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Acronyms

AMR	Advanced Microwave Radiometer
CLS	Collecte Localisation Satellites
CMEMS	Copernicus Marine Service
CNES	Centre National d'Etudes Spatiales
DUACS	Data Unification and Altimeter Combination System
DV	Default Value
ECMWF	European Centre for Medium-range Weather Forecasting
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
ESA	European Space Agency
GIM	Global Ionosphere Maps
GDR	Geophysical Data Record
GMSL	Global Mean Sea Level
HR	High Resolution Mode, also called Synthetic Aperture Radar (SAR) or Delay Doppler Altimetry (DDA)
HRMR	High Resolution Microwave Radiometer
LR	Low Resolution Mode (=LRM)
LUT	Look-Up Table
MLE	Maximum Likelihood Estimator
MQE	Mean Quadratic Error
MSS	Mean Sea Surface
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NTC	Non Time Critical
PB	Processing Baseline
RMC	Range Migration Correction
SSH	Sea Surface Height
SSHA	Sea Surface Height Anomaly(=SLA)
SLA	Sea Level Anomaly(=SSHA)
SSB	Sea State Bias
STD	Standard Deviation
SWH	Significant Wave Height
WTC	Wet troposphere Correction

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1 Introduction

Sentinel-6 is a collaborative Copernicus mission, implemented and co-funded by the European Commission, ESA, EUMETSAT, and the USA through NASA and NOAA.

EUMETSAT is responsible for Sentinel-6 operations as part of the Copernicus component of the EU Space Program. The Sentinel-6 Quality Assessment reports are generated by CNES as per the EUMETSAT–CNES agreement in the context of Copernicus.

Since the launch of the Sentinel-6 MF satellite on 21 November 2020, the PDAP Processing Baseline (PB) has been updated several times following satellite commissioning activities. This document presents a synthesis report describing the validation activities performed for the 2025 Sentinel-6 MF PDAP reprocessing using PB G01. Sentinel-6 MF NTC products have been reprocessed using PB G01 up to cycle 163 track 230. PB G01 was also used to generate operational data starting from cycle 160 track 1.

The present global report covers the complete reprocessed period of the Sentinel-6 MF mission, thanks to comparisons with the operational dataset. The analysis is performed over the ocean and uses 1 Hz data.

This report is split into eight main sections after this introduction and an executive summary, which presents the key elements of the reprocessing campaign:

- First, the **data used** are presented.
- The **data coverage** and measurement validity issues are then described.
- The impact of **model updates** is assessed.
- A synthesis of the **geophysical parameters derived from the altimeter and radiometer** is presented.
- The impact of the reprocessing on **mission performance** is evaluated.
- The analysis of the differences between Jason-3 and Sentinel-6 MF over the first **tandem phase**,
- The impact of the reprocessing on the **GMSL**,
- Compliance with **system requirements**.

2 Executive Summary

Data Analyzed

The assessment covers the complete Sentinel-6 Michael Freilich reprocessed dataset generated with Processing Baseline G01 (PB G01). The analyzed period extends from **17 December 2020 to 10 April 2025**, corresponding to **cycle 4 pass 13 to cycle 163 pass 230**.

Both altimeter acquisition modes are considered:

- **Low Resolution (LR)** mode using the MLE4 and Numerical Retracker (NR),
- **High Resolution (HR)** mode using the SAMOSA and NR retrackers.

The analysis is performed over the global ocean using 1 Hz data. The Processing Baseline G01 used for this reprocessing brought major improvements:

- The update from GDR-F to GDR-G standards on MDT, MSS, ocean and load tide models, as well as from POE-F to POE-G on the orbital solution.
- LUT updates for LR MLE4 retracker in Ku-band and MLE3 retracker in C-band computed to align LR MLE4 values on LR NR.
- The application of the vertical wave motion correction at 20Hz on both SAMOSA and HR NR.

Data Availability

Data availability is excellent, both globally and over ocean. Figure 1 illustrates the percentage of missing measurements, with availabilities of 99.73% in LR and 98.93% in HR in the reprocessed datasets.

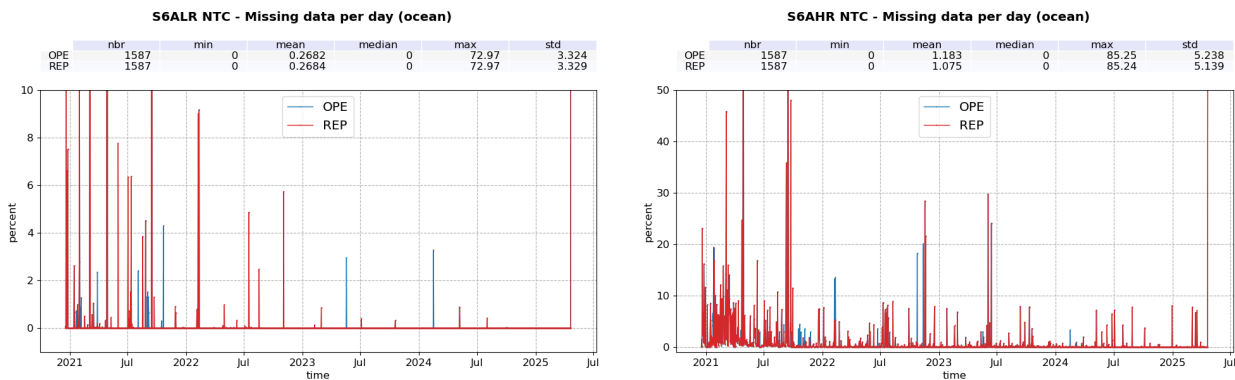


Figure 1: Percentage of ocean-only missing data for the operational and reprocessed datasets for LR (left) and HR (right)

Compared to the operational datasets, the reprocessing recovers several complete passes (two in LR and eight in HR) without introducing any new entirely missing tracks. Although minor data losses are observed on a limited number of passes, these have been clearly identified as production anomalies to be corrected in a future reprocessing campaign.

Data Validity

The validity of measurements is assessed through the monitoring of edited (invalidated) data based on land/ice masking, threshold criteria and along-track SSHA consistency. The daily percentage of invalid

measurements over the ocean is shown in Figure 2.

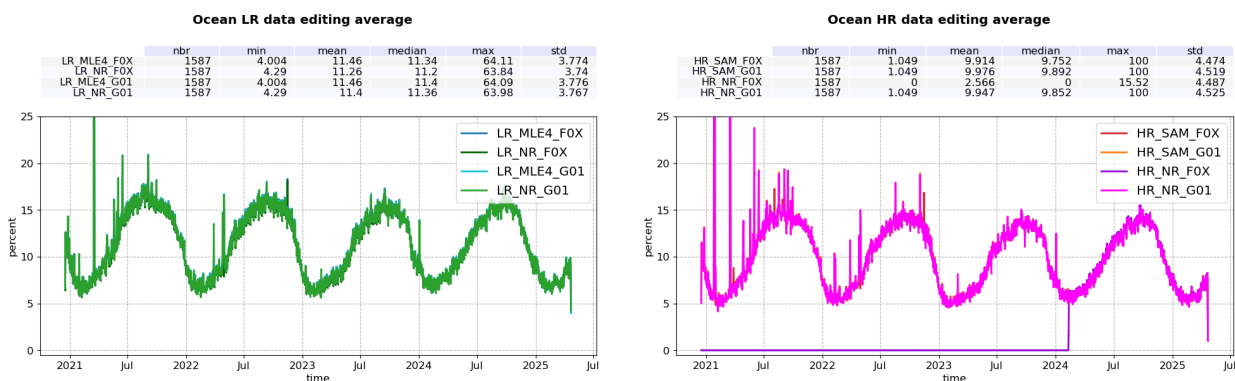


Figure 2: Percentage of invalid measurements for the operational (blue) and reprocessed (red for MLE4 and SAMOSA, green for NR) datasets over the ocean by day in LR (left) and HR (right).

Over the full time series, the proportion of edited data remains very stable and highly consistent between operational and reprocessed datasets:

- **LR**: about 11.5% for MLE4 and 11.4% for NR,
- **HB**: about 10.0% for SAMOSA and 9.9% for NR.

No long-term drift or systematic degradation of validity is associated with the G01 reprocessing. The few transient peaks visible in Figure 2 are linked to well-identified events (e.g. AMR-C calibration periods or temporary data losses) and are common to both operational and reprocessed datasets.

Altimeter Parameters

The monitoring of SWH, range, backscatter and wind speed demonstrates an overall improvement in internal consistency, in particular between retracker (figure 3). Notably, thanks to the new LUT, MLE4 is now aligned to LR NR retracker. However, a wave dependence persists in the range difference between LR and HR modes (figure 4) : about 2 cm between 1 and 7 m between NR retracker and about 4 cm between SAMOSA and MLE4.

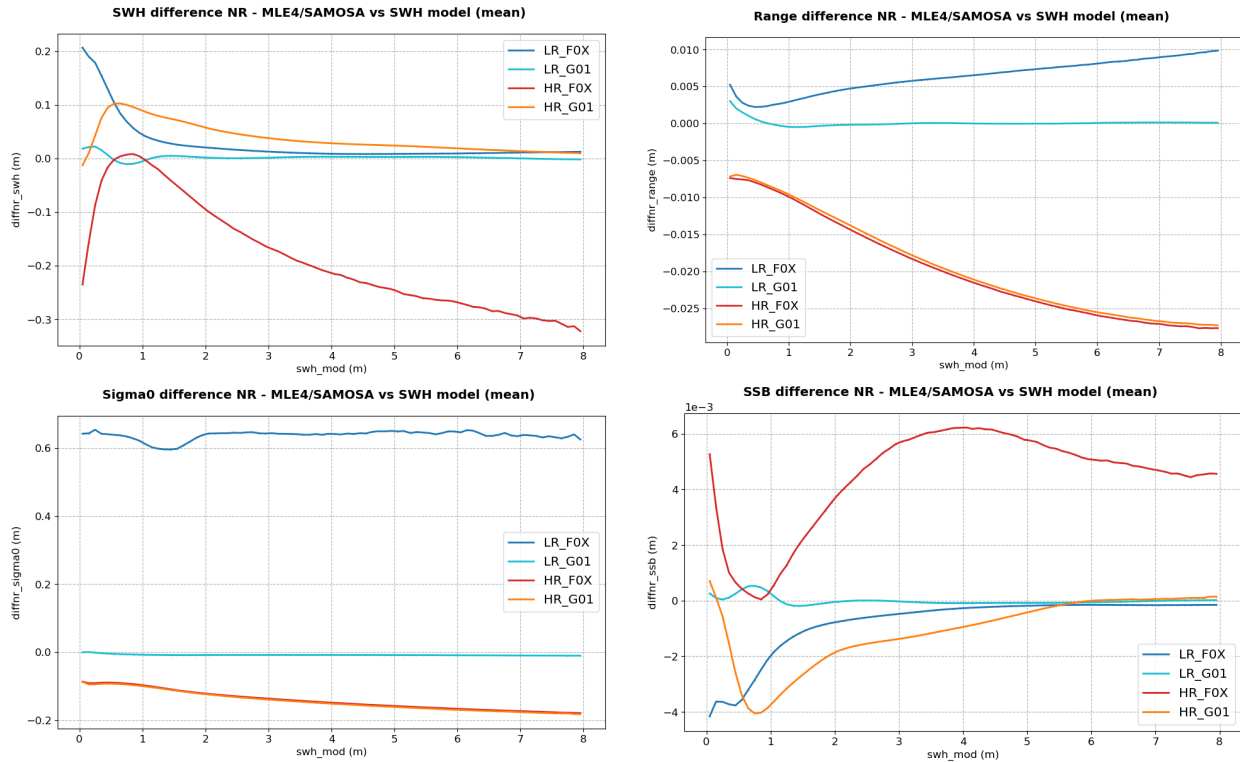


Figure 3: ERA5 model SWH dependency (right) of Sentinel-6 MF NR - MLE4/MLE4 differences: SWH (top left), range (top right), sigma0 (bottom left) and SSB (bottom right).

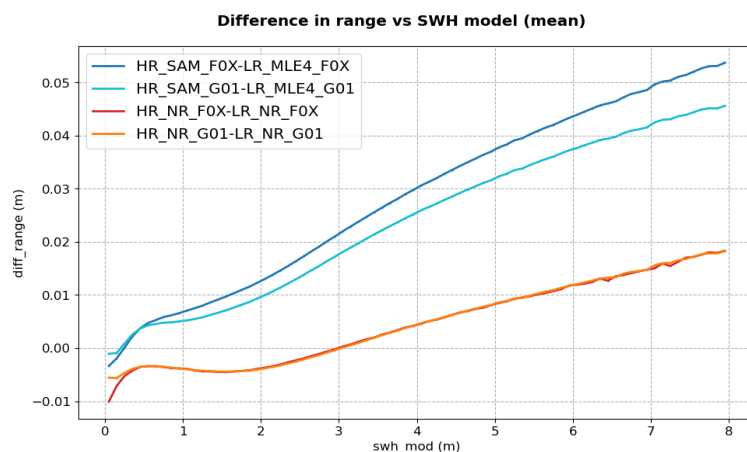


Figure 4: Sentinel-6 MF range differences HR minus LR as a function of ERA 5 model SWH

The application of the Vertical Wave Motion correction at 20 Hz in HR products leads to a clear reduction of HR SWH noise, while LR performance remains unchanged (figure 5).

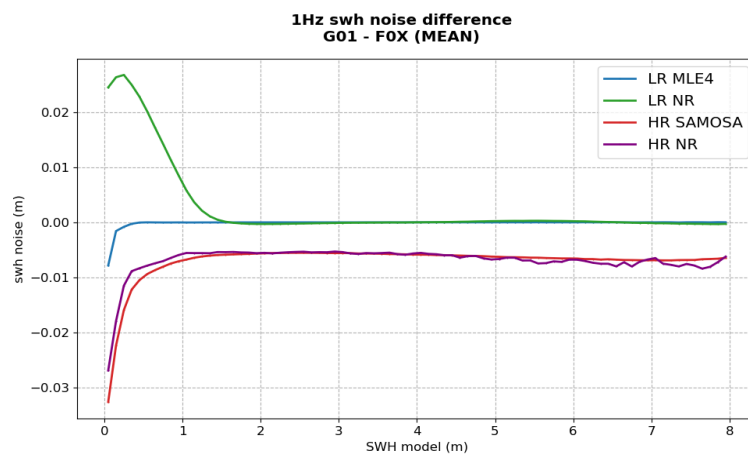


Figure 5: 1Hz SWH noise reprocessed minus operational difference as a function of ERA 5 model SWH

Sea Level Performance

Differences between operational and reprocessed Sea Surface Height Anomaly (SSHA) are small (a few millimetres in mean) and mainly driven by known changes in orbit, range and geophysical corrections.

Crossover analyses show a systematic reduction of the standard deviation of SSH differences by about 0.1–0.2 cm, and the disappearance of spurious 120-day oscillations thanks to the POE-G orbit solution (figure 6).

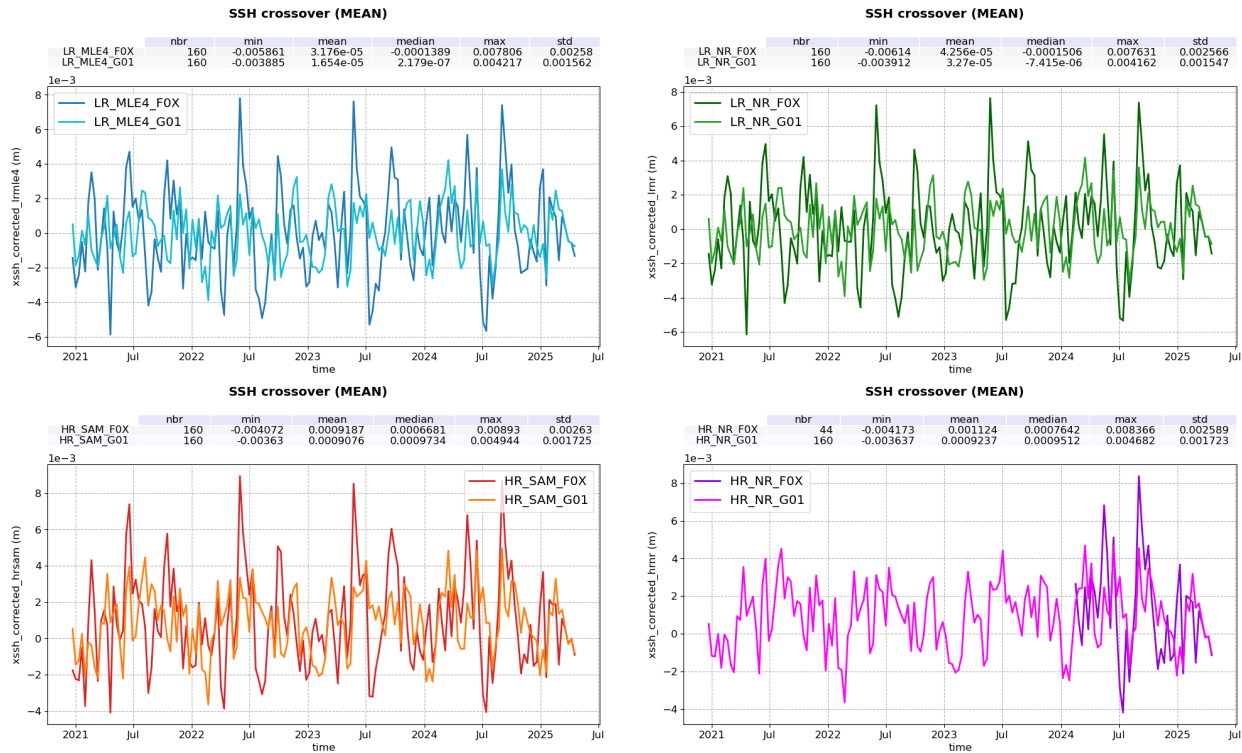


Figure 6: Monitoring of the mean SSH crossover difference per cycle (in meters). Top left: LR MLE4. Top right: LR NR. Bottom left: HR SAMOSA. Bottom right: HR NR.

Tandem Phase with Jason-3 and GMSL

During the tandem phase, Sentinel-6 MF and Jason-3 products exhibit excellent consistency (figure 7). Biases on key parameters involved in SSHA computation are reduced with the reprocessing, and no degradation of inter-mission continuity is observed.

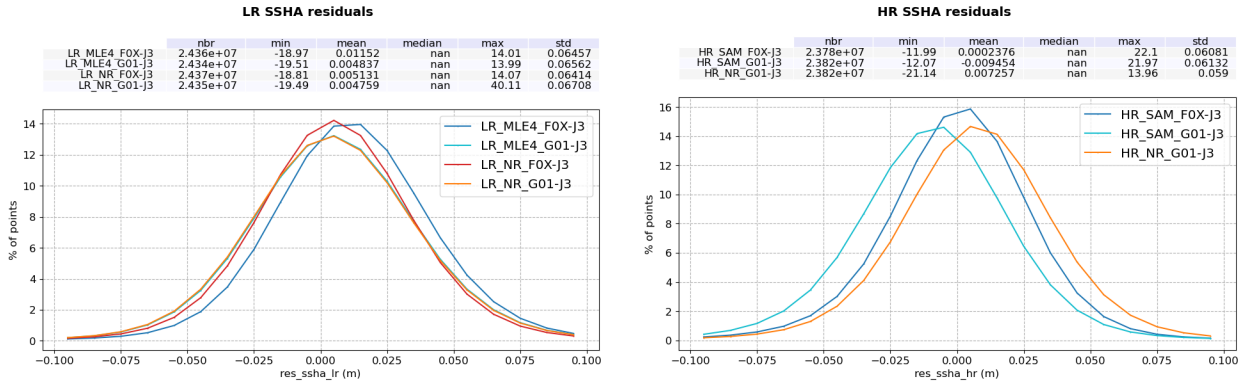


Figure 7: Histogram of product SSHA difference: Sentinel-6 MF minus Jason-3 for LR (left) and HR (right). Computed over the complete tandem period.

GMSL time series derived from Sentinel-6 MF are stable on both Side A and Side B, with offsets and uncertainties fully compatible with the previous Jason-3 reference (figure 8).

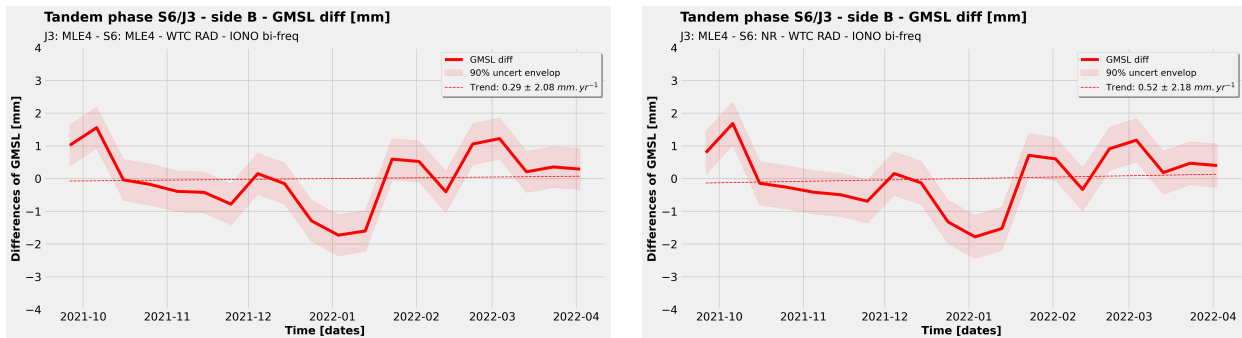


Figure 8: Time series of GMSL difference between Jason-3 and Sentinel-6 MF over the side B tandem phase for Sentinel-6 MF LR MLE4 (left) and LR MLE4 (right).

Overall Conclusion

The Sentinel-6 MF G01 reprocessing successfully improves data availability, maintains very high measurement validity and enhances internal and inter-mission consistency. All key mission performance indicators meet the system requirements, and the continuity of the long-term sea level record is preserved. The G01 reprocessed dataset is therefore validated and recommended as a robust reference for operational oceanography and climate applications.

3 Data used and processing

3.1. Sentinel-6 MF G01 reprocessed data

Sentinel-6 MF data have been reprocessed with Processing Baseline G01 (PB) for Non-Time Critical (NTC) timeliness, for both LR (Low Resolution) and HR (High Resolution) modes.

The main change introduced in this new G01 baseline is the **switch from GDR-F to GDR-G standards**. This update affects the orbit solution and uses improved geophysical corrections, as shown in Table 1.

Standard	GDR-F	GDR-G
Orbit	POE-F	POE-G
Ocean/load tide	FES-14	FES-22
MSS sol 1	CNES-CLS15	Hybrid CNES-CLS2023/Scripps/DTU
MSS sol 2	DTU2018	DTU2021
MDT	CNES-CLS MDT 2018	CNES-CLS MDT 2022

Table 1: Summary of the GDR-F to GDR-G standard update

Other changes in PB G01 include:

- LUT updates for Ku-band MLE4 and C-band MLE3 : alignment on LR NR values.
- Vertical Wave Motion (VWM) correction applied at 20 Hz in HR for both NR and SAMOSA retrackers.
- Addition of C-band complex echoes to L1A ALT products.
- Removal of MLE3 from Ku-band variables.
- Modification of the definition of ocean tide, which now directly includes the non-equilibrium tide. The definition of the SSHA field has also been updated accordingly.
- Use of ERA5 DAC up to July 2023.
- Correction of the geoid model.

A detailed description of the products can be found in the Sentinel-6 MF user handbook [2] and in the product notice [4].

The reprocessed dataset spans from 2020-12-17 21:21 to 2025-04-10 23:41, corresponding to the period from cycle 4 track 13 to cycle 163 track 230. Please note that PB G01 was deployed on 2024-03-13 06:16 (cycle 160 track 1), leading to an overlap between reprocessed and operational G01 data.

The analysis is performed over the ocean using 1 Hz data. All “ocean” retrackers were used: MLE4 and NR for LR mode, and SAMOSA and NR for HR mode.

In the following assessment, the reprocessed dataset is referred to as “REP” or “G01” in the figures.

3.2. Sentinel-6 MF operational data used for comparison

From 2020-12-17 at 22:17 (cycle 4 pass 14) to 2024-02-10 (cycle 120 pass 1), Sentinel-6 MF data were processed with PB F08. No data processed with a baseline earlier than F08 are present in this study thanks to the 2023 F08 reprocessing campaign [7]. On 2023-10-05 (cycle 107 pass 8), a patched version of PB F08 (PB F08p) was deployed to correct an anomaly affecting small SWH values for LR NR retracker (AR 2620).

From 2024-02-10 to 2024-03-13 (cycle 160 track 1), data were processed with PB F09.

The main change in the F09 baseline is the **addition of numerical retracker (NR) retrievals in HR products**. Numerical retracker accounts for PTR shape evolution through the use of in-flight PTRs. This new set of parameters does not replace but complements SAMOSA-derived parameters: both NR and SAMOSA retrievals are included in HR products. Unlike SAMOSA, this retracker also includes a skewness parameter at 0.1 and improves SWH estimates through the application of VWM correction.

Other changes in PB F09 include:

- Range walk correction in ALT L1 processing for both SAMOSA and HR NR retrackers.
- Addition of wave parameters (from Meteo-France) and AMR-only data in L2 products.

More details on PB F09 can be found in the associated product notice [3].

From 2024-03-13 onward, data were processed using the G01 baseline. An update was implemented on 2025-04-12 (cycle 162 pass 2), correcting the new Ku-band MLE4 and C-band MLE3 LUTs.

In the following assessment, the operational dataset is referred to as “OPE” or “F0X” in the figures.

3.3. Jason-3 data used for comparison

Between 2020-12-17 to 2022-04-07 (cycle 4 to 51 for Sentinel-6 MF), Sentinel-6 MF and Jason-3 are flying in tandem formation on the same ground track with only 30 seconds apart, Jason-3 ahead of Sentinel-6 MF.

In this current report, Jason-3 GDR-F standard with MLE4 retracking was used to compare to Sentinel-6 MF reprocessed data. A detailed description of the products can be found in the Jason-3 product handbook [8].

Sentinel-6 MF PB F08 and F09 and Jason-3 GDR-F share the same standards in terms of geophysical corrections: same tide models, same mean surface height, etc. This is not the case anymore with PB G01, see section 5 for more details. However, both GDR-F and GDR-G still overlap on some key points. In particular :

- for the wind speed, Collard algorithm is used on both missions
- for the sea state bias, Sentinel-6 MF uses the same Sea State Bias parametrization as Jason-3 GDR-F, both in LR and in HR.

