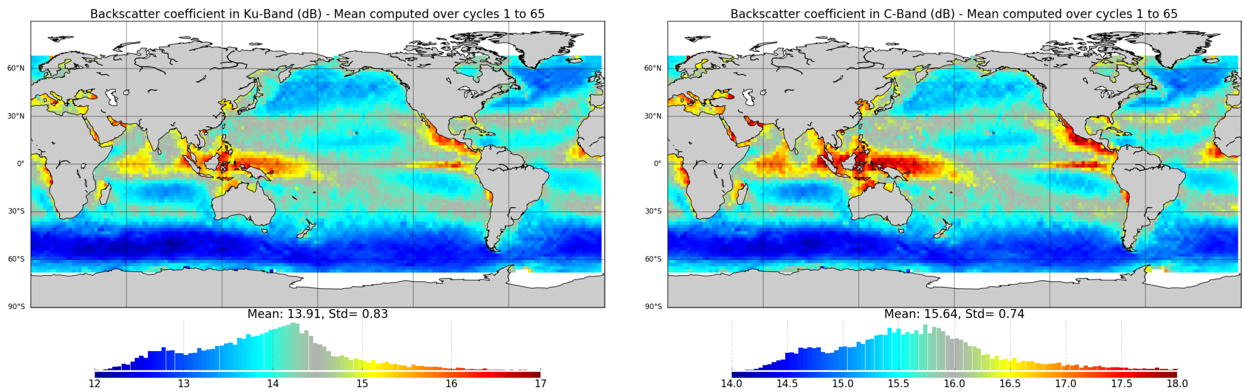


Figure 27 – Map of backscatter coefficient for Jason-3 averaged over cycles 1 to 65, in Ku-band (left) and in C-band (right).

4.5. Significant wave height

As for Sigma0 parameter, a very good consistency between both significant wave height is shown (see figure 28). In addition, until Jason-3 cycle 23 (tandem phase, observing the same ocean with only 1'20" apart), Jason-2 and Jason-3 measurements are identical. After Jason-2 move to interleaved orbit, the two missions are not as close as during tandem phase and measured swh are sightly different, but there is still no bias between Jason-2 and Jason-3 measured wave height in average.

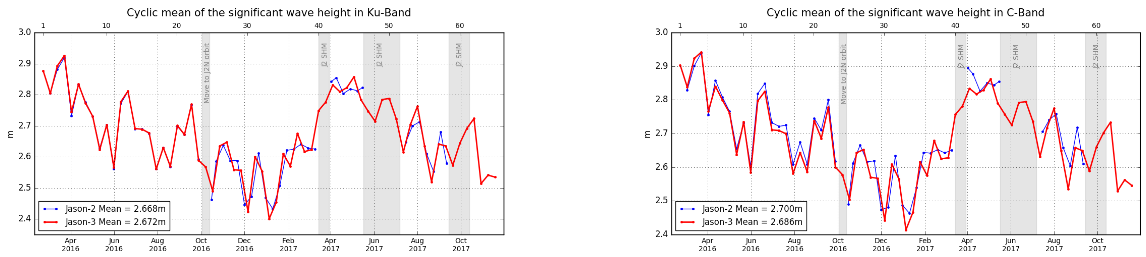


Figure 28 – Cyclic monitoring of significant wave height for Jason-2 and Jason-3 for Ku-band (left) and forC-band (right).

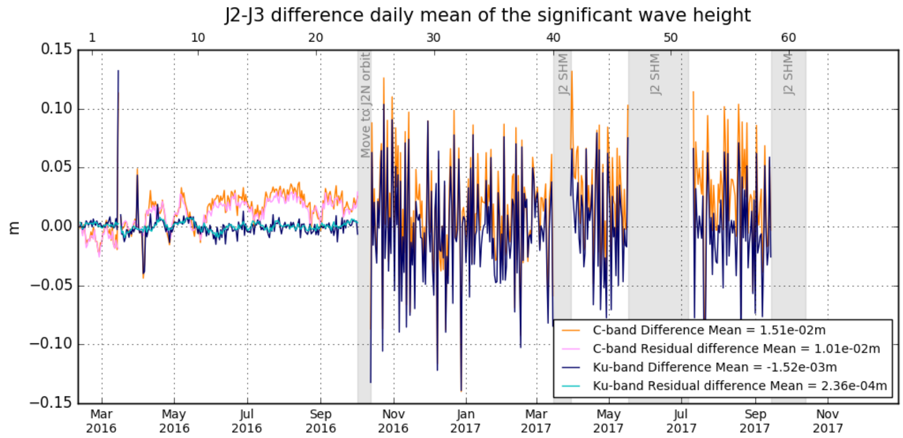


Figure 29 – Jason-2 - Jason3 difference daily monitoring of significant wave height.

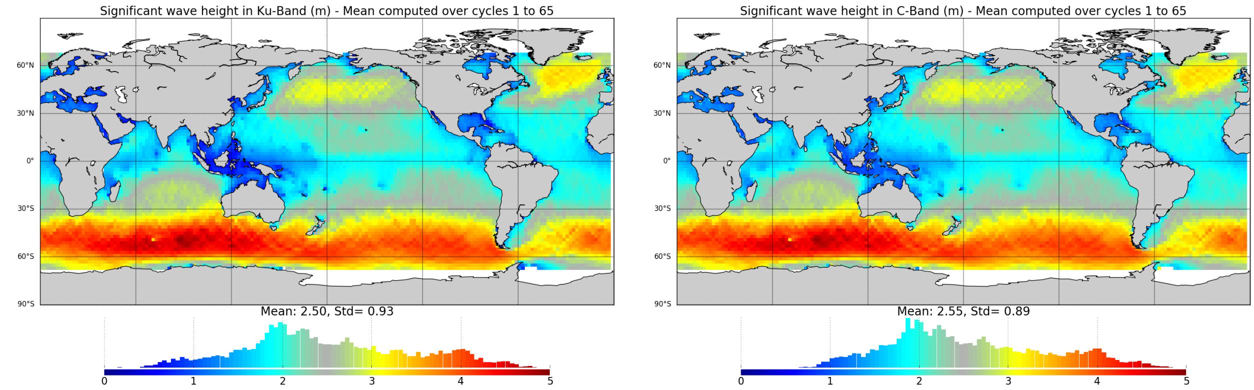


Figure 30 – Map of significant wave height for Jason-3 averaged over cycles 1 to 65, in Ku-band (left) and in C-band (right).

4.6. Dual-frequency ionosphere correction

The dual frequency ionosphere corrections derived from the Jason-3 and Jason-2 altimeters show a mean difference of about 0.56 cm (figure 31), with cycle to cycle variations lower than 1 mm.

Until the LUT changes that occurred during cycle 14 (for O/IGDRs), the mean bias between the two missions was 1 cm (for O/IGDRs). It turns then to 0.55 cm following "jumps" of Ku range (5 mm), C Range (1.5 cm) and sea state bias (0.1 mm). This event has an impact on Sea Level Anomalies retrieved from OGDRs and IGDRs products. For GDR products, the same LUT was used for the whole mission period, hence the absence of jump (see bottom and right of figure 31).

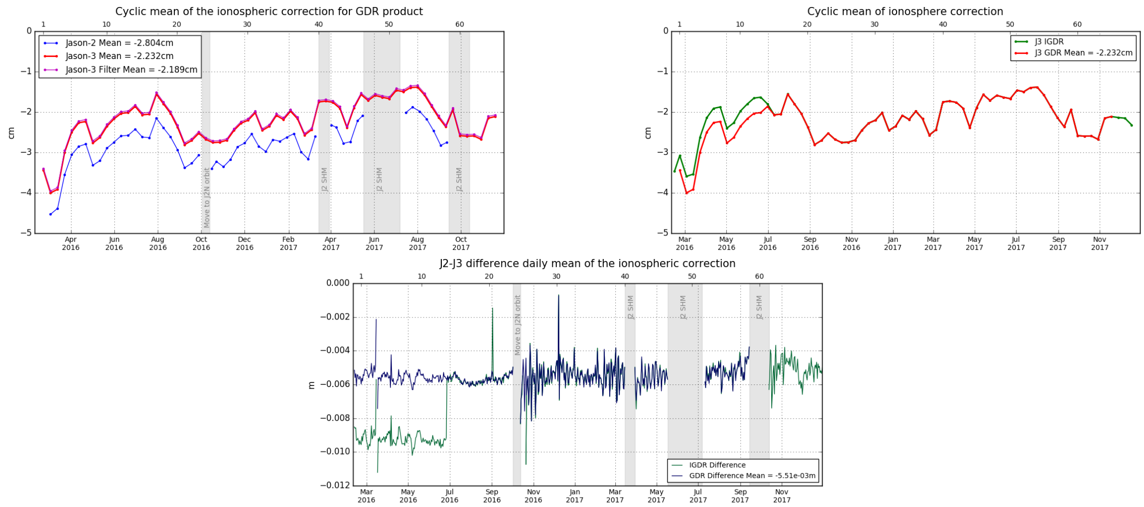


*Figure 31 – Cyclic monitoring of ionospheric correction for Jason-2 and Jason-3. (**left**). Cyclic monitoring of Jason-3 ionospheric correction for IGDR and GDR data (**right**). Jason-2 - Jason3 difference daily monitoring of ionospheric correction (**bottom**).*

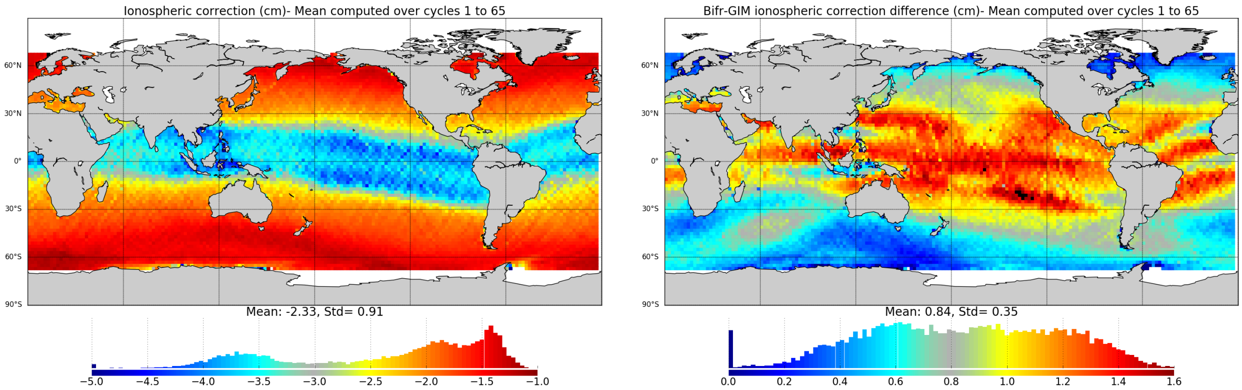


*Figure 32 – **Left:** Map of ionospheric correction for Jason-3 averaged over cycles 1 to 65. **Right:** Map of dual-frequency minus GIM ionospheric correction solutions.*

When comparing altimeter ionosphere correction to GIM correction (figure 33), mean as well as standard deviation of this difference present same variation for both missions.

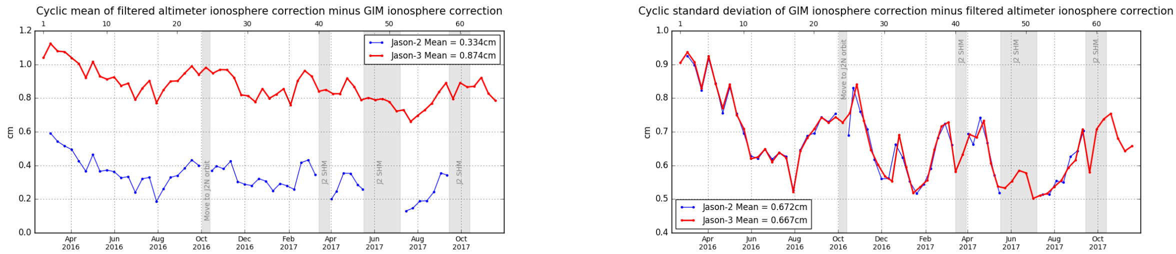


Figure 33 – Cyclic monitoring of GIM ionosphere correction minus filtered altimeter ionosphere correction for Jason-2 and Jason-3. Left: mean, right: standard deviation.

