CalVal Jason-2

Jason-2 validation and cross calibration activities (End of mission 2019)

Nomenclature : SALP-RP-MA-EA-23540-CLS

Issue : 1rev 2

Date : March 24, 2022

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Chronology Issues:		
Issue:	Date:	Reason for change:
1rev0	November 29, 2019	Creation
1rev1	February 18, 2022	Draft version
1rev1	March 24, 2022	Revision after comments from François Bignalet-Cazalet

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Index Sheet :	
Context:	
Keywords:	
Hyperlink:	

Distribution:		
Company	Means of distribution	Names
CLS	electronic copy	V.ROSMORDUC
CNES	electronic copy	thierry.guinle@cnes.fr francois.bignalet-cazalet@cnes.fr gerald.dibarboure@cnes.fr nicolas.picot@cnes.fr aqgp_rs@cnes.fr dominique.chermain@cnes.fr delphine.vergnoux@cnes.fr

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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

EOF End Of Life

GDR Geophysical Data Record

GIM Global Ionosphere Maps

GOT Global Ocean Tide

IGDR Interim Geophysical Data Record

JPL Jet Propulsion Laboratory (Nasa)

LRO/iLRO Long Repeat Orbit / intermediate Long Repeat Orbit

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

By succeeding to TOPEX/Poseidon and Jason-1 on their primary ground track, Jason-2 has extended the high-precision ocean altimetry data record. It was launched on June, 20th 2008 and its last measurement was on October, 1st 2019. Jason-2 was the reference mission on TOPEX/Poseidon historical ground track for mean sea level applications from 2008 and 2016. It was also used to observe mesoscale ocean dynamics. Over its last 3 years, from 2016 to 2019, many events occurred on Jason-2 mission. As for Jason-1 and TOPEX/Poseidon before it, Jason-2 was first moved to an interleaved at the same altitude in October 2016. Due to several gyro anomalies, system Safe Hold Modes (SHM) occurred and Jason-2 was moved to a Long Repeat Orbit (LRO) in July 2017. This orbit is approximately 27 km below the previous orbit. Thanks to this first year flying over Long Repeat Orbit, along-track data are available following an 8km resolution grid. During this period SHM occurred twice (in September 2017 and February 2018). After its move in July 2018 to an interleaved LRO (i-LRO) SHMs again occurred by four times (in oct-18, dec-18 and twice in feb-19). In addition to data from first year on LRO, this aim of this i-LRO was to provide data on a 4km resolution grid thanks to a complete second year of measurements, which is of great interest for geodesic community. Finally, mission has provided telemetry measurements until 1st October 2019 and ended after more than 11 years in flight.

This document presents the synthesis report concerning end of mission validation activities of Jason-2 GDRs under SALP contract supported by CNES at the CLS Space Oceanography Division. The purpose of this document is to report the mission events over its whole lifetime, and the major features of the data quality from the Jason-2 mission. Hereafter, we present the analyzes focusing on Jason-2 monomission and Jason-1/Jason-2 cross-calibration results. The assessment of the Jason-2 data quality is done via a description of the main performance metrics of the mission including:

- data coverage monitoring,
- edited measurements monitoring,
- accuracy and stability of SLA measurements check, by monitoring the performance of products at mono-mission crossovers and along-track over the whole mission lifetime.
- *Note that the analysis of relevant parameters derived from instrumental measurements and geophysical corrections are not analysed in this report, neither Global Mean Sea level monitoring (please refer to [7] for more details on these items).*

The SLA performances and consistency with Jason-1 are also described :

- During the tandem configuration (4th July 2008 to 26th January 2009) where both satellites were on the same ground track (This allowed to precisely assess parameter discrepancies between both missions in order to detect geographically correlated biases, jumps or drifts.)
- But even during the formation flight phase (after the end of the tandem phase),
- and after Jason-1 moved to its geodetic orbit, comparisons were still possible until the end of the Jason-1 mission in June 2013.

Note that Jason-3 was launched on 2016, January 17th. Cross-calibration analyzes between Jason-2 and Jason-3 are also performed, but shown in 2019 annual report of Jason-3 [10].
The last results on Jason-2 mission performance were presented in 2019 at OSTST in Chigago:

Jason-2 mission performance

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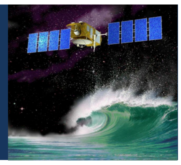


The Jason-2 is the reference mission on TOPEX/Poseidon historical ground track for mean sea level applications from 2008 et 2016. It is also used to observe mesoscale ocean dynamics. Over the last 3 years many events occurred on Jason-2 mission. As for Jason-1 and TOPEX/Poseidon before it, Jason-2 was first moved to an interleaved but at the same altitude orbit in October 2016. Due to several gyro anomalies, system Safe Hold Modes (SHM) occurred and Jason-2 was moved to a Long Repeat Orbit (LRO) in July 2017. This orbit is approximately 27 km below the previous orbit still used by Jason-3. Thanks to this first year flying over Long Repeat Orbit, along-track data are available following an 8km resolution grid. During this period SHM occurred twice (in September 2017 and February 2018). Since its move in July 2018 to an interleaved LRO (i-LRO) SHMs have again occurred by four times (in oct-18, dec-18 and twice in feb-19). In addition to data from first year on LRO, this i-LRO will allow to provide data on a 4km resolution grid thanks to a complete second year of measurements, which is of great interest for geodesic community. It was so decided to enter a hibernation phase for about 3 months, and to develop and then apply a strategy to switch between operational and healthy gyros, in order to reduce the SHM events risk.

Since 22nd May 2019, Jason-2 has been re-operating, and has provided telemetry measurements.

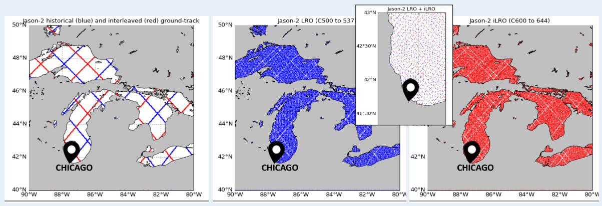
Finally, mission ended this month after more than 11 years in flight.

Data are analyzed and monitored in order to assess the quality of the products and how the system performance and data quality are affected (or not) by the last years events. The objective of this presentation consists in giving an overview of Jason-2 data coverage and data quality concerning altimeter and radiometer parameters, but also the performance of products at mono-mission crossovers and along-track over the whole mission lifetime.

Jason-2 timeline

Topex/Jason historical orbit	Interleaved orbit	First drifting orbit	Second drifting orbit
C001 → C303	C305 → C327	C500 → C537	C600 → C644
12/07/08 → 02/10/16	13/10/16 → 17/05/17	11/07/17 → 18/07/18	25/07/18 → 01/10/2019

The Jason-2 Long Repeat Orbit is approximately 27 km below the historical T/P orbit still used by Jason-3. The very long repeat cycle yields a fine grid : thanks to 1 year on Long Repeat Orbit, spatial resolution from J2 data is approximately 8-km, and reach 4-km thanks to iLRO: this high density of measurements is beneficial for marine geodesy (e.g. improvement of bathymetry and mean sea surface models).



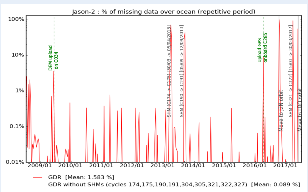
Cycle 001 to 303
Cycle 305 to 327

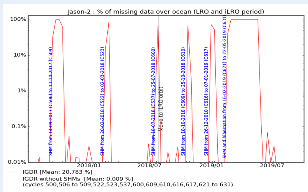
LRO, Cycle 500 to 537

iLRO, Cycle 600 to 644

Data coverage and quality

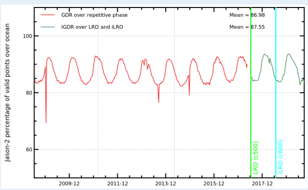
Data availability





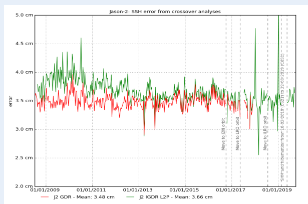
Very good data availability over ocean:
98.4 % over repetitive phase, calibrations and incidents included
After removing calibrations and incidents :
>99.9 % data are available over ocean over all repetitive, LRO & iLRO phases

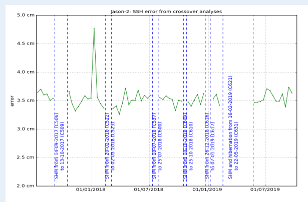
Valid data over ocean



An annual signal due to ice coverage cycle is visible (~9% of rejected data in average). Out of these rejected points, the editing process removes between 3% and 4% of data when no anomaly. This level is consistent for Jason-2 over each period (historical ground track, interleaved, then LRO and i-LRO).

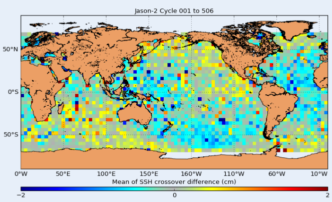
SSH differences at crossover points





Sea Surface Height (SSH) error for Jason-2 is deduced from crossovers analysis using radiometer data and selecting |latitudes| < 50°, bathy<-1000m, oceanic variability < 20 cm.

⇒ Error from SSH differences at crossover points analysis is close to **3.5 cm** for GDR data, and slightly higher but still stable for IGDR (L2P updates included) during Long Repeat Orbits phases.

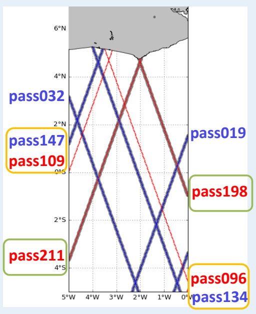


Spatial distribution of mean SSH differences shows geographically correlated patterns with differences remaining below 2 cm.

⇒ Crossovers analysis demonstrates the good performance of Jason-2 mission.

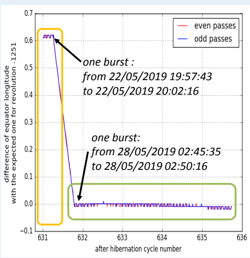
Focus on rewinding after hibernation

Cycle631: available points
Cycle621: available points
Cycle621: expected (theoretical) points



Jason-2 entered Safe Hold Mode on 2019/02/16. The last available IGDR points is on cycle 621 pass 151, at 13:25:51.
After the hibernation period of about 3 months, the first IGDR data happened on 2019/05/22 at 11:27:54, over **pass 056 of cycle 631**.

Thanks to a couple of maneuvers, a kind of rewinding on theoretical drifting ground track has been done.



Following the difference between equator longitude for a revolution and the expected one for the 1251st revolution before, shows that differences are around 0.62° from restart (at cycle 631 pass 056) to around cycle 631 pass 066 (*one burst : from 22/05/2019 19:57:43 to 22/05/2019 20:02:16*) . On the map, this is the case :

- between cycle 621 pass 096 and **cycle 631 pass 134**.
- between cycle 621 pass 109 and **cycle 631 pass 147**.

From cycle 631 pass 198 (2019/05/28) onwards, this difference drop under 0.01° (*one burst: from 28/05/2019 02:45:35 to 28/05/2019 02:50:16*).
Therefore, **cycle 631 pass 198** exactly cover the expected cycle 621 pass 236, and **cycle 631 pass 211** correspond to expected cycle 621 pass 249.

Conclusions

After more than 11 years in orbit, Jason-2 mission ended this month.
Jason-2 mission shows excellent performances in terms of data availability and quality.
Jason-2 LRO and iLRO data quality will allow to improve mean sea surface models out of historical ground track .
Jason-2 data greatly contributed to ocean dynamics understanding and climate sea level monitoring.
Its great quality of data and coherence with other missions will be improved by a future reprocessing in line with actual works over SARAL, TOPEX, and Jason-3 GDR-F.

2. Data used and processing status

2.1. Mission events

The following table (table 1) shows the major planned events during the Jason-2 mission. Altimeter and radiometer calibration events or fuel depletion maneuver burst are not mentionned, neither end-of-life fluidic passivation maneuvers. Note that non planned events as Safe Hold Modes are detailed forward in table 5.