S6MF Cycle	J3 Cycle	Calendar Dates
4	179	17-12-2020 – 27-12-2020
5	180	27-12-2020 – 06-01-2021

S6-MF Cycle	J3 Cycle	Calendar Dates
6	181	06-01-2021 – 16-01-2021
7	182	16-01-2021 – 26-01-2021
8	183	26-01-2021 – 04-02-2021
9	184	04-02-2021 – 14-02-2021
10	185	14-02-2021 – 24-02-2021
11	186	24-02-2021 – 06-03-2021
12	187	06-03-2021 – 16-03-2021
13	188	16-03-2021 – 26-03-2021
14	189	26-03-2021 – 05-04-2021
15	190	05-04-2021 – 15-04-2021
16	191	15-04-2021 – 25-04-2021
17	192	25-04-2021 – 05-05-2021
18	193	05-05-2021 – 15-05-2021
19	194	15-05-2021 – 25-05-2021
20	195	25-05-2021 – 03-06-2021
21	196	03-06-2021 – 13-06-2021
22	197	13-06-2021 – 23-06-2021
23	198	23-06-2021 – 03-07-2021
24	199	03-07-2021 – 13-07-2021
25	200	13-07-2021 – 23-07-2021
26	201	23-07-2021 – 02-08-2021
27	202	02-08-2021 – 12-08-2021
28	203	12-08-2021 – 22-08-2021
29	204	22-08-2021 – 01-09-2021
30	205	01-09-2021 – 11-09-2021
31	206	11-09-2021 – 21-09-2021
32	207	21-09-2021 – 30-09-2021
33	208	30-09-2021 – 10-10-2021
34	209	10-10-2021 – 20-10-2021
35	210	20-10-2021 – 30-10-2021
36	211	30-10-2021 – 09-11-2021
37	212	09-11-2021 – 19-11-2021
38	213	19-11-2021 – 29-11-2021
39	214	29-11-2021 – 09-12-2021

S6-MF Cycle	J3 Cycle	Calendar Dates
40	215	09-12-2021 – 19-12-2021
41	216	19-12-2021 – 29-12-2021
42	217	29-12-2021 – 08-01-2022
43	218	08-01-2022 – 18-01-2022
44	219	18-01-2022 – 27-01-2022
45	220	27-01-2022 – 06-02-2022
46	221	06-02-2022 – 16-02-2022
47	222	16-02-2022 – 26-02-2022
48	223	26-02-2022 – 08-03-2022
49	224	08-03-2022 – 18-03-2022
50	225	18-03-2022 – 28-03-2022
51	226	28-03-2022 – 07-04-2022

Table 2: Correspondence between S6MF cycles, J3 cycles, and calendar dates

4 Data coverage and validity of measurements

This section analyses the availability of Level-2 NTC data before and after the reprocessing. In addition, the edited (invalidated) measurements are monitored and examined.

4.1. Missing measurements

Sentinel-6 MF data availability is improved with the G01 reprocessing. In LR, two tracks are recovered (cycle 92 pass 237 and cycle 120 pass 131). In HR, eight passes are recovered (cycle 8 pass 129, cycle 10 pass 1, cycle 46 passes 21, 23, 97 and 99, cycle 92 pass 237, and cycle 120 pass 131). No new missing tracks are detected in either mode.

Tables 3 and 4 list, for LR and HR respectively, passes that are entirely missing, i.e. for which no product is available. None of these passes were ever produced, nor will they be in the future, as no corresponding Level-0 data exist.

Cycle	Pass
4	88, 152, 156
8	126 to 128
11	207 to 221
17	52 to 79, 83 to 86
23	230
24	230
31	84, 85, 88 to 90, 110, 112 to 114
46	22, 98

Table 3: List of entirely missing passes in LR.

Cycle	Pass
4	82 to 84, 88, 152, 198, 216, 226
5	32, 76, 78, 226
6	224, 232
7	226, 229, 230, 234
8	30, 46, 126 to 128, 226
9	102, 103, 178, 179, 204, 205, 254

10	42, 98, 128, 129, 150, 178, 179, 226, 252 to 254
11	26, 27, 102, 103, 128, 129, 178, 179, 207 to 221
12	26, 27, 48, 124, 128, 129, 178, 179, 204, 205, 226, 254
13	26, 27, 70, 178, 179, 254
14	48, 118, 146, 226
15	172
16	200 to 205
17	48 to 86, 88 to 90
21	166 to 168
23	230, 231
24	230, 231
28	33, 34
29	78, 106
30	196 to 207, 222
31	82 to 86, 88 to 95, 98 to 114
32	62 to 72, 224
41	2, 64
42	162
46	22, 98
61	36, 92, 246
62	20, 114, 160, 202, 254
64	124
69	144
74	147, 148, 154, 156, 202
77	148
81	140
84	234
94	150 to 156
95	148 to 152
107	136
133	170
134	138
140	14

152	168
160	6, 134

Table 4: List of entirely missing passes in HR.

Table 5 presents the total number of passes in the reprocessed dataset and the number of passes showing a different number of measurements compared to the operational dataset, using thresholds of 1 and 500 points (i.e. about 8 minutes and 20 seconds).

Although many measurements are recovered, some data are lost during the reprocessing. The losses are generally small—typically a few measurements per track. However, a few tracks are significantly affected: 10 passes in LR and 1 pass in HR lose more than 500 measurements. This issue has been traced to a Level-0 production anomaly during reprocessing, which will be corrected in the next campaign. 10 passes in LR present a loss greater than 500 measurements : cycle 20 track 182, 202 and 203, cycle 32 track 48, cycle 38 track 200, cycle 54 track 73, cycle 65 track 84, cycle 116 track 215, cycle 143 track 142 and cycle 163 track 230. In HR, 1 pass presents a loss greater than 500 measurements : cycle 160 track 126.

Parameter	LR	HR
Total number of passes in reprocessing	40540	40363
Passes with at least 1 more missing point than operational	131	29
Passes with at least 1 fewer missing point than operational	193	1995
Passes with at least 500 more missing points than operational	10	1
Passes with at least 500 fewer missing points than operational	17	50

Table 5: Number of passes with a different number of missing points in reprocessed vs. operational datasets.

The cyclic monitoring of available data for both datasets is shown in Figure 9 for global availability, and in Figure 10 for ocean availability. Global availability is excellent, with 99.86% of available measurements in LR and 95.25% in HR. Ocean availability is even higher, at 99.73% in LR and 98.93% in HR.

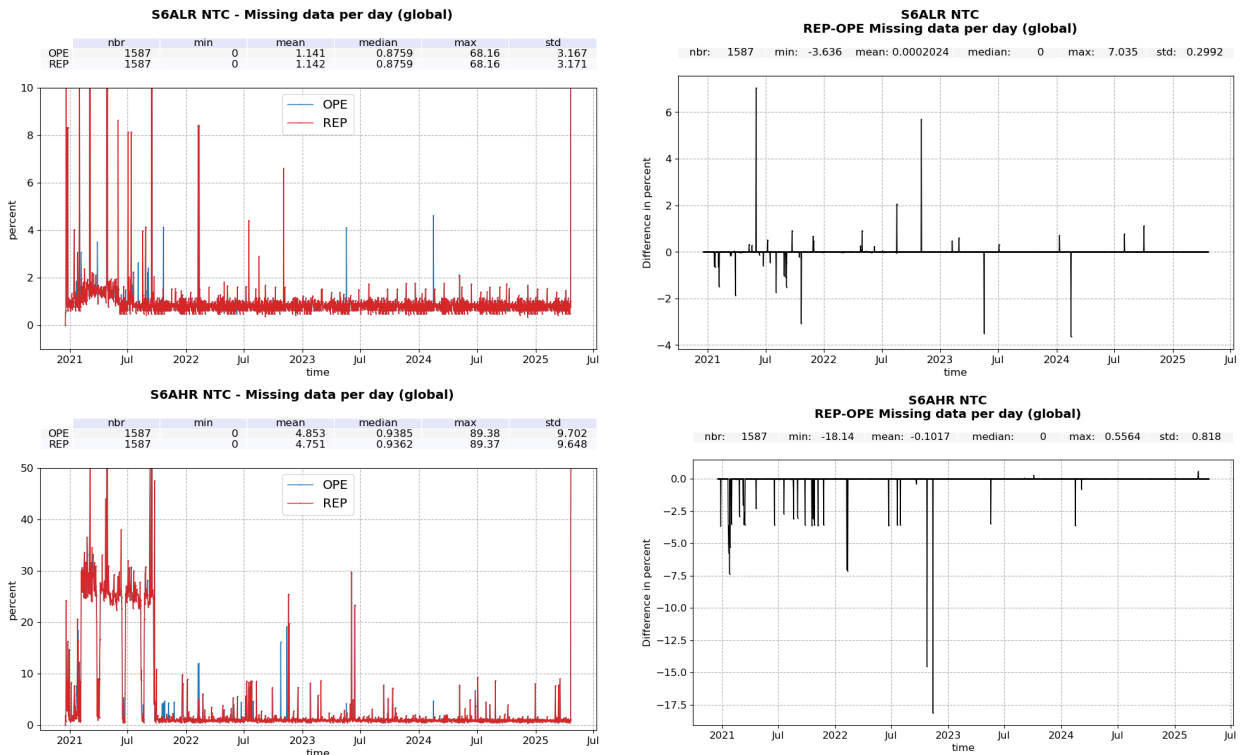


Figure 9: Percentage of globally missing data for the operational and reprocessed datasets (left) and their difference (right) for LR (top) and HR (bottom). Positive values on the difference plots indicate a loss of data in the reprocessing; negative values indicate a gain.

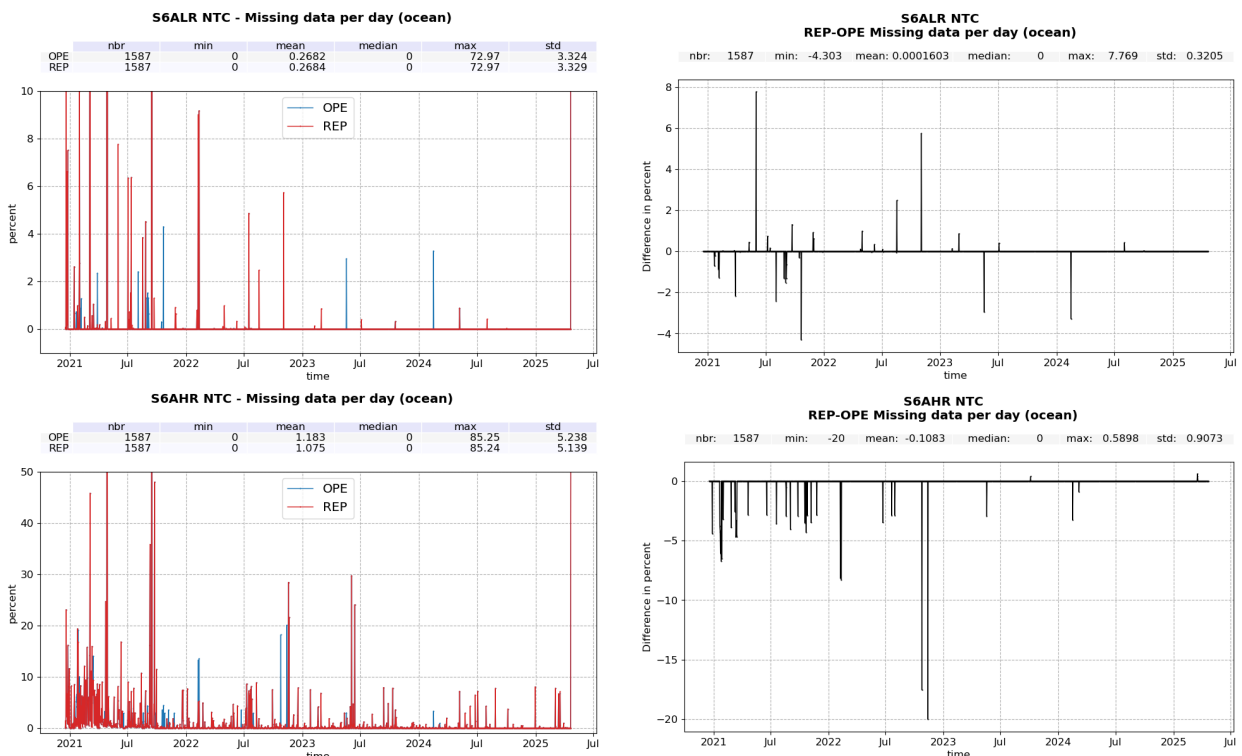


Figure 10: Percentage of ocean-only missing data for the operational and reprocessed datasets (left) and their difference (right) for LR (top) and HR (bottom). Positive values indicate a loss of data, negative values a gain thanks to the reprocessing.

4.2. Edited measurements

4.2.1. Overview

The outlier detection—or editing—step of the Cal/Val process aims at removing any measurement considered erroneous. It is crucial to the various metrics presented in this report. The definition of an erroneous measurement, as well as the accepted error level on the final sea level anomaly, is naturally a trade-off between accuracy and data coverage. Monitoring the percentage of valid and edited measurements also provides relevant information on mission performance.

A series of editing criteria are applied to detect outliers over the ocean. The process consists of four main steps:

- removal of all measurements over land using a land/water mask,
- removal of all measurements affected by sea ice,
- removal of all measurements exceeding predefined thresholds on several parameters,
- additional consistency checks on along-track SLA.

For each step, the number of detected outliers is routinely monitored at the Cal/Val level. The amount of removed data helps identify processing anomalies that may arise from instrumental, geophysical, or algorithmic changes. The procedure used here is dedicated to ocean applications, and the editing criteria remain unchanged in the reprocessing.

The daily percentage of edited measurements for the operational and reprocessed datasets over the ocean is shown in figure 11. Overall, the proportion of edited data is very similar between operational and reprocessed datasets. LR retrackers present slightly higher editing rates (11.5% and 11.4% for MLE4 and NR respectively) compared to HR (10.0% and 9.9% for SAMOSA and NR respectively). The prominent spike observed in all datasets in March 2021 results from an AMR-C 24h warm calibration that affected the ice flag (see section 4.2.2.). Other smaller spikes are statistical artefacts linked to variations in the number of available measurements.

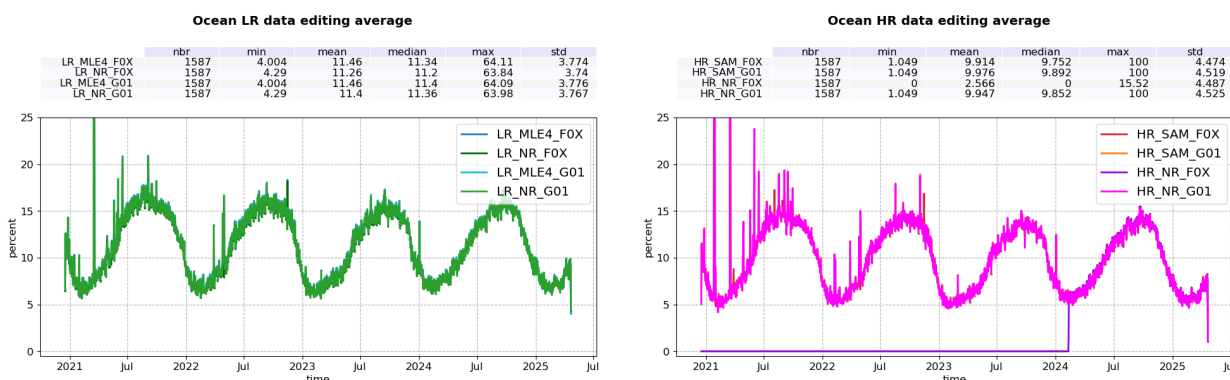


Figure 11: Percentage of invalid measurements for the operational (blue) and reprocessed (red for MLE4 and SAMOSA, green for NR) datasets over the ocean by day in LR (left) and HR (right).

4.2.2. Rejection on ice detection

The first step of the editing process removes all measurements flagged as affected by sea ice. The radiometer-derived ice flag (*rad_sea_ice_flag* in the products) is used to mask measurements contaminated by sea ice within the altimeter footprint.

The percentage of measurements edited using the ice-flag criterion is shown in figure 12 (4.93% with a annual variation between 1% and 11%). No significant difference is observed between operational and reprocessed datasets.

An AMR-C 24h warm target calibration conducted on 17–18/03/2021 (cycle 13 passes 20 to 45) caused the temporary unavailability of the ice flag, resulting in a spike in edited data on both operational and reprocessed datasets.

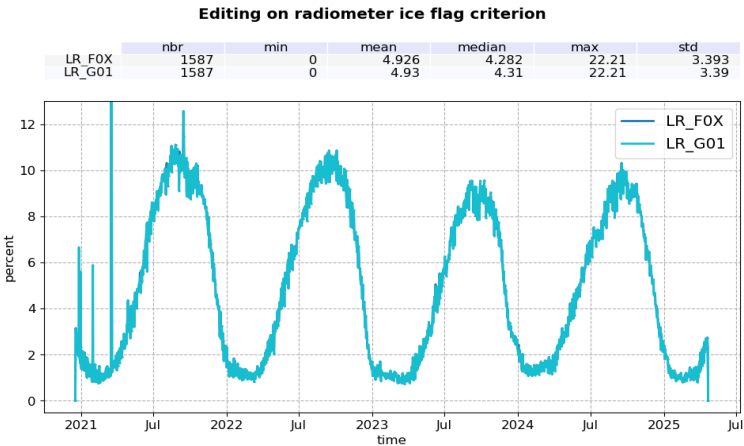


Figure 12: Percentage of edited measurements based on ice detection for the operational (blue) and reprocessed (cyan) datasets over the ocean by day.

4.2.3. Rejection based on threshold criteria

Once the measurements affected by sea ice are removed, the quality of the parameters retrieved by the altimeter—as well as that of the geophysical corrections—is checked using predefined thresholds. These thresholds and the corresponding percentages of rejected measurements are listed in table 6. The percentage of detected outliers for each parameter is closely monitored cycle by cycle, day by day, and pass by pass, by CLS Cal/Val routines.

Parameters	Min	Max	Unit	% rejected			
				LR MLE4	LR NR	HR SAM	HR NR
Sea surface height anomaly	-2	2	m	0.09/0.09	0.29/0.25	0.2/0.2	0.09/0.2
Sea surface height	-130	100	m	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
Nb measurements of range	10	N/A	None	0.17/0.17	0.0/0.0	0.01/0.01	0.0/0.0
Std. deviation of range	0	see (*)	m	0.58/0.57	0.92/0.85	0.93/0.97	1.05/1.11
Backscatter coefficient	7	30	dB	0.06/0.06	0.11/0.13	0.32/0.09	0.14/0.15
Nb measurements of sigma0	10	N/A	None	0.16/0.16	0.0/0.0	0.0/0.0	0.0/0.0
Std. deviation of sigma0	0	1	dB	1.95/1.95	2.4/2.57	0.78/0.77	1.0/1.02
Significant wave height	0	11	m	0.39/0.35	0.26/0.27	0.1/0.08	0.51/0.41
Altimeter wind speed	0	30	m.s-1	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
Sea State Bias	-0.5	0	m	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
Ionospheric correction filtered	-0.4	0.04	m	0.02/0.03	0.21/0.22	0.03/0.03	0.15/0.22
Square off nadir angle	-0.2	0.64	deg2	0.73/0.75	1.3/1.39	N/A	N/A
Equilibrium tide	-0.5	0.5	m	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
Combined atmospheric correction	-2	2	m	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
Dry tropospheric correction	-2.5	-1.9	m	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
Internal tide	-5	5	m	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
Ocean tide	-5	5	m	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
Pole tide	-15	15	m	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
Earth tide	-1	1	m	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
AMR wet tropospheric correction	-0.5	-0.001	m	0.08/0.08	0.09/0.09	0.08/0.08	0.1/0.09
Global statistics of edited measurements by thresholds				6.46/6.46	6.28/6.41	4.93/4.98	4.74/4.95

Table 6: Table of parameters used for editing and the corresponding percentages of edited measurements for each parameter for Sentinel-6 MF LR and HR. In LR MLE4 and HR, first values correspond to operational data, second values to reprocessed data.

(*) The maximum threshold for range standard deviation is set as function of significant wave height as follows:

- In LR:
 - for $SWH \leq 2m$: 0.192
 - for $SWH > 2m$: $0.018 * SWH + 0.156$
- In HR:
 - for $SWH \leq 2m$: 0.087
 - for $SWH > 2m$: $0.033 * SWH + 0.121$

Editing on thresholds (default values) LR

	nbr	min	mean	median	max	std
LR_MLE4_FOX	1587	0.4766	3.47	3.338	40.28	1.359
LR_NR_FOX	1587	0.4766	2.716	2.663	39.91	1.33
LR_MLE4_G01	1587	0.4766	3.478	3.319	40.28	1.405
LR_NR_G01	1587	0.4766	2.694	2.624	39.89	1.377

Editing on thresholds (out of bounds) LR

	nbr	min	mean	median	max	std
LR_MLE4_FOX	1587	1.278	3.062	3.052	4.908	0.5633
LR_NR_FOX	1587	1.37	3.624	3.639	5.872	0.8464
LR_MLE4_G01	1587	1.272	3.05	3.046	4.907	0.5594
LR_NR_G01	1587	1.431	3.778	3.805	5.949	0.6692

Editing on thresholds (default values) HR

	nbr	min	mean	median	max	std
HR_SAM_FOX	1587	0.286	3.137	3.013	38.82	1.337
HR_NR_FOX	1587	0	0.7096	0	3.681	1.176
HR_SAM_G01	1587	0.286	3.168	3.006	38.8	1.439
HR_NR_G01	1587	0.572	2.724	2.636	38.54	1.412

Editing on thresholds (out of bounds) HR

	nbr	min	mean	median	max	std
HR_SAM_FOX	1587	0.5355	1.86	1.737	95.57	2.761
HR_NR_FOX	1587	0	0.6192	0	4.09	1.044
HR_SAM_G01	1587	0.557	1.889	1.761	95.7	2.793
HR_NR_G01	1587	0.4766	2.303	2.206	95.96	2.808

4.2.4. Along-track SSHA consistency

The percentage of edited points based on SSHA pass statistics is shown in figure 14. Two occurrences are found in the reprocessed dataset, both corresponding to passes that show a significant loss of measurements (see section 4.1.):

- Cycle 20 pass 182 (01-06-2021 03:18:11.0 to 01-06-2021 04:14:22.0), in LR only. Reprocessed SSHA values are erroneous due to a range anomaly still under investigation. This pass also contains 795 fewer measurements than in the operational dataset.
- Cycle 84 pass 240 (28-02-2023 00:04:16 to 28-02-2023 00:59:44), for all retrackers. The reprocessed pass contains 445 fewer measurements than in F08, for a reason still under investigation. Remaining data include geophysical signals present in both datasets, but these gain more weight in the reprocessed version, skewing the mean of the track and causing its rejection.

Parameters	Set 1	Set 2
Selection		
Bathymetry	<-1000m	<-1000m
Coastal distance	>100km	>100km
Oceanic variability	<0.3m	<0.1m
Min number of measurements	3	200
Thresholds		
Mean (absolute value)	0.3m	0.15m
STD	0.4m	0.2m

Table 7: Table of parameters used for the editing on the SSHA pass statistics. These parameters are identical in HR and LR.

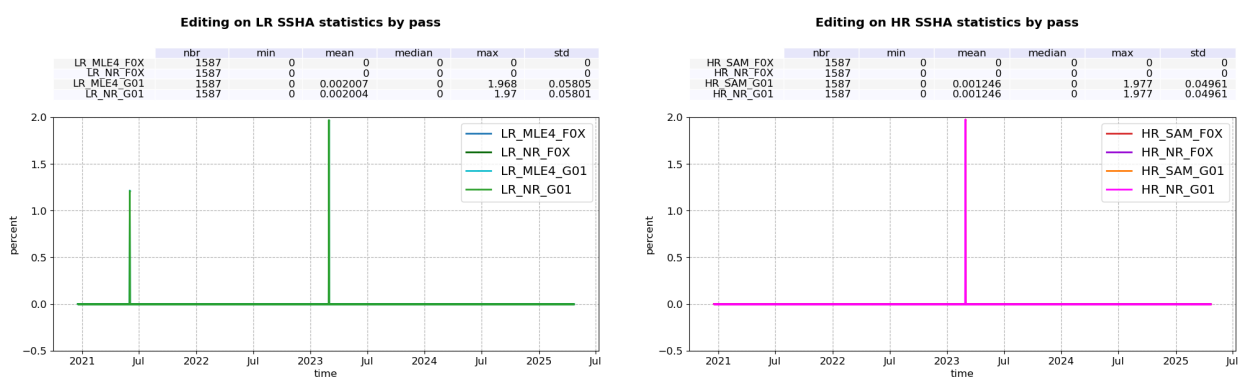


Figure 14: Percentage of edited measurements on SSHA pass statistics for the operational and reprocessed datasets over the ocean by day in LR (left) and HR (right).

5 Geophysical models

This section details the model updates between the operational and reprocessed datasets. Most of these updates are related to the new GDR-G standard.

5.1. GDR-G models update

The models updated as part of the new GDR-G standard in PB G01 are analysed in this section. Four models are impacted: the mean dynamic topography, the mean sea surface, and the ocean and load tides. More information on the GDR-G models can be found in the product notice [4].

5.1.1. Mean dynamic topography

The Mean Dynamic Topography (MDT) model has been updated from CNES-CLS MDT 2018 to CNES-CLS MDT 2022. Figure 15 presents the temporal monitoring (top-left panel), distribution (top-right panel), and map (bottom panel) of the reprocessed minus operational model difference. The distribution is centred on -0.2 mm, with variations up to 1.5 cm by pass and up to 3 cm regionally in areas of high MDT.

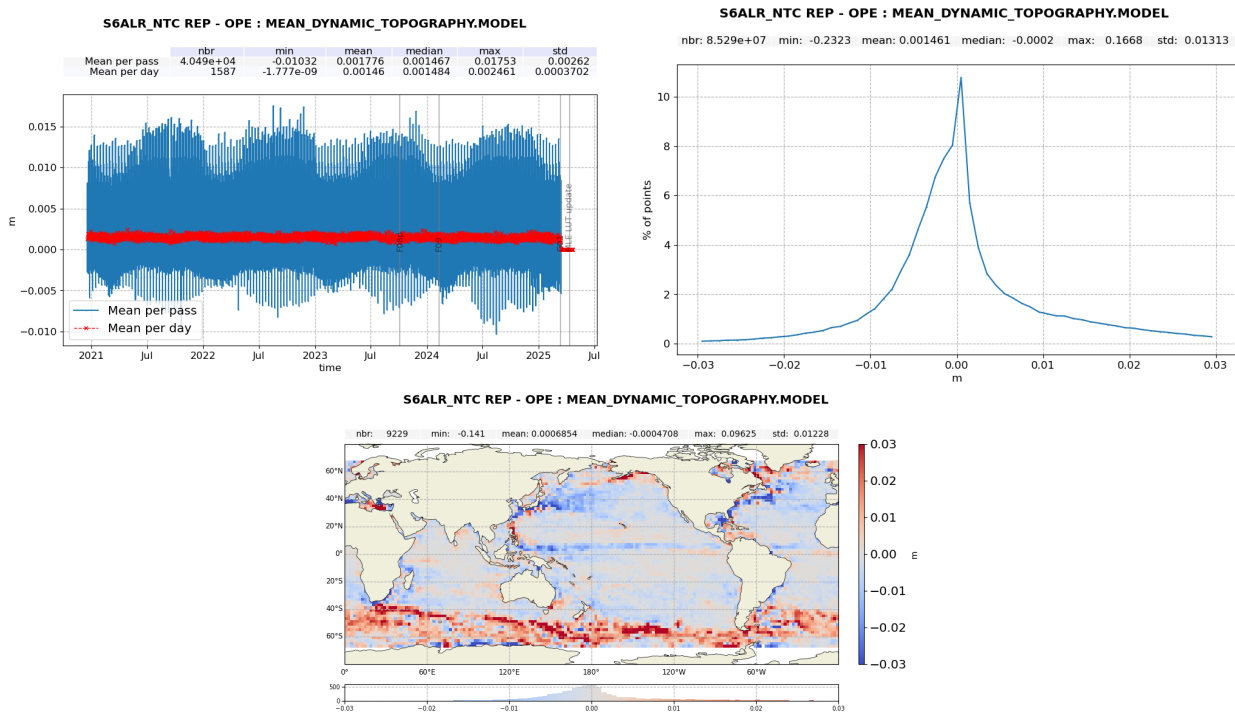


Figure 15: MDT model differences, reprocessed minus operational. Top-left: temporal monitoring by pass (blue) and by day (red). Top-right: distribution. Bottom: map.

5.1.2. Mean sea surface

Two Mean Sea Surface (MSS) solutions are available in the products, both of which have been updated in the GDR-G standard.

Solution 1, used in the SSHA computation, has been updated from CNES-CLS15 to Hybrid CNES-CLS2023/Scripps/DTU. Figure 16 presents the temporal monitoring (top-left panel), distribution (top-right panel), and map (bottom panel) of the reprocessed minus operational model difference. The distribution is centred on -0.8 mm, with variations up to +0/-2 mm by pass and up to 0.5 cm regionally in areas of strong MSS gradients.