4.7. AMR Wet Troposphere Correction

4.7.1. Overview

In order to evaluate radiometer wet troposphere correction, liquid water content, water vapour content and atmospheric attenuation, Jason-3 uses a three-frequency AMR radiometer (18.7, 23.8 and 34.0 GHz), similar to the one used on Jason-2.
Note that the 23.8 GHz channel is the primary water vapor sensing channel, meaning higher water vapor concentrations leads to larger 23.8 GHz brightness temperature values. As a consequence, top right and bottom right parts of figure 34 are correlated. Moreover, the 34 GHz channel and the 18.7 GHz channel, which have less sensitivity to water vapor, facilitate the removal of the contributions from cloud liquid water and excess surface emissivity of the ocean surface due to wind, which also act to increase the 23.8 GHz brightness temperature.

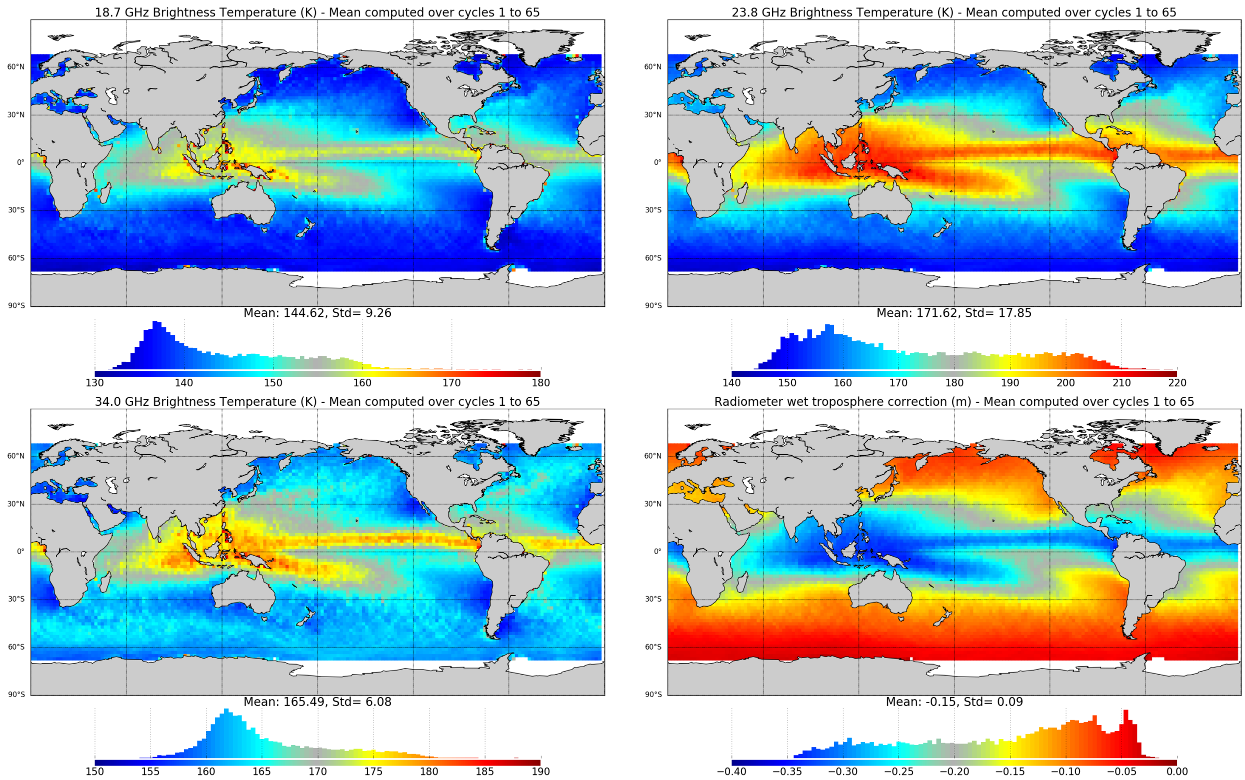
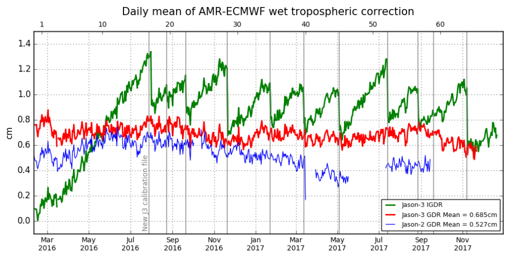


Figure 34 – Map of Jason-3 brightness temperatures averaged over cycles 1 to 65: 18.7 Ghz channel (top left), 23.8 Ghz channel (top right) and 34.0 Ghz channel (bottom left). Map of AMR wet troposphere correction for Jason-3 averaged over cycles 1 to 65(bottom right)

4.7.2. Comparison with the ECMWF model

The ECMWF wet troposphere correction has been used to check the Jason-2 and Jason-3 radiometer corrections. The cross-comparison between all radiometers and models available is necessary to analyze the stability of each wet troposphere correction. An overview of the wet troposphere correction importance for mean sea level is given in Obligis et al. [82]. The difference between AMR and model data is computed on a daily basis and is plotted on figure 35 for Jason-3 IGDR and GDR, and Jason-2 GDR for comparisons. As observed, Jason-3 AMR correction has a drift of more than half a millimetre per cycle for IGDRs (and OGDRs, not shown). Such behaviour is routinely monitored by JPL instrument expert team. Impact of drift is corrected through ground calibration (ARCS, Autonomous Radiometer Calibration System), also accounting for cold sky calibration. The first ARCS calibration occured at the end of cycle 17 and is visible on IGDR monitoring. As regards GDR data, AMR radiometer correction is calibrated at each cycle and the calibration coefficients are modified if necessary. It allows to correct the drift for GDR data (red curve on figure 35), nevertheless small drifts and jumps persist of up to 2 mm amplitude. They can be due to (among others) evolution of ECMWF model or ARCS calibrations.

In GDR, Jason-3 AMR-ECMWF model daily difference is about 6.9 mm and about 5.3 mm for Jason-2. Though Jason-3 radiometer wet troposphere correction is more stable for GDRs, Jason-3 and Jason-2 do not have exactly the same behaviour, with an inflexion point around cycle 13 and another one after Jason-2 moved to its new interleaved groundtrack on October 2016. With 2017 Safe Hold Modes, Jason-2 shows some jumps that are known to occur after restart.
Standard deviation of radiometer minus model wet troposphere correction is equivalent around 1.2 cm for both missions (right side of figure 35).



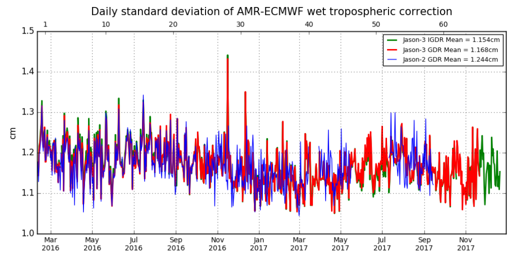


*Figure 35 – Daily monitoring of AMR minus ECMWF model wet tropospheric correction. mean **(left)** and standard deviation **(right)***

4.8. Altimeter wind speed

Jason-3 and Jason-2 present very close results in terms of wind speed. Jason-2 provides higher wind values than Jason-3 (7.80 vs 7.54 $m.s^{-1}$, figure 36).

The difference between the two missions is 0.26 $m.s^{-1}$ and can be separated in two phases: before and after GPS upload. The GPS upload occurred on March, 15th 2016 (Cycle 3) and corrected the square off nadir angle, i.e. the mispointing of the platform. Then from the restart of data production (March 18th) mispointing was set to value close to zero, which increases the sigma0 and decreases the wind speed.

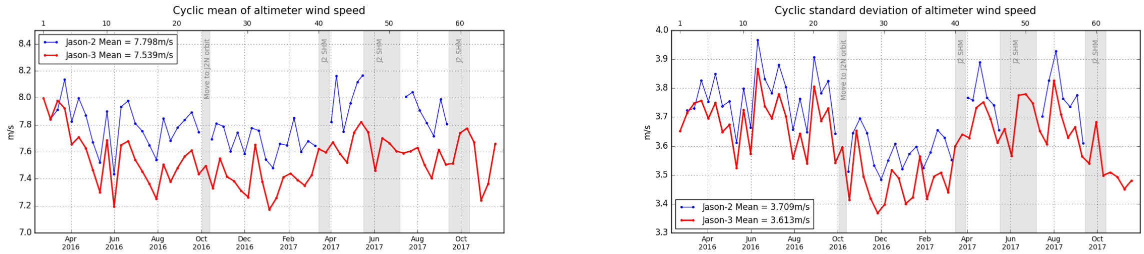


Figure 36 – Cyclic monitoring of altimeter wind speed mean (left) and standard deviation (right) for Jason-2 and Jason-3.

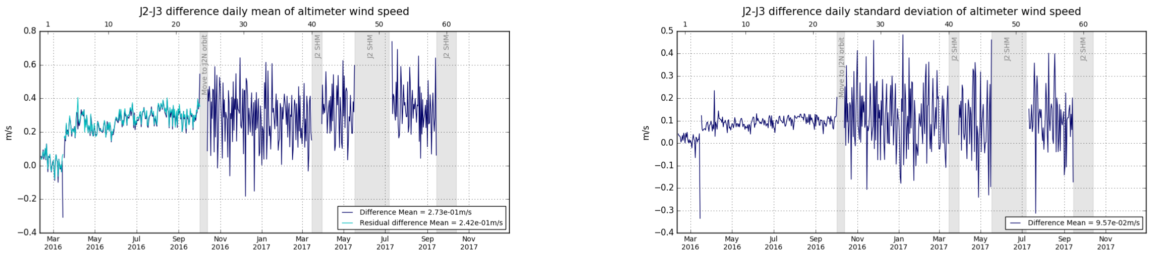


Figure 37 – Jason-2 - Jason3 difference daily monitoring of altimeter wind speed mean (left) and standard deviation (right).

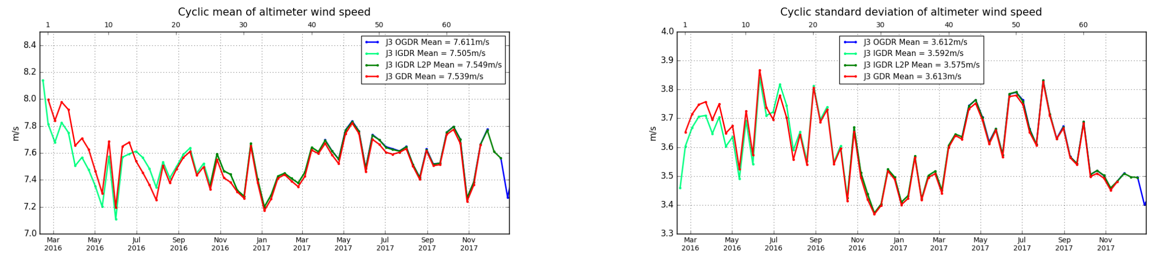


Figure 38 – Cyclic monitoring of Jason-3 altimeter wind speed for GDR, IGDR and OGDR data. Left: mean, right: standard deviation.

4.9. Sea state bias

Sea state bias (SSB) in Ku band from Jason-3 (-8.40 cm) and Jason-2 (-8.44 cm) present an excellent agreement both in average and in standard deviation (4.65 cm vs 4.61 cm, respectively).