Dates	Events	Impacts
4 July 2008 5h57	Start of Jason-2 Cycle 0	
4 July 2008 12h15	Start of Poseidon3 altimeter. Tracking mode : autonomous acquisition, median	Start of level2 product generation.
04 July 2008 13:47:52 to 04 July 2008 14:13:36	Poseidon3 altimeter. Tracking mode : Diode acquisition, median	
04 July 2008 14:14:39 to 17 July 2008 15:30:22	Poseidon3 altimeter. Tracking mode : Diode acquisition, SGT	
8 July 2008 4h45 - 5h25	Poseidon3 altimeter. Dedicated period for validation of tracking mode performances	small data gaps on corresponding passes [Cycle 0]
11 July 2008 13h00-13h01 and 13h04-13h12	Poseidon3 altimeter. Tracking mode : Diode-DEM (functional)	Functional test of DIODE-DEM tracking mode while onboard DEM was not correct, leading to wrong waveforms and so impacts on altimeter retracking outputs.
12 July 2008 1h20	Start of Jason-2 Cycle 001	
16 July 2008 7h10-17h08	Jason-2 Cycle 001: upload Poseidon-3 - DEM	Data gap on corresponding passes [Cycle 1, Pass 108-144]
17 July 2008 7h29-11h30	Jason-2 Cycle 001: upload Poseidon-3 - DEM	Data gap on corresponding passes [Cycle 1, Pass 108-144]
17 July 2008 15:30:22 to 31 July 2008 21:17:08 UTC	Poseidon-3 altimeter. Tracking mode : Diode acquisition, median	
31 July 2008 21:17:09 to 10 August 2008 19:15:39	Jason-2 Cycle 003: Poseidon3 altimeter. Tracking mode : Diode-DEM	
.../...		

Dates	Events	Impacts
10 August 2008 19:15:40 to 20 August 2008 17:14:10	Jason-2 Cycle 004: Poseidon3 altimeter. Tracking mode : Diode acquisition, median	
20 August 2008 17:14:11 to 30 August 2008 15:12:43	Jason-2 Cycle 005: Poseidon3 altimeter. Tracking mode : Diode-DEM	
30 August 2008 15:12:43 to 9 September 2008 13:11:15	Jason-2 Cycle 006: Poseidon3 altimeter. Tracking mode : Diode acquisition, median	
9 September 2008 13:11:15 to 19 September 2008 11:09:47	Jason-2 Cycle 007: Poseidon3 altimeter. Tracking mode : Diode-DEM	
19 September 2008 11:09:47 to 29 September 2008 09:08:19	Jason-2 Cycle 008: Poseidon3 altimeter. Tracking mode : Diode acquisition, median	
2 February 2009 06:55:11 to 15:58:05	Jason-2 Cycle 021:software upload to Poseidon-3	data gap between passes 204 and 213
11 Mai 2009 12:09 to 14 Mai 2009 13:09	Jason-2 Cycle 031: Upload Poseidon-3 (new DEM)	data gaps (northern hemisphere) for passes 154 to 231
4 June 2009 06:31:27 to 14 June 2008 04:29:59	Jason-2 Cycle 034: Poseidon3 altimeter. Tracking mode : Diode-DEM	
12 February 2010	Upload of Doris V8.0 flight software	improved OGDR orbit accuracy
16 September 2010	Jason-2 Cycle 081: Upload of DEM patch for Gavdos transponder calibration	data gap for passes 087 and 237
17 February 2011	GPSP OBS revert upload	
12-14 September 2012	DORIS OBS upload (DORIS restart on 19th September)	OGDR data gap (during the DORIS restart)
15 May 2013	update on Usingen receiver was done on 15-May-2013 at 11:05Z in order to solve a problem with the TM receiver	
.../...		

Dates	Events	Impacts
5-15 March 2014	Jason-2 Cycle 209: Tracking mode : Diode-DEM	gain of available measurements on earth
18 March 2014	Update of TRIODE software (for OGDR).	Reduction of 14days signal in OGDR SLA.
22 June-2 July 2014	Jason-2 Cycle 220: Tracking mode : Diode-DEM	gain of available measurements on earth
9 September 2014	Jason-2 cycle 228: switch to GPS-B (instead of GPS-A)	
25 May 2015	Jason-2 cycle 254: orbit standard switches to POE-E from this cycle onwards.	
5-6 April 2016	Jason-2 cycle 285: upload of new GPS On Board software	Data gap: no scientific products have been processed between April, 5 at 13:35:10 and April, 6 at 12:02:40.
2-13 October 2016 4-6 October 2016	from cycle 304 pass 001 to cycle 305 pass 163: move to interleaved ground track upload of a new DEM	Data gap: Poseidon-3 altimeter is put in WAIT mode.
05-15 December 2016	Jason-2 Cycle 311: Tracking mode : Diode-DEM	gain of available measurements on earth
July 2017	Move to Long Repeat Orbit	
19 July 2017	TC-GROUP (*2: first one during about 20sec and second one during around 4sec)	
03 November 2017	Upload flight software (6’56”)	
20-21 February 2018	BDR update	(ACG - PRI - TPG modifications)
02 March 2018	BDR update	(ACG - PRI - TPG modifications)
17 April 2018 (07:46)	AMR reset	
July 2018	Move to iLRO	(cycles number set to 600)
15 May 2019	DORIS software upload	(Update STAREC antenna height D type)
22 May 2019	Maneuver to place Jason-2 correctly in order to resume the geodetic cycle2, stopped on February 16th	
.../...		

Dates	Events	Impacts
12 July 2019	Swap GYRO1 to GYRO2	
24 July 2019	AMR reset	
10 September 2019	Fluidic passivation maneuver (1)	
11 September 2019	Fluidic passivation maneuver (2)	
28 September 2019	end of mission experiment phase commands	
01 October 2019	**End of Jason-2 mission**	
01-10 October 2019	End of mission commands	
09 October 2019	final shutdown of nominal and redundant POSEIDON instruments	
10 October 2019	Satellite passivated and decommissioned at 16:25:33 UTC	

Table 1 – Planned events

2.2. First Long Repeat Orbit [LRO]

Due to the gyro#1 and #2 status, the global ageing of the spacecraft, and the already existing recommandation from OSTST to move Jason-2 to a new orbit at 1309.5km, it was decided, during the exceptional JSG held on 2017 June 20th, to start the maneuvers to that new orbit. Jason-2 moved early July 2017 to a new Long Repeat Orbit (LRO). The new orbit was reached on July 8th and the onboard instruments have resumed nominal operations on July 11th.

The Jason-2 Long Repeat Orbit is approximately 27 km below the historical T/P orbit. The very long repeat cycle yields a fine grid of approximately 8-km: it is beneficial for marine geodesy (e.g. improvement of bathymetry and mean sea surface models).

The strategy is inherited from Jason-1 end-of-life (EOL) with a try to optimize all sub-cycles, shorter ones for sea-state and mesoscale, and longer ones for geodesy.More details can be found in the JA1-GM [19] and JA2-EOL papers [20].

The Jason-2 data products in the LRO phase follow a similar naming convention as was used when Jason-1 was moved to its drifting phase. Specifically, data products are provided in about 10-days cycles, with cycle numbering beginning at cycle number 500 and each cycle containing 254 passes (half orbit revolutions). The product version remain as version "D".

After one year on LRO, the Jason-2 spacecraft entered safe mode on Wednesday, July 18th 2018 at 09:00UTC, immediately interrupting its measurements. The analysis of the telemetry shows that the safe hold mode is consecutive to a gyro#1 disjunction. Thanks to investigations, those anomalies were then known and, as decided during JSG, the reconfiguration of the satellite on gyro#2 started immediately.

Note that Jason-2 first measurement on Long Repeat Orbit is on 11-07-2017 10:32:39 (cycle 500, pass 033). The last record on this orbit happened on 18-07-2018 08:29:10 (cycle 537, pass 211)

A focus on the data quality on Long Repeat Orbit was presented at OSTST meeting in 2017 [8]. Details are also available in 2017 Jason-2 data assessment annual report [7].

The Jason-2 LRO (Long Repeat Orbit) orbit has the following sub-cycles (near repeat) and cycle (exact repeat) on table 2. The first two sub-cycles are beneficial for sea-state and mesoscale operational applications respectively: they guarantee a nearly geographically homogeneous sampling for the temporal scales of interest (e.g. for operational model assimilation). The papers [19] and [20] explain how this sub-cycle sequence progressively composes finer-resolution grids through an apparent shift of lower resolution grids.

type	nodal days	days	revolutions	number of pass	size
sub cycle	4	3.97	51	102	
sub cycle	17	16.86	217	434	185km
sub cycle	81	80.31	1034	2068	40km
sub cycle	145	143.77	1851	3702	22km
cycle	371	367.84	4736	9472	8km

Table 2 – Cycle and sub-cycles for the Jason-2 LRO

As an example, sub cycles beginning and end dates for year 2017 are detailed in table3. Note that due to SHM, 17-days subcycle 005 is entirely missing.

sub cycle type	sub cycle number	begin	end
17 days	1	11-07-2017 10:32:39.505000	28-07-2017 07:02:57.91999
	2	28-07-2017 07:02:57.92000	14-08-2017 03:33:14.517999
	3	14-08-2017 03:33:14.518000	31-08-2017 00:03:31.596999
	4	31-08-2017 00:03:31.597000	16-09-2017 20:33:48.41999
	5	16-09-2017 20:33:48.42000	03-10-2017 17:04:03.770999
	6	03-10-2017 17:04:03.771000	20-10-2017 13:34:20.720999
	7	20-10-2017 13:34:20.721000	06-11-2017 10:04:40.556999
	8	06-11-2017 10:04:40.557000	23-11-2017 06:34:58.413999
	9	23-11-2017 06:34:58.414000	10-12-2017 03:05:16.118999
	10	10-12-2017 03:05:16.119000	26-12-2017 23:35:33.707999
	11	26-12-2017 23:35:33.708000	12-01-2018 20:05:50.896999
80 days	1	11-07-2017 10:32:39.505000	29-09-2017 17:59:59.566999
	2	29-09-2017 17:59:59.567000	19-12-2017 01:27:24.334999
145 days	1	11-07-2017 10:32:39.505000	03-12-2017 10:46:37.574999

Table 3 – 17 days, 80 days and 145 days sub-cycles dates for the Jason-2 LRO over year 2017

Global sub-cycles coverage is shown from figure 2 to figure 5. On the following maps, IGDR until 2017/12/03 are used. Theoretical points are deduced from MOE orbit files, with an exception: using this method do not allow to draw a theoretical ground track during SHM (MOE orbit files are not produced). In order to visualize missing points due to safe hold mode (14/09/2017 to 13/10/2017), predicted MOE is used. Red points indicate theoretical points location deduced from MOE orbit files, real mesurements from July to September (before SHM) are in dark blue and real point from October onwards (after SHM) are in cyan.

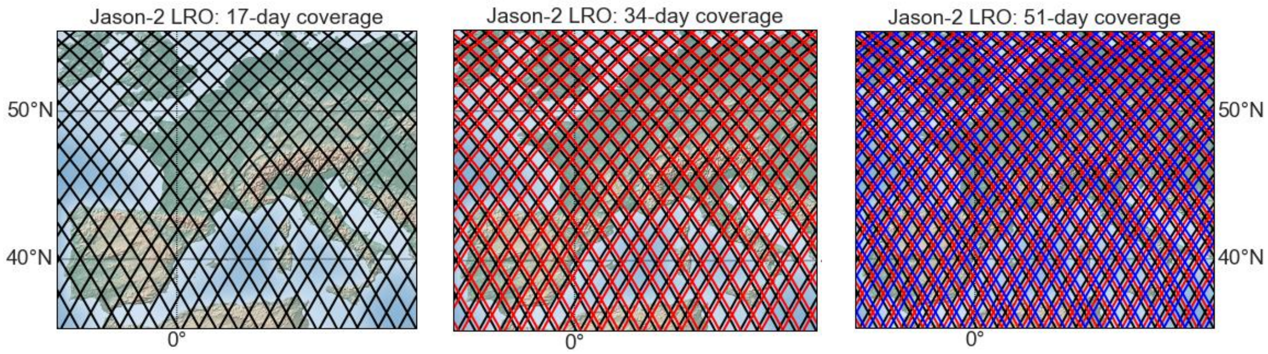


Figure 1 – Jason-2 LRO sampling for 3 subsequent periods of 17 days in black, red and blue (from public release)

Figure 2 shows 17 days subcycles 001 (top) to 004 (bottom) coverage, and figure 3 shows 17 days subcycles 006 (top) to 008 (bottom) coverage. Due to 2017-09-14 SHM, 17-days sub-cycle 005 is entirely missing , and 17-days sub-cycle 004 (figure 2) and 006 (figure 3) are partly missing.