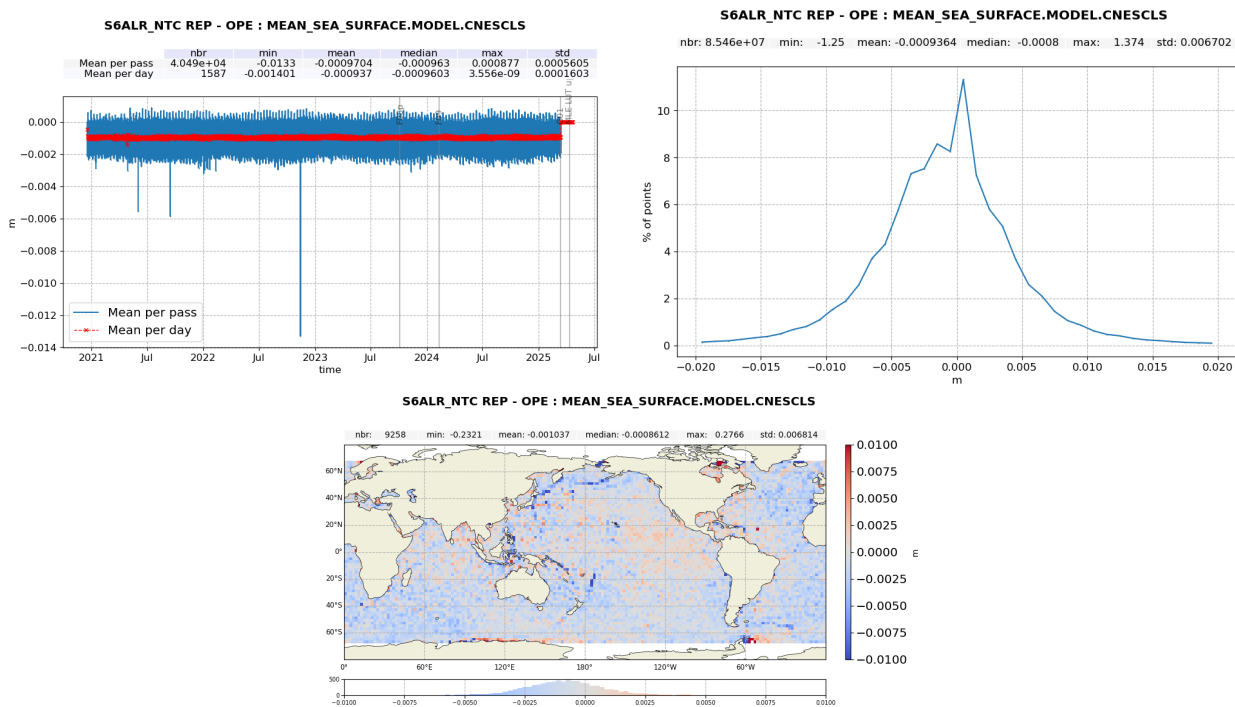


Figure 16: MSS solution 1 model differences, reprocessed minus operational. Top-left: temporal monitoring by pass (blue) and by day (red). Top-right: distribution. Bottom: map.

Solution 2 has been updated from DTU2018 to DTU2021. Figure 17 presents the temporal monitoring (top-left panel), distribution (top-right panel), and map (bottom panel). The distribution is centred on -1.2 mm, with variations up to 3 mm by pass and up to 2 mm regionally.

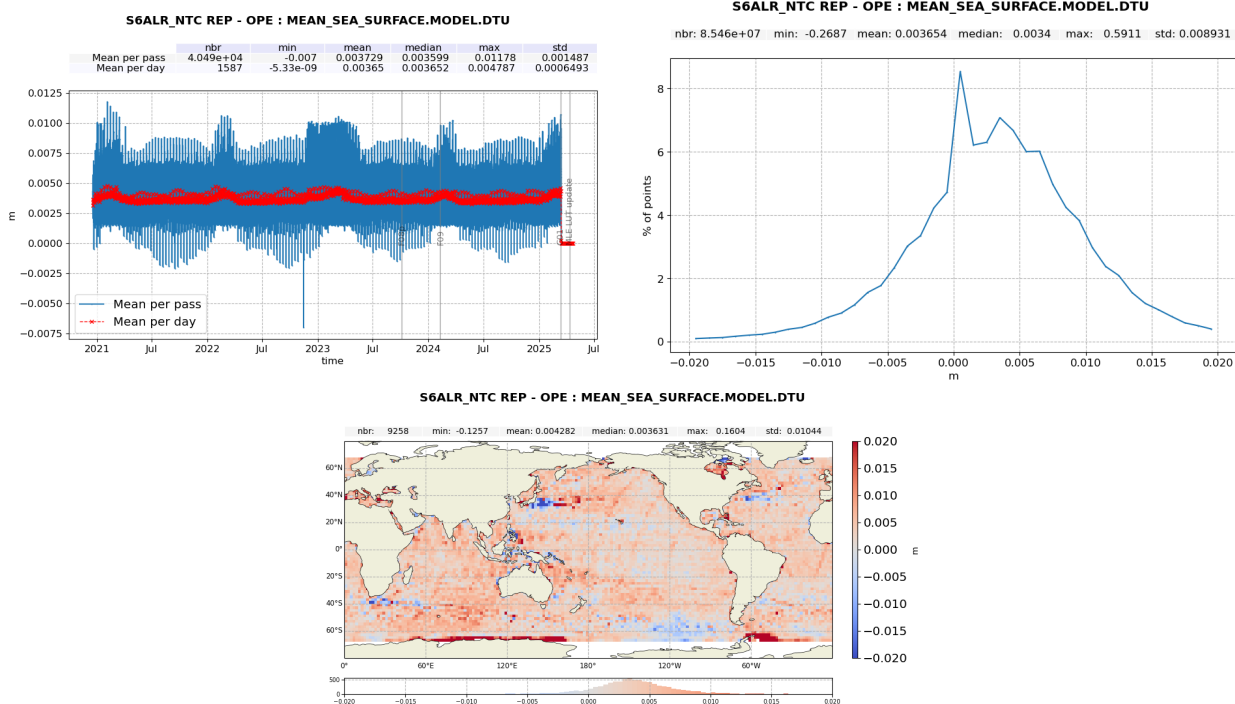


Figure 17: MSS solution 2 model differences, reprocessed minus operational. Top-left: temporal monitoring by pass (blue) and by day (red). Top-right: distribution. Bottom: map.

5.1.3. Ocean tide

Ocean tide solution 2, used in the SSHA computation, has been updated from FES14 to FES22. Note that the definition of this field has also changed, as it now includes the non-equilibrium tide. To ensure consistency, the non-equilibrium tide has been removed from the SSHA definition. Figure 18 shows the temporal monitoring (top-left), distribution (top-right), and map (bottom). This comparison is performed directly on the fields: the reprocessed dataset therefore includes the non-equilibrium tide, whereas the operational one does not. The distribution is centred on zero, with variations up to 1 cm by pass and up to several tens of centimetres regionally, particularly in polar and coastal areas.

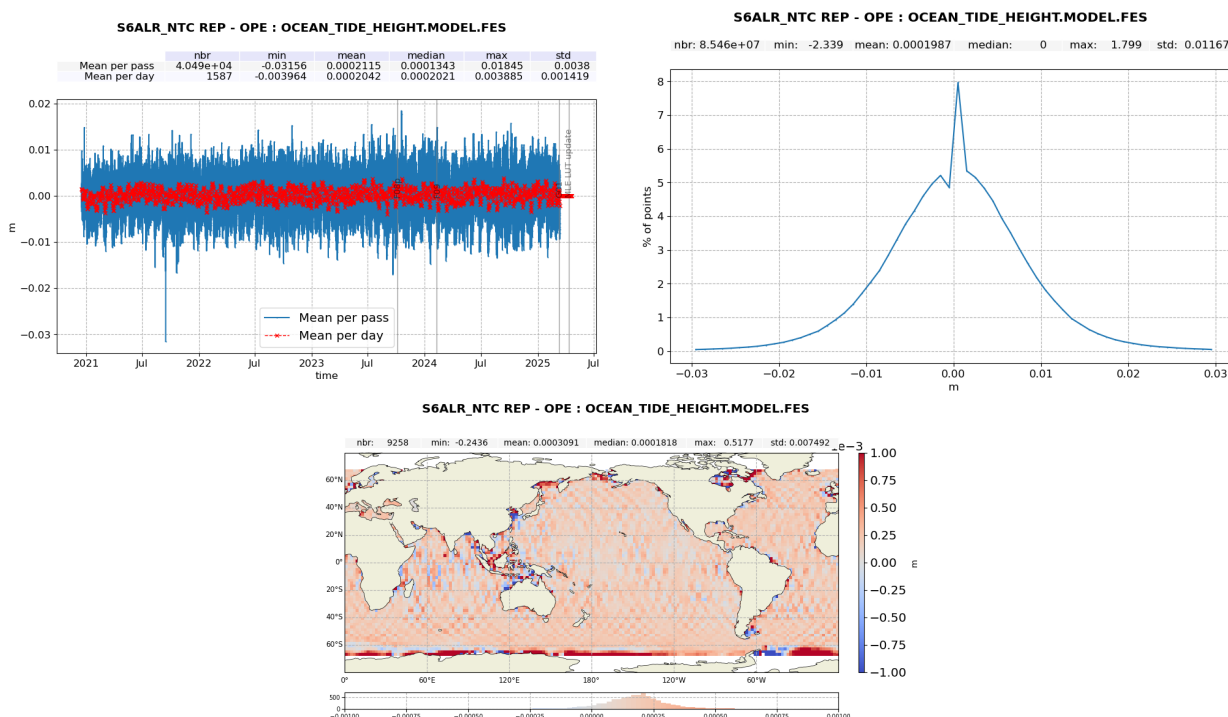


Figure 18: Ocean tide solution 2 model differences, reprocessed minus operational.
Top-left: temporal monitoring by pass (blue) and by day (red). Top-right: distribution.
Bottom: map.

5.1.4. Load tide

The load tide solution 2 has also been updated from FES14 to FES22. Figure 19 shows the temporal monitoring (top-left), distribution (top-right), and map (bottom). The distribution is centred on zero, with variations up to 2 mm by pass, including a 60-day oscillation, and up to a few millimetres regionally in polar areas.

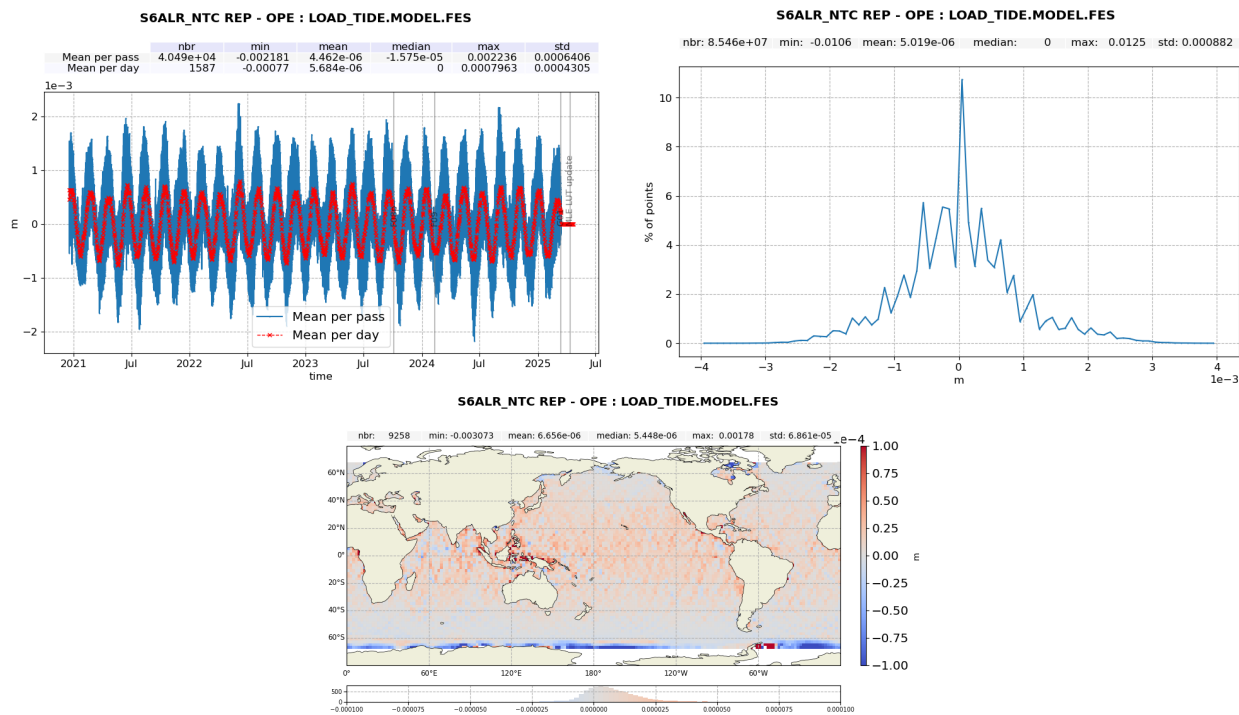


Figure 19: Load tide solution 2 model differences, reprocessed minus operational. Top-left: temporal monitoring. Top-right: distribution. Bottom: map.

5.2. Other model updates

Beyond the GDR-G updates, three additional models have been updated: the dry tropospheric correction, the dynamical atmospheric correction, and the geoid model.

5.2.1. Dry tropospheric correction

Figure 20 presents the temporal monitoring (top-left), distribution (top-right), and map (bottom) of the re-processed minus operational difference. The distribution is centred on zero, with variations up to 0.4 mm by pass and up to 0.05 mm regionally in polar regions. The root cause of these differences is still under investigation.

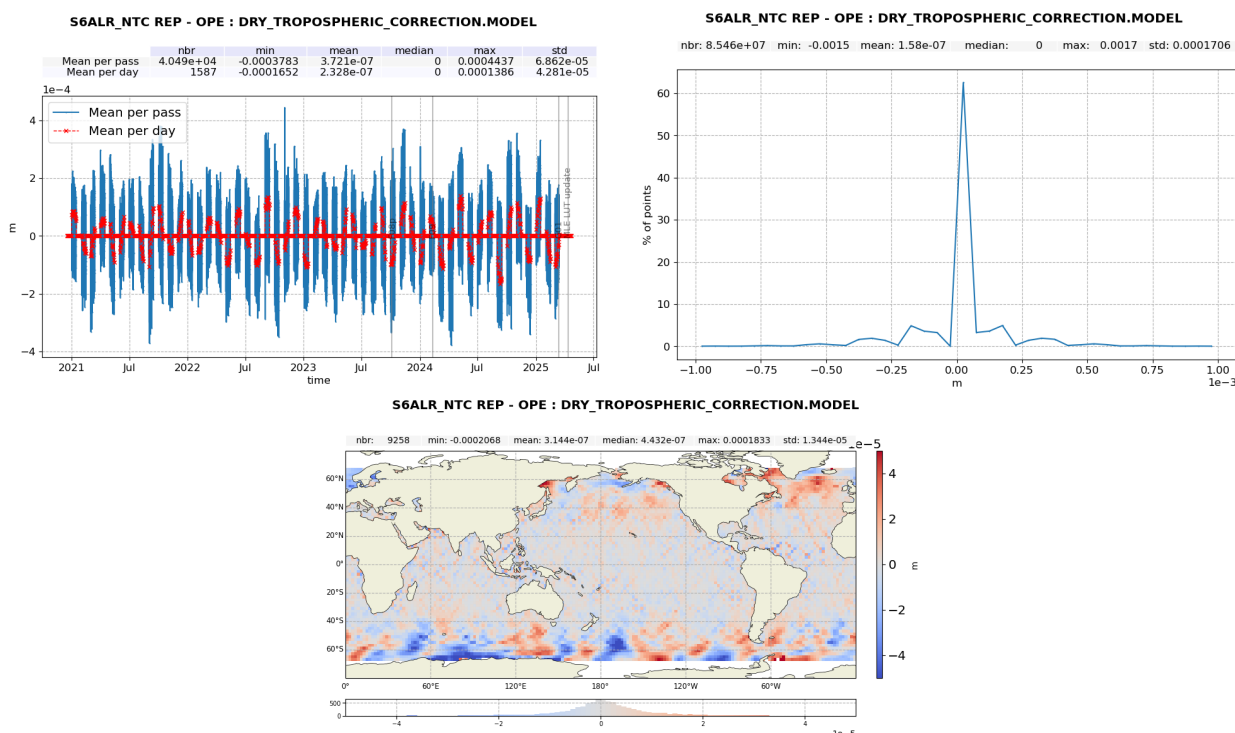


Figure 20: Dry tropospheric correction differences, reprocessed minus operational.
Top-left: temporal monitoring. Top-right: distribution. Bottom: map.

5.2.2. Dynamical atmospheric correction

The dynamical atmospheric correction (DAC) model has been updated using ERA5 data up to July 2023. After this date, both datasets use the operational DAC and therefore align. Figure 21 shows the temporal monitoring (top-left), distribution (top-right), and map (bottom). The distribution is centred on zero, with variations up to 5 mm by pass and up to 0.5 mm regionally.

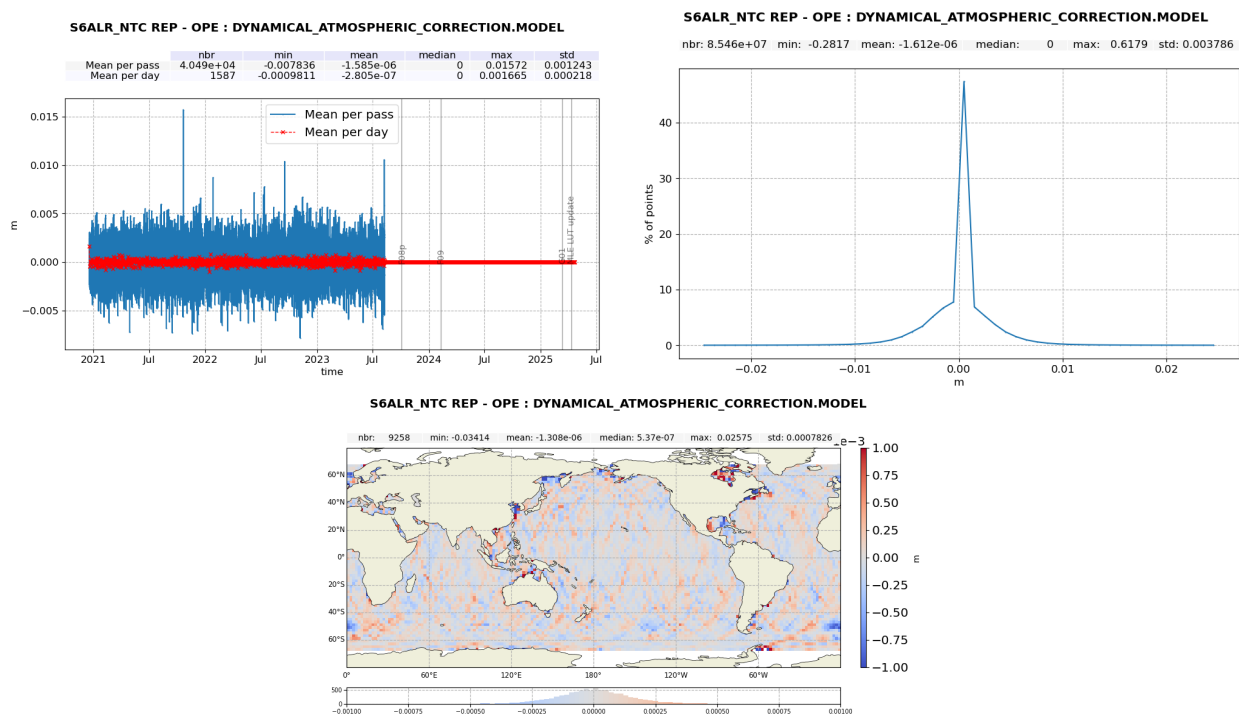


Figure 21: DAC model differences, reprocessed minus operational. Top-left: temporal monitoring. Top-right: distribution. Bottom: map.

5.2.3. Geoid model

An anomaly in the computation of the geoid model was affecting the data until April 2025. This issue has now been corrected over the entire time series in the reprocessed dataset. Figure 22 presents the temporal monitoring (top-left), distribution (top-right), and map (bottom). The distribution is centred on -0.8 mm, with variations up to 3.5 cm by pass and up to 4 cm regionally.

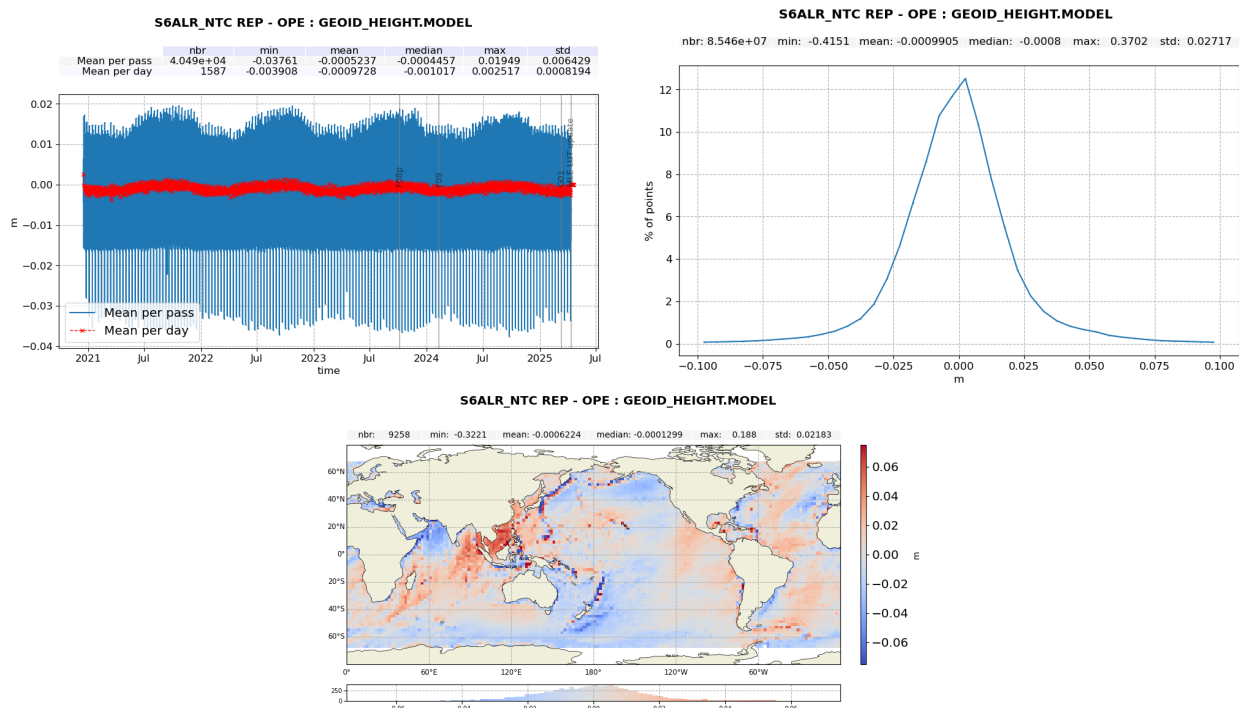


Figure 22: Geoid model differences, reprocessed minus operational. Top-left: temporal monitoring. Top-right: distribution. Bottom: map.

6 Geophysical parameters

6.1. Altimeter parameters

Parameters derived from the POS-4 altimeter are monitored in this section.

6.1.1. Significant Wave Height

6.1.1.1. LR

The time series of differences between the reprocessed and operational LR Ku-band Significant Wave Height (SWH) over the complete reprocessing period is presented in figure 23, and their distributions in figure 24. Several jumps are visible :

- -1.2 cm in MLE4 at the G01 LUT update
- 1 cm in LR NR at the correction of the small-wave anomaly introduced by the patched version of processing baseline F08 (F08p).

As expected, LR NR reprocessed SWH is identical to the operational dataset from PB F09 onward.

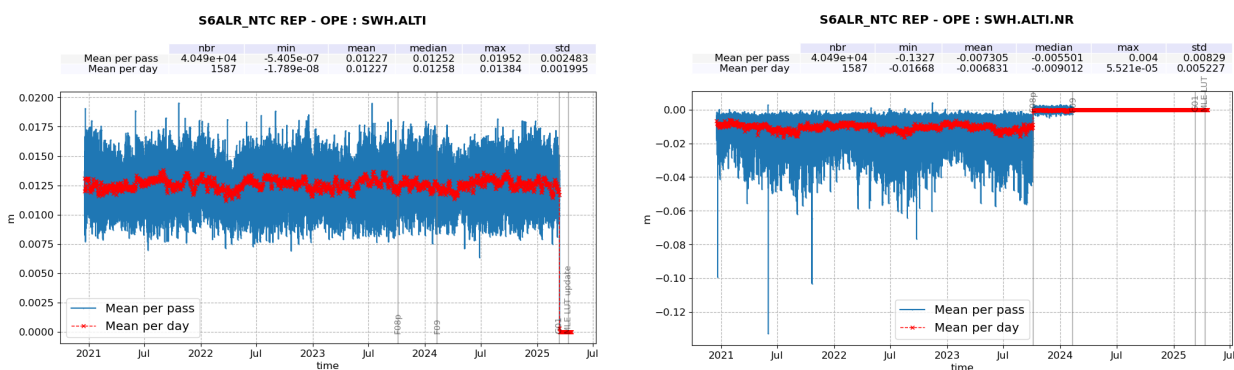


Figure 23: Time monitoring of the reprocessed minus operational Sentinel-6 MF Ku-band Significant Wave Height (in meters) by pass (blue) and day (red) for LR MLE4 (left) and LR NR (right).

The maps of the differences between reprocessed and operational datasets are presented in figure 25. In both cases, a dependency on SWH is visible, due to the SWH-dependent LUT update in MLE4 and to the small-wave anomaly correction in NR.

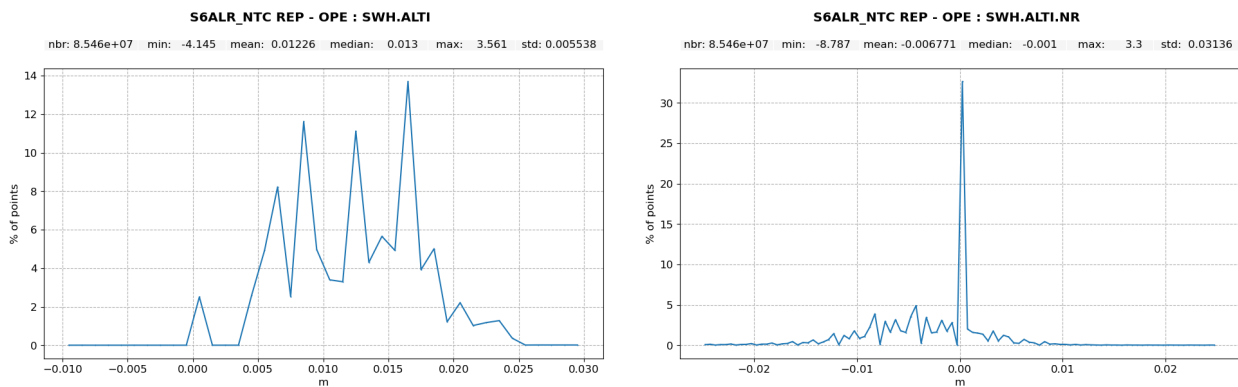


Figure 24: Distributions of Sentinel-6 MF SWH differences between reprocessed and operational datasets for LR MLE4 (left) and LR NR (right).