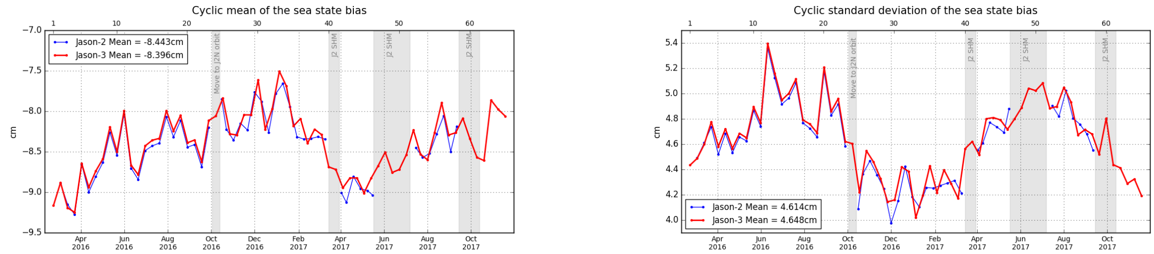


Figure 39 – Cyclic monitoring of the sea state bias mean and standard deviation for Jason-2 and Jason-3

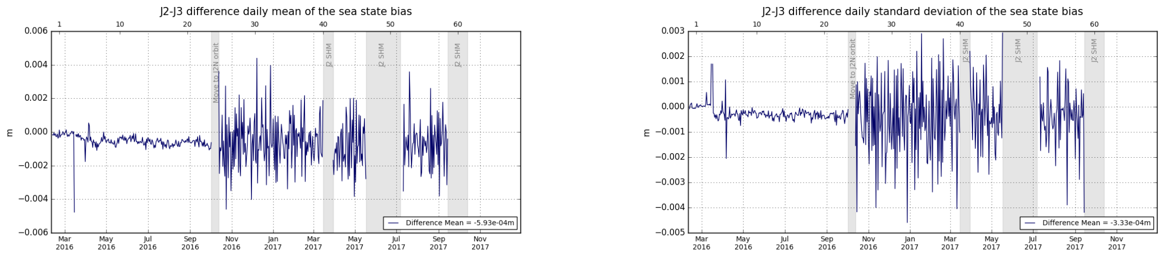


Figure 40 – Jason-2 - Jason3 difference daily monitoring of the sea state bias mean (left) and standard deviation (right).

5. SSH crossover analysis

5.1. Overview

SSH crossover differences are the main tool to estimate the whole altimetry system performances. They allow us to analyze the SSH consistency between ascending and descending passes. However in order to reduce the impact of oceanic variability, we select crossovers with a maximum time lag of 10 days. Mean and standard deviation of SSH crossover differences are computed from the valid dataset to perform maps or a cycle by cycle monitoring over all the altimeter period. In order to monitor the performances over stable surfaces, additional editing is applied to remove shallow waters (bathymetry above -1000m), areas of high ocean variability (variability above 20 cm rms) and high latitudes ($> |50| deg$). SSH performances are then always estimated with equivalent conditions. The main SSH calculation for Jason-3 (and Jason-2) are defined below.

$$SSH = Orbit - Altimeter\ Range - \sum_{i=1}^{n} Correction_i$$

with $Jason - 3\ Orbit = CNES\ orbit$ for GDR products, and

$$\begin{aligned}
\sum_{i=1}^{n} Correction_i &= Dry\ troposphere\ correction \\
&+ Dynamical\ atmospheric\ correction \\
&+ Radiometer\ wet\ troposphere\ correction \\
&+ Dual\ frequency\ ionospheric\ correction \\
&+ Non\ parametric\ sea\ state\ bias\ correction \\
&+ Ocean\ tide\ correction\ (including\ loading\ tide) \\
&+ Earth\ tide\ height \\
&+ Pole\ tide\ height
\end{aligned}$$

If no precision is done, in case of IGDR results, L2P updates are applied (ocean tide correction, mean sea surface model, mog2d dynamical atmospheric correction, see [118])
Note that due to Jason-2 SHM on 2017-09-14, comparisons between Jason-3 and Jason-2 can be done from Jason-3 cycle 1 to 58 only.

5.2. Mean of SSH crossover differences

The cycle by cycle mean of SSH differences is plotted in figure 41 for Jason-3 for OGDRs, IGDRs and GDRs. Mean of SSH differences at crossovers for Jason-3 IGDR products has noticeable negative values in average (-0.21cm for IGDR versus -0.07cm for GDR). A 120 day signal is visible for Jason-3 data, with a greater amplitude on GDR than IGDR (the investigation part 8.1. is dedicated to this topic.)

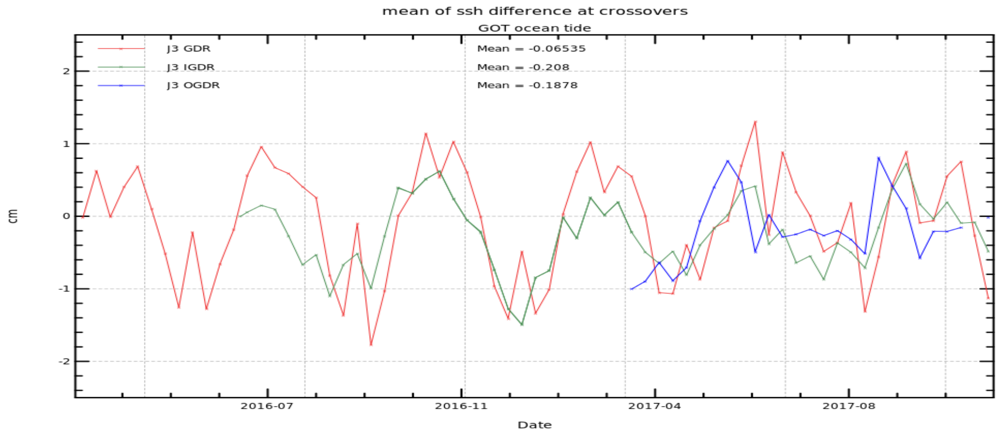


Figure 41 – Monitoring of mean of Jason-3 SSH crossover differences for OGDRs, IGDRs and GDRs. Only data with $|latitude| < 50°$, bathymetry < -1000m and low oceanic variability were selected.

This signal is not visible on Jason-2 GDR (left side of figure 42), but when updating ocean tide solution to FES2014 (right side of figure 42), there is such a signal for both missions. Note that even if FES correction appears to increase the SSH difference between ascending and decending observations, this does not mean that this correction degrades the data quality. This is also detailed in part 8.1..

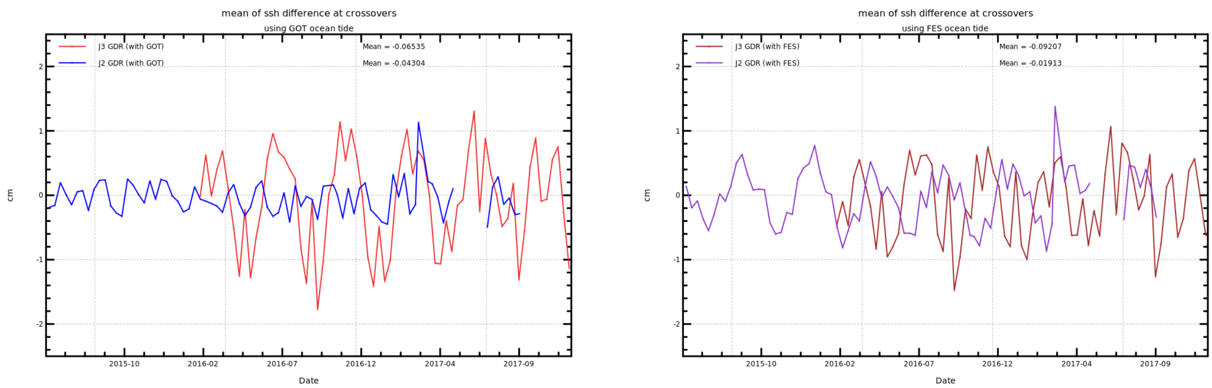


*Figure 42 – Monitoring of mean of SSH crossover differences for Jason-2 and Jason-3 for GDRs. Only data with $|latitude| < 50°$, bathymetry < -1000m and low oceanic variability were selected, computed with got ocean tide **(left)** or fes ocean tide **(right)***

The maps of mean SSH crossover differences on figure 43 were calculated using GDR products for Jason-3 and Jason-2. These maps highlight equivalent small geographic patterns for Jason-3 and Jason-2.

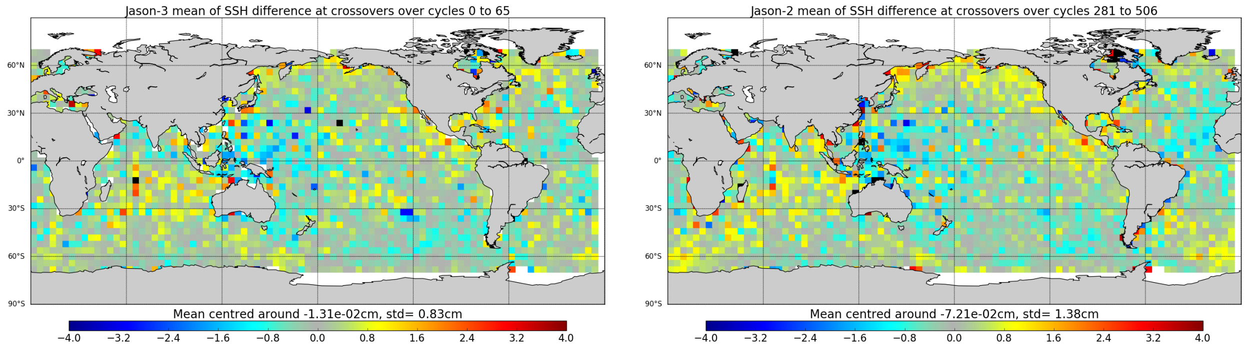


Figure 43 – Map of SSH crossovers differences mean for Jason-3 cycle 0 to 65(left) and for Jason-2 cycle 281 to 506 (right)

Dual-mission crossover performances are computed between Jason-3 and Jason-2 and presented figure 44. Mean SSH differences at Jason 3/Jason 2 crossovers is quite stable and around 3cm in average. The geographical pattern indicates some hemispheric biases, positive to the west, negative to the east. It corresponds to orbital signatures observed on sea surface height (right side of figure 44). Note that these 3 cm are due to processing differences as colocated Jason-2 minus Jason-3 non-corrected SLA (orbit - range - MSS) differences averaged over the period of tandem phase (cycle 001 to 023) shows an equivalent bias (left side of figure 48).

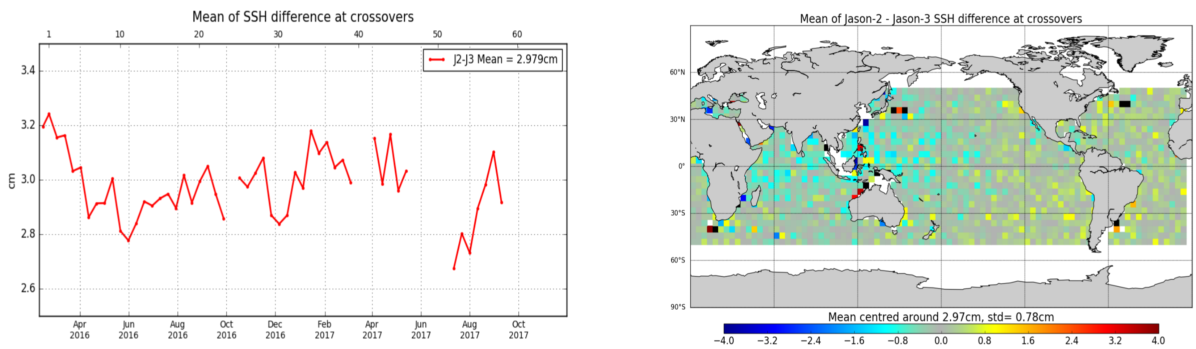


Figure 44 – Cyclic monitoring of Jason-2 - Jason-3 SSH crossover differences mean (left) and map over cycle 1 to 58 (right). Only data with $|latitude| < 50°$, bathymetry < -1000m and low oceanic variability were selected.