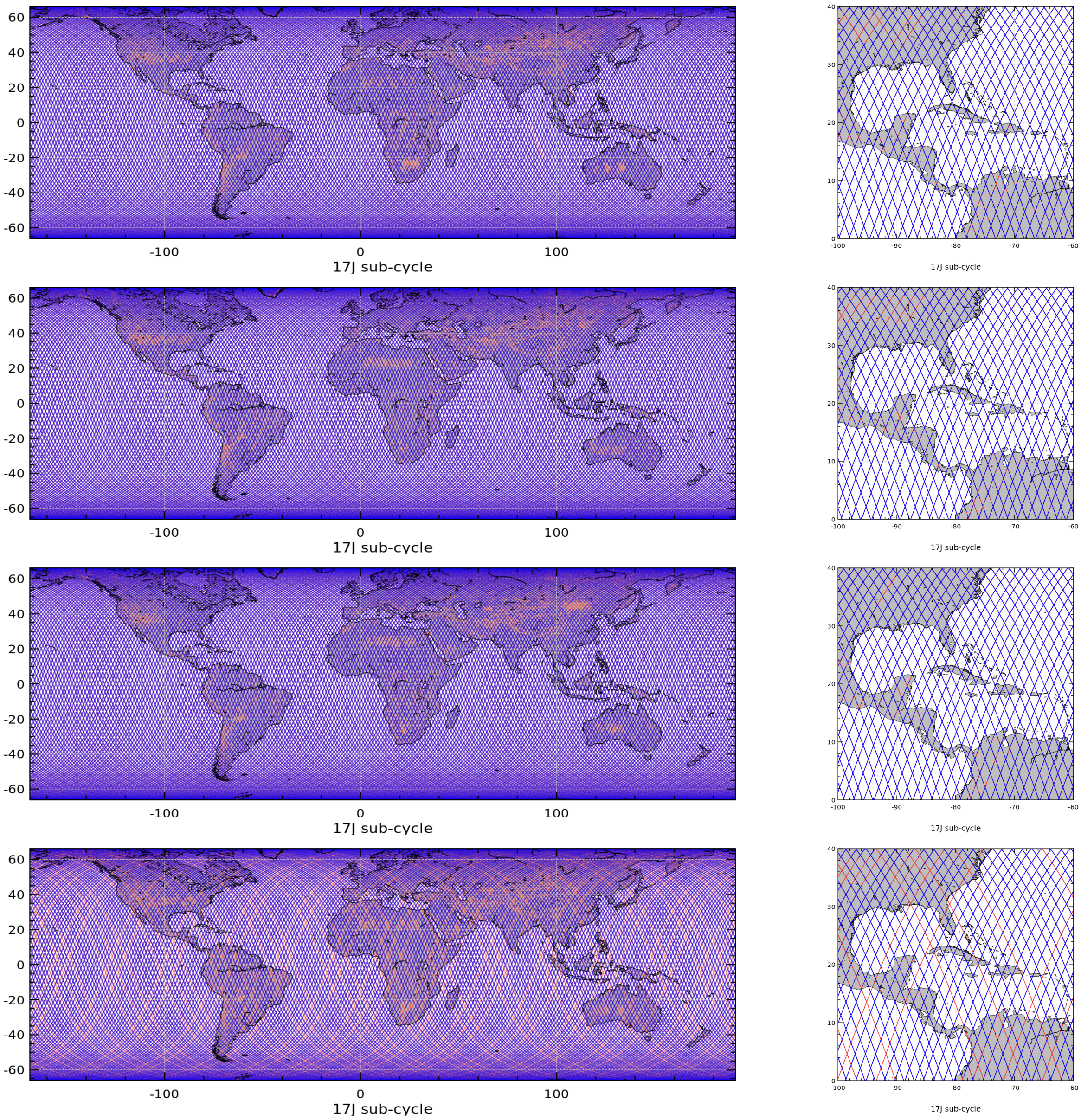


Figure 2 – 17days subcycle 001 to 004, red: missing theoretical points, blue: available measurements

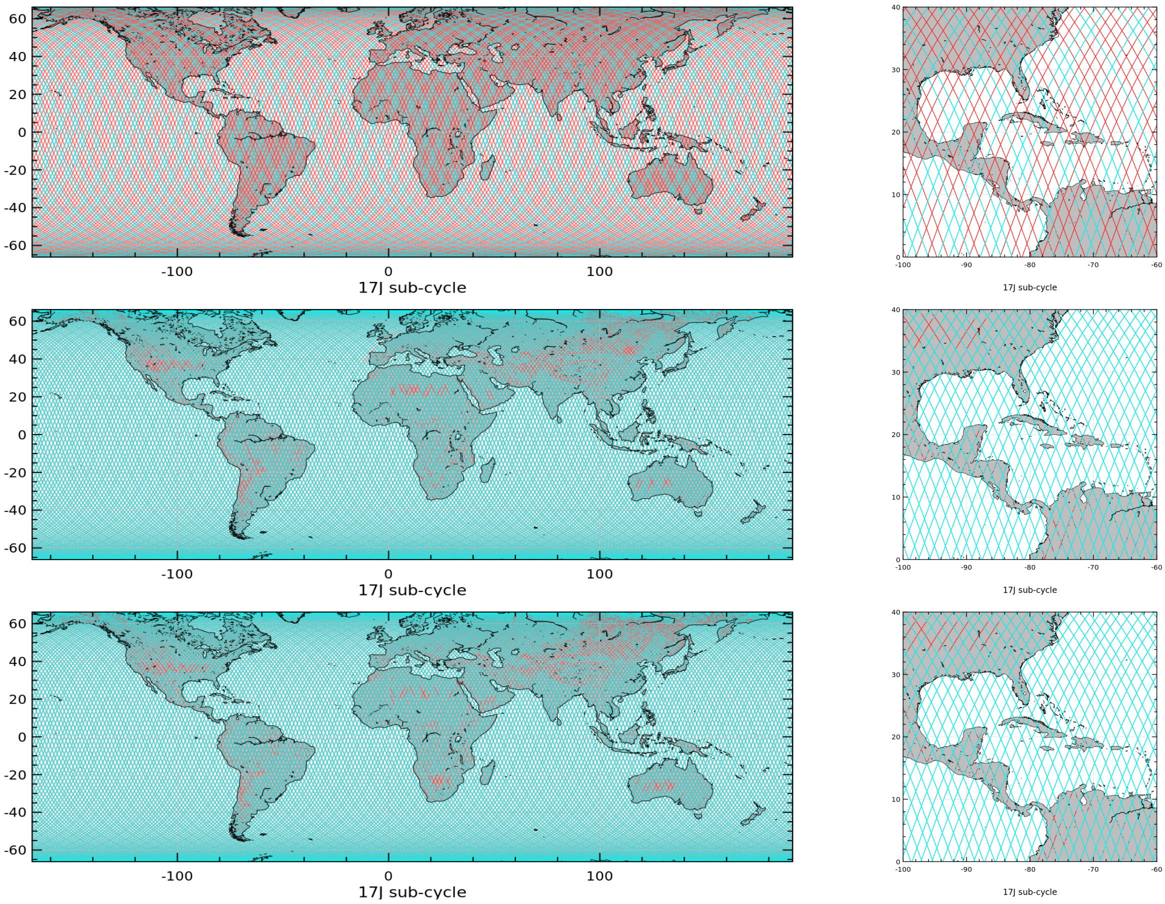


Figure 3 – 17-days subcycle 006 (top) to 008 (bottom) - after SHM (2017-09-14 to 2017-10-13), red: missing theoretical points, cyan: available measurements

Figure 4 shows 80 days subcycles 001 (top) and 002 (bottom) coverage. Except during SHM that occured over the end of the first 80-days sub cycle and the beginning of the second 80-days subcycle, data coverage is very good.
Figure 5 shows 145-days subcycles 001 coverage (red: missing theoretical points, blue: available measurements before SHM (2017-09-14 to 2017-10-13), cyan available measurements after SHM (2017-09-14 to 2017-10-13)).

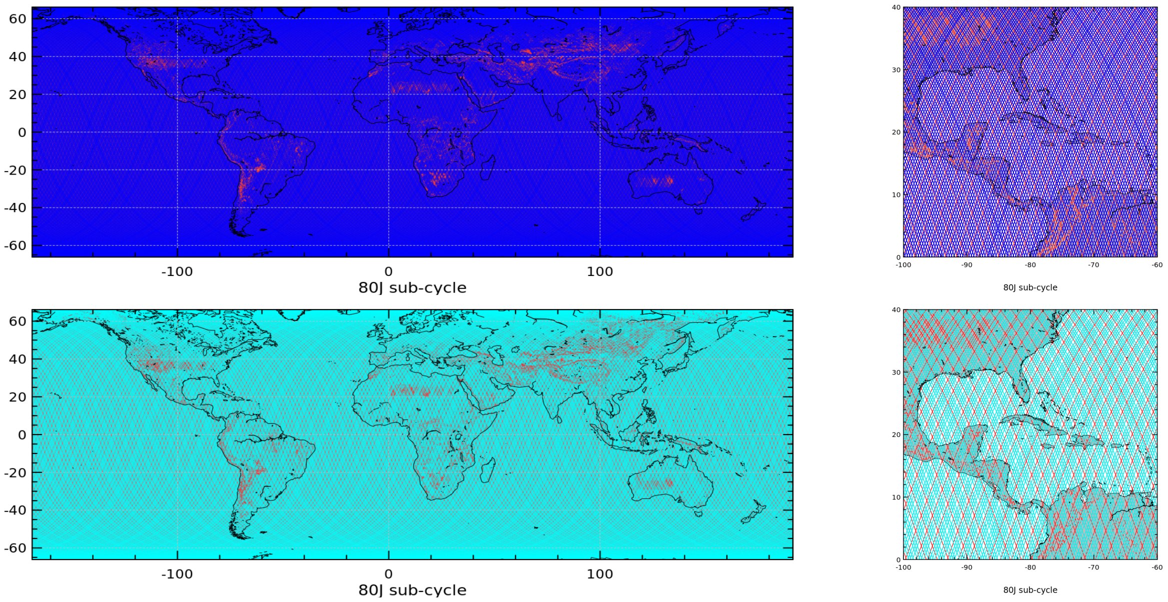


Figure 4 – 80-days subcycle 001 and 002, red: missing theoretical points, blue: available measurements before SHM (2017-09-14 to 2017-10-13), cyan available measurements after SHM (2017-09-14 to 2017-10-13)

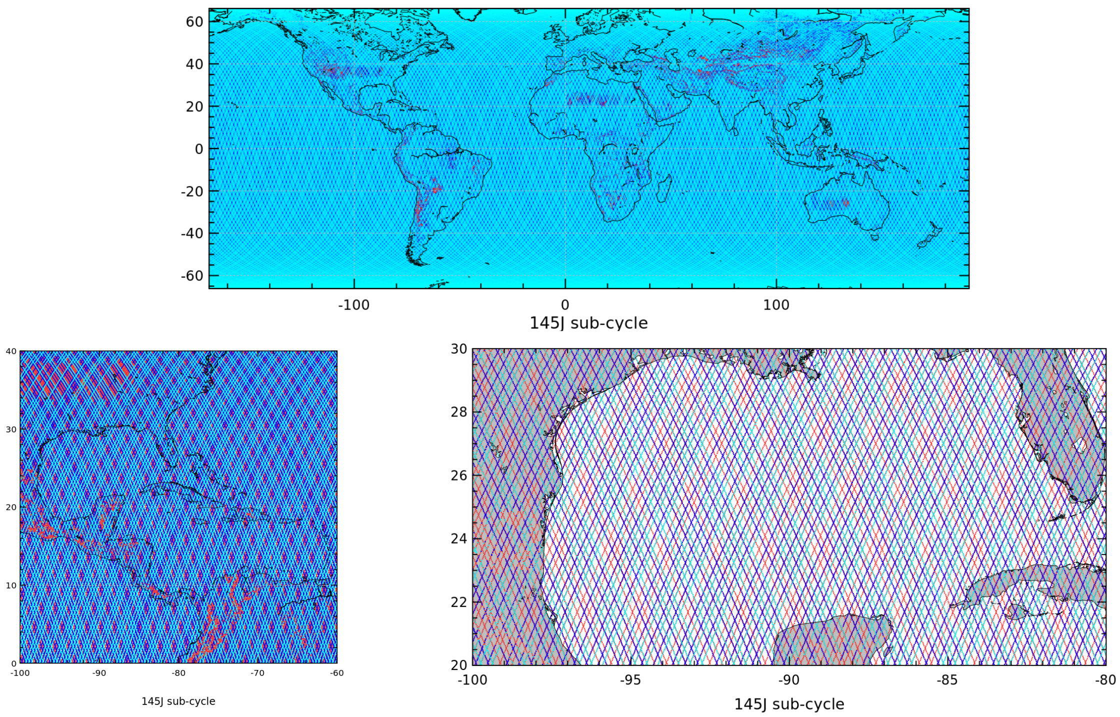


Figure 5 – 145-days subcycle 001, red: missing theoretical points, blue: available measurements before SHM (2017-09-14 to 2017-10-13), cyan available measurements after SHM (2017-09-14 to 2017-10-13)

2.3. Second Long Repeat Orbit [iLRO]

On July 16th 2018 Jason-2 has executed its first maneuver in order to be transferred to an Interleaved Long Repeat Orbit. A second maneuver was executed on July 18th in order to be placed on a ground track in the middle of the grid defined by the first geodetic cycle. **The aim was, at the end of this second geodetic cycle, and in addition to data from first year on LRO, to have geodetic data available on a 4 kilometer grid, which is of great interest for geodesic community.**

Note that the new cycle numbering for the i-LRO measurements were restarted from 600 at the beginning of this second geodetic cycle.