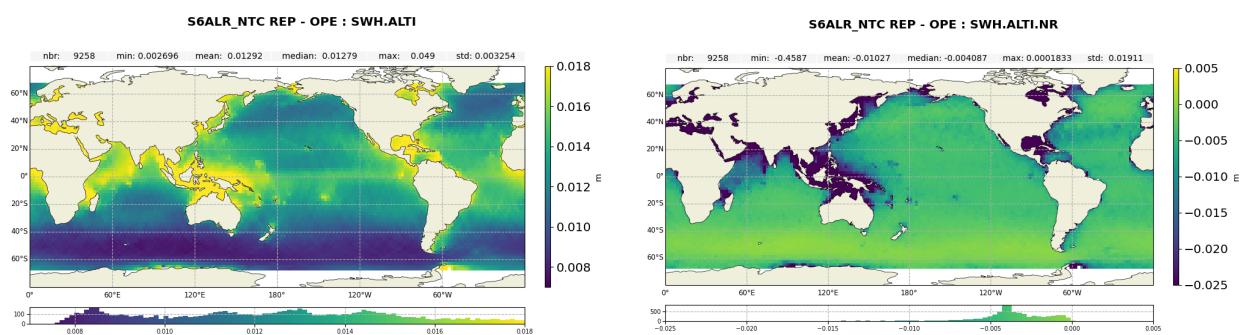


Figure 25: Maps of the LR SWH reprocessed minus operational datasets for LR MLE4 (left) and LR NR (right).

6.1.1.2. HR

The time series of differences between the reprocessed and operational HR SWH over the complete reprocessing period is presented in figure 26, and their distributions in figure 27. In HR SAMOSA, a first jump of about 3 cm occurs at the PB F09 update, caused by the introduction of the range-walk correction. A second jump of about 20 cm at PB G01 corresponds to the introduction of the vertical wave motion (VWM) correction in SAMOSA. In HR NR, a spike is visible in cycle 149 (tracks 230 to 238), corresponding to the correction during reprocessing of a VWM issue in the operational dataset caused by missing MFWAM model data. The reduction of pass-by-pass differences with PB G01 is due to the computation of the VWM at 20 Hz instead of 1 Hz previously.

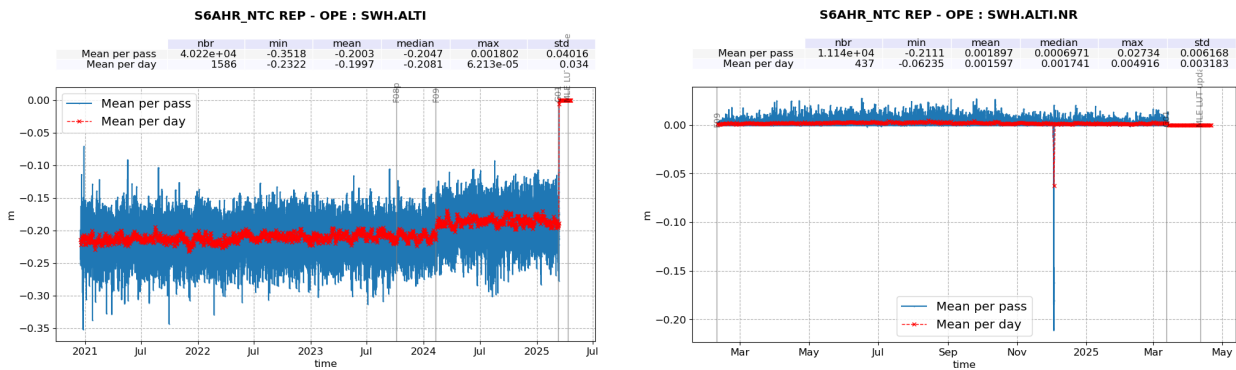


Figure 26: Time monitoring of the reprocessed minus operational Sentinel-6 MF Ku-band SWH (in meters) by pass (blue) and day (red) for HR SAMOSA (left) and HR NR (right).

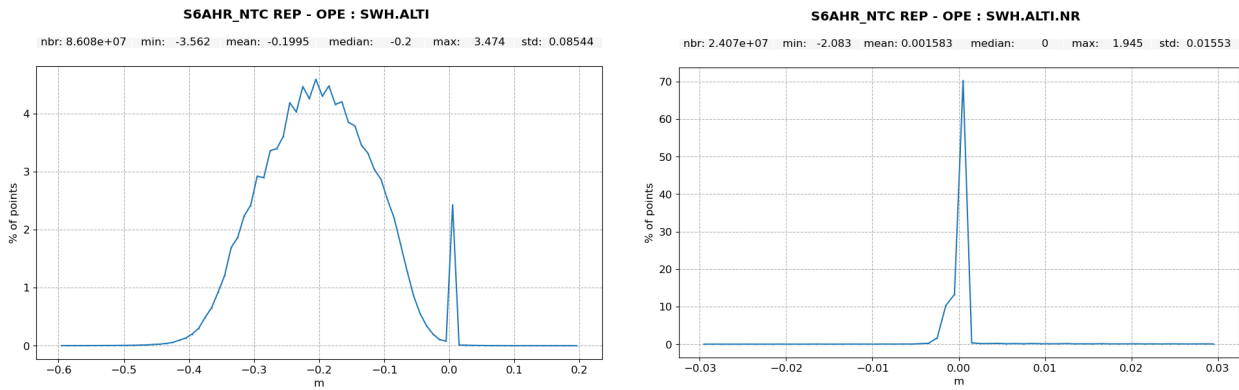


Figure 27: Distributions of Sentinel-6 MF SWH differences between reprocessed and operational datasets for HR SAMOSA (left) and HR NR (right).

The maps of the differences between reprocessed and operational datasets are presented in figure 28. In HR SAMOSA, an SWH correlation is visible due to the VWM correction. In HR NR, the anomalous tracks mentioned above are clearly visible. Most of the differences occur in small-wave regions, which are most affected by the computation of the VWM correction at 20 Hz in PB G01 instead of 1 Hz.

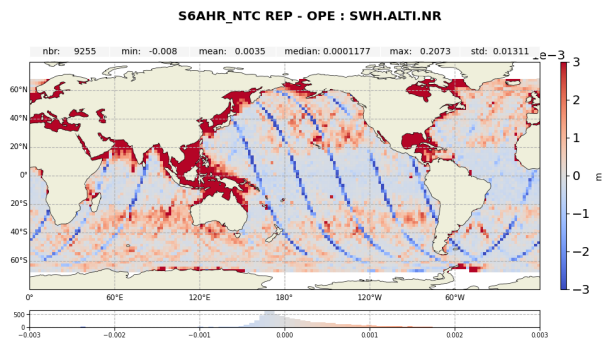
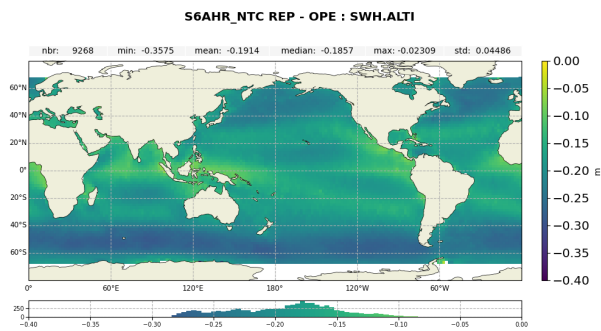


Figure 28: Maps of the HR SWH reprocessed minus operational datasets for HR SAMOSA (left) and HR NR (right).

6.1.1.3. Inter-retrackers comparisons

The monitoring of SWH differences between retrackerers (NR - MLE4/SAMOSA and HR - LR), as well as their correlations with SWH, is presented in figure 29. PB G01 brings a significant improvement in consistency between all retrackerers. The LR MLE4 - LR NR difference in G01 (cyan curve, top-left panel) shows an about 5 cm jump at the side A/B switch, linked to the fact that MLE4 is using the same LUT for both side-A and side-B and this MLE4 LUT has been re-computed using side-B data only (Cadier et al., 2024 [16]). The evolution is correlated to the PTR main lobe width. The oscillations are thermally-driven, linked and in synchronous with sun beta prime angle. In the reprocessed LR dataset (figure 30), the change of PTR main lobe width over side B time is 1 mm and the impact in SWH is 1 cm. This factor 10 is line from what have been seen in S3 SRAL. Also, this change of 1 cm over side-B time translates for MLE4 SSHA in a small drift through SSB.

The improvement in HR NR consistency at small SWH with respect to both HR SAMOSA (orange curve, top panels) and LR NR (orange curves, bottom panels) is due to the 20 Hz computation of the VWM correction. A residual 5 cm bias is visible in HR NR - LR NR (orange curves, bottom panels), already present in F09 and possibly linked to the T02 inputs of the VWM computation.

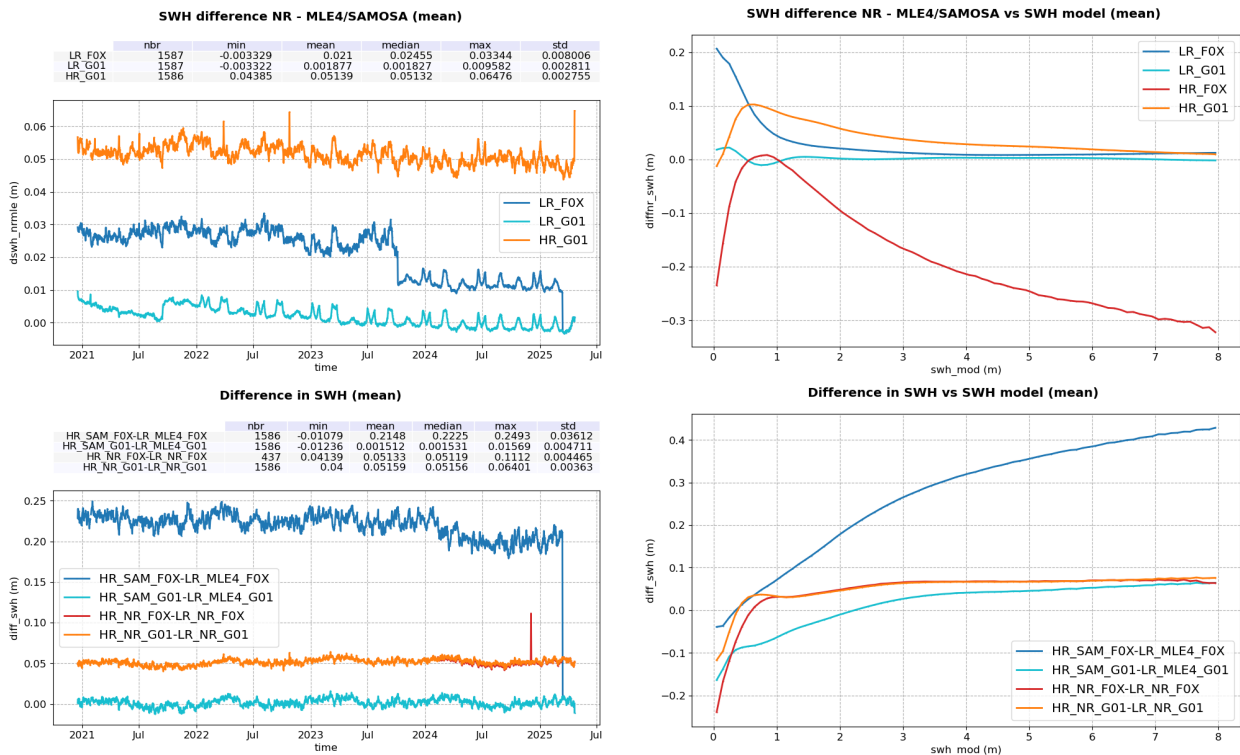


Figure 29: Time monitoring (left) and ERA5 model SWH dependency (right) of Sentinel-6 MF Ku-band SWH differences: NR - MLE4/SAMOSA (top) and HR - LR (bottom).

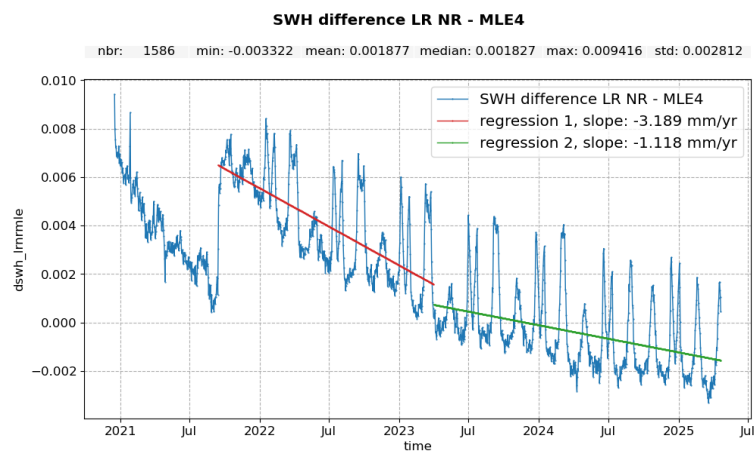


Figure 30: Time monitoring of LR NR - LR MLE4 Sentinel-6 MF Ku-band SWH difference.

6.1.1.4. Comparison with the ERA5 model

The daily monitoring of altimeter-derived SWH compared to the ERA5 model is presented in figure 31. In LR (left panel), all curves show similar variations, with a slight increase in the MLE4 bias (from 5.0 cm to 6.2 cm) and a slight decrease in the NR bias (from 7.6 cm to 6.4 cm). In HR (right panel), the SAMOSA bias is greatly reduced in G01 (from 26.7 cm to 6.4 cm) thanks to the VWM correction. The HR NR curves are consistent, with the remaining bias difference explained by the incomplete time coverage of the operational HR NR dataset. Note that the stability of ERA5 SWH timeseries is an open question, some variation have been attributed to the evolution of altimetry missions assimilated in the model.

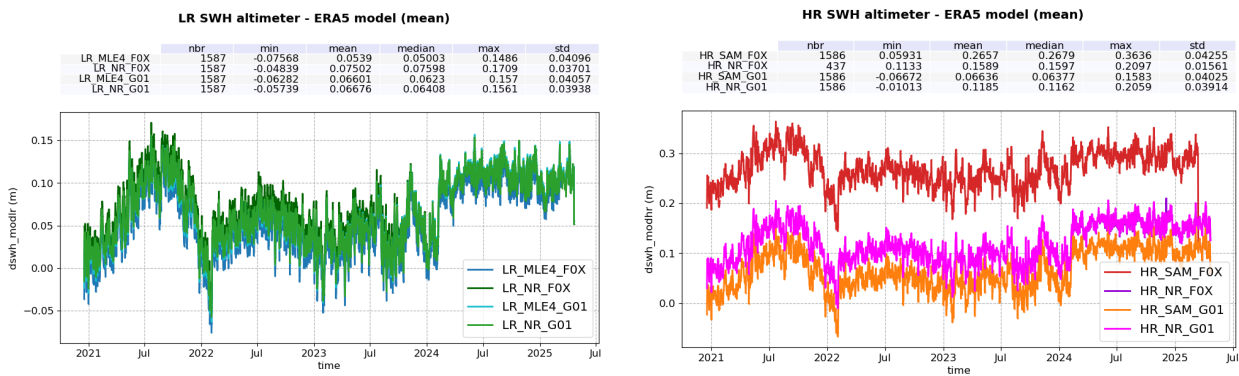


Figure 31: Time monitoring of Sentinel-6 MF altimeter - ERA5 model SWH difference (m), in LR (left) and HR (right).

6.1.1.5. LR C-band

Figure 32 presents the time series of the reprocessed minus operational LR C-band SWH and the corresponding map. A 25 cm jump is visible at the PB G01 update, caused by the LUT update. This LUT update is also SWH-dependent, explaining the observed geographical patterns.

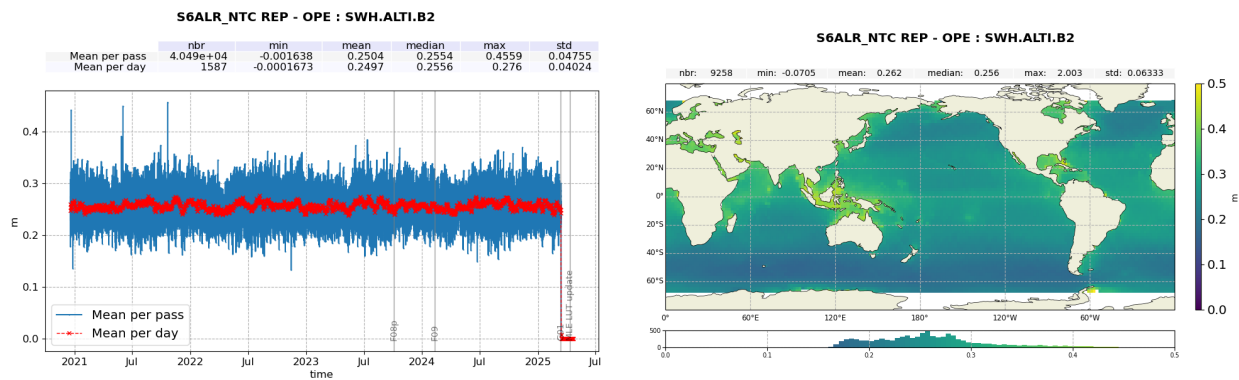


Figure 32: Monitoring (left) per day (red) and pass (blue), and map (right) of the reprocessed - operational C-band SWH difference.

6.1.2. Range

6.1.2.1. LR

The time monitoring of LR Ku-band range differences between reprocessed and operational datasets over the full period is shown in figure 33, and the corresponding distributions in figure 34. Several jumps are visible:

- +1.2 mm at the side A/B switch (Sept. 2021) for both time series, caused by the external path delay being different between sides in PB F08 but set to the Side B value for both Side A and Side B in the ground processing
- +1.9 mm in LR NR at the PB F09 update (Feb. 2024) due to an offset introduced in that baseline
- -7 mm and -1.2 mm in MLE4 and NR respectively at the PB G01 update (Feb. 2025), linked to the update of the external path delay and, in LR MLE4 only, an erroneous LUT update.
- +2 mm in LR MLE4 at the MLE4 LUT correction update (Mar. 2025)

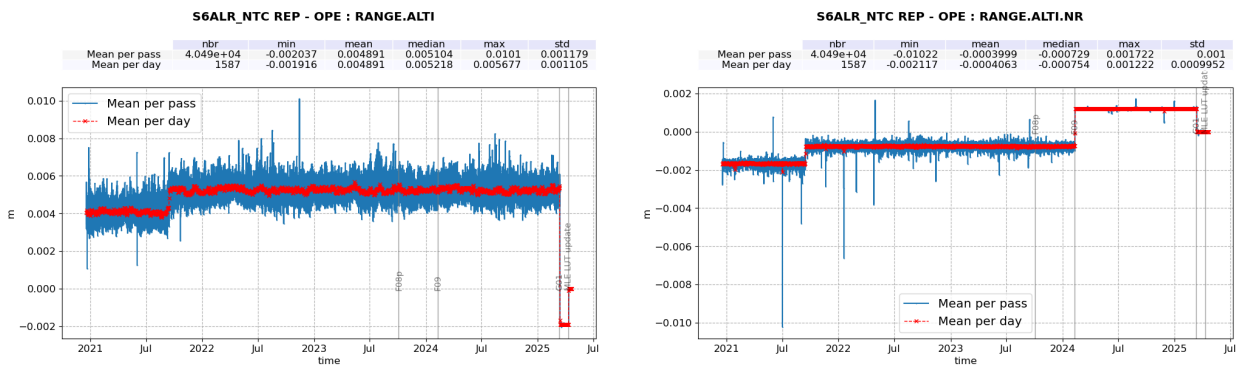


Figure 33: Time monitoring of the reprocessed minus operational Sentinel-6 MF Ku-band range (m) by pass (blue) and day (red) for LR MLE4 (left) and LR NR (right).

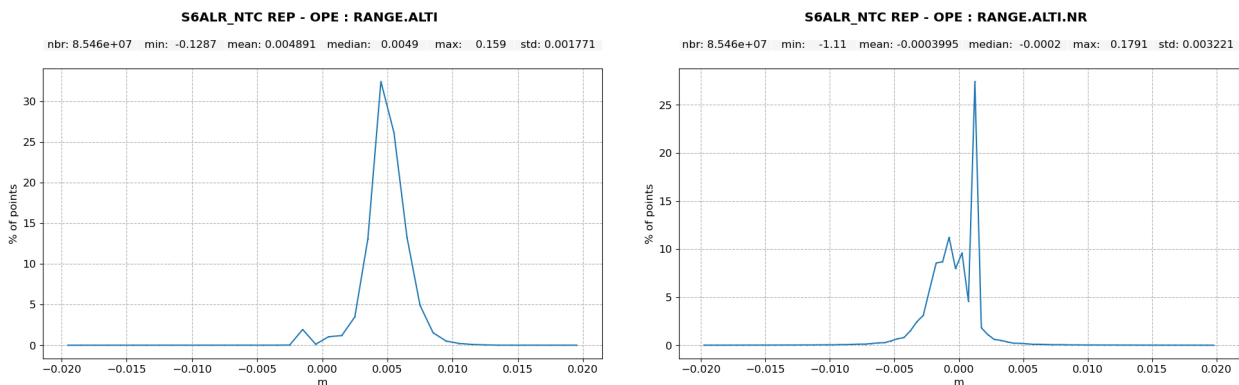


Figure 34: Distributions of Sentinel-6 MF LR range differences between reprocessed and operational datasets for LR MLE4 (left) and LR NR (right).

The maps of LR range differences are presented in figure 35. The LR MLE4 map shows SWH-correlated patterns, explained by the SWH-dependent MLE4 LUT update designed to correct the wave dependence of the NR - MLE4 difference. In the LR NR map, zones of high MSS gradient stand out, for a reason still under investigation.

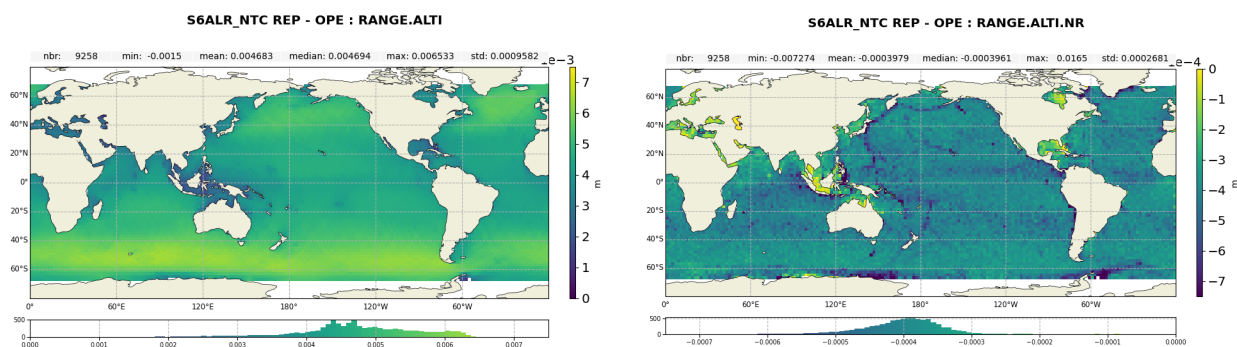


Figure 35: Maps of LR range differences (reprocessed - operational) for LR MLE4 (left) and LR NR (right).

6.1.2.2. HR

Time monitoring of HR range differences is presented in figure 36, and the corresponding distributions in figure 37. In HR SAMOSA, drifts associated with the range-walk correction are visible until PB F09 (introduction of range walk, producing a -2 mm jump). These drifts, slightly different between sides A and B and showing "M-shaped" patterns linked to the beta-prime angle, were already known (Dinardo 2022 [12]). This longer time series enables a better estimation of the drifts: 1.09 mm/year on side A and 0.97 mm/year on side B (figure 38), although they are not strictly linear. On both SAMOSA and NR curves, a -1.2 mm jump is visible at the PB G01 update due to the external path delay update.

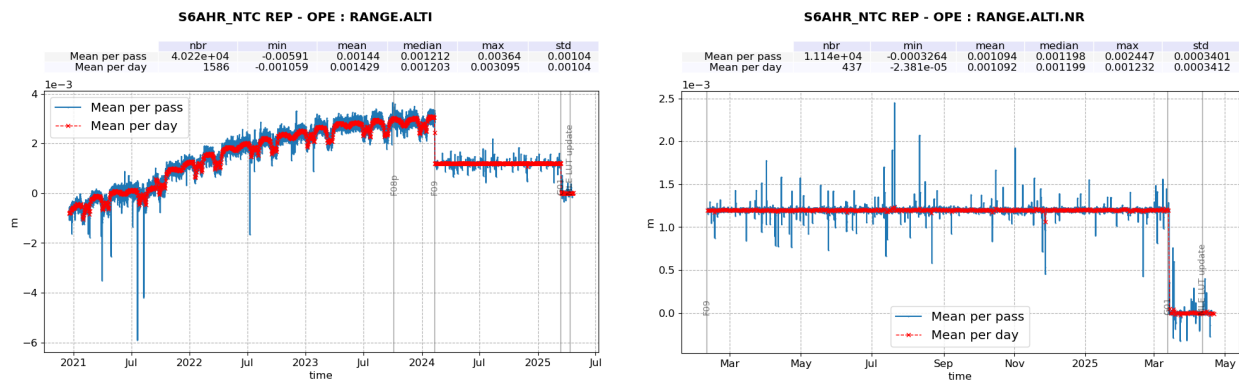


Figure 36: Time monitoring of the reprocessed minus operational Sentinel-6 MF Ku-band range (m) by pass (blue) and day (red) for HR SAMOSA (left) and HR NR (right).

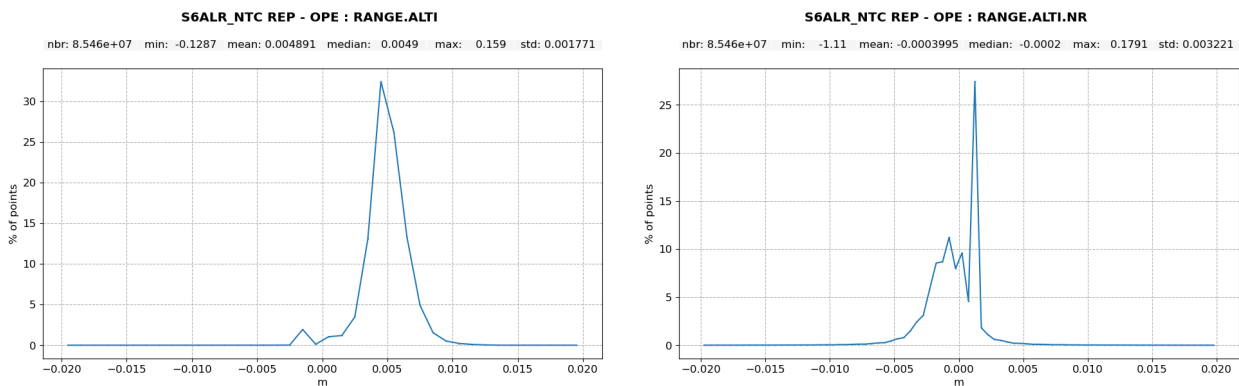


Figure 37: Distributions of Sentinel-6 MF HR range differences between reprocessed and operational datasets for HR SAMOSA (left) and HR NR (right).

The HR range maps are presented in figure 39. No specific pattern is visible.

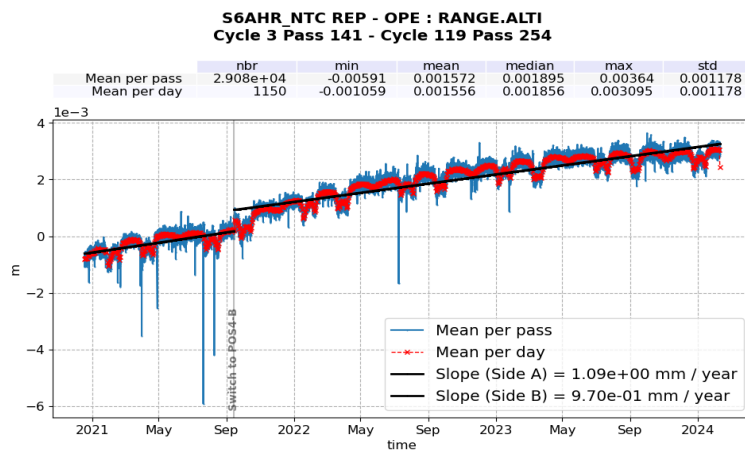


Figure 38: Time monitoring of G01 minus F08 Sentinel-6 MF Ku-band range for HR SAMOSA, with estimated slopes for sides A and B.