5.3. Standard deviation of SSH crossover differences

The cycle by cycle standard deviation of SSH crossovers differences are plotted for Jason-3 and Jason-2 in figure 45 after applying geographical criteria (bathymetry, latitude, oceanic variability). Both missions show very good performances, very similar and stable in time. No anomaly is detected. In GDR, the average figure is equivalent for both missions (4.96 cm rms for Jason-3, and 4.97 cm rms for Jason-2). This metric allows to estimate the system noise by dividing by $\sqrt{2}$ (3.51 cm).

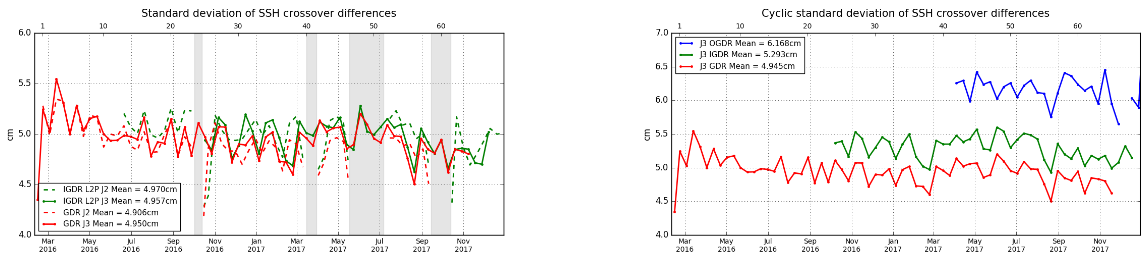


*Figure 45 – Cycle by cycle standard deviation of SSH crossover differences for Jason-2 and Jason-3 (**left**), and for Jason-3 using OGDRs, IGDRs and GDRs (**right**). Only data with $|latitude| < 50°$, bathymetry $<$ -1000m and low oceanic variability were selected.*

5.4. Estimation of pseudo time-tag bias

The pseudo time tag bias (α) is found by computing at SSH crossovers a regression between SSH and orbital altitude rate ($\dot{H}$), also called satellite radial speed: $SSH = \alpha\dot{H}$.
This empirical method allows us to estimate the potential real time tag bias but it can also absorb other errors correlated with $\dot{H}$. Therefore it is called "pseudo" time tag bias. The monitoring of this coefficient estimated at each cycle is performed for Jason-2 and Jason-3 in figure 46. Both curves are very similar highlighting an almost 59-day signal with almost no bias (close to -0.01 ms for Jason-2 and -0.02 ms for Jason-3). Both missions present 59 and 118 day signals. However, a 91-day signal appears for Jason-3. Such signal is not visible for Jason-2.
Using FES2014 ocean tide correction in SSH computation shows a reduction of 59-days signal, no 91-days signal, and a slightly higher 118-days one (purple curve).

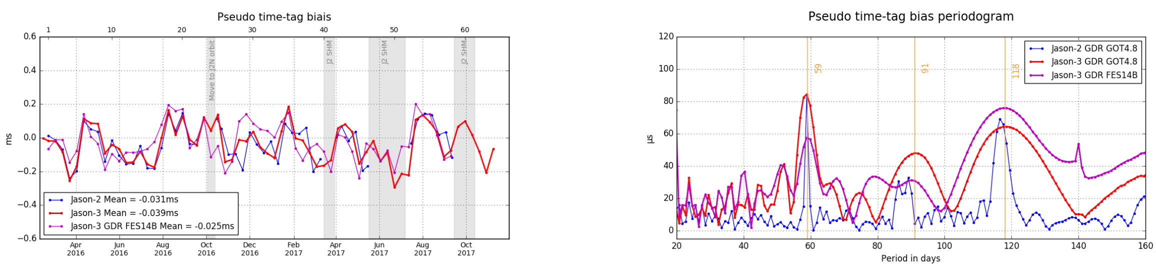


Figure 46 – Monitoring (left) and periodogram (right) of pseudo time-tag bias estimated cycle by cycle from GDR products for Jason-2 and Jason-3

6. Sea Level Anomalies (SLA) Along-track analysis

6.1. Overview

The Sea Level Anomalies (SLA) are computed along track from the substraction of the mean sea surface to the SSH, with the SSH calculated as defined in previous section 5.1. : $SLA = SSH - MSS$. SLA analysis is a complementary indicator to estimate the altimetry system performances. It allows us to study the evolution of SLA mean (detection of jump, abnormal trend or geographical correlated biases), and also the evolution of the SLA variance highlighting the long-term stability of the altimetry system performances. In order to take advantage of the Jason-3/Jason-2 tandem flight (cycles 1 to 23), we performed direct SLA comparisons between both missions during this period.

6.2. Mean of SLA differences between Jason-3 and Jason-2

The daily monitoring of mean SLA differences between Jason-2 and Jason-3 data over the tandem phase is plotted on figure 47, where this SSH bias is computed with and without the SSH corrections. During this period, both types of curves are very similar and stable in time with variations close to 1 mm rms, except that they are spaced out by a 0.75 cm bias (0.61 cm when using ECMWF model wet troposphere correction). This bias can result from differences between Jason-3 and Jason-2 sea state bias model used, and to a small amount due to ionosphere correction differences. The global average SSH bias is close to 2.98 cm using SSH corrections (2.84 cm when using ECMWF instead of radiometer wet troposphere correction) and 2.23 cm without. However, the more crucial point for scientific applications is to insure that there is no drift between both missions, since the global bias can be corrected a fortiori.

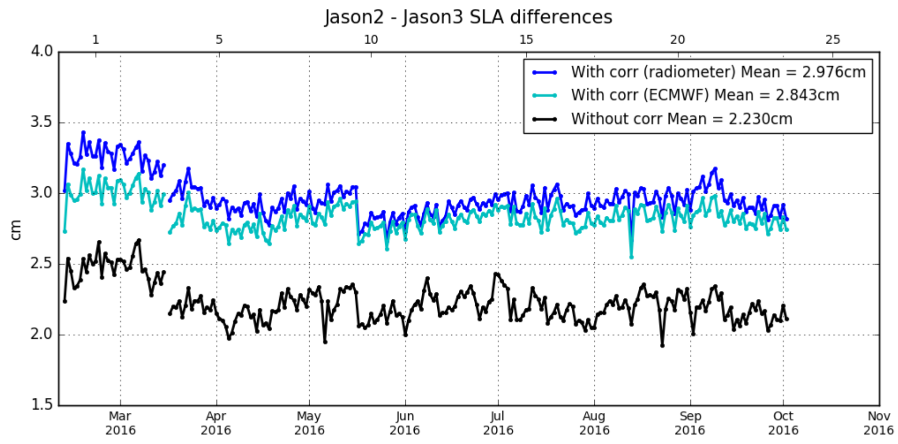
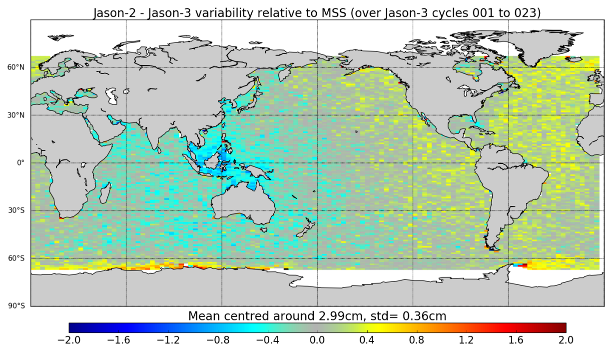


*Figure 47 – Daily monitoring of SSH bias between Jason-2 and Jason-3 before Jason-2 moved to interleaved ground-track in October 2016: SSH bias without applying geophysical corrections (**black**) and with corrections using radiometer wet troposphere correction (**blue**) or using ECMWF model wet troposphere correction (**cyan**).*

Colocated Jason-2 minus Jason-3 SLA differences averaged over the period of tandem phase (cycle 001 to 023) are shown on left side of figure 48. As both satellites measure the same oceanic features only 1'20" apart, only a weak hemispheric bias is visible (likely due to differences in orbit processing). Since Jason-2 has moved to its new interleaved orbit, maps of direct Jason-2 minus Jason-3 SLA measurements are no longer available. But differences of gridded SLA for Jason-2 and Jason-3 can be made. This difference is quite noisy for one cycle, especially as both satellites are shifted in time and sea state changes especially in regions of high ocean variability. Therefore figure 48 shows an average over SLA grid differences from Jason-3 cycles 025 to 058. High variability regions as Gulf Stream and Antarctic circumpolar current are visible.



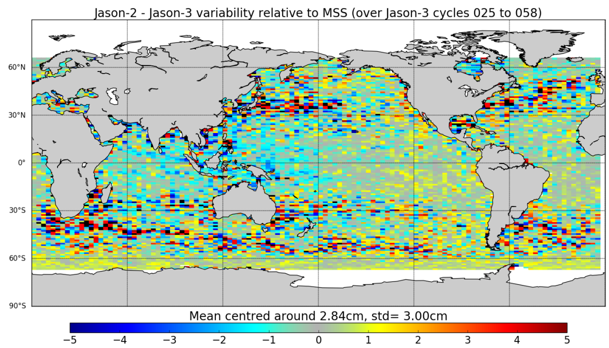


Figure 48 – GDR data. Caution: color map ranges are different between the two figures. ***Left:*** *Map of SLA difference between Jason-2 and Jason-3 over tandem phase* ***Right:*** *Map of Jason-2 and Jason-3 SLA differences for Jason-3 cycles 025 to 058*

6.3. Standard deviation of SLA differences between Jason-3 and Jason-2

The monitoring of SLA standard deviation has been computed for both missions (figure 49).

Note that this metric is very dependant to the MSS reference solution used to compute SLA. IGDR-L2P standard deviation of SLA (green curves) is lower than GDR (red curves) thanks to L2P updates that include a change from IGDR product MSS referenced on 7 years to a solution referenced on 20 years. In addition, Jason-2 MSS solution in GDR product (red dotted line) moved from MSS CNES/CLS 2011 with a 7 years reference to MSS CNES/CLS 2015 (20 years reference) when move to LRO: that explains a better performance on Jason-2 GDR dataset from July 2017 onwards. The change of reference period from 7 years to 20 years integrates the evolution of the sea level in terms of trends, but also in terms of interannual signals at small and large scales (e.g. Niño/Niña) in the additional 13 years: changing from a 7 to 20 years reference period leads to better interannual signals and oceanic anomalies (see [96] for more details about the change on reference period).

Cartography of standard deviation of spatial Jason-1 minus Jason-2 SLA differences (not shown here) does not show any anomaly. It varies indeed in function of noise on measurements, which depends on significant wave height. Therefore, standard deviation of SLA differences is higher in regions with important significant wave heights.

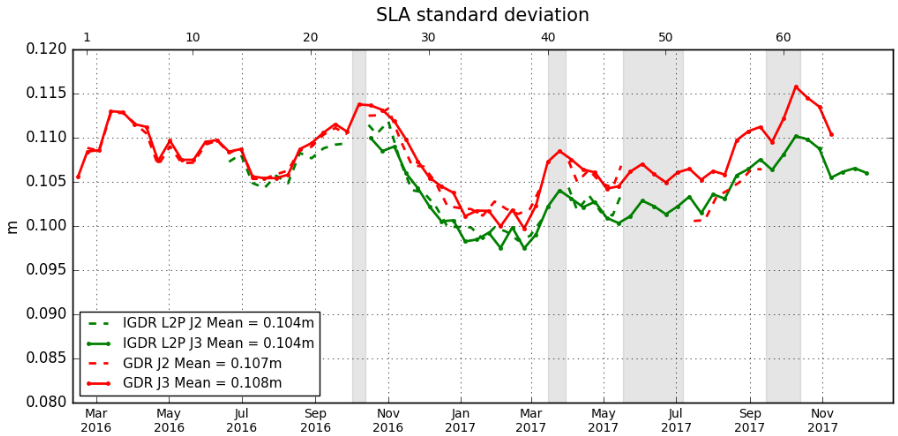


Figure 49 – Cyclic monitoring of Jason-2 and Jason-3 SLA standard deviation for GDRs and IGDRs

6.4. Sea level seasonal variations

From Sea Level Anomalies computed relative to the Mean Sea Surface CNES-CLS 2011, the surface topography seasonal variations have been mapped in table 7 for the overall Jason-3 data set. Major oceanic signals are shown clearly by these maps: it allow us to assess the data quality for oceanographic applications.