The reconfiguration to safe hold mode (18/07/2018, see end of first LRO) has been triggered after the last maneuver, which means Jason-2 were ready to provide measurements. After its move in July 2018 to this interleaved LRO (i-LRO) SHMs again occurred by four times (in oct-18, dec-18 and twice in feb-19). It was so decided to enter a hibernation phase for about 3 months, and to develop and then apply a strategy to switch between operational and healthy gyros, in order to reduce the SHM events risk. With the aim to avoid misisng data in the 4 km grid coverage, it was also decided to operate a king of rewind to the ground track point where data gap began on february 2019. From 22nd May 2019, Jason-2 were re-operating, and has provided telemetry measurements until 1st October 2019.

Focus on rewind after hibernation:
Jason-2 entered Safe Hold Mode on 2019/02/16. The last available IGDR points is on cycle 621 pass 151, at 13:25:51. After the hibernation period of about 3 months, the first IGDR data happened on 2019/05/22 at 11:27:54, over pass 056 of cycle 631. Thanks to a couple of maneuvers, a kind of rewinding on theoretical drifting ground track has been done.

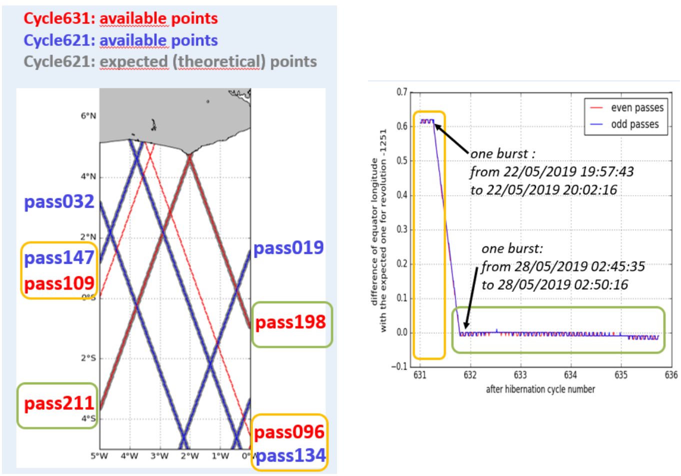


Figure 6 – Jason-2 rewind on theoretical drifting ground track after hibernation (2019)

Following the difference between equator longitude for a revolution and the expected one for the 1251st revolution before (right of Figure 6), shows that differences are around 0.62° from restart (at cycle 631 pass 056) to around cycle 631 pass 066 (one burst : from 22/05/2019 19:57:43 to 22/05/2019 20:02:16) . On the map (left of Figure 6), this is the case :

- between cycle 621 pass 096 and cycle 631 pass 134.
- between cycle 621 pass 109 and cycle 631 pass 147.

From cycle 631 pass 198 (2019/05/28) onwards, this difference drop under 0.01° (one burst: from 28/05/2019 02:45:35 to 28/05/2019 02:50:16), see right of Figure 6. Therefore, cycle 631 pass 198 exactly cover the expected cycle 621 pass 236, and cycle 631 pass 211 correspond to expected cycle 621 pass 249, as shown on the map (left of Figure 6).

Note that Jason-2 first measurements on second Long Repeat Orbit is on 25/07/2018 08:26:36 (cycle 600, pass 176). Finally, Jason-2 last measurement was on 01-10-2019 at 06:50:45 (cycle 644, pass147).

2.4. Models and Standards History

Three versions of the Jason-2 Operational Geophysical Data Records (OGDRs) and Interim Geophysical Data Records (IGDRs) have been generated up to now.

- These three versions are identified by the version letters "T" (for test), "C" and "D" in the product filename. For example,
  - version "T" IGDRs are named "JA2_IPN_2PT",
  - version "C" IGDRs are named "JA2_IPN_2Pc",
  - and version "D" IGDRs are named "JA2_IPN_2Pd".
- All three versions adopt an identical data record format described in Jason-2 User Handbook [1].
- Versions "T" and "C" differ only slightly (names of variables are corrected and 3 variables added).
- Version "T" O/IGDRs were the first version released soon after launch and was disseminated only to OSTST community.
- Version "C" O/IGDRs were first implemented operationally from data segment 141 of cycle 15 for the OGDRs (3rd December 2008) and cycle 15 for the IGDRs.
- Version "C" of Jason-2 data is consistent with version "C" of Jason-1 data.
- Version "D" O/IGDRs were first implemented operationally from data segment 78 of cycle 150 for the OGDRs (31st July 2012) and cycle 150 for the IGDRs.
- GDR data switched to version "D" from cycle 146 onwards, but previous cycles 1 to 145 were reprocessed in version "D" during 2012. Therefore the whole Jason-2 mission is available in GDR version "D".

The table 4 below summarizes the models and standards that are adopted for version "D" of Jason-2 data. Differences with the previous version ("T" / "C") are detailed in [4]). More details on some of these models are provided in Jason-2 User Handbook document [1].

Model	Product version "D"
Orbit	Based on Doris onboard navigator solution for OGDRs. DORIS tracking data for IGDRs (exept for cycles 20 to 78 : DORIS + SLR tracking). Using POE-E standards from 25/05/215 onwards. DORIS+SLR+GPS-A tracking data for GDRs cycles 1 to 225. DORIS + SLR tracking for GDRs for cycles 226 and 227) DORIS+SLR+GPS-B tracking data for GDRs from cycle 228 onwards. Using POE-C standard for GDRs until cycle 254 and POE-E from cycle 254 onwards
Altimeter Retracking	"Ocean MLE4" retracking: MLE4 fit from 2nd order Brown analytical model: MLE4 simultaneously retrieves the 4 parameters that can be inverted from the altimeter waveforms: • Epoch (tracker range offset) → altimeter range • Composite Sigma → SWH • Amplitude → Sigma0 • Square of mispointing angle (Ku band only, a null value is used in input of the C band retracking algorithm) "Ocean MLE3" retracking: MLE3 fit from 1st order Brown 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
…/…	

Model	Product version "D"
Altimeter Instrument Corrections	Two sets: • on set consistent with MLE4 retracking • on set consistent with MLE3 retracking
Jason-2 Advanced Microwave Radiometer (AMR) Parameters	Using calibration 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
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 until cycle 327. MSS_CNES_CLS15 from cycle 500 onwards
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 Dealiasing 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 and M4 load tide included.
Tide Solution 2	FES2004 + S1 and M4 ocean tides. S1 and M4 load tides ignored
.../...	

Model	Product version "D"
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
Altimeter Wind Speed	Wind speed table derived from Jason-1 data (Collard, [14]). In addition, a calibration bias of 0.32 is applied to JA2 Ku-band sigma0 prior wind speed computation.
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 4 – Models and standards adopted for the Jason-2 version "D" products. Adapted from [1]

– During 2012, the whole Jason-2 mission was reprocessed in GDR-D standard. For more details, please refer to the reprocessing reports [4] and [3].

– **Note that orbit switched to standard POE-E from GDR cycle 254 (25-05-2015) onwards.**

– From cycle 170 to 178, the flag "qual_inst_corr_1hz_sig0_ku" was wrongly set to one because of an out of thresholds criterion. From cycle 179 onwards, the flag "qual_inst_corr_1hz_sig0_ku" won't constantly be set as the threshold used to set this flag has been adjusted in the processing chain, in order to take into account the natural instrumental drift.

– **Change of MSS GDR standard:** To improve the Sea Surface Height Anomaly (SSHA) data quality in the Jason-2 LRO data products an updated Mean Sea Surface (MSS) model has been adopted. The new MSS model is the latest CNES/CLS MSS 2015 solution [21], which is referenced to the 20-year period spanning 1993-2012. The MSS model provided on the prior data products (version "D" products during the 10-day exact repeat phase) was the 2011 solution, referenced to the 7-year period spanning 1993-1999 and has a lower quality on LRO ground tracks. The global bias between these two MSS models is approximately 2.5 cm, due to their different reference periods. Users are therefore cautioned that the SSHA values provided on the respective version "D" data products from the LRO and 10-day exact repeat mission phases are biased by 2.5 cm. The SSHA provided on the version "D" LRO-phase products is lower by 2.5 cm than on the 10-day exact-repeat-phase products.

2.5. Main processing events summary

End of 2008 Jason-2 data were already available to end users in OGDR (3h data latency) and IGDR (1-2 days data latency).

- They were first released in version T and switched at cycle 015 to version C.
- They stayed in this version till cycle 149 (till 2012/07/31 12:01:59 for OGDR).

GDR data were released in standard version C during August 2009. During 2012 the whole GDR dataset was reprocessed in GDR-D version.
→ **A description of the different Jason-2 products is available in the OSTM/Jason-2 Products handbook [1].**

As concerned mission events that impact processing, note that :

- Since 5th of April 2013 (cycle 175), platform moduleB has been used.
- During cycle 226 and 227, the precise orbit ephemeris (orbit in GDR) was based on DORIS and SLR only due to payload GPS unavailability. From cycle 228 onwards, GPS-B (instead of GPS-A) is operational.
- Since cycle 254 (25-05-2015), POE-E orbit standard has been applied.
- Jason-2 was moved from its original groundtrack to its new interleaved groundtrack on October 2016 (from October 2nd at 11 :53 UTC (end of cycle 303) until 13-10-2016 at 20:00:00 (cycle 305, pass 164)).
- After several Safe Hold Modes in March and May 2017, Jason-2 was moved to a Long Repeat Orbit (LRO) at the beginning of July 2017 (see 2.2.). In order to improve data quality, mean sea surface solution in products has been modified to CNES/CLS 2015 solution from cycle 500 (first cycle on LRO) onwards.
- In July 2018, Jason-2 was moved to a second Long Repeat Orbit (iLRO). Cycle numbering is then set to 600 at the beginning of this new phase (see 2.3.).
- After the hibernation period of about 3 months between 2019/02/16 and 2019/05/22, a kind of rewinding on theoretical drifting ground track has been done in order to avoid missing areas on targeted data grid (see 2.3.).

2.6. Data Used

In this report, data used are GDR-D from cycle 1 to 506 (until 14/09/2017) and IGDR until cycle 644 (01/10/2019).
Note that in order to improve their product quality (and also to use as much as possible same corrections for multimission products), DUACS system applies some updates to IGDR data (see [22]). 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. Data availability

This section presents a summary of major satellite or ground segment events that occurred over mission lifetime. Table 5 gives a status about the number of missing passes (or partly missing) for GDRs, as well as the associated events for each cycle.

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. Jason-2 can use several onboard tracking modes: Split Gate Tracker (ie the Jason-1 tracking mode, used for cycle 0 and half of cycle 1), Diode/DEM (used for cycles 3, 5, 7, 34, 209, 220 and 311) and median tracker (used for the other cycles). These different tracking modes are described by [15]. Thanks to the new modes of onboard tracking compared to Jason-1 (median tracker and Diode/DEM), the data coverage over land surface was dramatically increased in comparison with Jason-1 depending on the tracker mode and the period (see [7] for details).

Figure 7 shows the percentage of missing measurements for Jason-2 over ocean computed with respect to a theoretical possible number of measurements. It represents the percentage of missing measurements relative to the full coverage, when limited to ocean surfaces. The mean value is about 1.6% for Jason-2 repetitive phase, and near 20.8% over the drifting periods (due to SHMs during the last two years of the mission). All the missing measurements events are described on table 5. When computing the percentage of missing measurements without taking into account the cycles where big anomalies occurred (SHM) or move of orbit, the mean value of missing measurements lowers down to 0.1%. This weak percentage of missing measurements is mainly explained by technical or operator problems (such as network problems for example) or scheduled events (like altimeter expert calibrations performed every 6 months or software upload), and finally by the rain cells and sigma0 blooms, as these sea states can disturb significantly the Ku-band waveform shape leading to an altimeter lost of tracking.