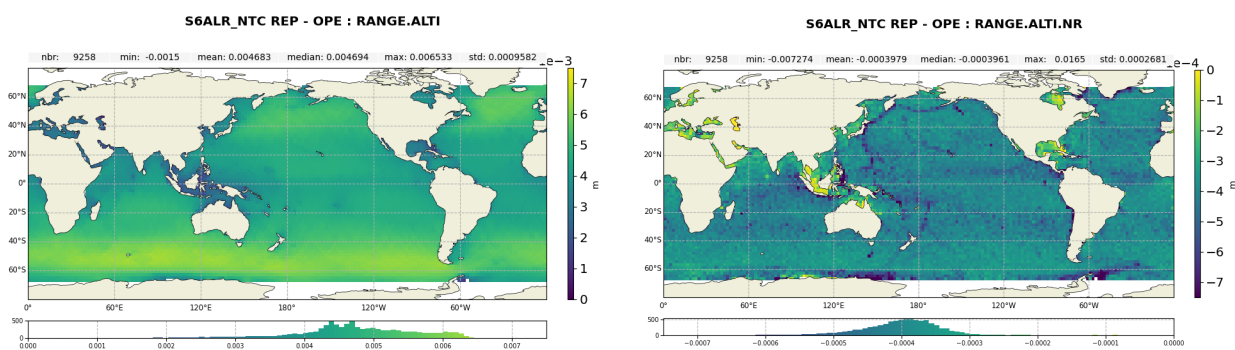


Figure 39: Maps of HR range differences (reprocessed - operational) for HR SAMOSA (left) and HR NR (right).

6.1.2.3. Inter-retrackers comparisons

Monitoring of range differences between retrackers (NR - MLE4/SAMOSAs and HR - LR), as well as their SWH correlations, is presented in figure 40. The MLE4 LUT update brings significant improvements: LR MLE4 is fully consistent with LR NR in G01 (cyan curve, top-right panel). The SWH correlation of its difference with HR SAMOSA (cyan curve, bottom-right panel) is also reduced. In the top-left panel, no long-term trend is visible on side B for LR MLE4 - LR NR and HR SAMOSA - HR NR. However, zooming in on LR MLE4 - LR NR (figure 41) reveals a long-term effect on side B as well, first decreasing until April 2023, then increasing. The drift is well correlated to the PTR side-lobe evolutions [15] with a noticeable change in the difference between left and right side-lobes in January 2023. Both MLE4 and LR NR use the same external path delay, making the difference between MLE4 and LR NR, the external path delay contribution cancels out and its impact is then null. The HR SAMOSA - HR NR difference (orange curve, top-left panel) is too noisy for detailed analysis.

In both cases, a jump is visible at the side A/B switch. For the jump is linked to the fact that MLE4 is using the same LUT for both side-A and side-B and this MLE4 LUT has been re-computed using side-B data only. Strictly, MLE4 should use two different LUTs : one for side A (computed with side-A data) and one for side-B (computed with side-B data) since the PTR of side-A and side-B are different in shape. For HR it is caused by the SAMOSA alpha-p LUT, which is the same for both sides while should be a different LUT per side.

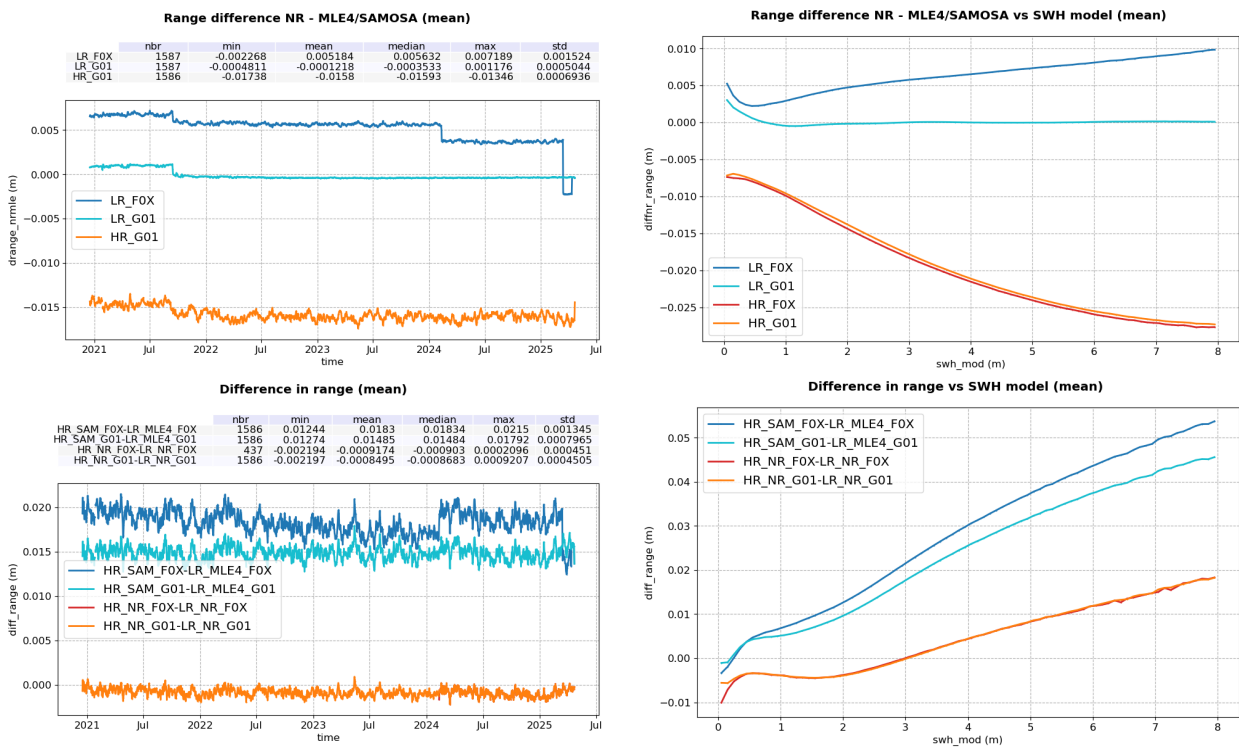


Figure 40: Time monitoring (left) and ERA5 SWH dependency (right) of Sentinel-6 MF Ku-band range differences: NR - MLE4/SAMOSAs (top) and HR - LR (bottom).

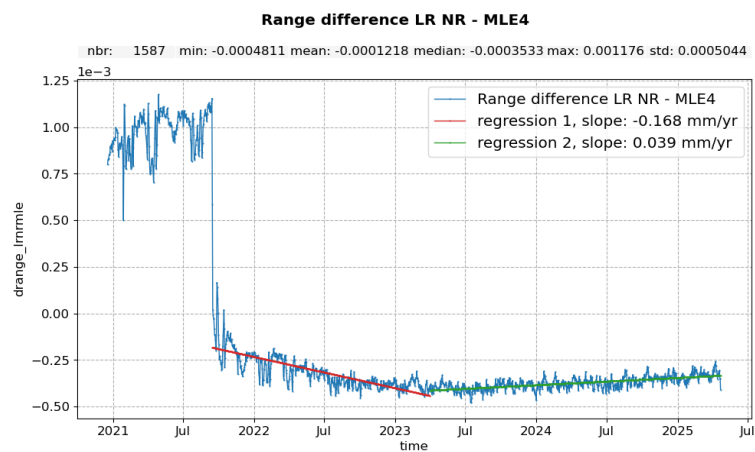


Figure 41: Time monitoring of LR MLE4 - LR NR Sentinel-6 MF Ku-band range difference.

6.1.2.4. LR C-band

Figure 42 presents the time series of the reprocessed minus operational LR C-band range and the corresponding map. Jumps occur at the side B switch (external path delay) and at the G01 update (external path delay update and MLE3 LUT update).

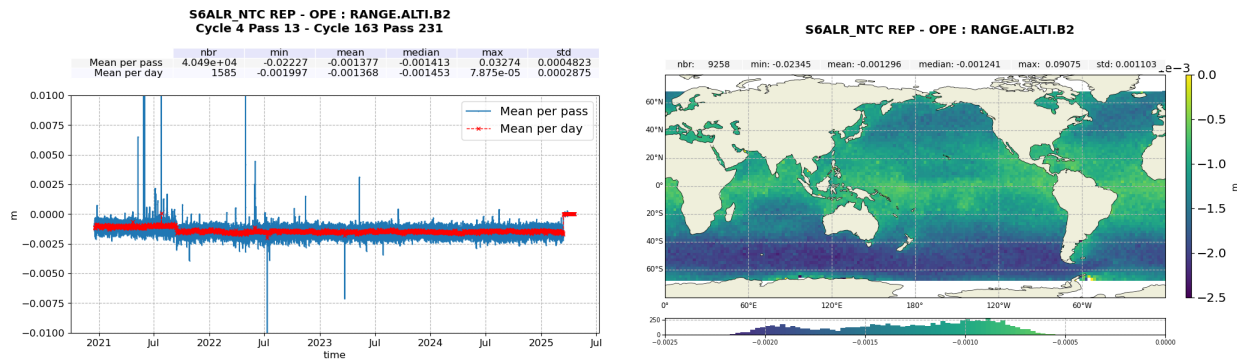


Figure 42: Monitoring (left) per day (red) and pass (blue), and map (right) of the reprocessed - operational C-band range difference.

6.1.3. Backscatter coefficient

6.1.3.1. LR

The time monitoring of the differences in LR Ku-band sigma0 between reprocessed and operational datasets over the complete reprocessing period is presented in figure 43, and their distributions in figure 44. Several jumps are visible:

- -0.04 dB at the side A/B switch due to a g -scaling difference between sides, for both MLE4 and NR,
- -0.91 dB at the PB F09 update due to the total power definition update for MLE4,
- +0.02 dB and +0.04 dB at the PB G01 update in MLE4 and NR respectively, composed of -0.02 dB from the LUT update (MLE4 only) and +0.04 dB from the g -scaling update.

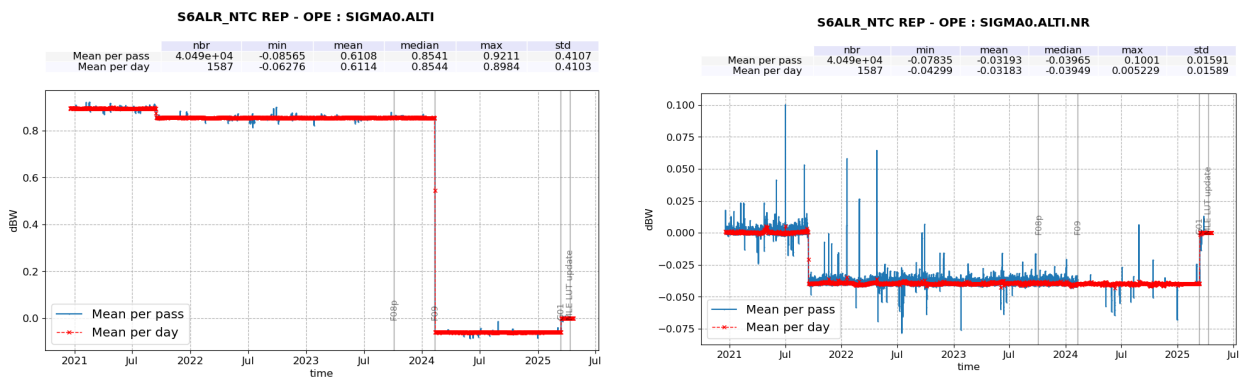


Figure 43: Time monitoring of the reprocessed minus operational Sentinel-6 MF Ku-band sigma0 in dB by pass (blue) and day (red) for LR MLE4 (left) and LR NR (right).

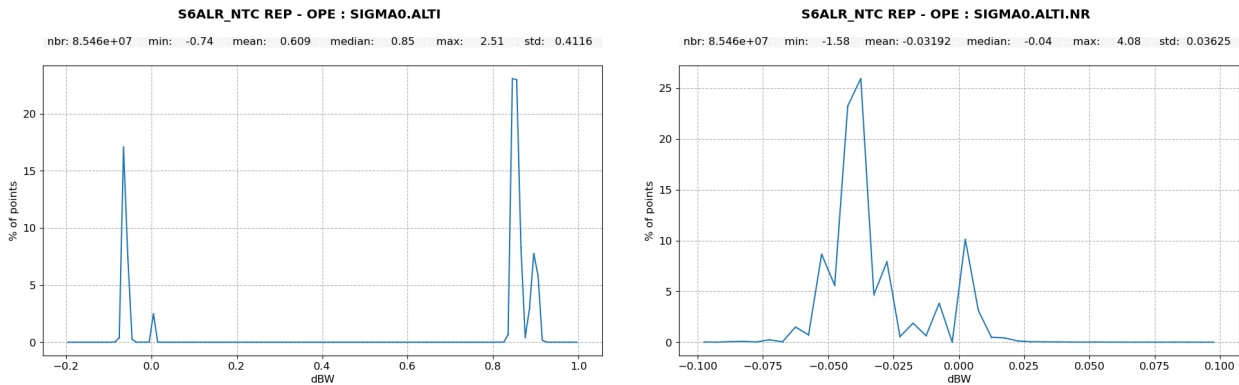


Figure 44: Distributions of Sentinel-6 MF sigma0 differences between reprocessed and operational datasets for LR MLE4 (left) and LR NR (right).

When comparing G01 reprocessed data to G01 operational data only, several passes show extremely small yet unexpected differences of about 0.01 dB (figure 45). The impacted passes are: cycle 160 tracks 134, 158, 159, 163, 164, 165, and cycle 161 tracks 102 and 103. This effect impacts all LR and HR retracers, is visible in sigma0 related parameters such as wind speed and SSB, and remains under investigation.

The maps of the differences between reprocessed and operational datasets are shown in figure 46. In both retracers, the Caspian Sea presents a distinct offset compared to the open ocean, which is still under investigation. In MLE4, no clear pattern emerges outside polar regions. In NR, wet areas show larger differences, due to the F09 update which improved NR retracers in cases of peaky waveforms.

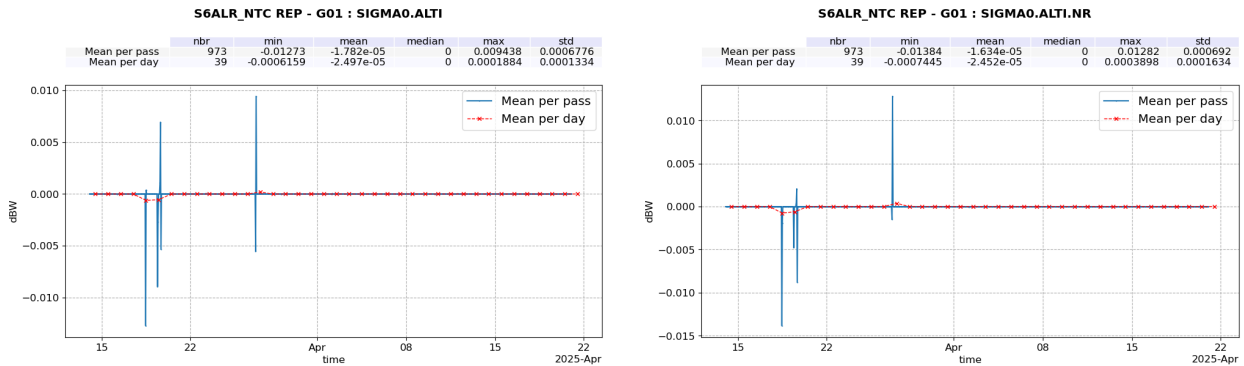


Figure 45: Time monitoring of the G01 reprocessed minus G01 operational Sentinel-6 MF Ku-band sigma0 in dB by pass (blue) and day (red) for LR MLE4 (left) and LR NR (right).

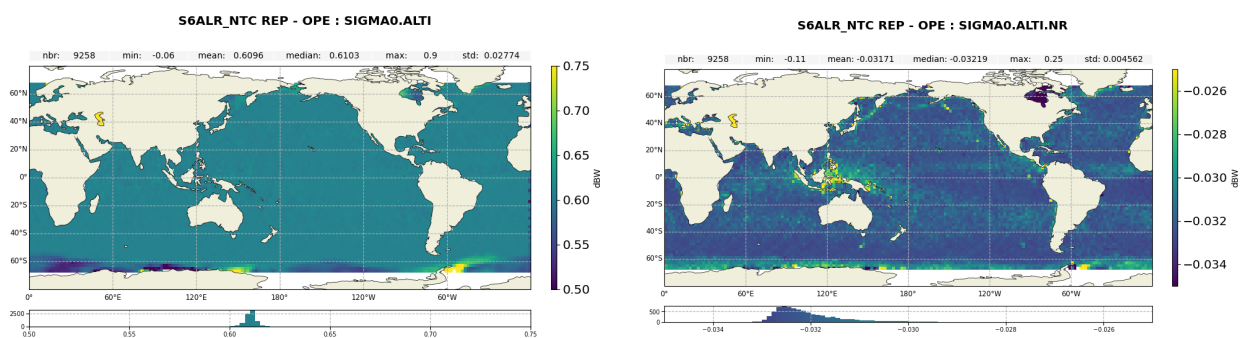


Figure 46: Maps of the LR sigma0 reprocessed minus operational datasets for LR MLE4 (left) and LR NR (right).

6.1.3.2. HR

The time monitoring of the differences in HR sigma0 between reprocessed and operational datasets over the complete reprocessing period is presented in figure 47, and their distributions in figure 48. In HR SAMOSA, several jumps are visible:

- -0.04 dB at the side A/B switch due to a g -scaling difference between sides,
- +6.14 dB at the PB F09 update due to the sigma0 computation correction,
- +0.04 dB at the PB G01 update due to the g -scaling update, also visible in HR NR.

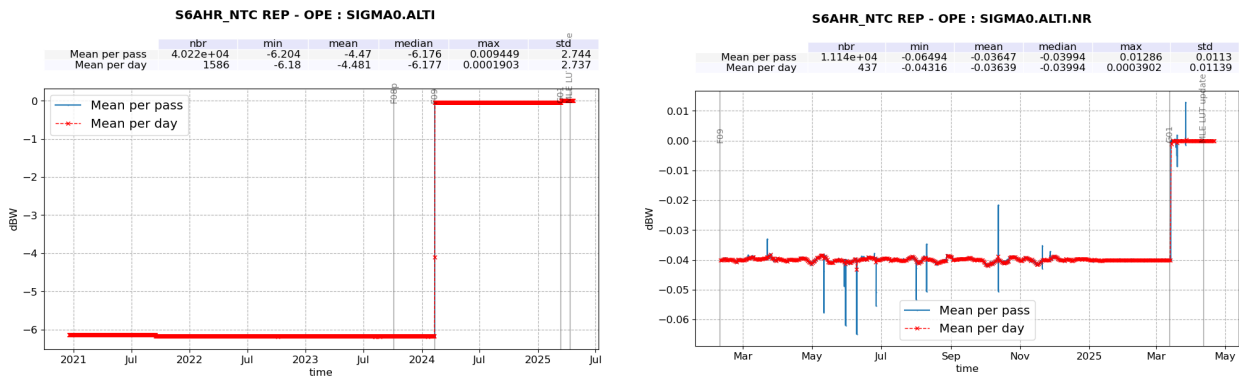


Figure 47: Time monitoring of the reprocessed minus operational Sentinel-6 MF Ku-band sigma0 in dB by pass (blue) and day (red) for HR SAMOSA (left) and HR NR (right).

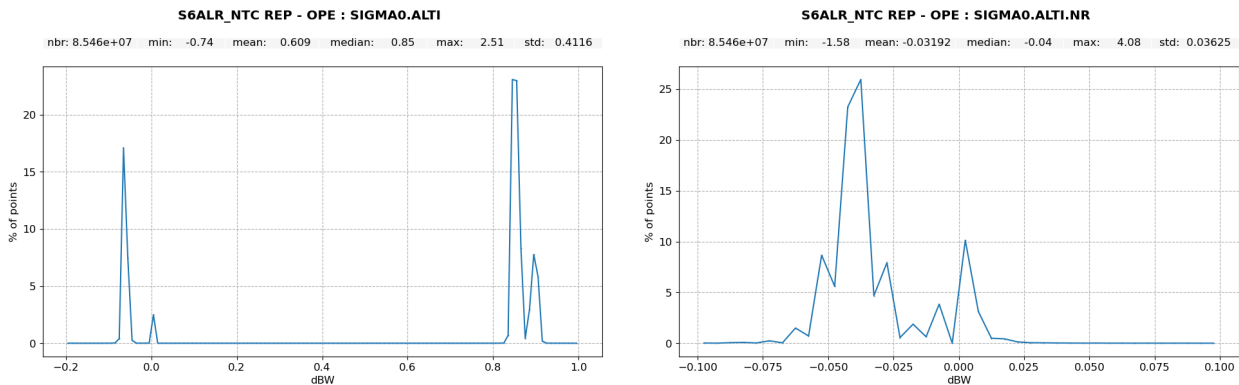


Figure 48: Distributions of Sentinel-6 MF sigma0 differences between reprocessed and operational datasets for HR SAMOSA (left) and HR NR (right).

The maps of the differences between reprocessed and operational datasets are shown in figure 49. No clear geographical pattern is visible outside polar regions.

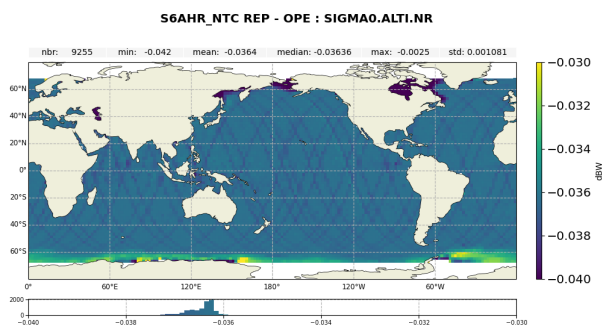
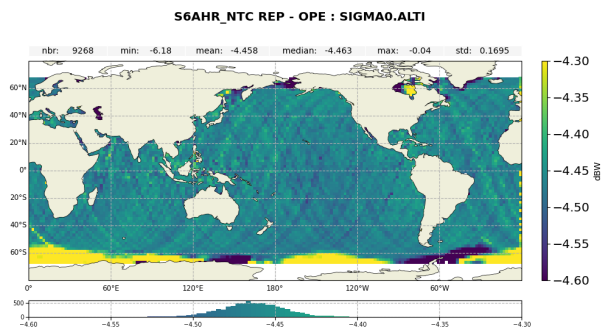


Figure 49: Maps of the HR sigma0 reprocessed minus operational datasets for HR SAMOSA (left) and HR NR (right).

6.1.3.3. Inter-retrackers comparisons

The monitoring of sigma0 differences between retrackers (NR - MLE4 and HR - LR) and their correlations with SWH is shown in figure 50. Only reprocessed time series are displayed, as the operational sigma0 contains multiple offsets that mask more subtle behaviours. The mean bias between HR SAMOSA and HR NR is -0.13 dB, with an increase of about 0.02 dB over the full mission. The LR NR - LR MLE4 time series (zoom figure 51), has a smaller increase of +0.005 dB. As for range (section 6.1.2.3.), these drifts can be linked to PTR ageing (evolution of the PTR side-lobes), which is accounted in an approximated way in MLE4 and SAMOSA retrackerers. The LR NR - LR MLE4 noticeable slope change in 2023 is also visible in the difference between left and right side-lobes [15]. The almost monthly oscillations are thermally-driven and linked and in synchronous with sun beta prime angle. Additionally, LR MLE4 and LR NR are perfectly aligned in G01 (cyan curve in the top-right panel of figure 50), as expected.

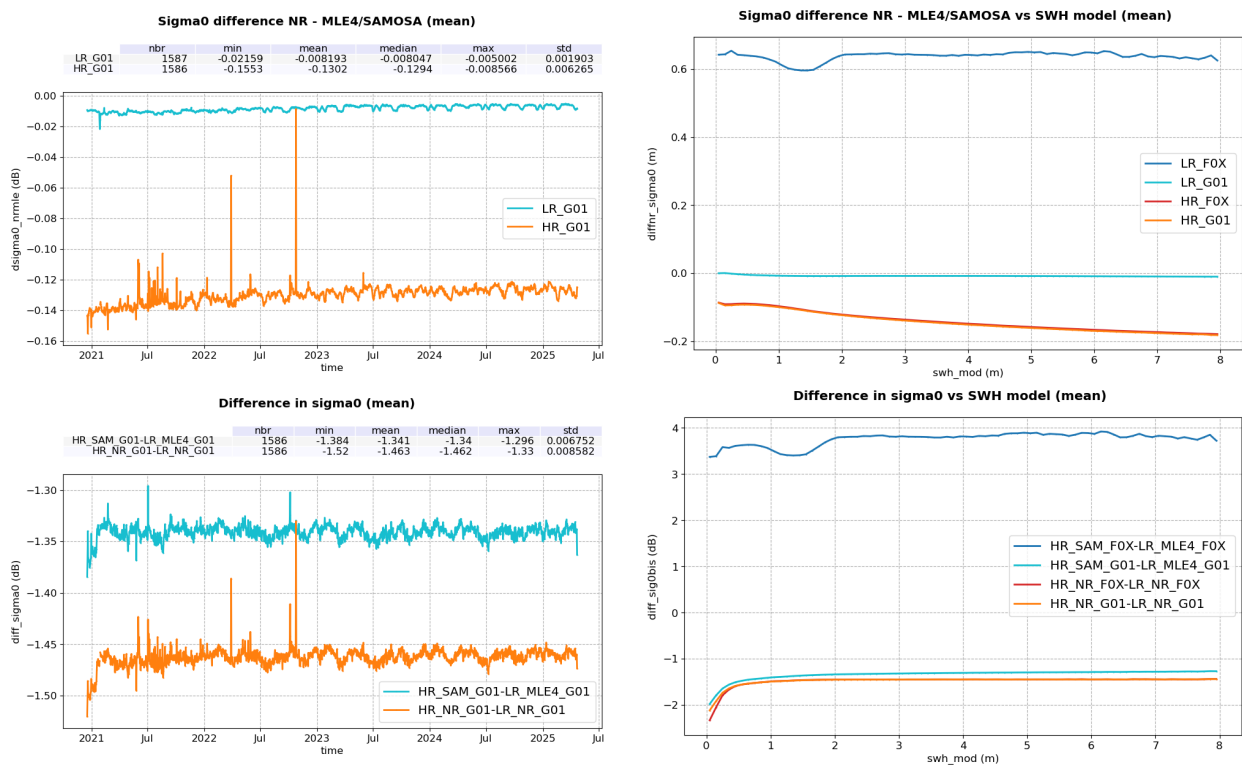


Figure 50: Time monitoring (left) and ERA5 model SWH dependence (right) of Sentinel-6 MF Ku-band sigma0 differences: NR - MLE4/SAMOSA (top) and HR - LR (bottom).