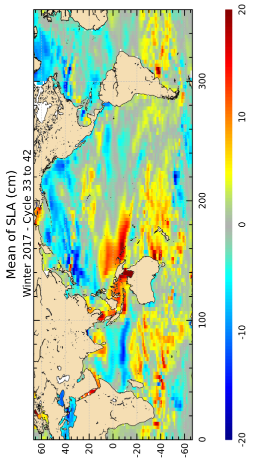
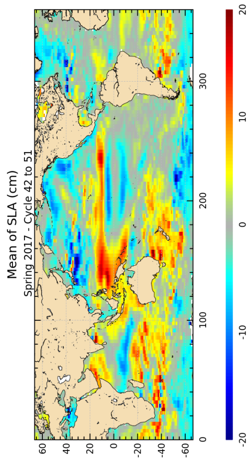
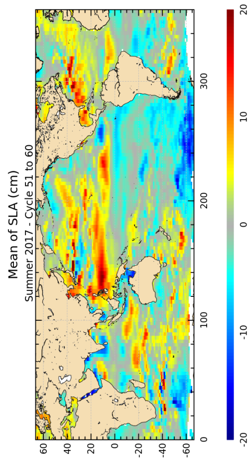
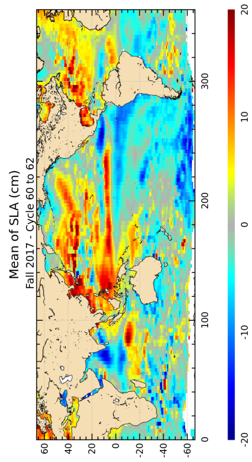
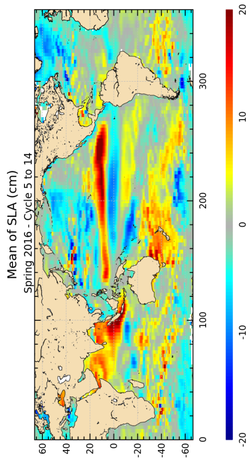
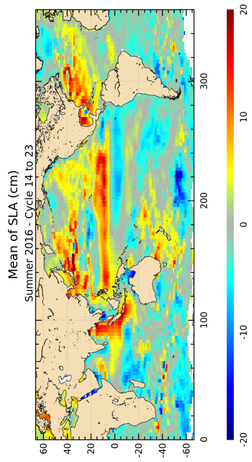
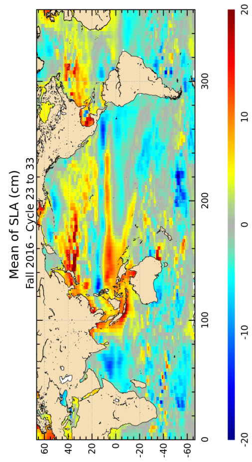
	Winter	Spring	Summer	Fall
2017				
2016				

Table 6 – Seasonal variations of Jason SLA (cm) for years 2016 and 2017

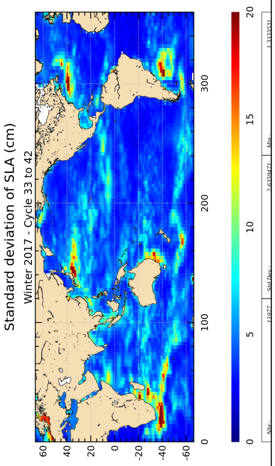
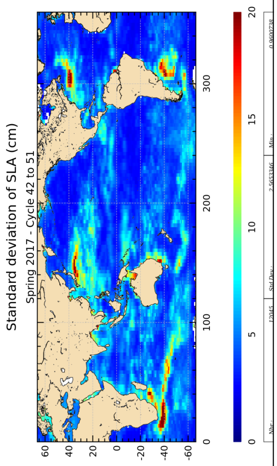
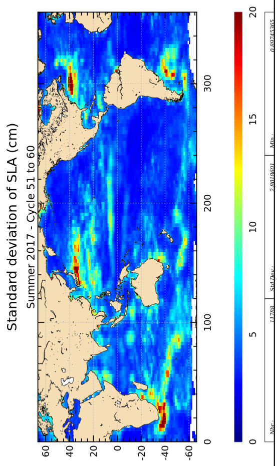
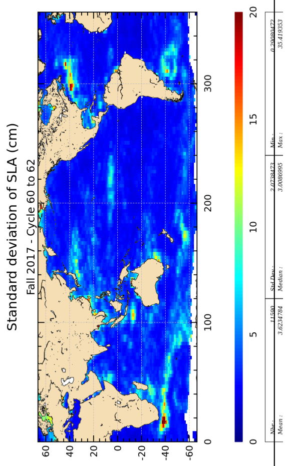
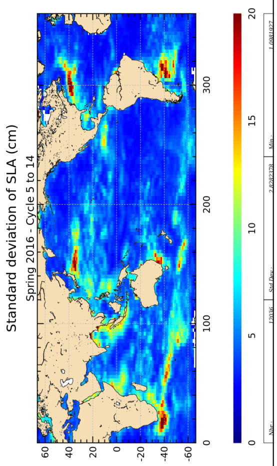
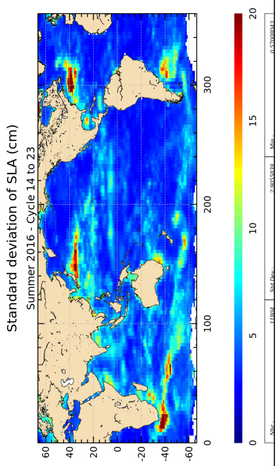
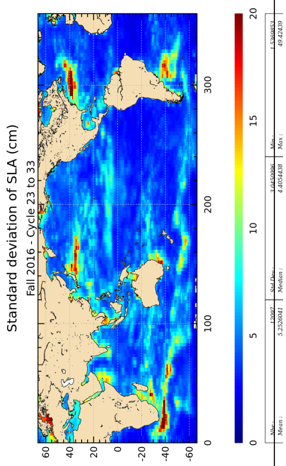
	Winter	Spring	Summer	Fall
2017				
2016				

Table 7 – Seasonal variations of Jason SLA standard deviation (cm) for years 2016 and 2017

7. Mean Sea Level (MSL) calculation

For more details about Mean Sea Level studies, see dedicated annual report of activities [114]. This report includes the description of the Mean Sea Level indicator, the comparisons between altimetry and tide gaudes measurements, the comparisons between altimetry and *ARGO+GRACE* measurements and specific studies linked with MSL activities.

7.1. Mean sea level (MSL) calculation of reference time serie and regional MSL trends

Data from Jason-3 mission were introduced in DUACS system end of September 2016 (when Jason-2 moved to its new interleaved orbit). Over the tandem phase of Jason-3 (till cycle 023), both Jason-2 and Jason-3 satellites flew on the same ground track, only 1mn20s apart. They therefore measured the same features, allowing to calibrate Jason-3. This allowed to link precisely the MSL time series of Jason-2 and Jason-3. The uncertainty of the bias value between the two time series is less than 1 mm. The evolution of the ocean mean sea level can therefore be precisely observed on a continual basis since 1993 thanks to the 4 reference missions: TOPEX/Poseidon, Jason-1 (from may 2002 to october 2008), Jason-2 (from october 2008 to may 2016) and now Jason-3 (since june 2016).

Wet troposphere correction, inverse barometer correction, GIA (-0.3 mm/yr) are applied to calculate the MSL and the data series are linked together accurately thanks to the tandem flying phases. The following global bias are applied: -2.260 cm between T/P&Jason-1, 3.900 cm between Jason-1/Jason-2 and 2.880 cm between Jason-2/Jason-3. An exhaustive overview over possible errors impacting the MSL evolution is given in [114]. Furthermore, annual and semi-annual signals are removed from the time serie and a 2-month filter is applied. For more details, see MSL Aviso Website: http://www.aviso.altimetry.fr/msl.

Though mean sea level trend is globally positive, it is inhomogeneous distributed over the ocean: locally, sea level rise or decline up to ± 10 mm/yr are observed on right panel of figure 50 (note that this map of regional MSL trends is estimated from multi-mission grids (Ssalto/DUACS products) in order to improve spatial resolution).

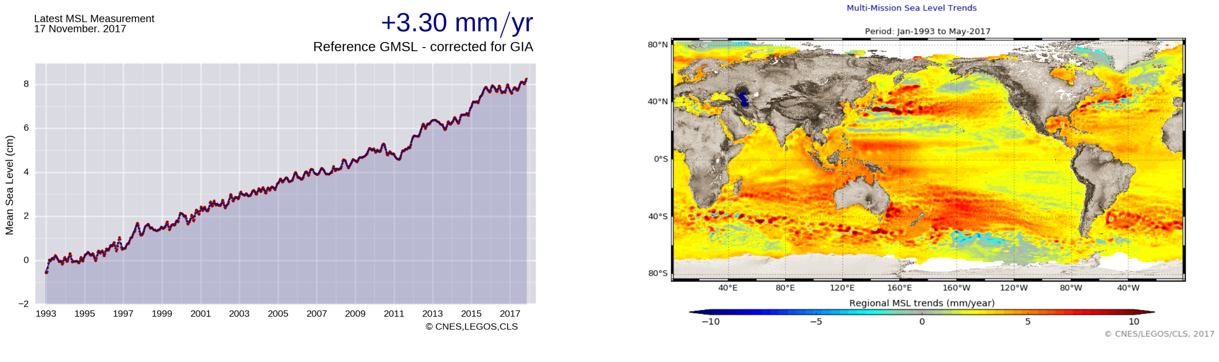


Figure 50 – Global (left) and regional (right) MSL trends from 1993 onwards.

7.2. External data comparisons with tide gauges

In order to assess the global MSL trend, comparisons to independent in-situ datasets are of great interest. Method and data used for MSL comparisons between altimetry and tide gauges measurements are detailed in [114] part 3. Comparisons of MSL time series between altimetry and Tide Gauges are done from L2P products with CMEMS 2018 standards. As concerned Jason-3 comparisons, a positive drift of about $+0.8mm/yr$ is detected but not reliable due to the short time period used (1.3 years): uncertainty is higher than $3mm/yr$ over such a short period.