The main missing events over the historical ground track happened in 2013 and 2016. During 2013, Jason-2 entered in safe hold mode twice in March (from 25/03/2013 to 29/03/2013 and from 30/03/2013 until 05/04/2013, during cycles 174 and 175) and a third time in September (from 05/09/2013 to 12/09/2013, during cycles 190-191). During 2016, data are missing between April, 5 at 13:35:10 and April, 6 at 12:02:40 as no altimeter measurements have been performed (altimeter in wait mode) during this period to allow the upload of new GPS onboard software.
Jason-2 was moved from its original groundtrack to its new interleaved groundtrack on October 2016: October 2nd at 11 :53 UTC (end of cycle 303) the Poseidon-3 altimeter is put in WAIT mode and there is no more measurement until the end of the move to interleaved ground track (13-10-2016 at 20:00:00 (cycle 305, pass 164)). After several Safe Hold Modes in March and May 2017, Jason-2 was moved to a Long Repeat Orbit (LRO) at the beginning of July 2017.
During its first LRO drifting period, Jason-2 encountered several SHM events on September 2017, February and March 2018 and finally, just before move to second drifting phase, in July 2018. Over the second drifting period (called iLRO), SHMs have again occurred by four times (in October 2018, December 2018 and twice in Febrauray 2019). Finally, Jason-2 last measurement was on 01-10-2019 at 06:50:45 (cycle 644, pass147).

Note that there is a gap in cycle numbering between 328 and 499, before move to LRO, and from cycle 537 to 599, before move to iLRO.

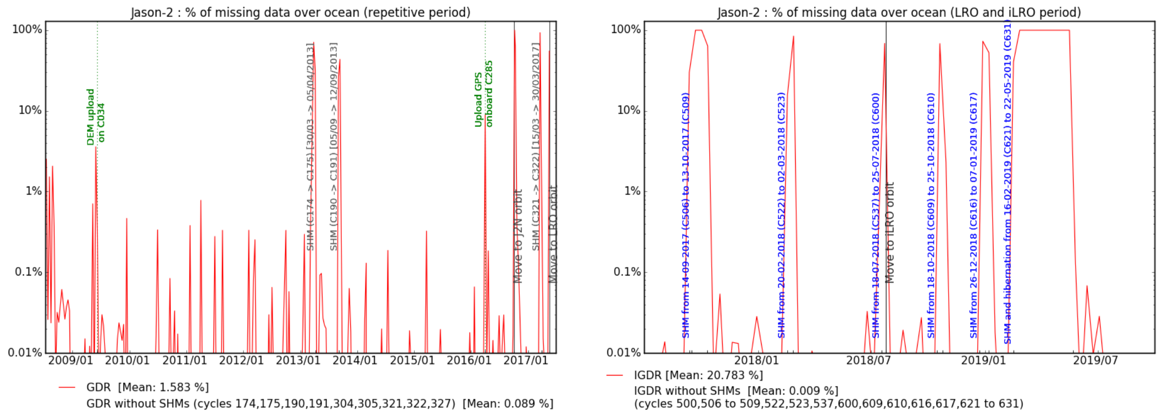


Figure 7 – Percentage of Jason-2 missing measurements over ocean. For repetitive orbit from cycle 001 to 303 (left) or over LRO and iLRO from cycles 500 to 644 (right)

The following table gives an overview over missing data and why it is missing.

Jason-2 Cycles/Pass	Dates	Events
000/222-224	10/07/2008 - 18:28:02 to 20:25:04	Missing telemetry (Usingen station pb)
000/232	11/07/2008 - 03:57:08 to 04:30:30	Partly missing due to altimeter calibration (long LPF)
000/235	11/07/2008 - 07:01:28 to 07:27:41	Partly missing due to altimeter calibration (CNG step)
001/44-46	13/07/2008 - 17:40:00 to 19:37:30	Missing telemetry (Usingen station pb)
001/48-50	13/07/2008 - 21:37:02 to 23:30:00	Missing telemetry (NOAA station pb)
001/108-144		several passes partly missing due to upload of new DEM (planned unavailability)
003/032-035	02/08/2008 - 02:23:45 to 05:46:30	Passes 32 and 35 are partly missing, passes 33 and 34 are completely missing due to missing telemetry (Usingen)
005/236-241	29/08/2008 - 21:44:56 to 30/08/2008 02:52:07	Missing telemetry (Usingen station pb): passes 237 to 240 completely missing, passes 236 and 241 partly missing
.../...		

Jason-2 Cycles/Pass	Dates	Events
006/232	08/09/2008 - 15:48:00 to 16:21:22	pass 232 partially missing due to altimeter calibration (long LPF)
006/235	08/09/2008 - 18:53:00 to 19:19:10	pass 235 partially missing due to altimeter calibration (CNG step)
016/73	10/12/2008 - 15:11:19 to 15:13:27	pass 73 partially missing due to 1) upload of correction for low signal tracking anomaly and 2) memory dumps (planned unavailability)
026/33	18/03/2009 - 05:09:15 to 05:10:44	pass 33 has approximately 90 seconds of missing ocean measurements in gulf of guinea (probably due to missing telemetry)
029/209-210	23/04/2009 - 20:18:36 to 20:35:11	data gap over land (on transition between passes 209 and 210) due to missing telemetry
031/154-231	11/05/2009 12:09 to 14/05/2009 13:09	Upload of new DEM leading to missing portions (northern hemisphere) for passes 154 to 231
033/204-213	02/06/2009 - 06:55:11 to 15:58:05	Passes 205 to 212 are completely missing. Passes 204 and 213 are partly missing with respectively 100% and 96% of missing measurements over ocean. This is due to software upload to Poseidon-3.
034/232	13/06/2009 - 07:07:03 to 07:40:23	Due to long calibration, pass 232 is partly missing with 65% of missing measurements over ocean.
034/235	13/06/2009 - 10:11:41 to 10:37:50	Due to calibration CNG step, pass 235 is partly missing with 8% of missing measurements over ocean.
037/54	06/07/2009 - 02:33:12 to 02:34:33	pass 054 has a small data gap due to missing PLTM
053/57	11/12/2009 - 20:38:19 to 21:29:43	passes 57 and 58 have a data gap due to Gyro calibration
053/232	18/12/2009 - 16:39 to 17:12	pass 232 has a data gap due to CAL2 calibration
053/235	18/12/2009 - 19:43	pass 235 has a 26 minutes data gap due to CNG calibration (mostly over land)
072/199	23/06/2010 - 19:15:37 to 19:16:59	pass 199 has small data gap due to missing telemetry
073/232	05/07/2010 - 00:09:33 to 00:42:54	pass 232 has a data gap due to CAL2 calibration
.../...		

Jason-2 Cycles/Pass	Dates	Events
073/235	05/07/2010 - 03:14:11 to 03:40:20	pass 235 has a data gap due to CNG calibration (mostly over land)
081/087	16/09/2010 - 16:40:22 to 16:52:48	pass 087 has a data gap due to upload of DEM update (for GAVDOS transponder calibration)
081/237	22/09/2010 - 13:07:27 to 13:18:12	pass 237 has a data gap due to upload of DEM update (for GAVDOS transponder calibration)
084/031	14/10/2010 - 06:02 to 06:11:15	Calibration (I2 and Q2)
084/031-032	14/10/2010 - 06:12 to 06:21:15	Calibration (I and Q)
084/043	14/10/2010 - 17:00:57 to 17:02:39	pass 043 has a small data gap due to missing PLTM
094/231	29/01/2011 - 04:50 to 04:55	Calibration CAL1 (14% of missing ocean data)
094/232	29/01/2011 - 05:38 to 06:11	Calibration CAL2 (65% of missing ocean data)
094/235	29/01/2011 - 08:37 to 09:03	Calibration CNG (mostly over land, 9% of missing ocean data)
101/133-135	04/04/2011 - 18:49:08 to 21:03:48	Telemetry outage at Usingen, passes 133 to 135 have respectively 23%, 100%, and 91% of missing ocean data
110/158-159	04/07/2011 - 00:27:29 to 01:27:29	Gyro calibration. Passes 158 and 159 have respectively 18% and 88% of missing ocean data
115/232	25/08/2011 - 11:07:35 to 11:40:56	Calibration CAL2: 65% of missing ocean data
115/235	25/08/2011 - 14:12 to 14:38	Calibration CNG: mostly over land, 8% of missing ocean data
132/232	10/02/2012 - 00:42:26 to 01:14:03	Calibration CAL2: 65% of missing ocean data
132/235	10/02/2012 - 03:47:11 to 04:13:20	Calibration CNG: mostly over land, 8% of missing ocean data
135/105	05/03/2012 - 19:54:49 to 20:26:14	technical problem and operator error: 25% of missing ocean data
136/191	19/03/2012 - 02:15:18 to 02:50:11	problem of ACK: 56% of missing ocean data
.../...		

Jason-2 Cycles/Pass	Dates	Events
145/143	14/06/2012 - 11:41:15 to 11:42:58	pass 143 has a small data gap due to missing telemetry
145/248	18/06/2012 - 13:20:10 to 13:21:29	pass 248 has a small data gap
147/022	29/06/2012 - 13:45:30 to 13:49:46	pass 022 has a small data gap due to missing telemetry (8% of missing ocean data)
147/134	03/07/2012 - 22:41:25 to 22:43:58	pass 134 has a small data gap due to operator error (5% of missing ocean data)
154/210	14/09/2012 - 07:45:08 to 07:46:07	pass 210 has a small portion of missing data in central Pacific
156/232	05/10/2012 - 00:07:08 to 00:40:30	Calibration CAL2: 66% of missing ocean data
156/235	05/10/2012 - 03:11:47 to 03:37:57	Calibration CNG: mostly over land, 9% of missing ocean data
168/158-159	29/01/2013 - 03:08:20 to 04:02:37	Gyro calibration. Passes 158 and 159 have respectively 14% and 100% of missing ocean data
172/96-97	07/03/2013 - 08:18:37 to 09:30:49	Operator error. Passes 96 and 97 have respectively 72% and 52% of missing ocean data
174/43-161	25/03/2013 - 02:42 to 29/03/2013 17:53	First Safe Hold Mode. Pass 43 has 63% of missing ocean data and passes 44 to 161 are entirely missing
174-191/175-83	30/03/2013 - 21:57 to 05/04/2013 14:49	Second Safe Hold Mode. About cycle 174, pass 191 has 9% of missing ocean data and passes 192 to 254 are entirely missing. About cycle 175, passes 1 to 82 are entirely missing and pass 83 has 90% of missing measurements over ocean.
178/234		Due to a problem with TM receiver, pass 234 is partly missing (north of pacific) and has 10% of missing measurements over ocean
179/ 38		Due to a problem with TM receiver, pass 38 has 6.8% of missing measurements over ocean
182/235	19/06/2013 from 22 :33 :29 to 22 :59 :37	pass 235 has a data gap due to CNG calibration (mostly over land)
.../...		

Jason-2 Cycles/Pass	Dates	Events
190/185 - 191/116	05/09/2013 at 07 :44 :17 to 12/09/2013 at 12 :25 :52	Third Safe Hold Mode. Concerning cycle 190, pass 185 has 10.2% of missing measurements over sea and passes 186 to 254 are entirely missing. Concerning cycle 191, passes 1 to 115 are missing.
197/035	07/11/2013 - 20:45	Pass 35 has a small data gap.
198/235	25/11/2013 - 14:04:02 to 14:37:35	Calibration (I and Q) with 8% of missing ocean data
207/178	20/02/2014 - 14:30:33 to 14:43:50	24.6% of global missing data and 11.8% missing data over ocean due to DEM upload
208/027	24/02/2014 - 14:38:26 to 14:52:07	40.7% missing data over ocean due to recurring network problems between Fairbanks and SOCC
218/235	11/06/2014 - 21:34:36 to 22:13:13	Poseidon3/Jason2 special calibration. 9% missing data over ocean
222/114	16/07/2014 - between 20:05:19 and 20:10:34 and between 20:23:21 and 20:34:51	Gyro calibration. Pass 114 has 73% of missing ocean data
226/235	07/12/2014 - 09:13:54 TU (26 minutes and 10 seconds)	Poseidon3/Jason2 special calibration. Only 8.3% of missing measurements over ocean (most of the missing measurements are over land.)
247/227-228		Passes 227 and 228 are partly missing due to telemetry dropouts during pass and ack sent by mistake at ground station. 13.91% of pass 228 is missing (over land only). 80.37% of pass 227 is missing (76.69% over sea).
256/235	23/06/2015 16:44:28 TU (26 minutes and 10 seconds)	Poseidon3/Jason2 special calibration. Only 8.3% of missing measurements over ocean (most of the missing measurements are over land.)
275/235	29/12/2015 02:16:30 TU (26 minutes and 10 seconds)	Poseidon3/Jason2 special calibration. Only 8.3% of missing measurements over ocean (most of the missing measurements are over land.)
285/217-241	05/04/2016 13:35:10 to 06/04/2016 12:02:40	Upload of new GPS On Board software.
287/024	17/04/2016 20:15:50 to 20:39:41	Data dropout at Fairbanks (pass 024 is partly missing)
.../...		