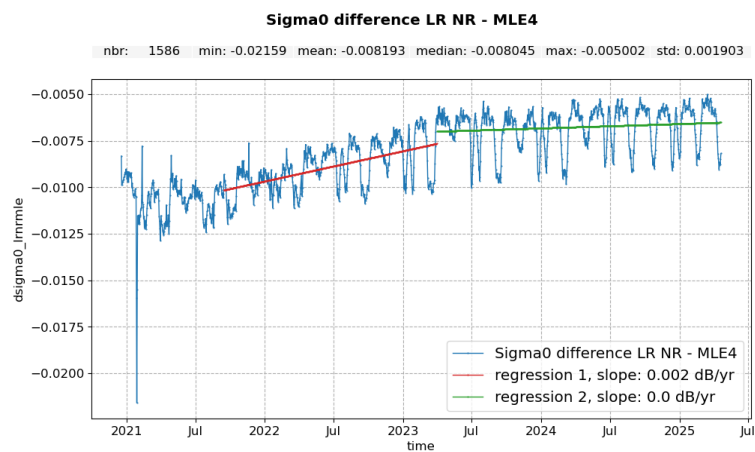


Figure 51: Time monitoring of Sentinel-6 MF Ku-band sigma0 difference: LR NR - LR MLE4.

6.1.3.4. LR C-band

Figure 52 shows the time series of the reprocessed minus operational LR C-band sigma0 and the corresponding map. The -0.91 dB jump at the F09 update is caused by the change in the total power definition. No geographical pattern is visible.

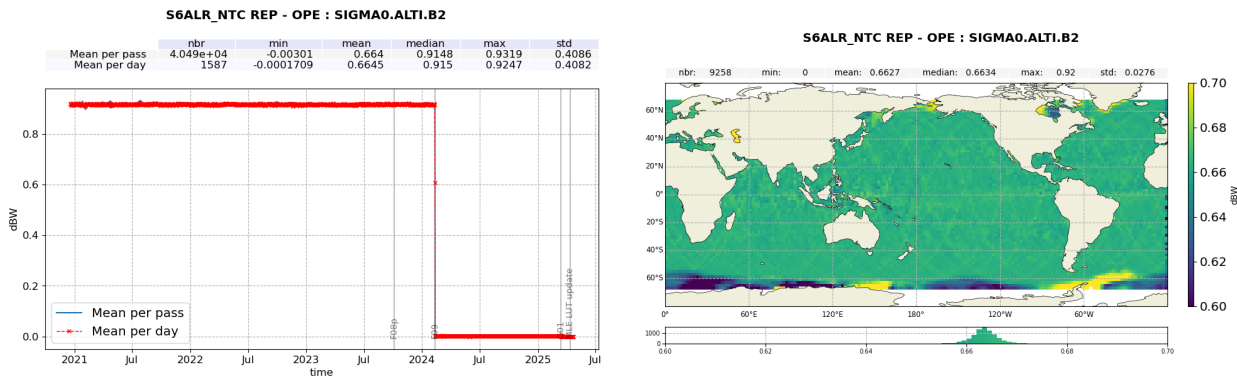


Figure 52: Monitoring (left) per day (red) and pass (blue), and map (right) of the reprocessed minus operational C-band sigma0 difference.

6.1.4. Altimeter Wind Speed

6.1.4.1. LR

The time monitoring of the differences in LR Ku-band wind speed between reprocessed and operational datasets over the complete reprocessing period is presented in figure 53, and their distributions in figure 54. Several jumps are visible in the time series:

- +10 cm/s at the side A/B switch due to calibration bias and g -scaling changes, visible in both MLE4 and NR.
- +1.5 cm/s at the F09 update due to the total power correction in the sigma0 computation (MLE4 only).
- +23 cm/s and +27 cm/s in MLE4 and NR respectively at the G01 update due to the MLE4 LUT update (MLE4 only) and g -scaling update in sigma0 (MLE4 and NR).

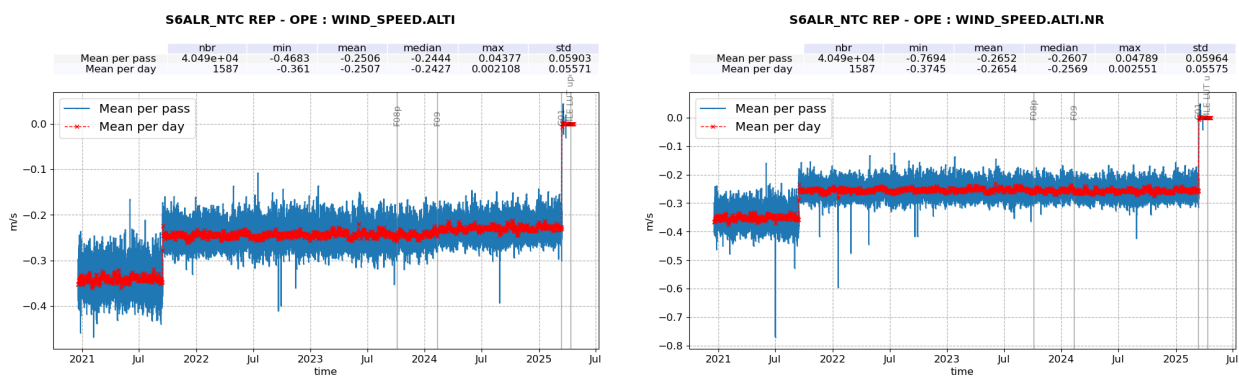


Figure 53: Time monitoring of the reprocessed minus operational Sentinel-6 MF Ku-band wind speed by pass (blue) and by day (red) for LR MLE4 (left) and LR NR (right).

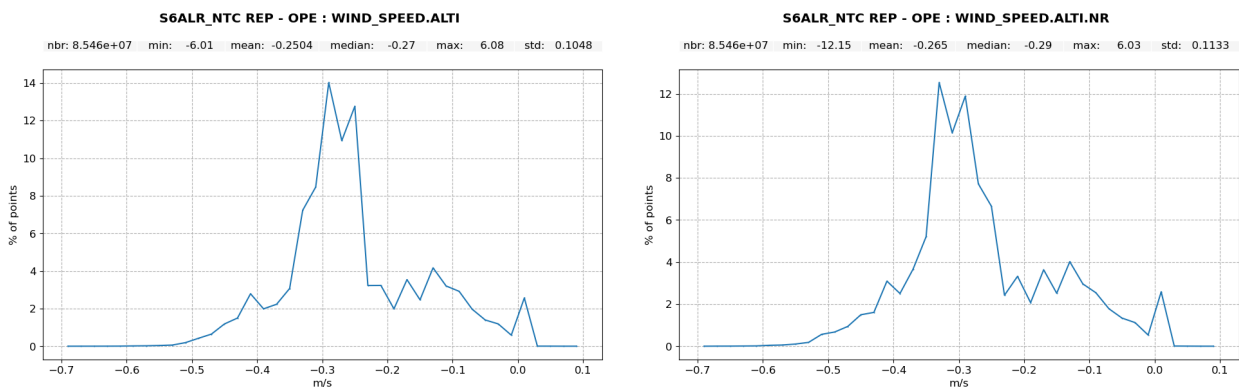


Figure 54: Distributions of Sentinel-6 MF wind speed differences between reprocessed and operational datasets for LR MLE4 (left) and LR NR (right).

Maps of wind speed differences between reprocessed and operational datasets are shown in figure 55.

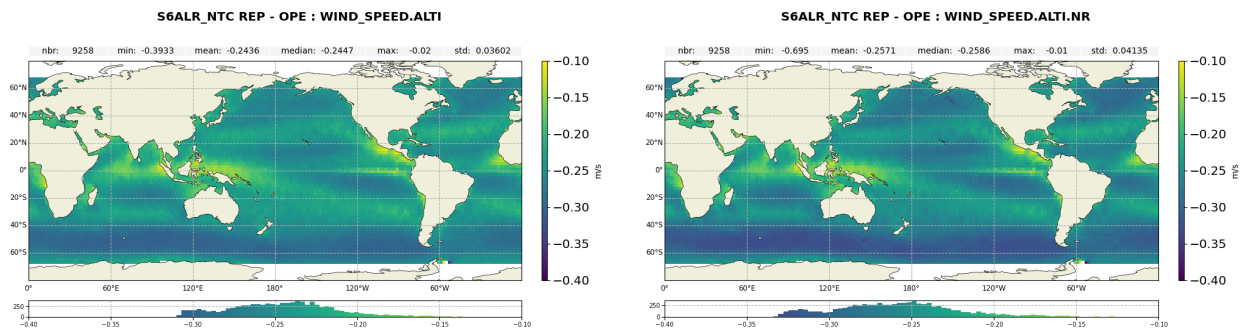


Figure 55: Maps of LR wind speed differences (reprocessed minus operational) for LR MLE4 (left) and LR NR (right).

6.1.4.2. HR

The time monitoring of HR wind speed differences between reprocessed and operational datasets over the complete reprocessing period is presented in figure 56, and their distributions in figure 57. A jump of +20 cm/s and +16 cm/s for SAMOSA and NR, respectively, is visible at the G01 update and is linked to the *g*-scaling update in sigma0.

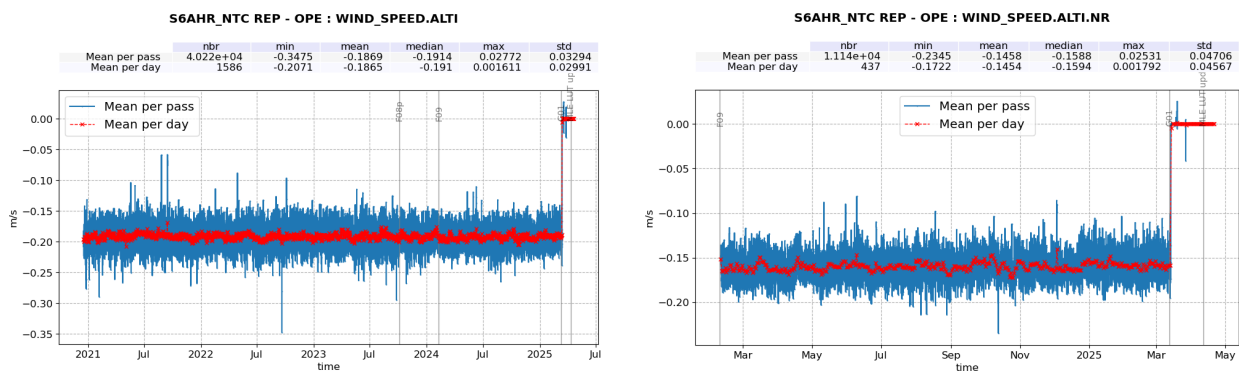


Figure 56: Time monitoring of the reprocessed minus operational Sentinel-6 MF Ku-band wind speed by pass (blue) and by day (red) for HR SAMOSA (left) and HR NR (right).

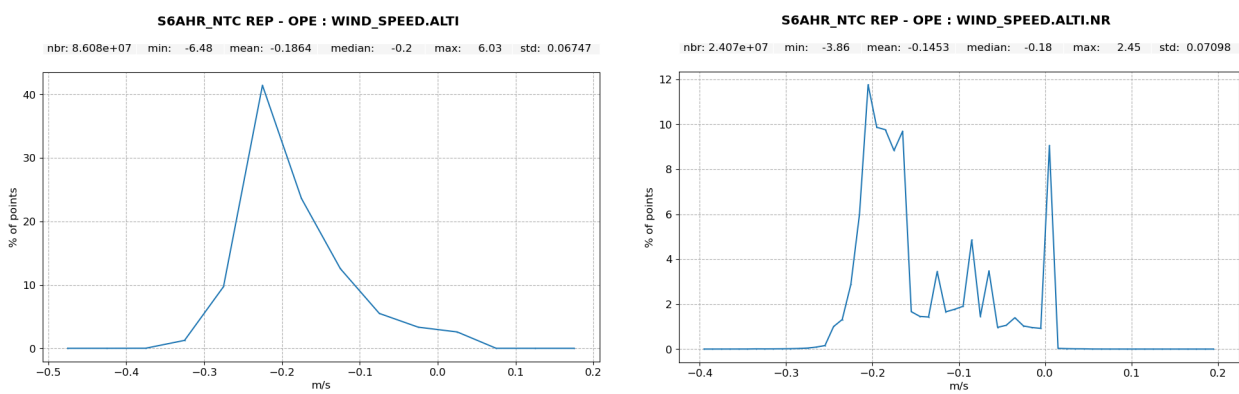


Figure 57: Distributions of Sentinel-6 MF wind speed differences between reprocessed and operational datasets for HR SAMOSA (left) and HR NR (right).

Maps of wind speed differences are shown in figure 58.

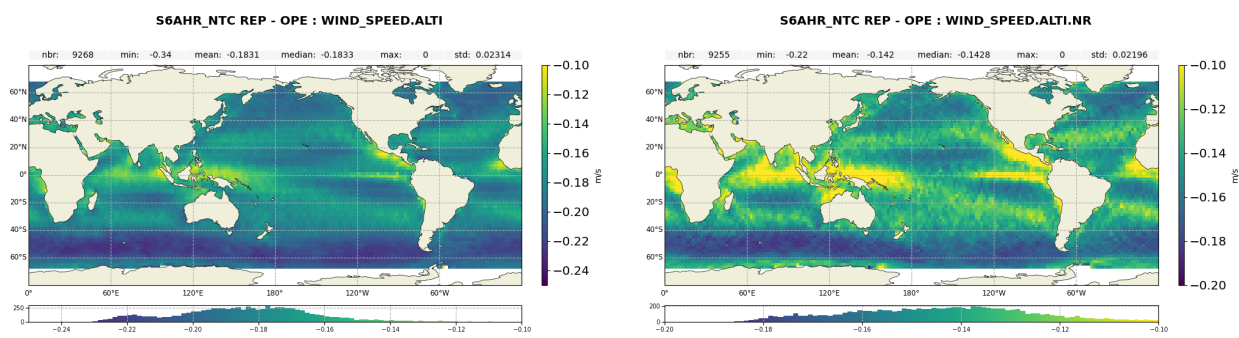


Figure 58: Maps of HR wind speed differences (reprocessed minus operational) for HR SAMOSA (left) and HR NR (right).

6.1.4.3. Inter-retrackers comparisons

Monitoring of wind speed differences between retrackers (NR - MLE4/SAMOSA and HR - LR), as well as their correlations to SWH, is presented in figure 59. In the HR - LR time series (bottom-left panel), a jump is visible on 2021-01-18 across all curves. This results from a star-tracker update that impacted HR and LR wind speed differently through sigma0: HR retrackers do not estimate mispointing from the waveform, unlike LR retrackers. Thanks to the MLE4 LUT update in G01, LR MLE4 wind speed is now fully aligned with LR NR and shows a reduced correlation with SWH compared to HR SAMOSA (cyan curves in the top-right and bottom-right panels). The bias between HR NR and LR NR in G01 (orange curves in the bottom panels) is also significantly reduced, from -9.4 cm/s to 0.7 cm/s.

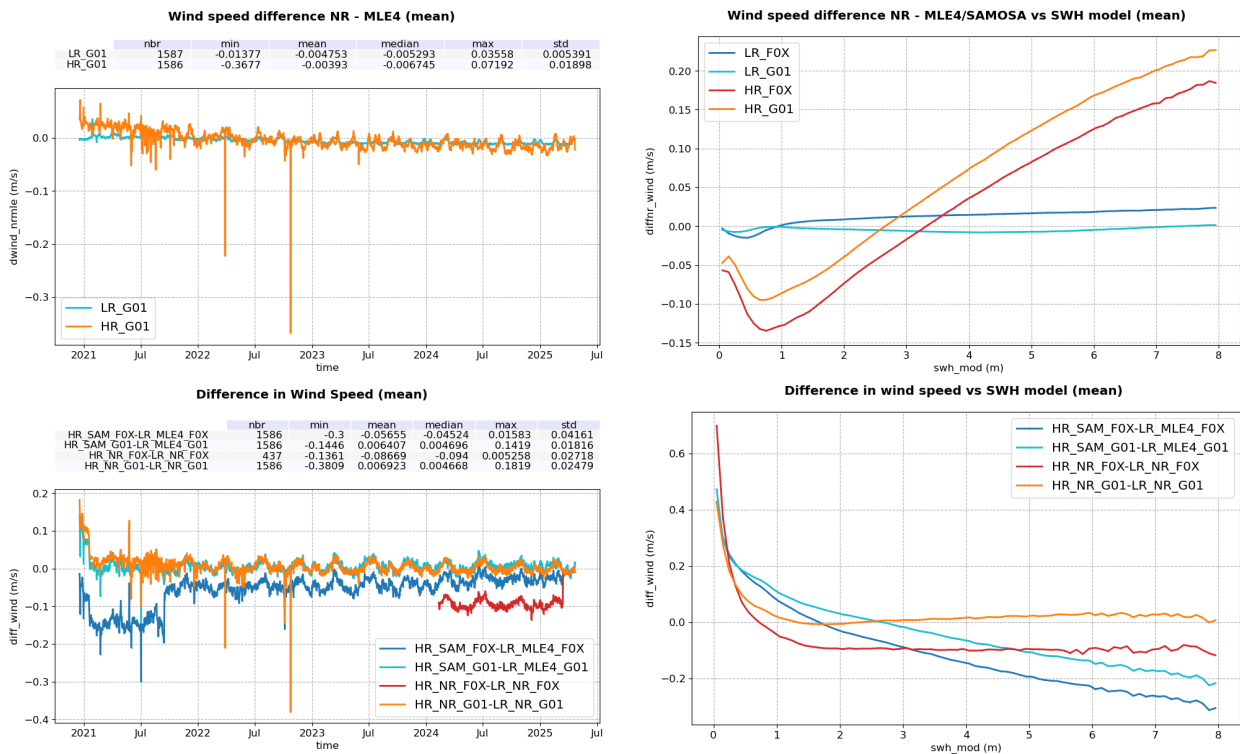


Figure 59: Time monitoring (left) and ERA-5 model SWH dependency (right) of Sentinel-6 MF Ku-band wind speed differences: NR - MLE4/SAMOSA (top) and HR - LR (bottom).

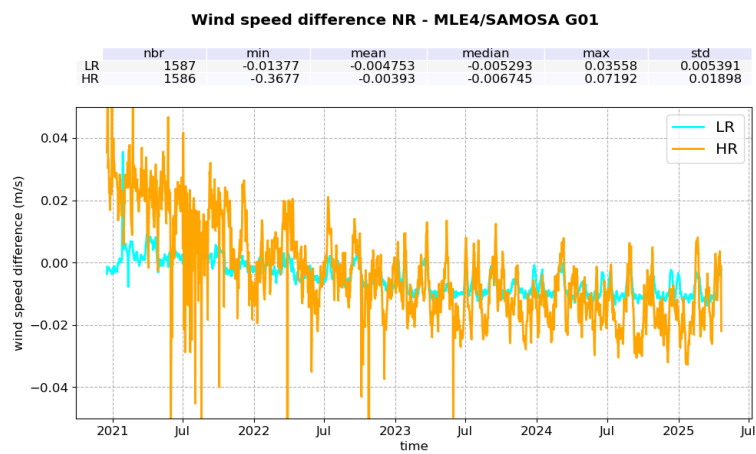


Figure 60: Time monitoring of the Sentinel-6 MF Ku-band wind speed difference: NR - MLE4/SAMOSA.

6.1.4.4. Comparison to ECMWF model

The daily monitoring of the comparison between altimeter-derived wind speed and the ECMWF model is presented in figure 61. In LR (left panel), NR and MLE4 reprocessed datasets are aligned, and their biases decrease from 31.8 and 32.5 cm/s respectively to 6.8 and 6.5 cm/s in G01. Similarly, HR biases (right panel) decrease from 25.2 and 18.3 cm/s to 6.5 and 6.0 cm/s for HR SAMOSA and HR NR, respectively. Apart from these improvements, the time series remain stable. Figure 62 presents the daily monitoring of the standard deviation to the model. The standard deviation is lower in G01 for all retrackerers : from 1.45 and 1.46 m/s in MLE4 and NR to 1.44 m/s, and from 1.38 to 1.35 m/s in SAMOSA. HR NR comparison cannot be made as the time coverage is very different between operational and reprocessed time series.

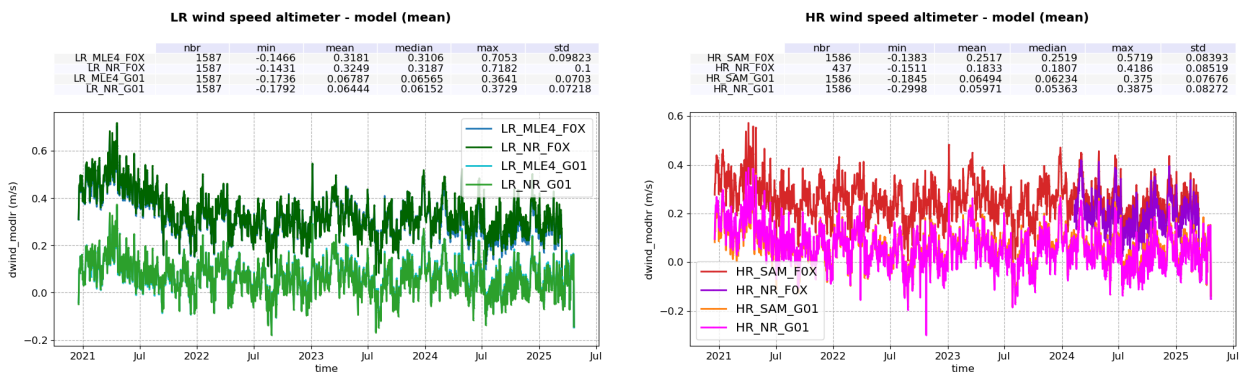


Figure 61: Time monitoring of Sentinel-6 MF altimeter - ECMWF model wind speed differences (m/s), in LR (left) and HR (right).

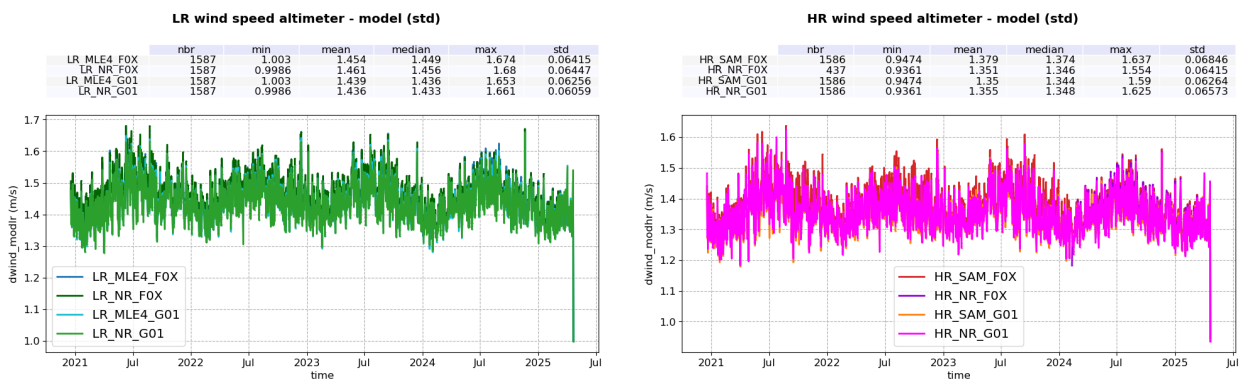


Figure 62: Time monitoring of Sentinel-6 MF altimeter - ECMWF model wind speed differences (m/s), in LR (left) and HR (right).

6.1.5. Sea State Bias

6.1.5.1. LR

The time series of differences in the LR Ku-band Sea State Bias (SSB) between reprocessed and operational datasets over the full reprocessing period is shown in Figure 63, and the corresponding distributions in Figure 64. In LR MLE4, two jumps of approximately -1.5 mm are visible in the time series: one at the side A/B switch and another at the PB G01 update. In LR NR, three jumps can be observed: -0.2 mm at the side A/B switch, -0.4 mm at the F08p update (due to the small-waves correction in LR NR), and -0.7 mm at the G01 update.

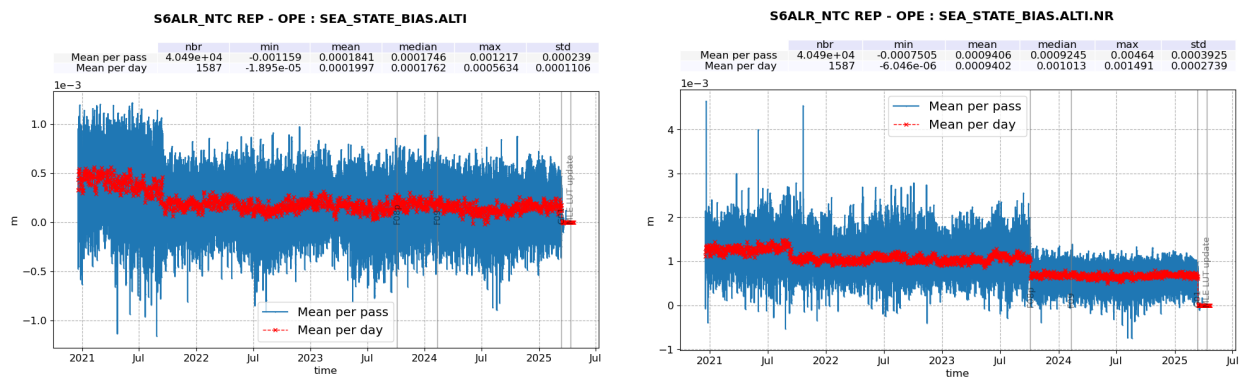


Figure 63: Time monitoring of the reprocessed minus operational Sentinel-6 MF Ku-band Sea State Bias (meters) by pass (blue) and day (red) for LR MLE4 (left) and LR NR (right).

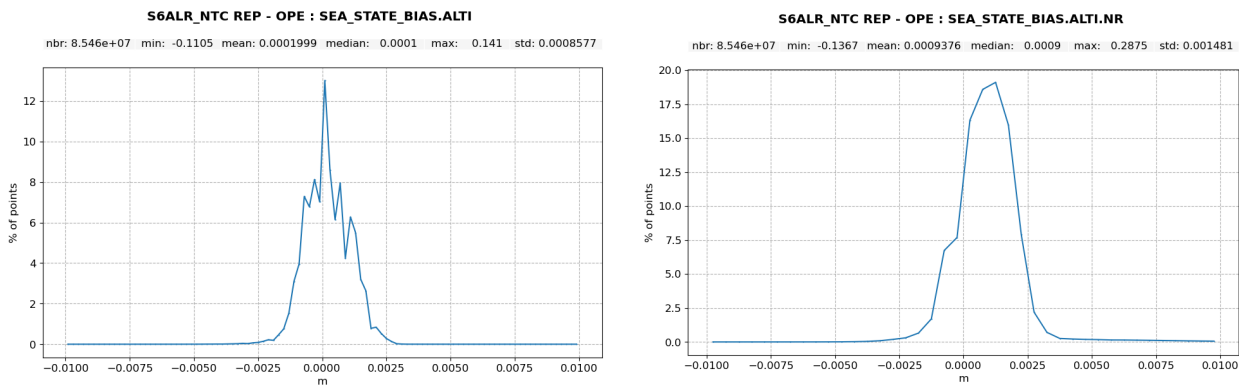


Figure 64: Distributions of SSB differences between reprocessed and operational datasets for LR MLE4 (left) and LR NR (right).

The maps of differences between reprocessed and operational datasets are presented in Figure 65. SWH-dependent patterns are visible for both retracker: in MLE4 due to the LUT update affecting SWH and sigma0, and in LR NR due to the small-waves patch introduced in F08p.