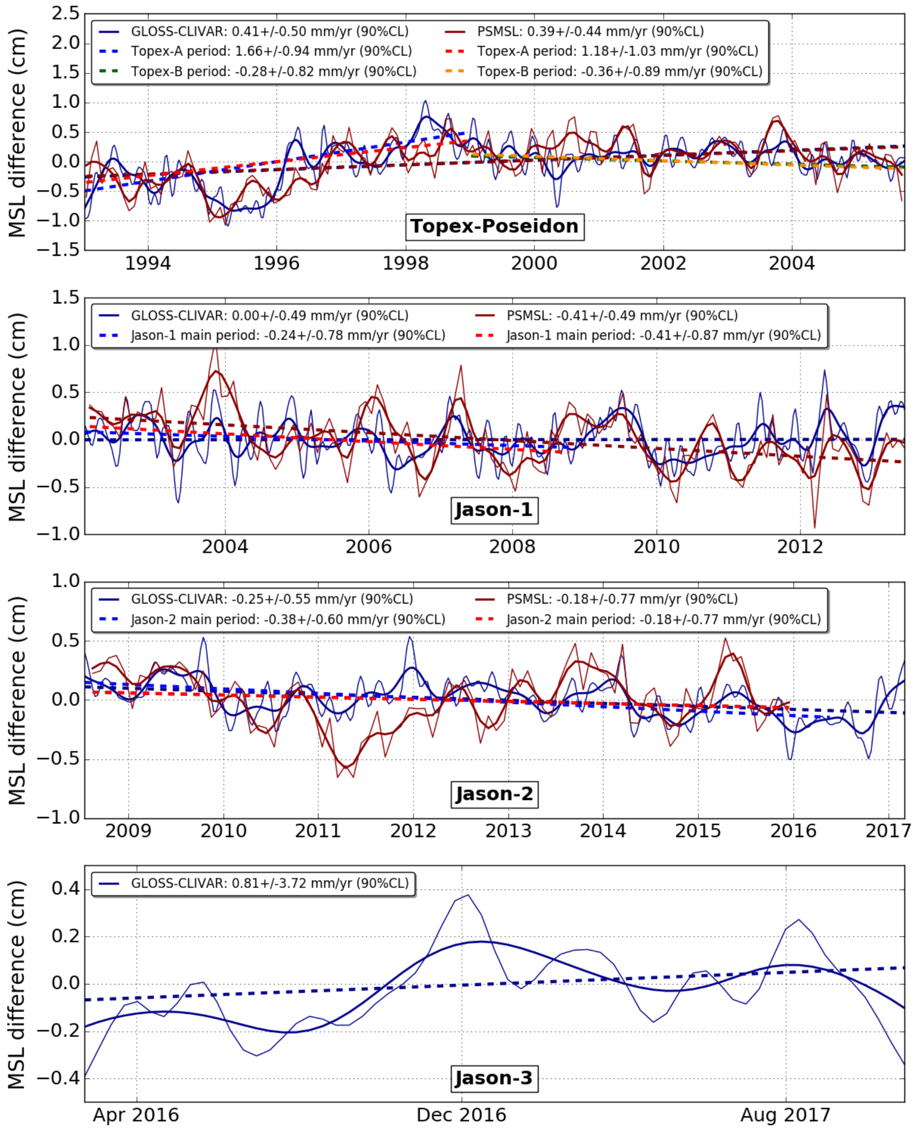


Figure 51 – Evolution of GMSL differences between altimeter and tide gauges for reference missions used in the GMSL indicator calculation (TOPEX/Poseidon, Jason-1, Jason-2 and Jason-3) with the GLOSS/CLIVAR network (blue line) and the PSMSL network (red line). Signal lower than 2 months and annual signals have been removed. The blue dashed line is the trend obtained applying a generalized least square method.

From end of 2016, Jason-3 has become the reference mission for GMSL. Linked to the TOPEX-

Poseidon/Jason-1/Jason-2 serie, comparisons are done to the reference missions AVISO GMSL indicator. The MSL differences presented in [114] shows a global drift very slightly positive ($< 0.1mm/yr$) over the full period with an uncertainty of $0.39mm/yr$ to $0.45mm/yr$ (against tide gauges network that are used).

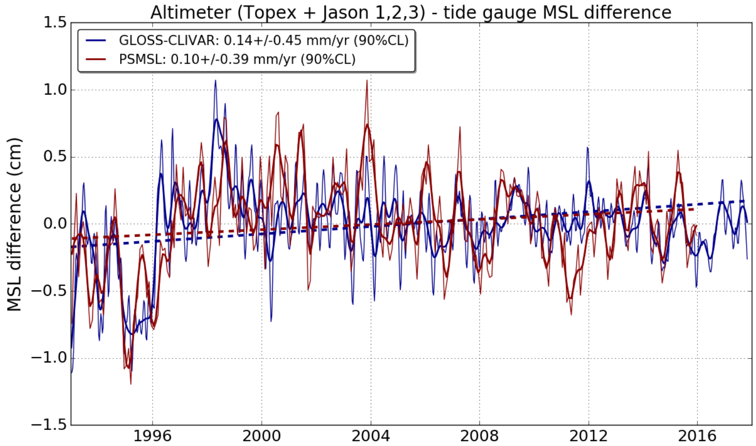


Figure 52 – Evolution of global MSL differences from altimeter / tide gauges comparisons (GLOSS/CLIVAR and PSMSL network) from TOPEX/Poséidon, Jason-1, Jason-2 and Jason-3 L2P products linked together.

8. Investigations

8.1. 120 day signal on SSH difference at crossovers

Cyclic monitoring of mean differences at crossover points (with geophysical selection applied to remove shallow waters (bathymetry above -1000m), areas of high ocean variability (variability above 20 cm rms) and high latitudes ($> |50|deg$)) shows on Jason-3 a 120 days signal (see figure53). Such a signal was visible on Jason-2 (but with a smaller amplitude) using POE-D orbit solution, and has been reduced with POE-E orbit solution (in GDR from cycle 254 onwards). This signal is visible on both GDR and IGDR data, but is slightly smaller with IGDR. Note that there is a particular behaviour during yaw fix periods (bottom part of figure 53).

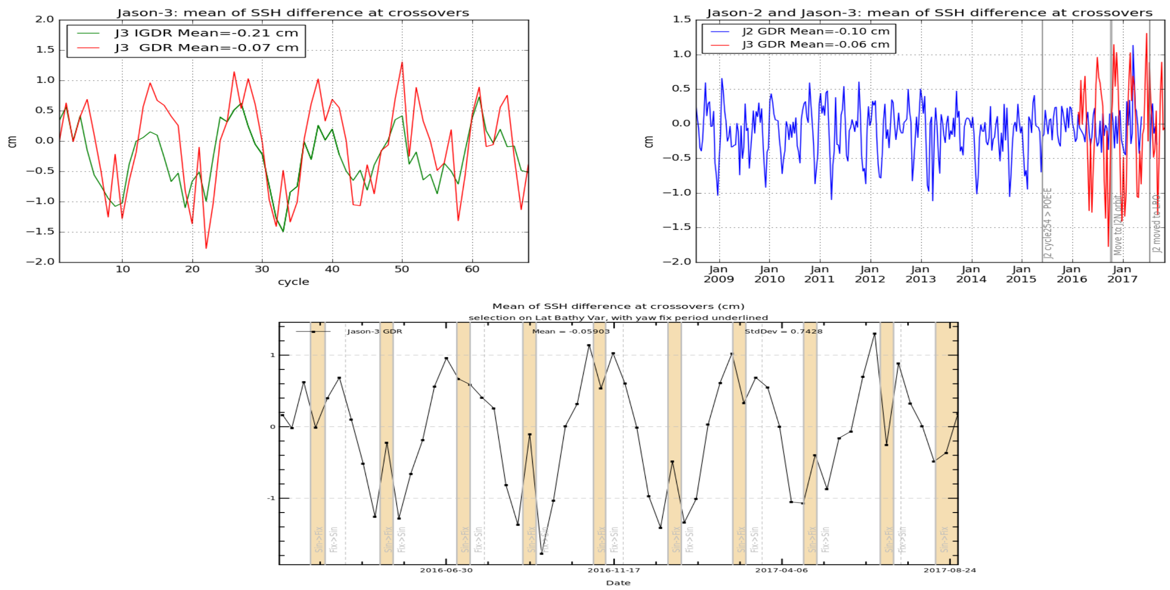


*Figure 53 – **Left** Monitoring of Jason-3 mean of SSH difference at crossover for GDR and IGDR from products and DUACS. **Right:** Monitoring of Jason-2 and Jason-3 mean of SSH difference at crossover. **Bottom**: Yaw fix periods.*

8.1.1. Orbit solution impact

The main difference between IGDR and GDR is the orbit solution, and 120-days signal could be linked to the way orbits solutions are computed. In order to understand this unexpected 120-days signal on Jason 3 mean SSH at crossover, the performance using 3 different orbit solutions are analyzed and compared with the POE-E (the one used in the product):

- JPL Pure GPS orbit, availability: cycle 0 to 38
- POE Pure DORIS, availability: cycle 3 to 39
- POE Pure DORIS with reduced dynamics, availability: cycle 3 to 39

First of all, DORIS and DORIS with reduced dynamics orbits show differences with POE close to 0.02-0.03 cm, this is close to -0.2cm for JPL Orbit (figure 54).

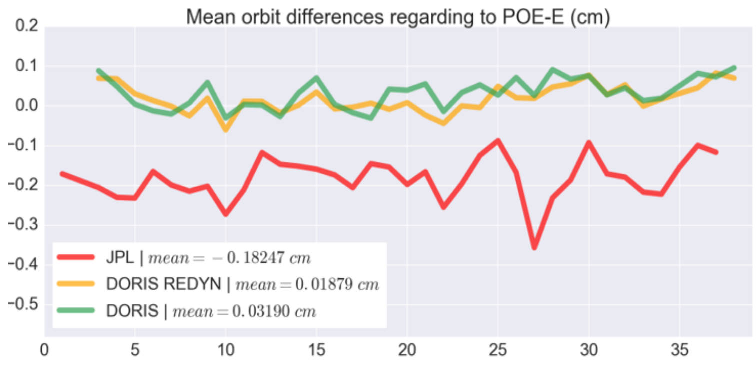


Figure 54 – Difference between studied orbits with POE-E solution

The 120 days signal visible on mean difference of SSH at crossovers with POE is also visible on DORIS and DORIS REDYN (with a similar order of magnitude as pure DORIS solutions). The studied signal is slightly smaller with JPL orbit (figure 55). The signature on crossover during 'yaw fix' time periods is only visible for POE-E (for DORIS solutions only once on cycle 21). On right of figure 55, Jason-3 120 days signal variations are greater than on Jason 2 crossover performance monitoring for all types of orbits solutions, including JPL one.

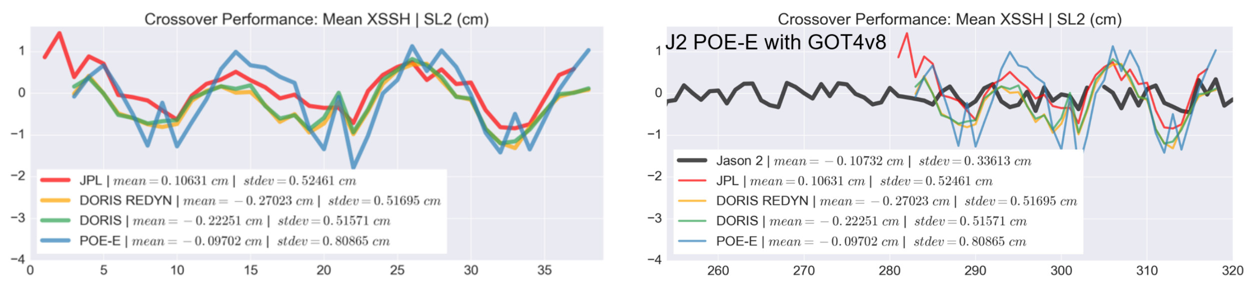


*Figure 55 – Mean SSH difference at crossovers with geographical selection. **Left:** For Jason-3 data (Jason-3 cycle 1 to 39) using different orbit solutions. **Right:** Comparison to Jason-2 data (Jason-2 cycle 254 to 320).*

The different orbit solutions are analyzed in term of Ascending/Descending consistency. As expected CNES and JPL orbits are equivalent, and more homogeneous than pure DORIS (figure 56).