Jason-2 Cycles/Pass	Dates	Events
294/211	03/07/2016 13:26:00 TU (26 minutes and 10 seconds)	Poseidon3/Jason2 special calibration.
295	12/07/2016	AMR cold sky calibration
297/123	29/07/2016	cycle 297 pass 123 has dotted line of missing measurements : 66 points over ocean
301	05/09/2016	AMR cold sky calibration
304/001-305/164	02/10/2016 11:53:32 to 13/10/2016 20:00:00	move to interleaved ground track. Data gap: Poseidon-3 altimeter is put in WAIT mode.
305/164 to 307/094	13/10/2016 to 30/10/2016	missing parts of passes due to calibrations badly located over ocean
307	07/11/2016	AMR cold sky calibration
308/071	08/11/2016 from 23:11:19 to 23:13:48	pass 071 has 5.09% of missing measurements over sea due to telemetry loss
310		there are some non continuous missing points on pass 146 (2.4% over ocean) on 01-12-2016 around 17:32 to 17:35.
312	CAL CNG on 2016-12-25 00:26:00 (26 minutes and 10 seconds)	part of pass 235 is missing due to Poseidon3/Jason2 special calibration. Only 5.0% of missing measurements over ocean (most of the missing measurements are over land.)
314	10/01/2017	AMR cold sky calibration
317		Pass 70 has 3.2% of ocean data missing due to missing TM. There are several discontinuous gaps on a section of the track
318	26/02/2017	AMR cold sky calibration
321/18 + 19 to 254 322/001 to 136 + 137		Abnormal gyros status triggered a SAFE HOLD MODE starting at 2017-03-15 19:19:58 (on cycle 321) and ending on cycle 322 at 2017-03-30 08:47:30.
322/170 + 171	Gyrometers calibration on 31/03/2017 from 15:29:59 UTC to 16:10:27 UTC	Due to gyro calibration, passes 170 and 171 are partially missing with respectiveley 54.83% and 35.45% of missing data (70.86% and 41.20% over sea).
.../...		

Jason-2 Cycles/Pass	Dates	Events
323	CNG Calibration on 13/04/2017 from 02:10:00 to 02:36:10 mainly on land	due to the CNG calibration, 5% of missing data on ocean on pass 235 (north of the Red Sea).
324		10 consecutive points are missing on track 97.
324	26/04/2017	AMR cold sky calibration
327/111 + 112 to 254		Abnormal gyros status triggered a SAFE HOLD MODE starting at 2017-05-17 at 22:26:57. Passes 112 to 254 are missing, and pass 111 has 31.49% of missing data (7.74% over ocean).
500		New numbering after move to LRO. 222 passes only in that cycle: passes 1 to 32 are missing (restart after SHM and move of orbit).
500/038	11/07/2017 from 15:40:41 to 15:47:02	part of pass 038 is missing in Indian Ocean(related to slew before AMR Calibration)
500	CNG Calibration on 11/07/2017 at 13:17:00	(26mn 10s mostly over land)
500	11/07/2017	AMR cold sky calibration
503	13/08/2017	AMR cold sky calibration
	04/09/2017	AMR cold sky calibration
506 (part of 178 + 179 to 254), + 507, +508, 509 (1 to 161 + part of 162)	from 14/09/2017 06:12:04 to 13/10/2017 05:59:12	Safe Hold Mode
511	01/11/2017	AMR cold sky calibration
511	03/11/2017	Software dump from EEPROM
515	14/12/2017	AMR cold sky calibration
517, pass103	28/12/2017 20:41 to 21:07	CNG calibration

.../...

Jason-2 Cycles/Pass	Dates	Events
		approximately 50% of the pass data (in large majority over land) is missing
518	04/01/2018	AMR cold sky calibration
521	02/02/2018	AMR cold sky calibration
522 + 523	20/02/2018 18:40:09 until March 3 at 9 :56 UTC	Safe Hold Mode cycle 522 : approximately 25% points of pass 215 are missing and passes 216-254 are not available cycle 523 : passes 1-214 are not available and approximately 86% of pass 215 is missing
523	02/03/2018	BDR update
526	01/04/2018 between 01 :38 :00 and 2 :04 :10 UTC	CNG calibration 99% of gap over land
528	16/04/2018	AMR cold sky calibration
533	07/06/2018	AMR cold sky calibration
535	26/06/2018 between 07 :14 :59 and 07 :41 :10 UTC	CNG calibration 95% of gap over land.
537	18/07/2018 at 8 :29 :09 UTC	Safe Hold Mode There are only 211 passes. Approximately 75% of pass 211 and all of passes 212 onward are missing
		orbit change
600	Orbit transfer from LRO to interleaved LRO.	Passes 1 to 175 are missing. Passes 176 onwards are available.
600, pass 245	28/07/2018 01 :11 :31 UTC	AMR cold sky calibration
603, pass 025	18/08/2018 02 :19 UTC	AMR cold sky calibration
606, pass 151	21/09/2018 14 :00 UTC for 26min 10s	CNG calibration

.../...

Jason-2 Cycles/Pass	Dates	Events
		99% of the gap occurs over land.
607, pass 088	28/09/2018 at 23 :58 UTC	AMR cold sky calibration
609, pass 046	17/10/2018 at 02 :22 UTC	AMR cold sky calibration
609 + 610	18/10/2018 11 :41 :34 UTC	Safe Hold Mode cycle 609 passes 82 onwards are not available. cycle 610, passes 1-6 are missing.
613, pass 157	29/11/2018 at 20 :57 UTC	AMR cold sky calibration
615, pass 187	20/12/2018 at 18 :33 UTC	AMR cold sky calibration
616 + 617	26/12/2018 at approximately 01 :30 UTC	Safe Hold Mode cycle 616 passes 70 onwards are not available. cycle 617, passes 1-133 are missing.
618, pass 144	17/01/2019 at 15 :56 UTC	AMR cold sky calibration
620, pass 182	07/02/2019 at 21 :08 UTC	AMR cold sky calibration
621 to 631	16/02/2019 at approximately 14 :56 UTC to 25/05/2019	Safe Hold Mode Cycle 621, passes 152 onwards are not available. Hiberation period. Cycle 631, passes 1-55 are missing
631, pass 166	26/05/2019 at approximately 18 :33 UTC	AMR cold sky calibration. The 383-second gap occurred over the Indian Ocean. Approximately 22% of ocean data are missing
633, pass 118	13/06/2019 at approximately 15 :15 UTC	AMR cold sky calibration. The 383-second gap occurred over the Indian Ocean. Approximately 32.4% of ocean data are missing
635, pass 061	01/07/2019 at 03 :30 UTC for 26min 11s	CNG calibration
.../...		

Jason-2 Cycles/Pass	Dates	Events
636, pass 067	11/07/2019 05 :44 :47 (UTC) to 05 :52 :03	AMR cold sky calibration
638, pass 121	02/08/2019 01 :32 :39 (UTC) to 01 :39 :55	AMR cold sky calibration
642, pass230	14/09/2019 18 :01 :35 (UTC) to 18 :08 :51	AMR cold sky calibration
644	28/09/2019	AMR cold sky calibration
644	01/10/2019 06:48:00	**end of Jason-2 mission**

Table 5 – Missing pass status

3.2. Edited measurements

The more of 11 years of Jason-2 data show excellent quality, with a very good level of valid points over ocean, round 87% (only 13% of ocean measurements are discarded over the 4 phases of the mission, see Figure 8). An annual signal due to ice coverage cycle is visible (about 9% of rejected data in average). Out of these rejected points, the editing process removes between 3% and 4% of data when no anomaly. This level is consistent for Jason-2 over each period (historical ground track, interleaved, then LRO and i-LRO).
For more details, all the results on the GDR data quality analysis (available only over cycles 001 to 506, i.e. until September 2017) can be found on the last CalVal mission performances over ocean yearly report [7].

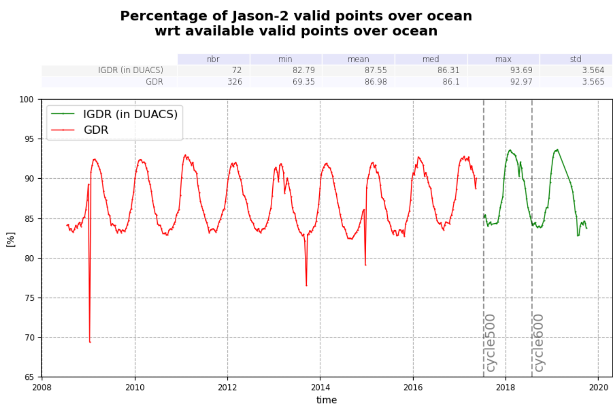


Figure 8 – Percentage of Jason-2 valid points over ocean (with reference to available points). Note that GDR data are used over repetitive period, from cycle 001 to 327 (red) and IGDR over LRO and iLRO from cycles 500 to 644 (green)

4. SSH crossover analysis

4.1. Overview

SSH crossover differences are the main tool to analyze 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 data set 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-2 and Jason-1 are defined below.

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

with $Jason-1/Jason-2\ Orbit = CNES\ orbit$ for GDR products, and

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

In 2016, Jason-1 GDR were available in version E. In order to allow better comparisons between Jason-1 and Jason-2, some standards of Jason-2 were updated (only when comparisons are done with Jason-1 GDR-E).

Note that from 7th of May 2012 (Jason-1 cycle 500, which corresponds to end of Jason-2 cycle 141) and until the end of the Jason-1 mission (21st of June 2013, during Jason-2 cycle 183), Jason-1 was on a geodetic ground-track.
If no precision is done, in case of IGDR results, DUACS updates are applied (ocean tide correction, mean sea surface model, mog2d dynamical atmospheric correction, see [22])

4.2. Mean of SSH crossover differences

The average cycle by cycle mean of SSH differences is around -0.1 cm (see figure 9) for Jason-2 GDR and Jason-1 GDR. It reaches -0.7 cm in case of mean SSH differences at crossovers for Jason-2 IGDR dataset (using MOE orbits, and DUACS updates for some corrections), with noticeable negative values, as can be seen on left of figure 9. In addition, the IGDR (updated with DUACS standards) data monitoring shows a 120 day signal that is reduced in case of GDR. This signal is particularly visible after move to standard D at cycle 150 for IGDR (orbite solution from POE-C to POE-D). The difference of behaviour for IGDR and GDR is partly explained by the way the solar radiation pressure is taken into account in orbit solution computation (different for MOE and POE). Thanks to the orbit standard E (an identical modeling of solar radiation pressure is planned for MOE and POE) applied from cycle 254 onwards, the 120 day signal on IGDR is slightly reduced. In addition, even the remaining 120 day signal on GDR is reduced with POE-E. Note that the choice of ocean tide solution used to compute sea surface height impacts the amplitude of the observed 120 days signal (see figure 10, the last Jason-2 CalVal mission performances over ocean yearly report [7] for more details, and a more thorough investigation detailed in Jason-3 2017 annual report [9]). This correction is set to GOT4.8 for the whole GDRs reference ssha, but DUACS system have updated IGDR ssha with FES model from the CMEMS-v2 version, implemented on April 13th 2016 (mid Jason-2 cycle 286), onwards. For Jason-2 compared to Jason-1 (using standards from Jason-1 GDR-E products), the curves do not highlight any anomaly. However, a higher 120 day signal is visible for Jason-1 data.