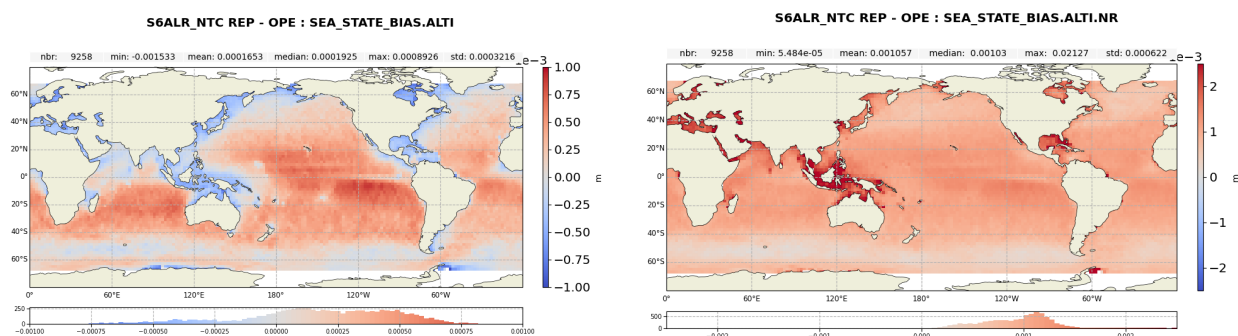


Figure 65: Maps of LR SSB differences (reprocessed minus operational) for LR MLE4 (left) and LR NR (right).

6.1.5.2. HR

The time series of HR SSB differences between reprocessed and operational datasets is shown in Figure 66, and their distributions in Figure 67. In HR SAMOSA, two jumps are visible: -1 mm at the F09 update and -6.5 mm at the G01 update. In HR NR, a -0.5 mm jump is observed at the G01 update.

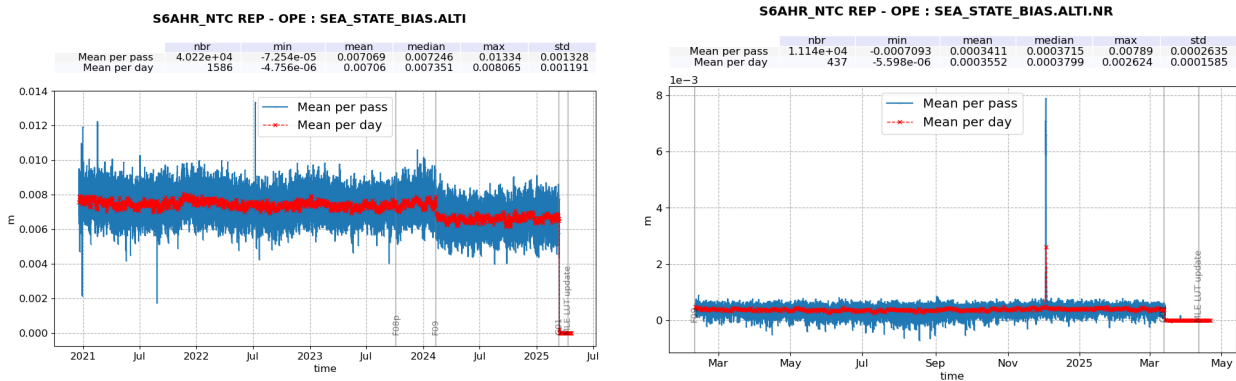


Figure 66: Time monitoring of reprocessed minus operational Sentinel-6 MF Ku-band SSB (meters) by pass (blue) and day (red) for HR SAMOSA (left) and HR NR (right).

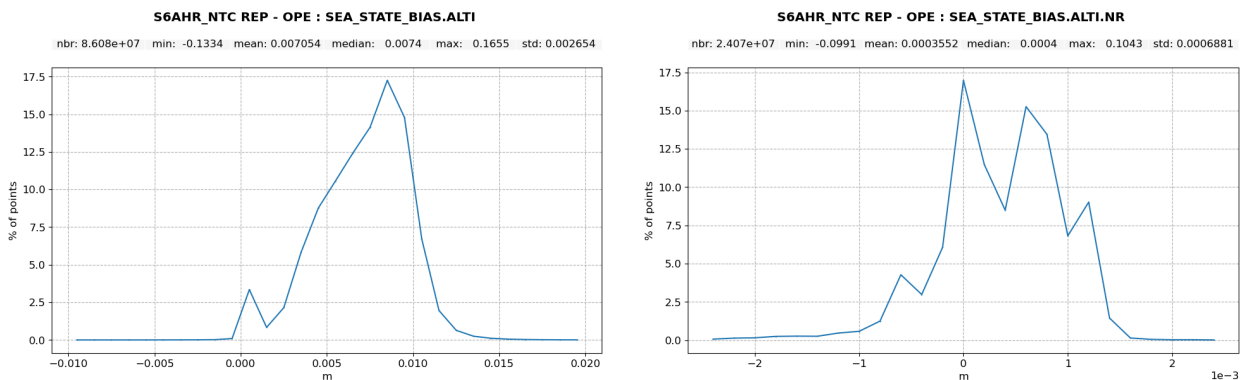


Figure 67: Distributions of HR SSB differences (reprocessed minus operational) for HR SAMOSA (left) and HR NR (right).

The maps of differences between reprocessed and operational datasets are displayed in Figure 68, showing patterns correlated with wind speed.

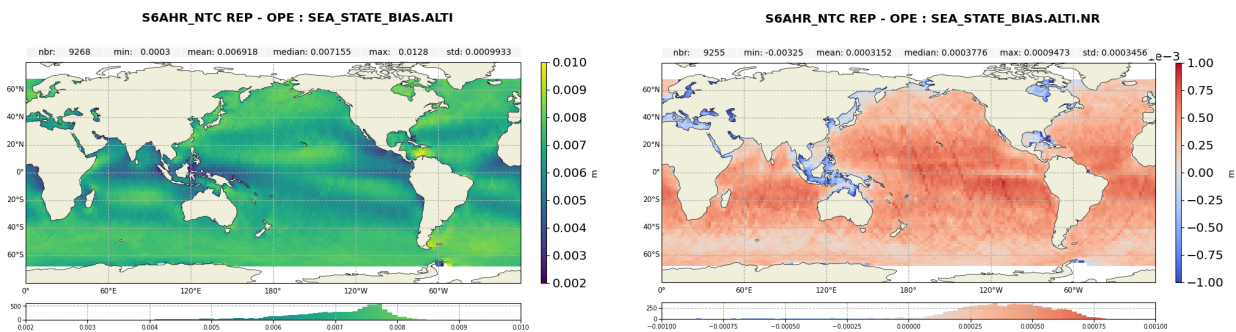


Figure 68: Maps of HR SSB differences (reprocessed minus operational) for HR SAMOSA (left) and HR NR (right).

6.1.5.3. Inter-retrackers comparisons

The monitoring of SSB differences between retrackers (NR - MLE4/SAMOSA and HR - LR), together with their correlation with SSB, is shown in Figure 69. For NR - MLE4/SAMOSA (top-left panel), both G01 curves follow the same variations, with a drift of about +0.5 mm throughout the side B period, linked to the PTR evolution accounted in an approximate way in MLE4 and SAMOSA. "M-shaped" patterns associated with the beta-prime angle are also visible in the LR NR - MLE4 differences, whereas the HR NR - SAMOSA time series is too noisy to clearly reveal them. The improvement linked to the MLE4 LUT update in G01 is clearly visible (cyan curves), with LR MLE4 becoming fully consistent with LR NR, and the SWH correlation in the MLE4 - SAMOSA difference being significantly reduced. HR NR is also more consistent with LR NR in G01 (orange curves in the top panels), showing a marked reduction in SWH dependence.

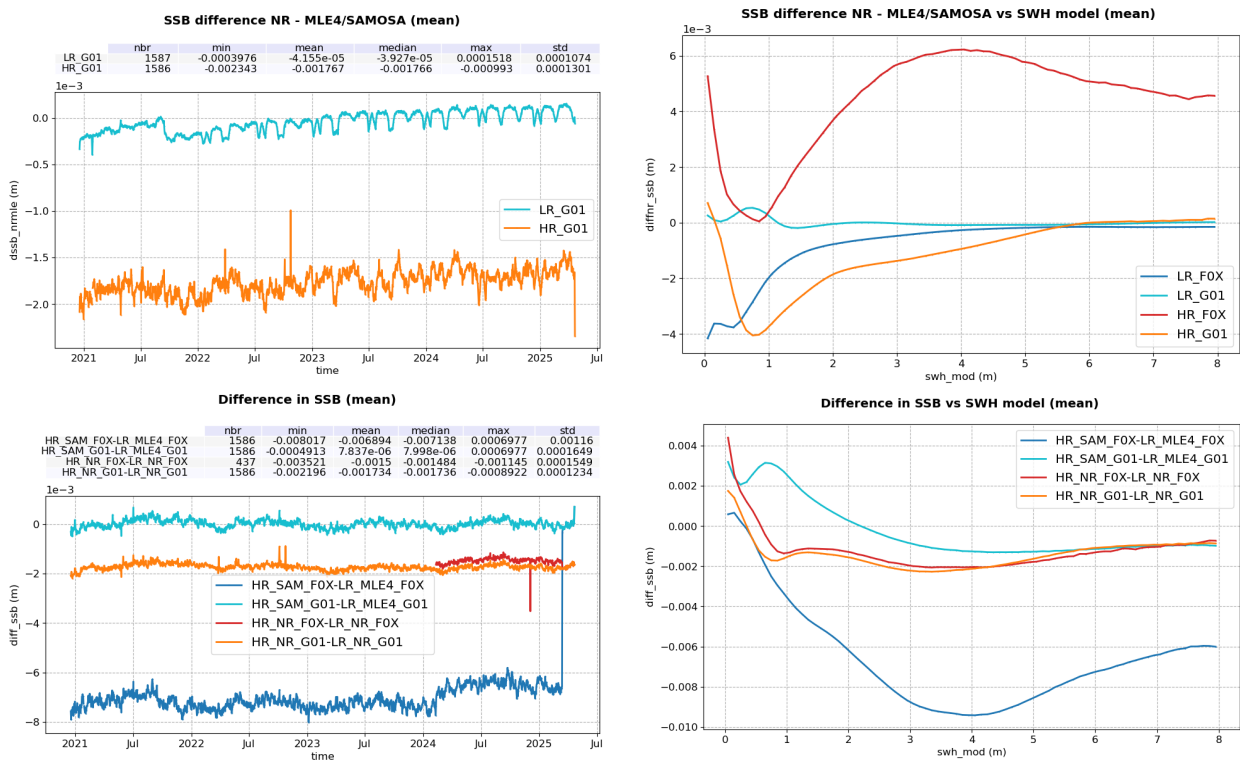


Figure 69: Time monitoring (left) and ERA5-model SSB dependency (right) of SSB differences: NR - MLE4/SAMOSA (top) and HR - LR (bottom).

6.1.6. Altimeter ionosphere correction

The Sentinel-6 MF altimeter ionospheric correction is derived from LR data, using both Ku- and C-band measurements. In HR products, the ionospheric correction is copied from the LR products and is therefore identical. In this section, the filtered ionospheric correction from the altimeter is analysed. The time monitoring of differences between the filtered ionospheric corrections from the reprocessed and operational datasets over the complete reprocessing period is shown in figure 70. In MLE4, small jumps are visible at the side A/B switch (+0.5 mm), at the PB G01 update (-1.7 mm) and at the MLE4 LUT update (+0.4 mm). In NR, jumps are visible at the side A/B switch (+0.3 mm), at the PB F09 update (+0.4 mm) and at the PB G01 update (-0.4 mm).

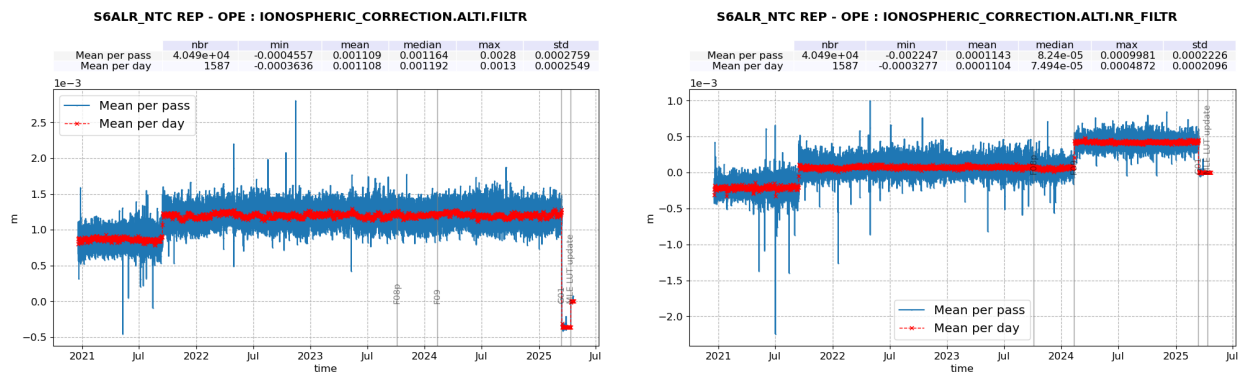


Figure 70: Time monitoring of the reprocessed minus operational Sentinel-6 MF Ku-band filtered ionospheric correction in meters by pass (blue) and day (red) for LR MLE4 (left) and LR NR (right).

Figure 71 shows the daily monitoring of the NR - MLE4 filtered ionospheric correction difference. The G01 time series is much more stable than that of the operational dataset, with only a -0.25 mm jump at the side A/B switch. This jump comes from MLE4 retracker and is linked to the side-B-computed LUT being applied on side A. On side B, LR MLE4 and LR NR are fully consistent.

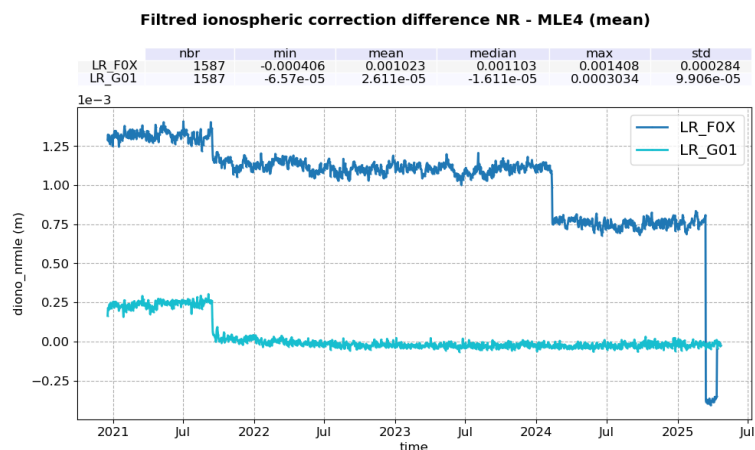


Figure 71: Time monitoring of the NR - MLE4 filtered ionospheric correction difference per day in cm.

The reprocessed Sentinel-6 MF altimeter ionospheric corrections show a similar bias to the GIM model correction (1.2 cm) as their operational counterparts. All time series follow identical variations. An upward trend is visible, caused by an imprecise scaling of the GIM ionospheric correction with solar activity (as seen on figure 73). Spikes observed in 2024 and 2025 are linked to anomalies in the GIM correction caused by solar storms.

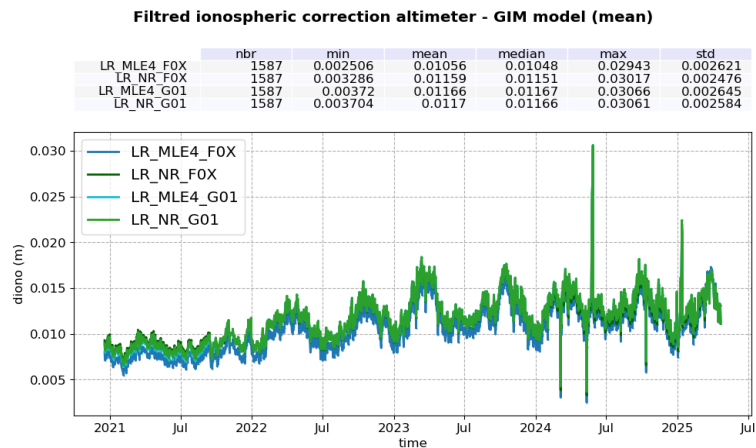


Figure 72: Time monitoring of the Sentinel-6 MF ionospheric correction difference: Altimeter Filtered minus GIM model (m) per day.

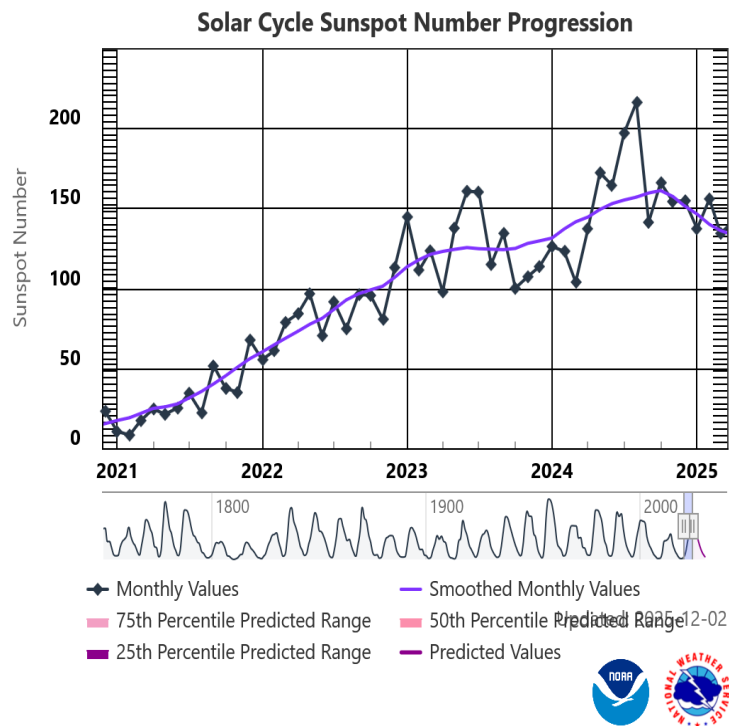


Figure 73: Solar cycle sunspot number progression on the reprocessing time period. Figure from the NOAA Space Weather Prediction Center.

6.1.7. Mispointing

In this section, the square of the off-nadir angle derived from LR waveforms using MLE4 and NR retrackers is analysed. The time monitoring of differences in LR Ku-band mispointing between reprocessed and operational datasets over the complete reprocessing period is shown in figure 74, and the corresponding maps are presented in figure 75. In MLE4, the time series is stable except for a +0.0044° jump linked to the MLE4 LUT update. This LUT update is correlated with SWH, which explains the SWH-dependent pattern visible on the map. In NR, the daily mean is identical between both datasets, but the pass-by-pass mean differs during the F08 operational period. This is due to the improvement of LR NR mispointing in the presence of peaky waveforms introduced in PB F09. This also explains why the largest differences on the map are found in wet, polar and coastal areas, where waveform degradation is more likely.

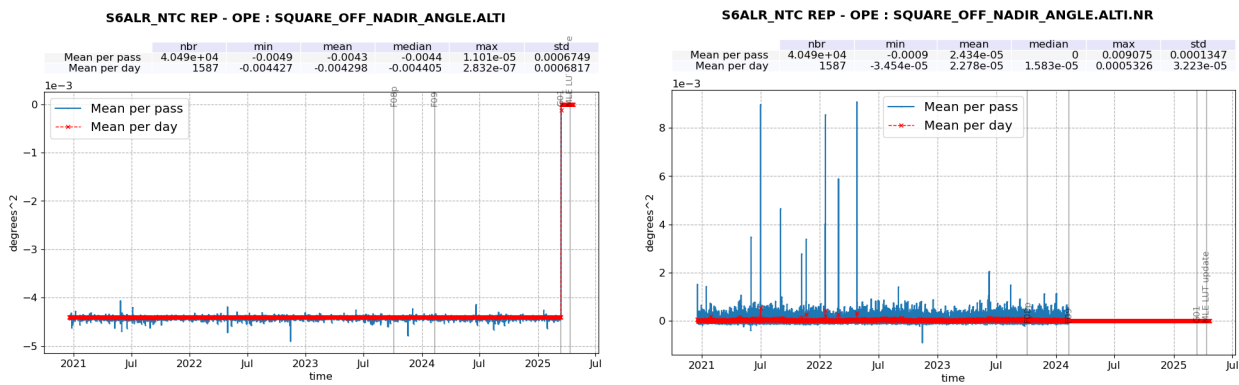


Figure 74: Time monitoring of the reprocessed minus operational Sentinel-6 MF Ku-band mispointing by pass (blue) and day (red) for LR MLE4 (left) and LR NR (right).

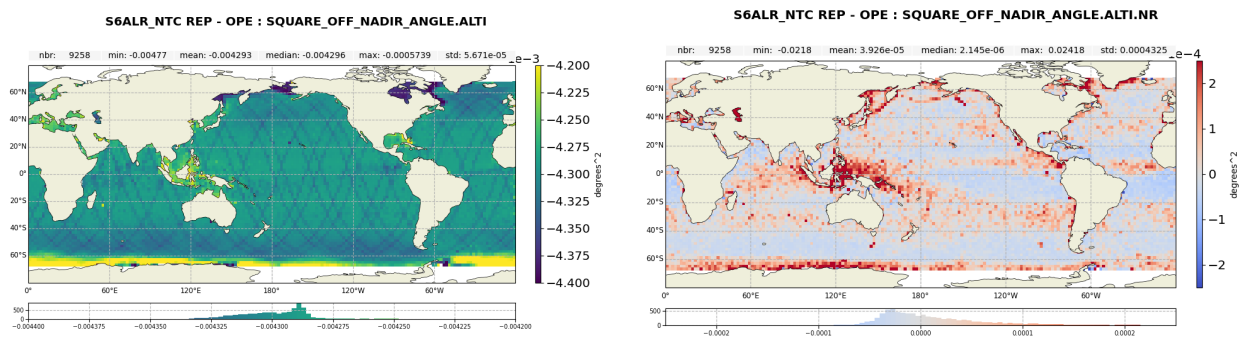


Figure 75: Maps of LR mispointing differences (reprocessed minus operational) for LR MLE4 (left) and LR NR (right).

6.2. Wet tropospheric correction from radiometer

6.2.1. Differences between operational and reprocessed WTC

The mean difference between operational and reprocessed WTC is shown in figure 76 (left panel). Differences range from -2 to 2 mm per day, with long-term variations. From 2025-01-13 (cycle 154, pass 8), corresponding to the introduction of the current radiometer coefficient values, the differences converge to zero. The map of these differences, displayed in the right panel of figure 76, shows very small differences (about 0.1 mm) in coastal and polar areas.

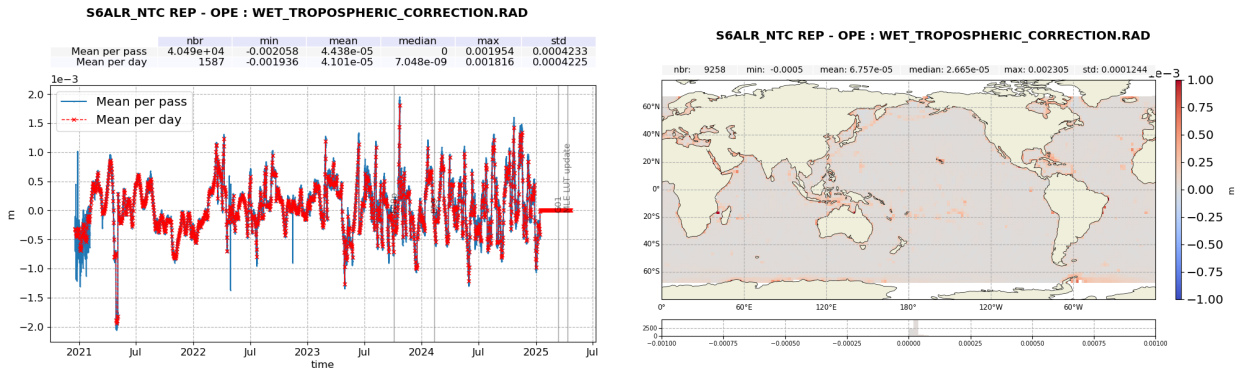


Figure 76: Monitoring (*left*) per day (red) and per pass (blue), and map (*right*) of the reprocessed minus operational LR WTC difference.

6.2.2. Differences between radiometer and model WTC

Monitoring the differences between radiometer and model WTC highlights any jump or drift between the two retrievals and is presented in figure 77. The mean-difference curves show similar variations for both operational and reprocessed datasets, except for the two drifts described in the previous section. Three phases are visible, induced by two events (figure 77, left panel):

- On 27-28 April 2021 (cycle 17), a -6 mm jump is observed in the bias, preceded by a progressive increase starting in early March 2021 of similar amplitude. The jump coincides with a satellite restart. Its amplitude is about 1 mm larger in the reprocessed dataset. A possible link between the restart and this jump is under investigation.
- On 13 October 2021 (cycle 34), a +2 mm jump is observed. This event is linked to an update in the ECMWF model (see [9] for details).

The corresponding maps (figure 78) are visually identical between the reprocessed and operational datasets, as expected.

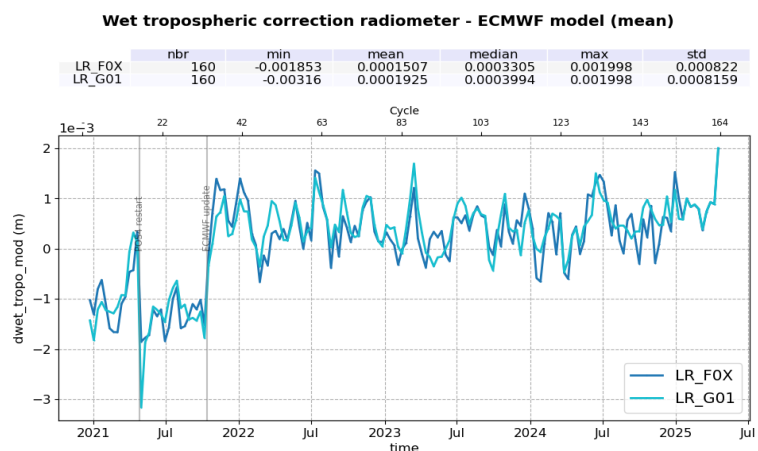


Figure 77: Time monitoring of wet tropospheric correction difference (m): radiometer WTC minus ECMWF model WTC (cyclic mean).

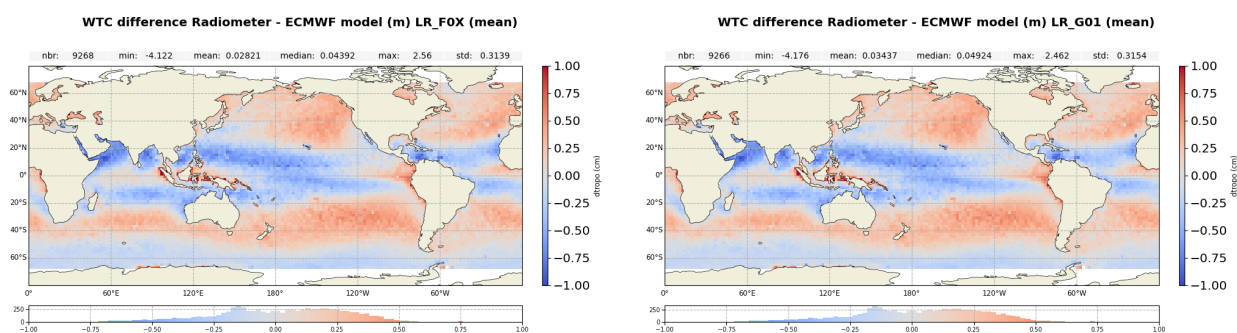


Figure 78: Map of WTC difference (radiometer minus ECMWF model, in meters) for the Sentinel-6 MF operational dataset (**left**) and reprocessed dataset (**right**). Computed over the complete reprocessing period.

7 Mission performance

7.1. Sea Level Performance

The Sea Surface Height Anomaly (SSHA) is the most well-known parameter derived from satellite altimetry. It corresponds to the elevation of the sea surface relative to a reference Mean Sea Surface (MSS) and reflects oceanic variability and climatic phenomena (such as the Gulf Stream, El Niño, etc.). It is computed as follows:

$$SSHA = Orbit - Altimeter\ range - \sum(GeophysicalCorrections) - Mean\ Sea\ Surface$$

The details of the geophysical corrections are provided in the Sentinel-6 ALT Level-2 Product Generation Specification [10].