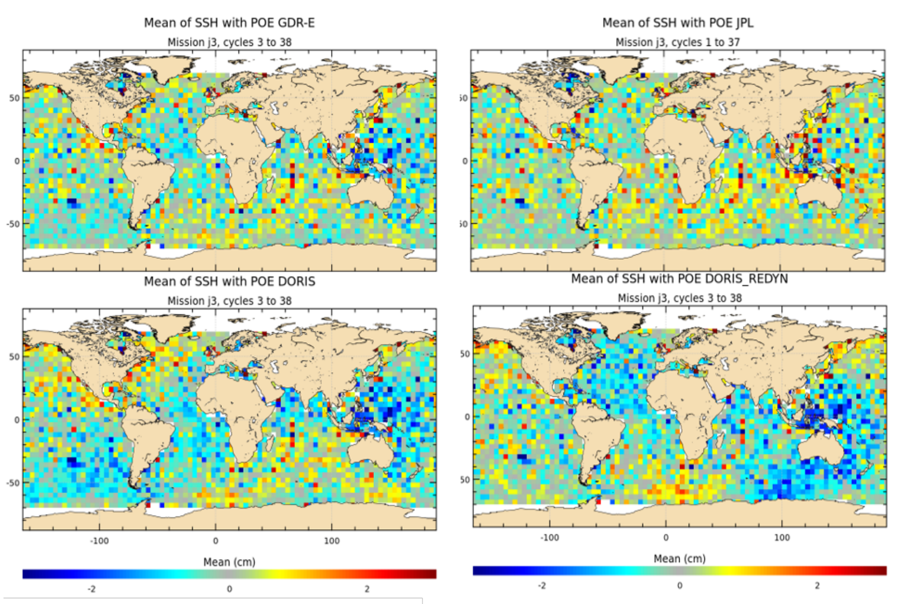


Figure 56 – Mean of SSH difference at crossover points over Jason-3 cycle 1 to 38 using POE-E (top left), JPL solution (top right), Pure DORIS (bottom left) or DORIS with REduced DYNamics (bottom right).

In terms of variance performance at crossovers (figure 57 and figure 58) , GPS JPL orbit is better than bitechnic CNES solution (-0.45cm² vs 0.34cm²). Surprisingly, pure DORIS solution is equivalent (even slightly better below 50°) than the bitechnic solution.

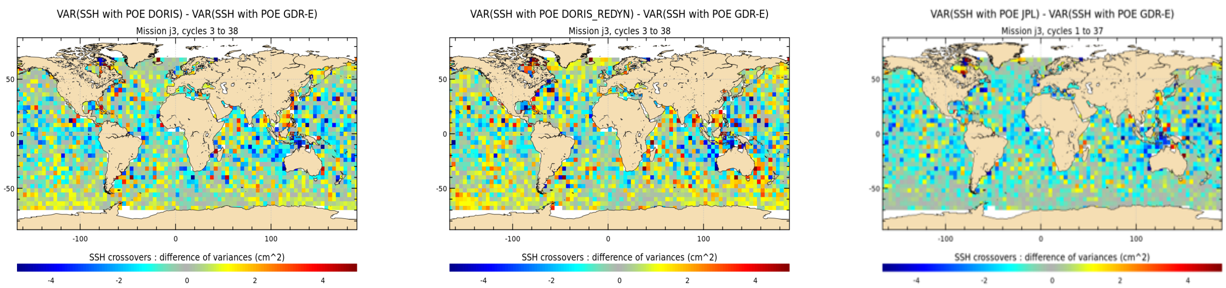


Figure 57 – Maps of variance performance at crossovers for studied orbit solution compared to GDR standard (POE-E). ***Left:*** *Pure DORIS* ***Middle:*** *DORIS with REduced DYNamics* ***Right****: JPL solution*

JPL Pure GPS solution presents a lower 120-day signal than the CNES orbits on Jason-3 BUT still higher than Jason-2.

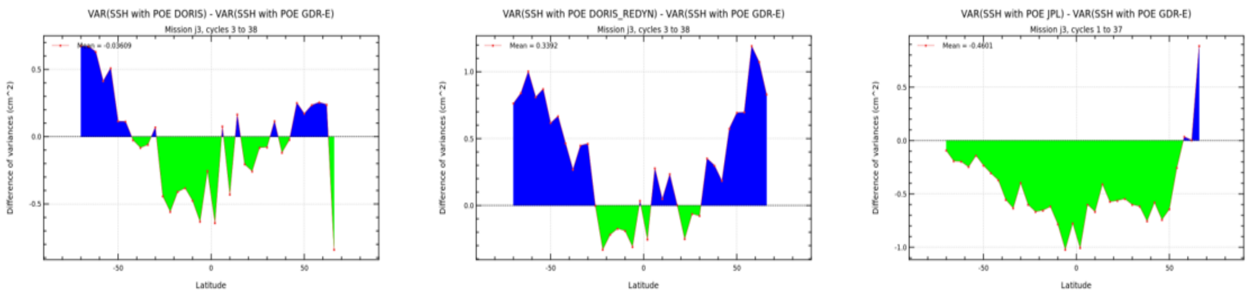


*Figure 58 – cyclic monitoring of variance performance at crossovers for studied orbit solutions compared to GDR standard (POE-E). **Left:** Pure DORIS **Middle:** DORIS with REduced DYNamics **Right**: JPL solution*

8.1.2. Ocean tide solution impact

As it was shown before, a 120 days signal is visible (see figure 59) on mean of differences at crossover points with Jason-3 GDR (red), Jason-3 IGDR (green), and Jason-2 IGDR (yellow) data, but is not visible with Jason-2 GDR (blue) data.

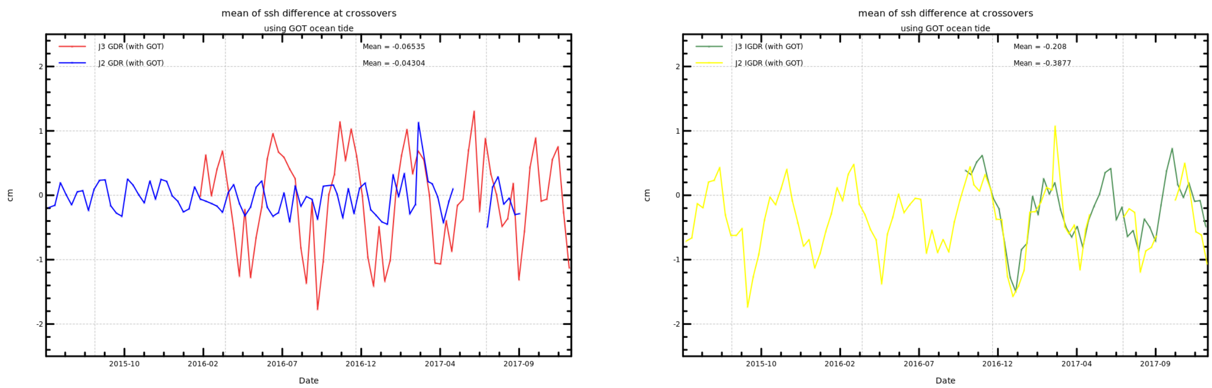


*Figure 59 – Monitoring of Jason-2 and Jason-3 mean of SSH difference at crossover for GDR **(left)** and IGDR **(right)** with GOT4.8 ocean tide solution.*

Using FES_{2014} ocean tide solution to compute mean of SSH differences at crossover for Jason-3 GDR data, 120 days signal is reduced (from red to brown on the left of figure 60). It disappears on IGDR Jason-3 using the same update (from green to cyan curve on the middle of figure 60). On right part of figure 60, using FES_{2014} solution in Jason-2 SSH reveals a 120 days signal on mean differences at crossovers monitoring.

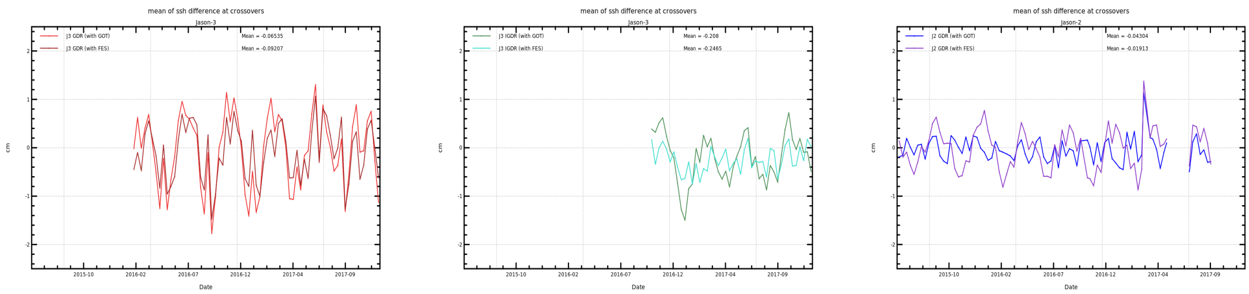


Figure 60 – Monitoring of Jason-2 and Jason-3 mean of SSH difference at crossover for GDR against different ocean tide solution: Jason-3 ***(left)*** *or Jason-2* ***(right)****.* ***Middle:*** *Jason-3 IGDR*

Using a FES_{2014} ocean tide solution for both (Jason-2 and Jason-3) GDR dataset shows (left of figure 61) a quite equivalent signal in terms of amplitude.

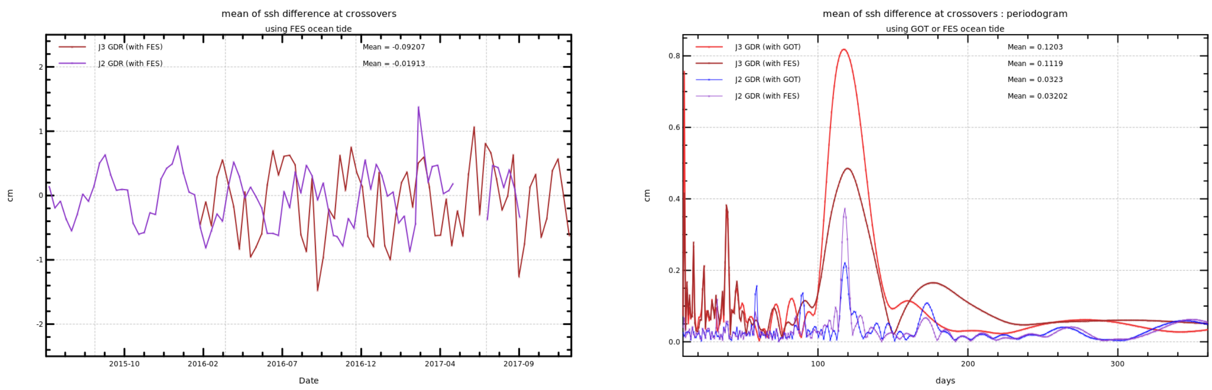


Figure 61 – Periodograms of the mean SSH difference at crossovers with geographical selection for Jason-3 and Jason-2 GDR data ***(right)****. Monitoring of Jason-2 and Jason-3 mean of SSH difference at crossover for GDR with FES2014 ocean tide solution.*

The 120 days signal disappears for both JPL and DORIS solutions when using FES_{2014} tide model (figure 62).
This analysis reveals that **a 120 days signal can appear on Jason mean difference at crossovers, depending on the ocean tide solution used to compute the Sea Surface Height.**

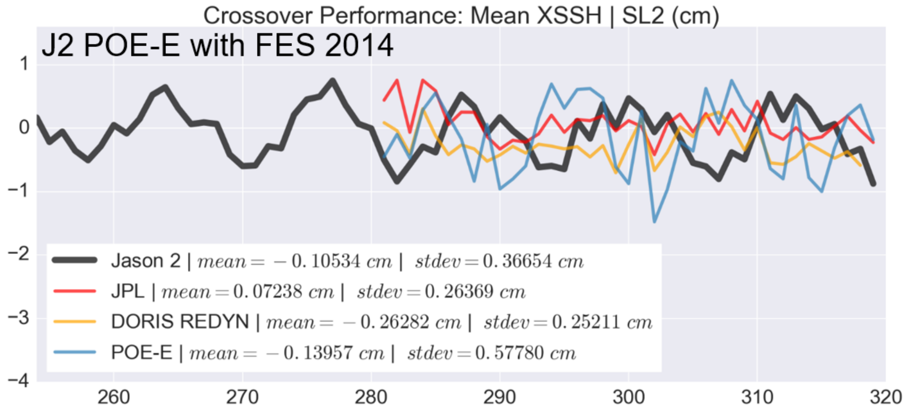


Figure 62 – Mean SSH difference at crossovers with geographical selection for Jason-3 data (Jason-3 cycle 1 to 39) using different orbit solutionsand comparison to Jason-2 data (Jason-2 cycle 254 to 320) using FES2014 ocean tide correction in SSH computation.