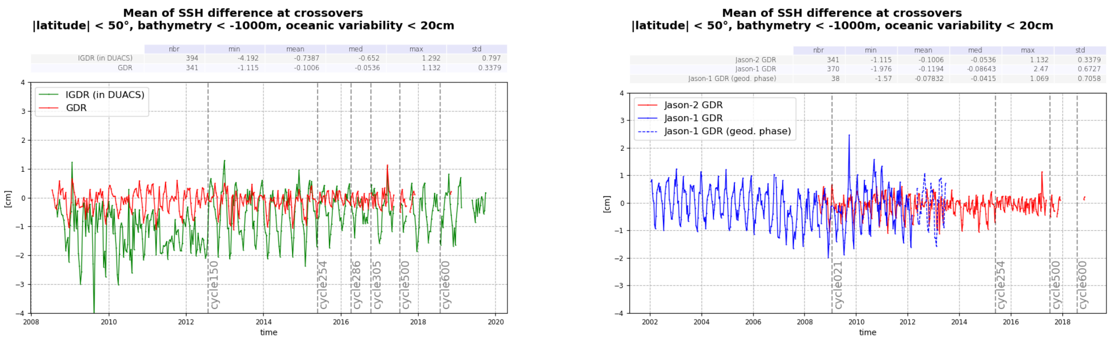


*Figure 9 – Monitoring of mean of SSH differences at crossover points for Jason-2 GDR and IGDR (including DUACS updates) (**left**), and Jason-2 GDR wrt Jason-1 GDR (**right**).*

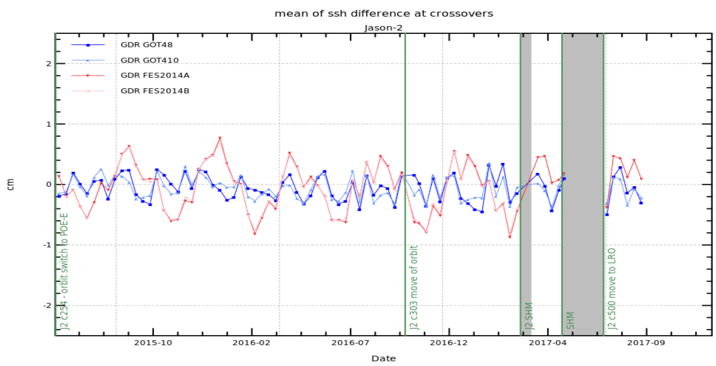


Figure 10 – Mean of SSH crossovers differences for Jason-2 against ocean tide solution used to compute SSH.

The map of mean SSH crossover differences plotted figure 11 was calculated using Jason-2 GDR products, no strong geographically correlated patterns are detected. Nevertheless, there is a slight geographically correlated pattern on the map with GDR-D orbit solution (POE-D until cycle 253 and POE-E from cycle 254 onwards). This pattern disappears using only the final POE-E solution (see details about POE-E in [6], [5] and [11]). This pattern might be related to the 120 day signal, as it disappears in the same time as the 120 day signal is reduced in the periodogram of the final POE-E solution (not shown here).

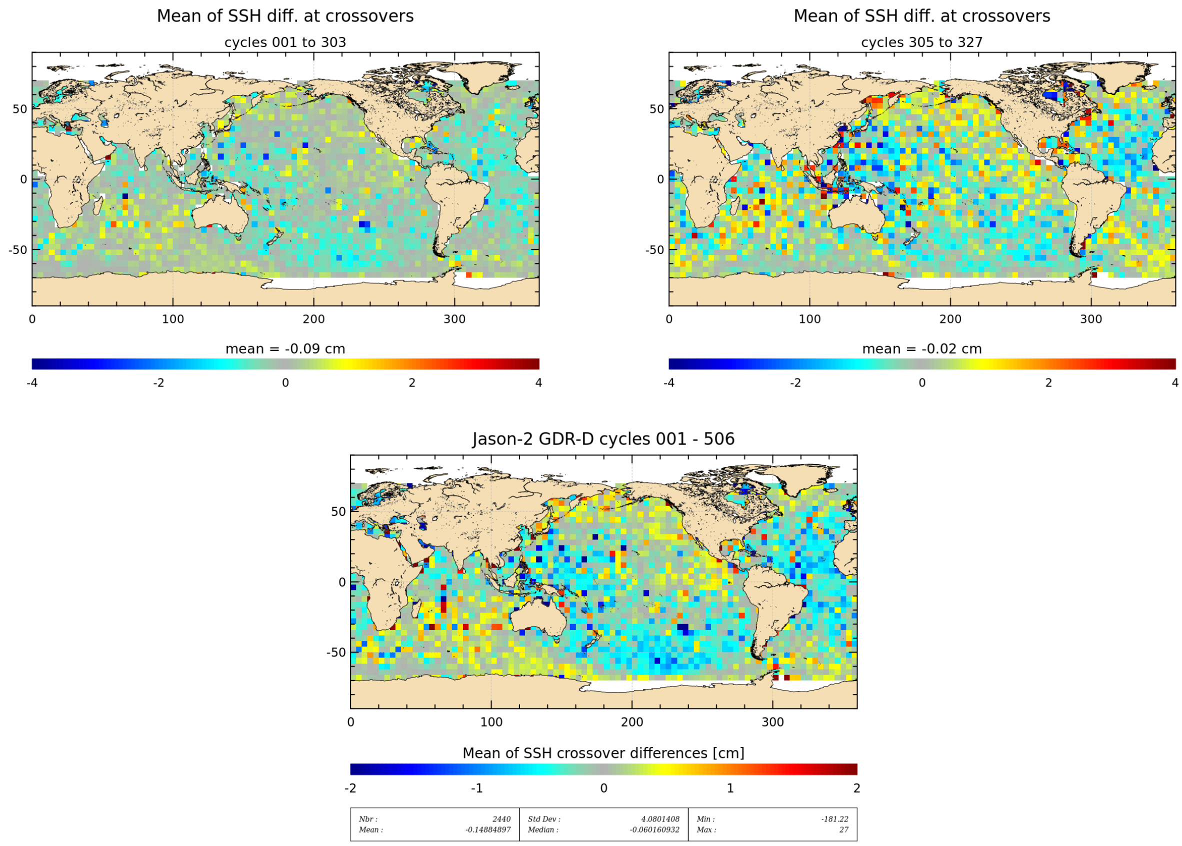


Figure 11 – Bottom: Map of mean of SSH crossovers differences for Jason-2 cycle 1 to 506. Note that for cycles 1 to 253, GDR orbit is POE-D. GDR have been available with orbit POE-E since cycle 254. Left: Map of mean of SSH crossovers differences for Jason-2 cycle 1 to 303. Right: Map of mean of SSH crossovers differences for Jason-2 cycle 305 to 327 (less than a year)

4.3. Error deduced from SSH crossover differences standard deviation

The cycle by cycle error deduced from SSH difference at crossovers are plotted for Jason-2 and Jason-1 in figure 12 after applying geographical criteria (bathymetry, latitude, oceanic variability) as defined previously (chapter 4.1.). Both missions show very good performances, very similar and stable in time. No anomaly is detected. The average figure is 3.51 cm for Jason-1, and 3.48 cm for Jason-2 data (right of figure 12). Keeping in mind that during the Jason-1/TOPEX tandem phase in 2002, the same statistic using Jason-1 GDR-A products was close to 4.35 cm (see [17]), this illustrates the improvements performed in the altimetry ground processing since the Jason-1 launch especially thanks to new retracking algorithms, new geophysical corrections (oceanic tidal, dynamic atmospheric correction, ...) and new orbit calculations. Jason-2 show very good performances and GDR show the same performance on LRO and iLRO as on previous orbit.

When comparing the performances of the different Jason-2 data types (IGDR, GDR), the improvement involved with the update of standard is particularly visible at cycle 150 on green curve (IGDR standard move from 'C' to 'D'). Error is slightly reduced from IGDR to GDR datasets, as expected (left of figure 12), mainly thanks to POE orbit solution instead of MOE.

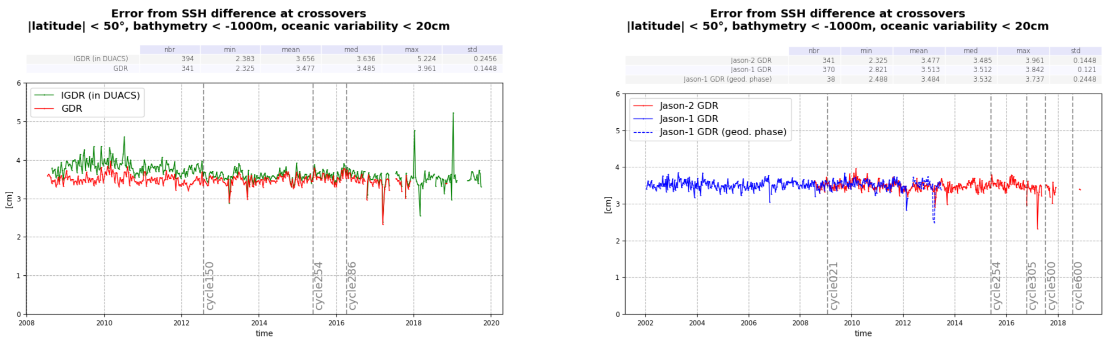


Figure 12 – Monitoring of error from SSH differences at crossover points for Jason-2 GDR and IGDR (including DUACS updates) ***(left)****, and Jason-2 GDR wrt Jason-1 GDR* ***(right)****.*

4.4. 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 velocity: $SSH = \alpha \dot{H}$
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-1 and Jason-2 in figure 13. Both curves are very similar highlighting a 59-day signal with almost no bias (close to -0.01 ms for Jason-1 and -0.02 ms for Jason-2).
Before the Jason-2 reprocessing the GDR-T showed a bias of -0.29 ms (still visible on IGDR monitoring before cycle 150). The origin of constant part of the pseudo time tag bias was found by CNES [13] and so corrected in the Jason-2 GDR-D and Jason-1 GDR-E product (see also the Jason-2 [1] and Jason-1 [12] handbooks). The 59 day-signal is reduced for Jason-1 pseudo-datation bias thanks to the use of GOT4.10 ocean tide solution (see [2] and [6]).

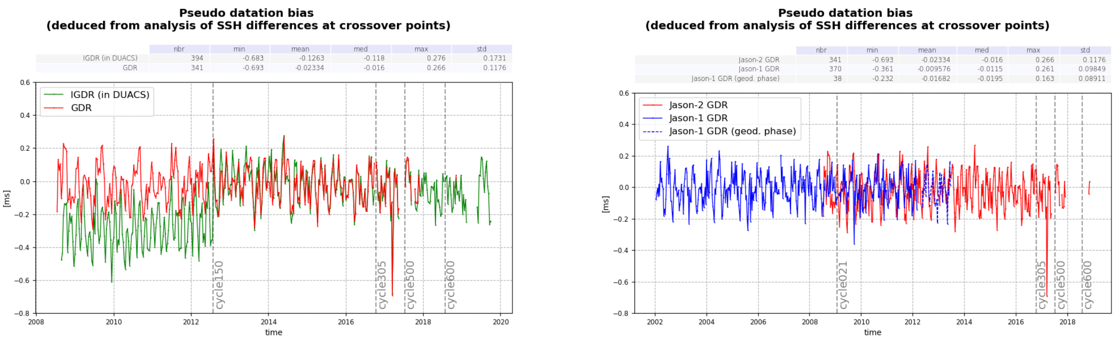


*Figure 13 – Monitoring of pseudo time-tag bias estimated cycle by cycle from GDR products for Jason-2 GDR andIGDR (including DUACS updates) (**left**), and Jason-2 GDR wrt Jason-1 GDR (**right**).*

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

5.1. Overview

The Sea Level Anomalies (SLA) are computed along track from the SSH minus the mean sea surface with the SSH calculated as defined in previous section 4.1. : $SLA = SSH - MSS$

SLA analysis is an additional 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-2/Jason-1 tandem phase (cycles 1 to 20), we performed direct SLA comparisons between both missions during this period. Corrections applied in SSH calculation are theoretically the same for Jason-1 and Jason-2 since both satellites measure the same ocean. Thus, it is possible to not apply them in order to obtain directly information on the altimeter range and the orbit calculation differences. However, as the stability of both ground passes is not exact (the ground track is maintained within a window of $\pm$ 1 km across-track distance from the theoretical ground track), SLA measurements have to be projected and interpolated over the Jason/TOPEX theoretical ground pass after applying the MSS in order to take into account cross-track effects on SSH.

$$\Delta SLA_{J1-J2} = [(Range_{Ku} - Orbite - MSS)_{J1}]_{\bar{T}} - [(Range_{Ku} - Orbite - MSS)_{J2}]_{\bar{T}}$$

This allows us also to select the intersection of both datasets and compare exactly the same data. After Jason-1 ground track change to its interleaved ground track, direct SLA comparisons are no more possible. Thus, global statistics computed cycle by cycle are just basically compared.

Note that for better comparison with Jason-1, Jason-2 GDR-D are updated using Jason-1 GDR-E standards (POE-E orbit, Got4.10 ocean tide, MSS_CNES_CLS_2011 (with reference period of 20 years), Tran2012 sea state bias, and recomputed ionosphere correction (using Tran2012 ssb)).

5.2. Mean of SLA differences between Jason-2 and Jason-1

The cycle by cycle monitoring of mean SLA differences between Jason-1 data and Jason-2 is plotted in figure 14 over all their common period. During the tandem phase, the 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 bias. The global average SSH bias is close to 0.9 cm without corrections, which represents the difference between the two systems. This difference is -0.2 cm using SSH corrections and -0.3 cm when using ECMWF instead of radiometer wet troposphere correction. 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. When Jason-1 was moved to a geodetic ground track, a small jump is visible on Jason-1 minus Jason-2 difference. In addition, a small drift remains after Jason-1 safe hold mode in March 2013 (Jason-2 cycles 171 to 173, black dots at the end of the curve): it seems to be related to radiometer wet troposphere solution as it is not visible using model wet troposphere correction (green dots) (see [2] for more details).

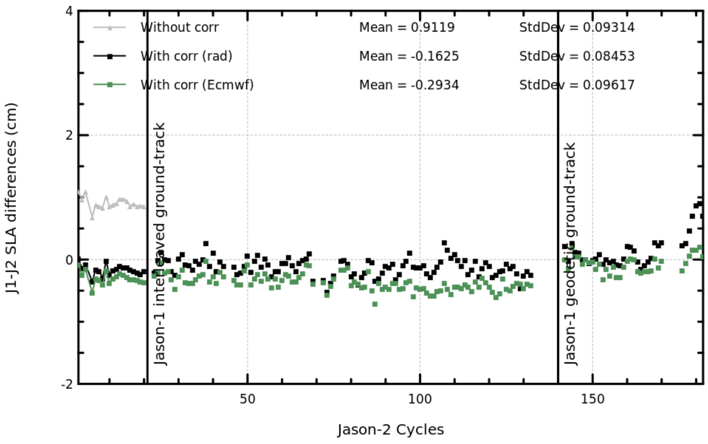


Figure 14 – Cycle by cycle monitoring of SSH bias between Jason-1 and Jason-2 before and after Jason-1 ground-track change (black curve and dots) and SSH bias without applying corrections in SSH calculation for both missions only during the tandem phase (gray curve).

Figure 15 shows the mean differences between Jason-1 and Jason-2 during tandem phase (cycles 1 to 20). In order to obtain directly information on the altimeter range and the orbit calculation differences, spatial uncorrected SLA (orbit - range - MSS) differences (only during the Jason-1/Jason-2 tandem phase) between both missions is plotted in top right side of figure 15. It shows a weak hemispheric bias lower than 1 cm. These differences are in relationship with orbit calculation differences. Though for both satellites POE-E was used, there are some differences between Jason-1 POE-E and Jason-2 POE-E, for Jason-1 orbit computation the GPS data are no longer available, whereas they are used for the Jason-2 POE computation. Jason-2 POE is therefore based on two orbit determination techniques (Doris and GPS, Laser is used for validation), whereas Jason-1 POE (over the Jason-2 period) is based on two orbit determination techniques (Doris and Laser). When using GSFC std 0905 orbits for both satellites (bottom of figure 15) the hemispheric bias disappears (the same result has been found using GSFC std 1204 orbit solution, but it is not shown here). When considering corrected SLA, Jason-1 and Jason-2 SLA are quite homogeneous thanks to the update of sea state bias with the OSTST 2012 solution for both satellites (top left of figure 15), and except the change in global bias, only orbit minus range minus mss differences patterns remind.

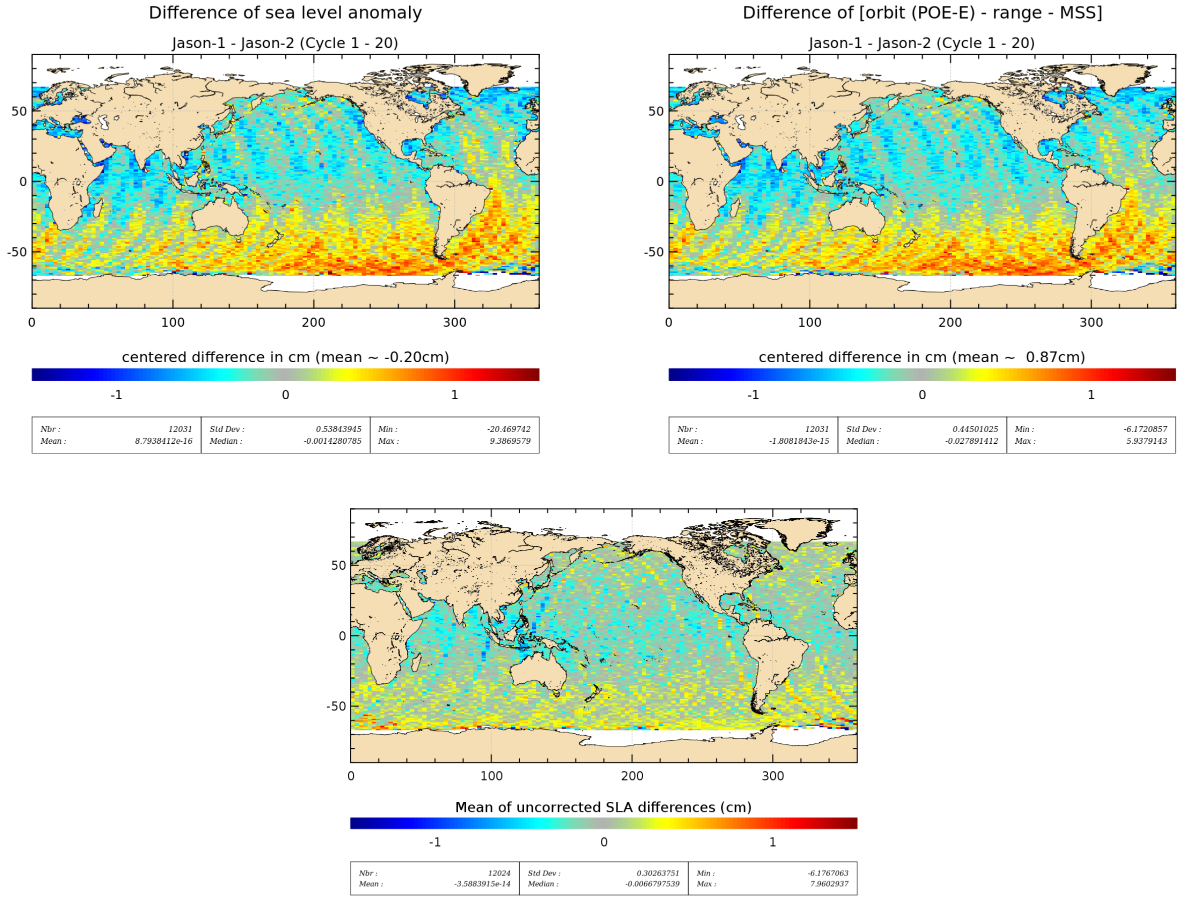


*Figure 15 – **Top left:** Maps of SLA (orbit (POE-E) - range - geophysical corrections - MSS 2011 (ref20)) mean differences between Jason-1 and Jason-2 during tandem phase (cycles 1 to 20), using Jason-2 updated GDR-D and Jason-1 GDR-E (the map is centered around the mean of 0.2 cm).**Top right:** without applying geophysical corrections. **Bottom:** using GSFC09 orbits without applying geophysical corrections*

5.3. Standard deviation of along-track SLA

Over the repetitive period, standard deviation of along-track GDR for Jason-2 is 10.9 cm. Note that on figure 16, some updates are done compared to IGDR L2 products, in particular a 20years reference is used for MSS since mid-2012 (see [22]), so that IGDR-L2P SLA standard deviation (green curve) is lower than the GDR values (red curve) from this update to end of mission. 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 [18] for more details about the change on reference period).

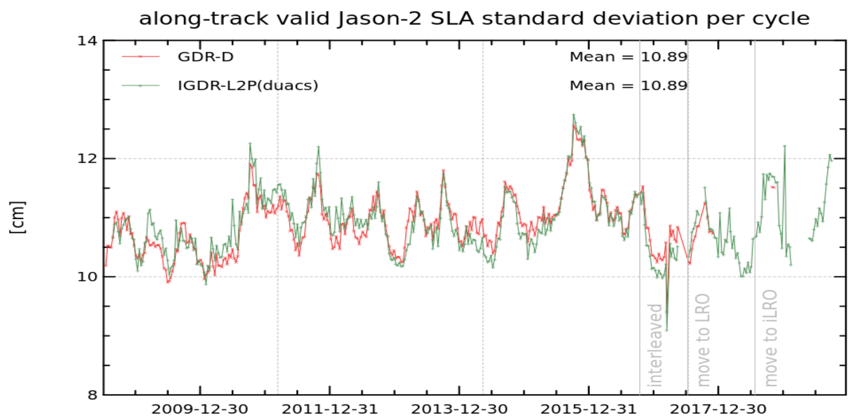


Figure 16 – Cycle by cycle monitoring of SLA standard deviation for Jason-2 GDR or IGDR used in DUACS system (note that some updates are done compared to IGDR L2 products).

To improve the Sea Surface Height Anomaly (SSHA) data quality in the Jason-2 LRO data products, an updated Mean Sea Surface (MSS) model has been adopted. The new MSS model is the CNES/CLS MSS 2015 solution [21], which is referenced to the 20-year period spanning 1993-2012 (see 2.4.). The MSS model provided until cycle 327 was the 2011 solution, referenced to the 7-year period spanning 1993-1999 and has a lower quality on LRO ground track: the choice of MSS solution impacts the error that is seen between 50 km and 600 km out of historical ground track (see dedicated to MSS part in GDR-E Jason-1 reprocessing report [2]).
The monitoring of SLA standard deviation has been computed for both missions (plotted in figure 17). As concerned Jason-1, the blue curve is drawn using the standards that are in the GDR-E products (contain the MSS CNES/CLS 2011 referenced over 20years), whereas GDR-D standards are used to Jason-2 (red curve has been computed using the MSS CNES/CLS 2011 referenced over 7years and purple curve and green curve have been computed using respectively the MSS CNES/CLS 2011 and MSS CNES/CLS 2015 both referenced over 20years).

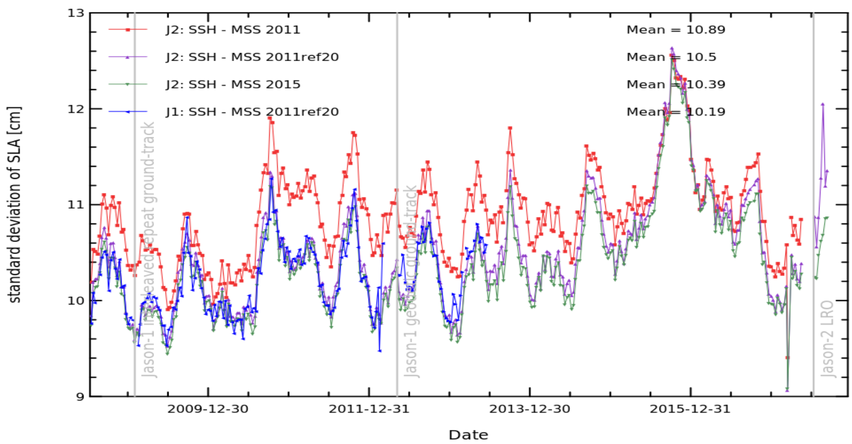


Figure 17 – Cycle by cycle monitoring of SLA standard deviation for Jason-1 and Jason-2 (using different MSS solutions)

6. Conclusion

Jason-2 provided sea level measurements from 4th of July, 2008 until 1st of October, 2019. **The more of 11 years of Jason-2 data show excellent quality during Jason-2 flight on historical ground track, on interleaved ground track, and even after move to drifting orbits (LRO and i-LRO)**

Scientific studies and operational applications therefore benefit from the combination of altimeter data from several missions. The 2012 reprocessing of the whole mission in GDR-D standard has improved the dataset in comparison to the GDR-T standard for meso-scales, as well as on longer time scales (consistency between ascending and descending passes is improved).

The main points of this performance assessment are summarized below:

- Jason-2 provides an excellent coverage of the ocean, with more than 99% of measurements available over ocean, out of SHM or planned events.
- Data quality is excellent, with only 3.3% of edited measurements (after remove of land and ice flagged points).
- Standard deviation of daily SLA average differences is about 10.4 to 10.9 cm against MSS solution that is used,
- At crossovers Jason-2 shows a standard deviation of 4.9 cm.

All these metrics confirm the excellent data quality of the Jason-2 mission.

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