8.1.3. Conclusion

An unexpected 120-day signal on mean difference of Sea Surface Height at crossover points appears on Jason-3 GDR (POE-E orbit). The followed metric shows different results depending on the choice of orbit solution. This could be due to a bad taken into account of the GPS part. This is confirmed by the analysis of CNES Pure DORIS POE solutions as studies show a lower 120-day signal and better performance of variance for low latitudes. This is also confirmed by the analysis of JPL GPS orbits, over the same time period (JPL Pure GPS solution presents a lower 120-day signal than the CNES orbits BUT still higher than Jason-2). The study also highlights that this signal depends on ocean tide correction that is applied to compute SSH, particularly on Jason-2 data. As FES_2014 solution is mainly hydrodynamic model (has only a slight dependance to altimetry data), and metrics computed using this ocean tide solution show a 120-day signal on both missions Jason-2 and Jason-3, further investigations on orbit solutions for both missions could explain it. For more information about orbit solutions, see [30].

8.2. Digital Elevation Model unboard upload

A Digital Elevation Model (DEM) onboard upload has been performed on POSEIDON-3B/JASON-3 from the 29/08/2017 at 13:41:14 to the 31/08/2017 at 22:10:38, i.e. from pass 99 to 160 of cycle 57. It was presented at OSTST2017 (see [116]).

This update aims at adding new hydrologic target such as rivers and lakes. 110 lakes and more than 2700 virtual stations over lakes and rivers have been added (from 1644 virtual stations up to 4366).

The process followed during the update was:

- 29/08/2017 at 13:41:14: DEM patch
- 30/08/2017 at 14:00:15: DEM dump with BDR modification
- 31/08/2017 at 14:22:58: LV dump with acquisition mode set to autonomous acquisition / tracking instead of DIODE + DEM tracking
- 31/08/2017 at 22:04:59: Restart in DIODE + DEM mode.

As shown on figure 63, the acquisition mode changed during the DEM upload:

- acquisition mode flag set to “DIODE + Digital Elevation Model tracking” over ocean from passes 1 to 99 (until 29-08-2017 13:41:14) and 160 (from 31-08-2017 22:10:38) to 254
- acquisition mode flag set to “autonomous DIODE acquisition / tracking” over ocean from passes 99 to 123
- acquisition mode flag set to “autonomous acquisition / tracking” over land and ocean from pass 125 to 159

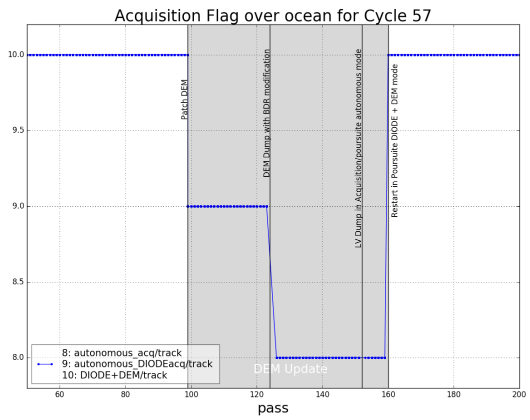


Figure 63 – Monitoring of the acquisition flag over ocean during cycle 57.

This DEM onboard upload is accountable for missing data over cycle 57, as illustrated on figure 64:

- Pass 123 has 23.91% of missing measurement (15.44% over ocean). Pass 124 is missing. Pass 125 has 96.16% of missing measurement (100% over ocean).
- Pass 151 has 12.40% of missing measurement (8.57% over ocean). Pass 152 has 100% of missing measurement over ocean. Pass 153 has 98.40% of missing measurement (100% over ocean).

In addition during this cycle (not linked to DEM upload), note that missing data over pass 159 (passing through Africa and west Asia) are due to an AMR Cold sky calibration maneuver (see Table 1).

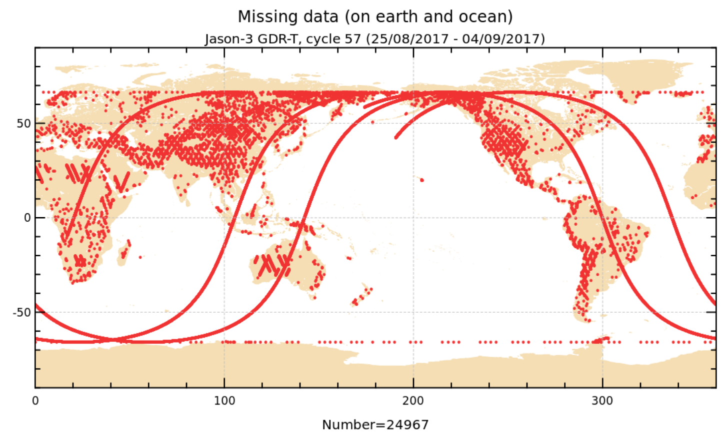


Figure 64 – Map of missing data over land and ocean for cycle 57.

From this update, the backscatter coefficient error has drop of about 0.03dB to remain at about 0.361 dB (0.39dB before the update).

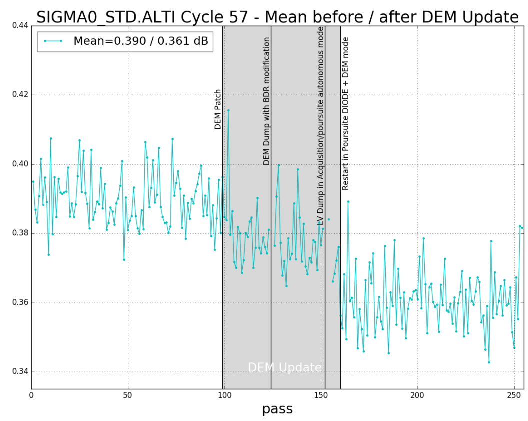


Figure 65 – Monitoring of the backscatter coefficient standard deviation during cycle 57.

8.3. Updated Jason-3 wind speed and SSB solutions

An update to Jason-3 wind speed and sea state bias was proposed by Ngan Tran & al. at OSTST2017 (see [115]).

It is proposed to update the Jason-3 wind speed (WS) estimates by both applying a bias on MLE4 sigma0 (-0.16dB) and using the Jason-2 based wind speed model [Tran, 2015] instead of the Jason-1 version [Collard, 2005]. In this case, the histogram characteristics (shape and mean value) are closer to those observed from ECMWF data. The Sea State Bias (SSB) correction to sea surface height measurement is an empirical correction that is computed specifically for each altimeter. With the successful launch of the Jason-3 mission on January 2016, 1-year based solutions (2D and 3D) have been developed from collinear dataset. As reported, the differences between Jason-3 (MLE4, 2D, updated WS) with respectively 2015 Jason-1 and 2012 Jason-2 solutions display narrow distributions with standard deviation of about 3 mm and averaged differences of 1 cm.

Updated 3D SSB (not presented here) solution is also available and displays larger improvement (0.8 cm^2) in variance reduction at crossovers when one compares with the Jason-2 based version currently used to generate the GDR products. These activities have been done within the SALP and Jason-3 PEACHI prototype projects.

The MLE4 solution is applied to Jason-3 GDR dataset (see figure 66). Global bias between the two solutions (5 cm) is due to the way this solution was computed and do not represent a real geophysical bias.

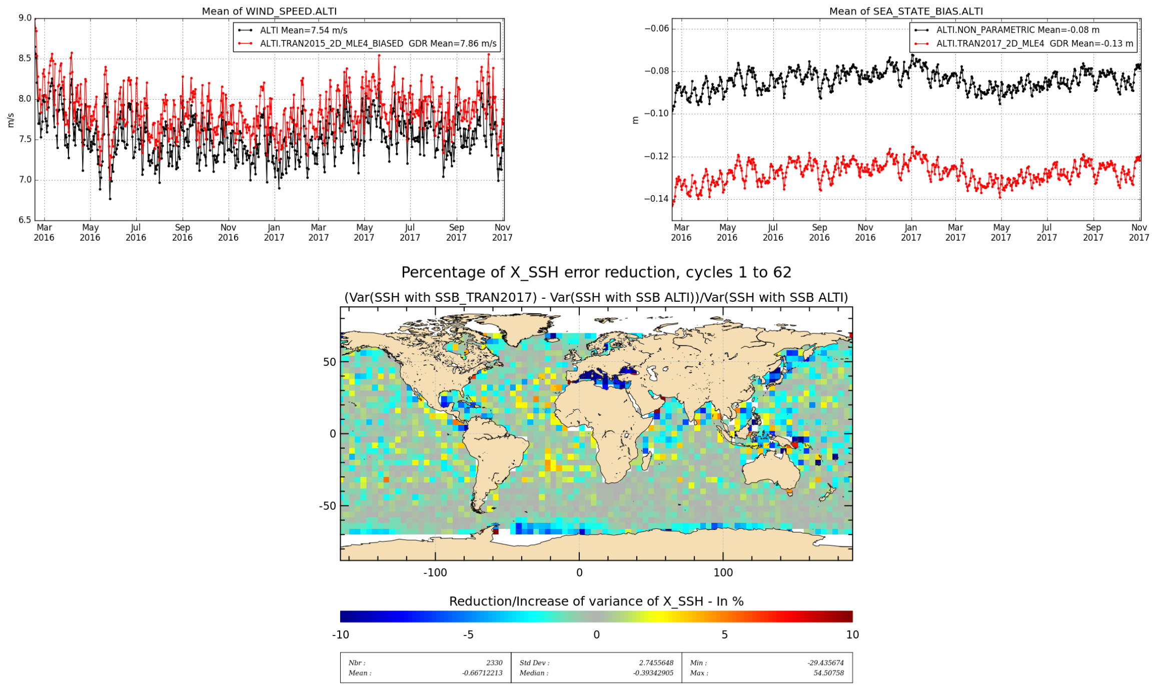


*Figure 66 – Tran2017 Wind Speed in m/s and Sea State Bias in cm (**top**). Map of differences at crossovers error reduction compare to GDR standards solutions (**bottom**).*

9. Conclusion

Jason-3 was launched on January 17th, 2016. Since February 12th, Jason-3 was on its operational orbit following Jason-2 with 80 seconds delay on the same ground track. OGDR/IGDR products were opened to users end of June 2016, whereas the GDR products (GDR-D) were available from November 2016 onwards (NB: GDR-T are also equivalent to GDR-D).

The verification phase allowed extensive analysis and validation of the data, as both satellites observed the same geophysical phenomena until October 2nd 2016 when Jason-2 was moved to its interleaved ground track. This tandem flight phase has shown that Jason-3 data quality is excellent, at least of the same order as the Jason-2 one.

The main points of the performance assessment are summarized below:

- Ocean data availability is excellent and similar between Jason-3 and Jason-2 with a percentage greater than 99.9% after removing specific events or big anomalies.
- Data quality is also very good with only 3.4% of measurements not consistent with altimeter and radiometer parameters threshold criterion. Jason-2 presents an equivalent percentage of edited data.
- The altimetry parameters analysis highlights a similar behaviour compared to Jason-2. Some biases exist as between dual-frequency ionosphere correction, but they are stable.
- At crossovers, Jason-3 shows performance similar to Jason-2 with a standard deviation lower than 5 cm. However mean difference analysis highlights a 120-days signal, which is present for both missions and could be further reduced by alternative orbit solutions.
- At crossovers between Jason-3 and Jason-2, SSH performance presents excellent results with an SLA biais of about 3cm. The consistency between both SLA is good with a small geographically correlated signal (lower than 0.5 cm in GDR) due to orbit quality.

Thanks to these good results, Jason-3 became the reference mission to ensure the continuity of Global Mean Sea Level monitoring on September 2016.

10. References

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