7.1.1. LR

The monitoring of Sentinel-6 MF LR SSHA is shown in figure 79. For both retrackers, the two curves show a slight divergence over the full period. This behaviour is confirmed in figure 80, with drifts of -0.4 mm/yr and -0.9 mm/yr in MLE4 and NR respectively. It is consistent with the jumps observed in the range (see section 6.1.2.1.). The standard deviation is slightly lower for the NR reprocessed dataset (10.4 cm vs 10.5 cm in the operational dataset), while it is similar in MLE4. Table 9 summarizes biases between reprocessed and operational SSHA, as well as their main contributors.

Parameter	LR MLE4	LR NR
Orbit	-2 mm [11]	
Range	4.9 mm	-0.4 mm
SSB	0.2 mm	0.9 mm
Iono	1.1 mm	0.1 mm
MSS	-0.9 mm	
SSHA	-7.3 mm	-1.7 mm

Table 8: LR SSHA biases and main contributors between reprocessed and operational datasets

Maps of LR SSHA are presented in figure 81. No significant differences are visible between datasets.

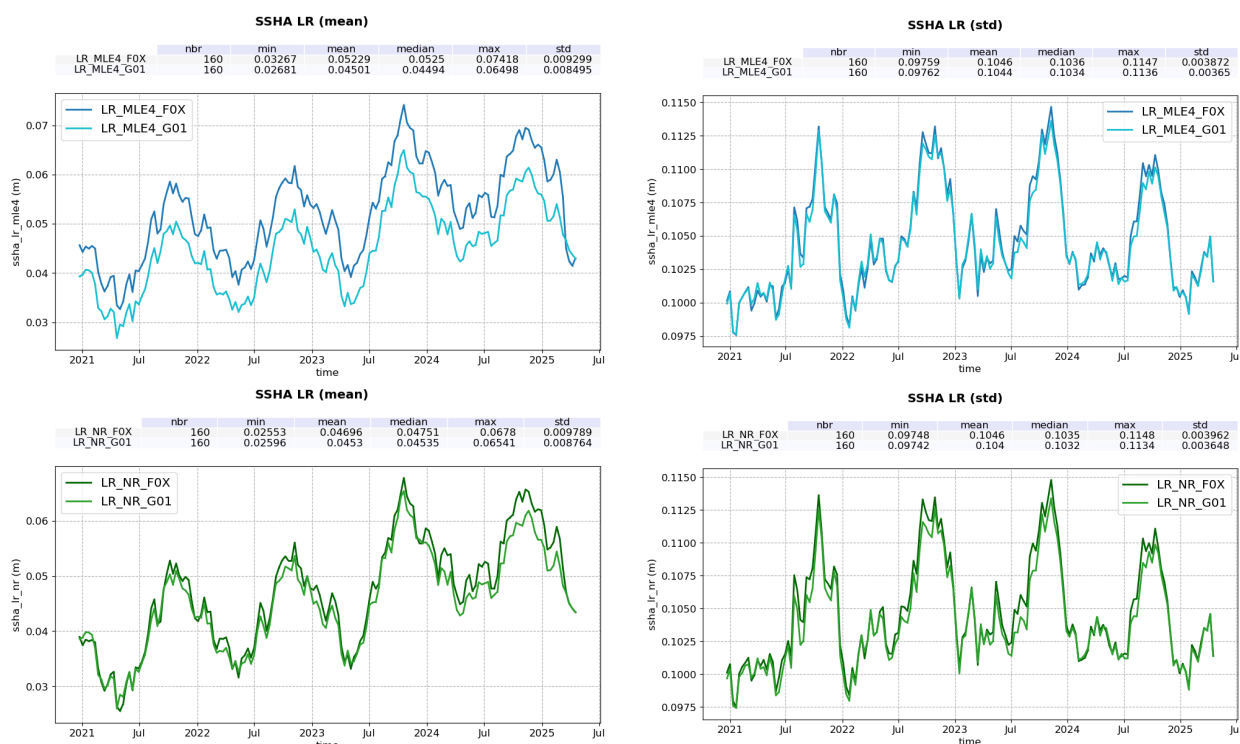


Figure 79: Time monitoring of LR Sentinel-6 MF SSHA in meters, excluding the Caspian Sea, daily mean (left) and daily standard deviation (right), for MLE4 (top) and NR (bottom).

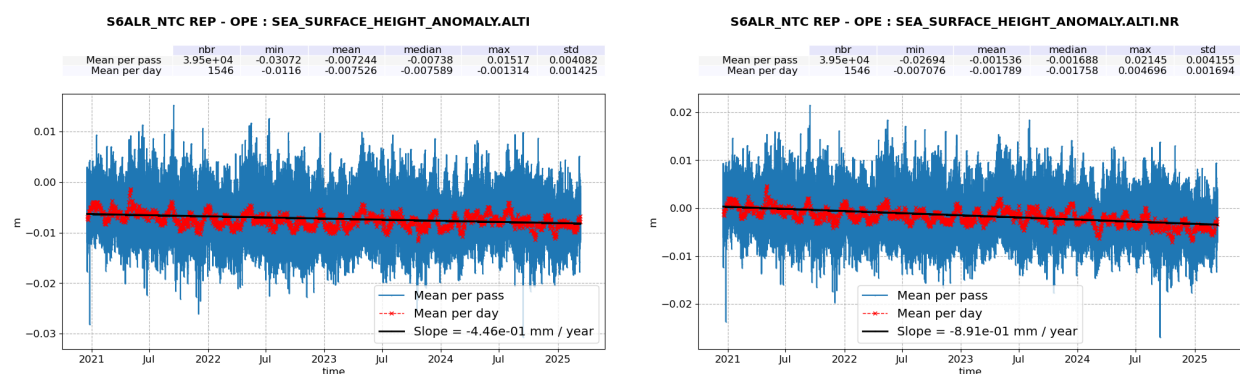


Figure 80: Time monitoring of Sentinel-6 MF LR operational minus reprocessed SSHA in meters, daily (red) and per pass (blue), for MLE4 (left) and NR (right), up until cycle 159 pass 254 (PB G01 update).

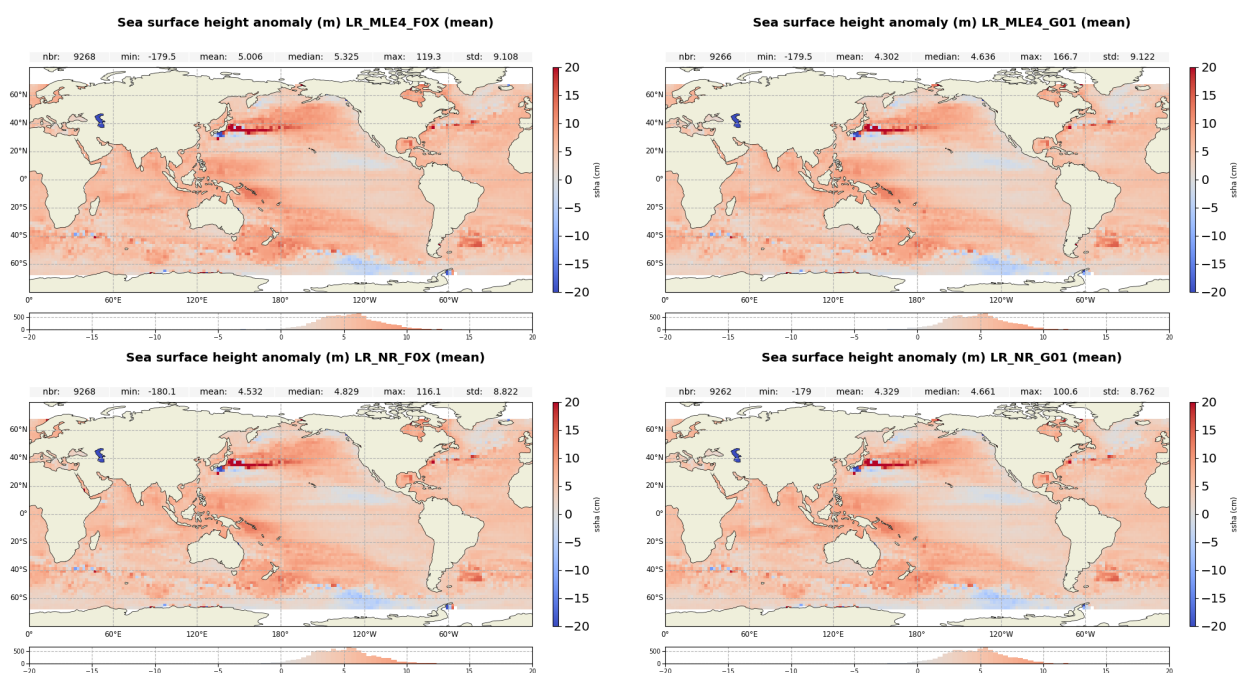


Figure 81: Maps of Sentinel-6 MF LR SSHA in meters for the operational (left) and reprocessed (right) datasets, for MLE4 (top) and NR (bottom).

7.1.2. HR

The monitoring of Sentinel-6 MF HR SSHA is shown in figure 82. With the SAMOSA retracker, temporal variations are similar between datasets, and the standard deviation is slightly lower in the reprocessed dataset (10.3 cm vs 10.4 cm). With NR, temporal variations are also consistent. The monitoring of the difference between operational and reprocessed datasets is shown in figure 83. A drift of -0.4 mm/yr is visible in SAMOSA time series, as well as a -1.8 mm/yr slope in HR NR, albeit on a much smaller time period. While LR NR, LR MLE4 and HR NR provide similar SSHA averages (4.5 cm, 4.5 cm and 4.8 cm respectively), a significant bias remains for SAMOSA, with an average of 3.0 cm. Table 9 summarizes biases between reprocessed and operational SSHA, as well as their main contributors.

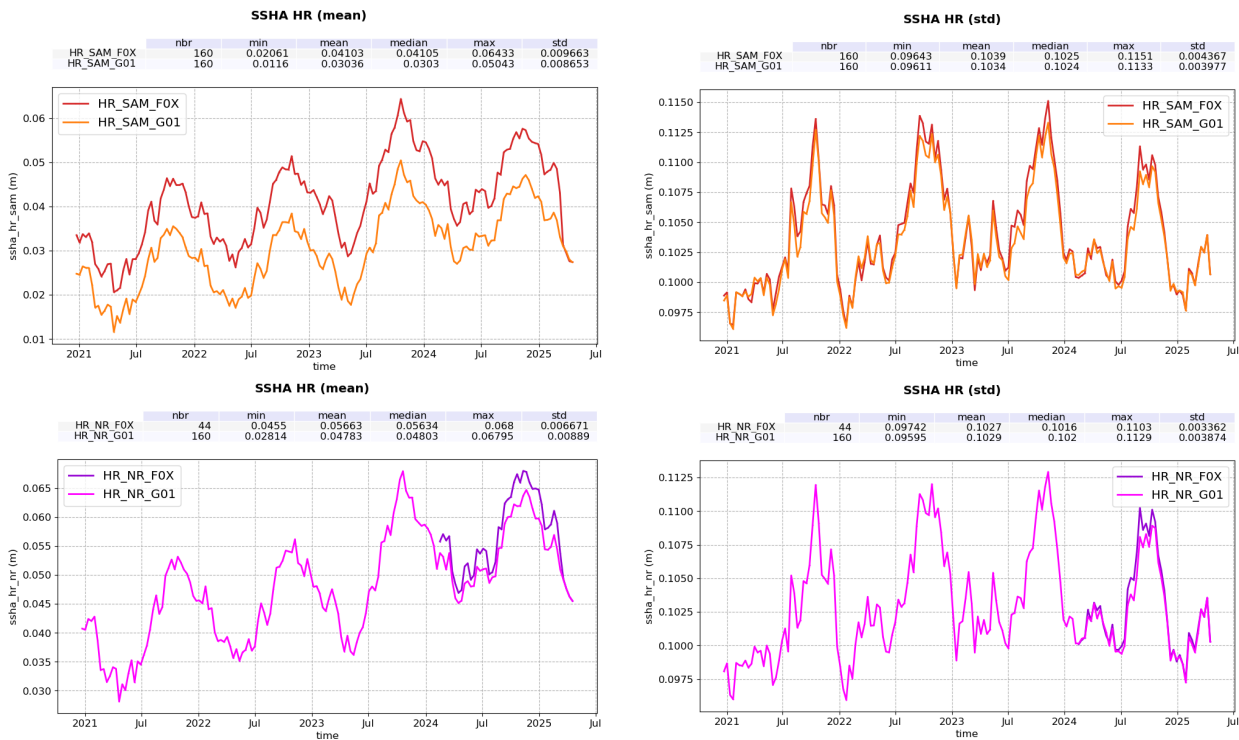


Figure 82: Time monitoring of HR Sentinel-6 MF SSHA in meters, excluding the Caspian Sea, daily mean (left) and standard deviation (right), for SAMOSA (top) and NR (bottom).

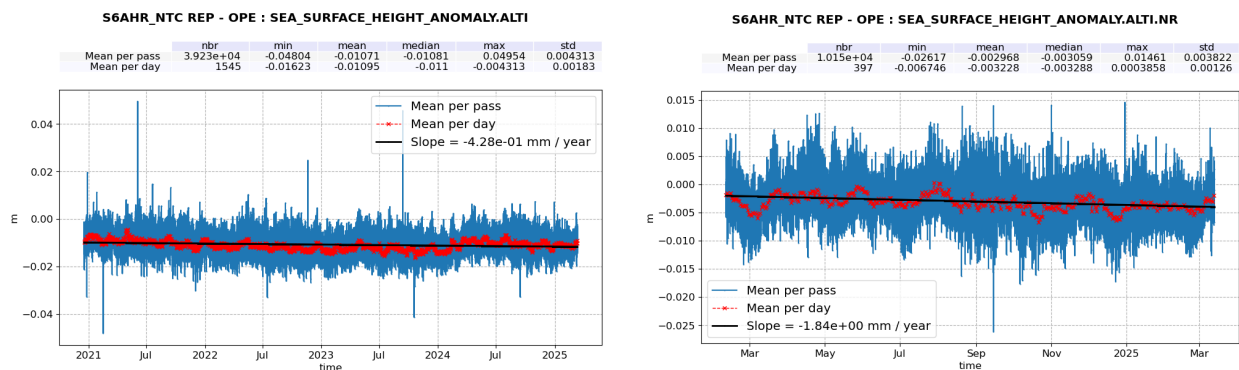


Figure 83: Time monitoring of Sentinel-6 MF HR operational minus reprocessed SSHA in meters, daily (red) and per pass (blue), for SAMOSA (left) and NR (right) up until cycle 159 pass 254 (PB G01 update).

Maps of HR SSHA are given in figure 84. No significant differences are visible between datasets.

Parameter	HR SAMOSA	HR NR
Orbit	-2 mm [11]	
Range	1.4 mm	1.1 mm
SSB	7.1 mm	0.4 mm
Iono	1.1 mm	0.1 mm
MSS	-0.9 mm	
SSHA	-10.7 mm	-2.9 mm

Table 9: HR SSHA biases and main contributors between reprocessed and operational datasets

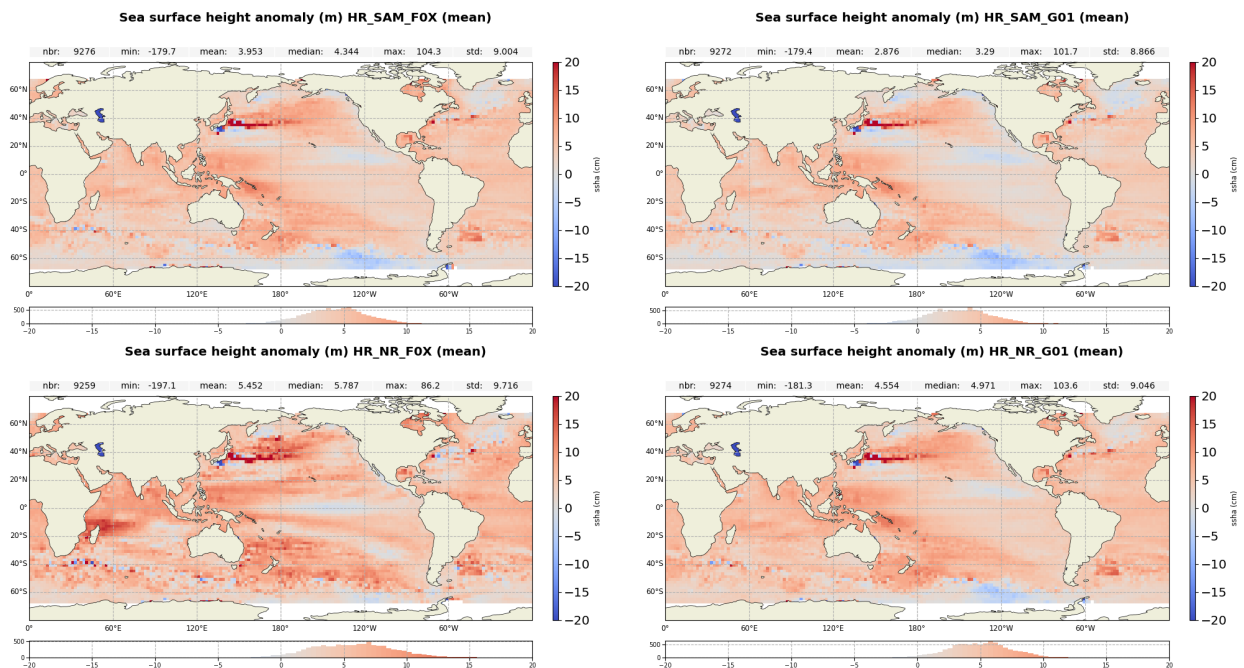


Figure 84: Maps of Sentinel-6 MF HR SSHA in meters for operational (left) and reprocessed (right) datasets, for SAMOSA (top) and NR (bottom).

7.1.3. Inter-retracker comparison

The monitoring of SSHA differences between retrackers (NR - MLE4/SAMOSA and HR - LR), as well as their correlations with SWH, is presented in figure 85. Corresponding G01 maps are presented in figure 87. Apart from the +1.4 mm and +2.2 mm jumps between side A and B for LR and HR respectively, the differences in the top-left panel show small drifts in LR (see figure 86). As with the range (section 6.1.2.3.), these jumps likely originate from the MLE4 LUT and SAMOSA alpha-p LUT not being adapted for side A. The day-to-day variability is larger in the HR NR - HR SAMOSA difference. On side B, the bias is close to zero (0.4 mm) for LR NR - MLE4, while it remains larger (1.8 cm) for HR NR - SAMOSA. The HR NR - LR NR difference (orange curve, bottom-left panel) and the HR SAMOSA - LR MLE4 difference (cyan curve) are also stable over time, with biases of 2.6 mm and -1.5 cm respectively. The improvement introduced by the MLE4 LUT update is clearly visible, with LR MLE4 now fully consistent with LR NR (cyan curve, top-right panel).

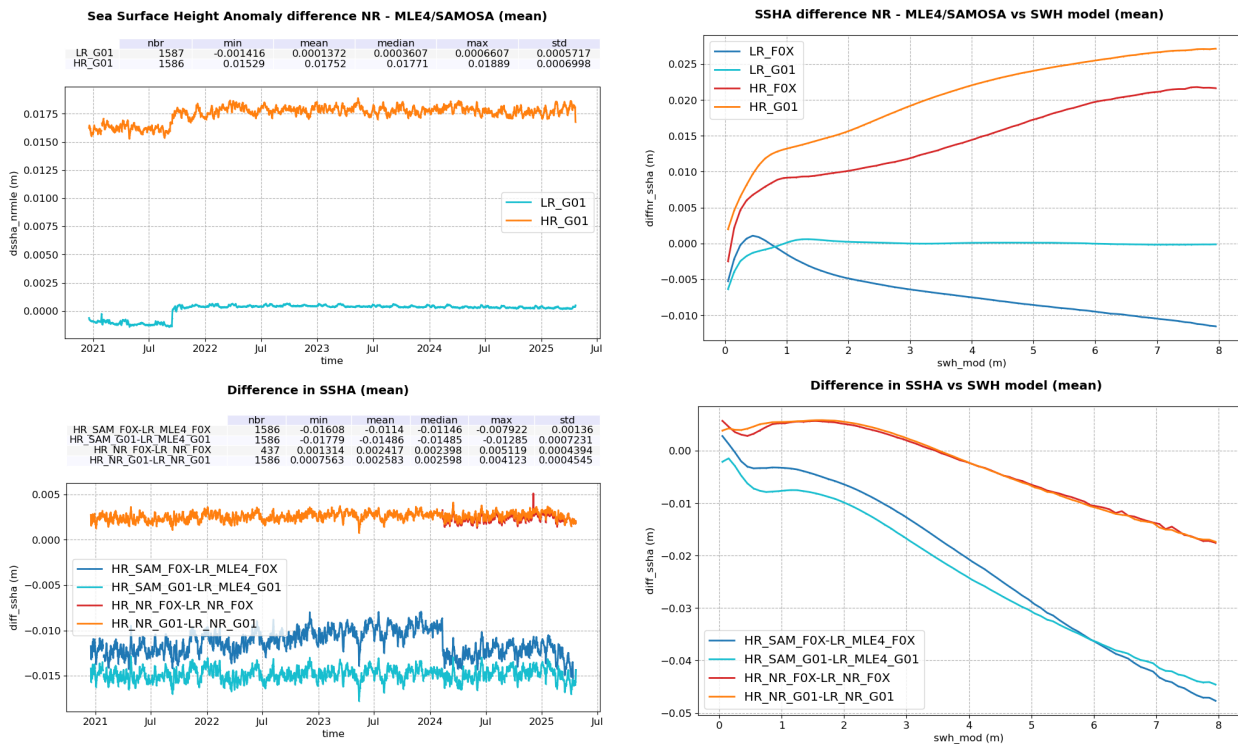


Figure 85: Time monitoring (left) and ERA-5 model SWH dependence (right) of Sentinel-6 MF SSHA differences: NR - MLE4/SAMOSA (top) and HR - LR (bottom).

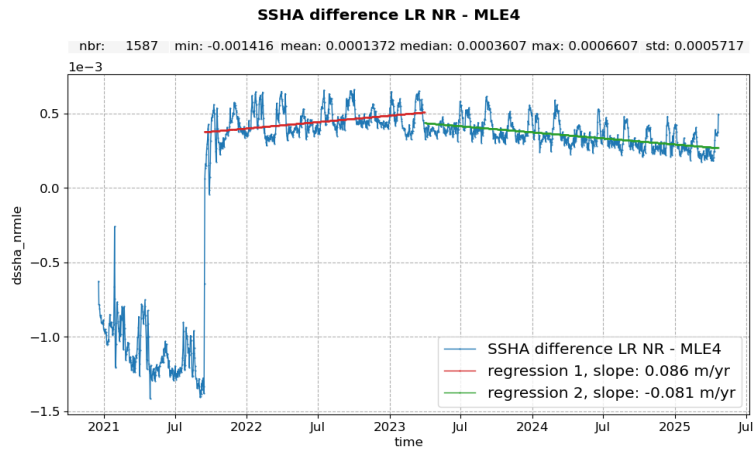


Figure 86: Time monitoring of the Sentinel-6 MF SSHA difference: NR - MLE4.

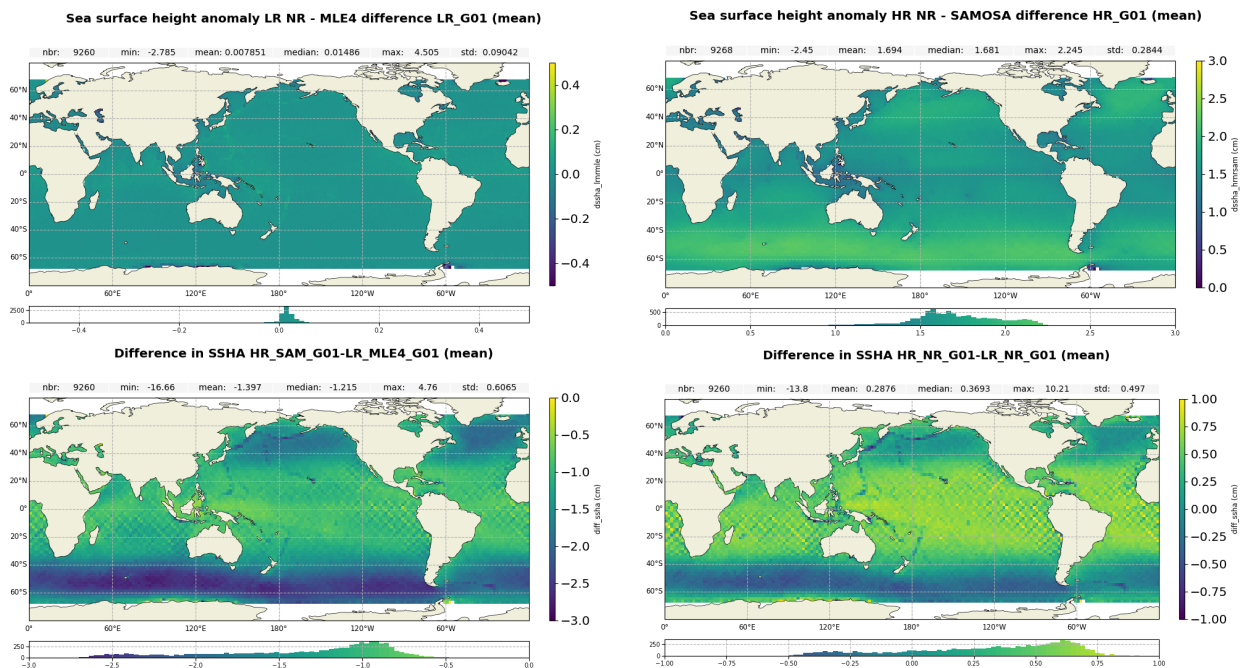


Figure 87: Map of Sentinel-6 MF G01 SSHA differences: LR NR - MLE4 (top left), HR NR - SAMOSA (top right), SAMOSA - MLE4 (bottom left) and HR NR - LR NR (bottom right)

7.2. Crossover analysis

Sea Surface Height crossover differences correspond to SSH differences between ascending and descending passes at their intersection points. They are routinely analysed to assess data quality and SSH performance. Crossover differences are computed on a per-cycle basis using valid measurements and a maximum time lag of 10 days, in order to limit the impact of ocean variability. Ideally, the mean crossover difference should be close to zero, and the standard deviation as small as possible.

However, the SLA can vary within 10 days, especially in high-variability regions. In addition, due to reduced data availability (e.g., seasonal sea-ice coverage), several geophysical correction models are less accurate at high latitudes. Therefore, an additional geographical selection—removing shallow waters, areas of high oceanic variability and latitudes above 50° —is applied for cyclic monitoring.

Table 10 summarizes the mean and standard deviation of SSH crossover differences for all datasets. Temporal evolutions are shown in figures 88 and 89. A very small reduction of the mean is visible for LR MLE4 and LR NR. In all cases, the standard deviation is lower in the reprocessed dataset by about 0.1 cm, and by about 0.2 cm for HR NR, although completeness differs significantly between time series. For all retrackers, the operational dataset shows 120-day oscillations in the mean, which are absent or strongly damped in the reprocessed dataset. This feature is linked to the updated radiation pressure model in the new POE-G orbit solution [11].

Retracker	Mean		Standard deviation	
	OPE [cm]	REP [cm]	OPE [cm]	REP [cm]
LR MLE4	0.01	0.00	4.72	4.62
LR NR	0.01	0.00	4.71	4.60
HR SAMOSA	0.09	0.09	4.50	4.42
HR NR	0.11	0.09	4.58	4.40

Table 10: Mean and standard deviation of SSH crossover differences.

Maps of SSH crossover differences are shown in figures 90 and 91 for LR and HR respectively. No significant differences appear between the operational and reprocessed datasets.

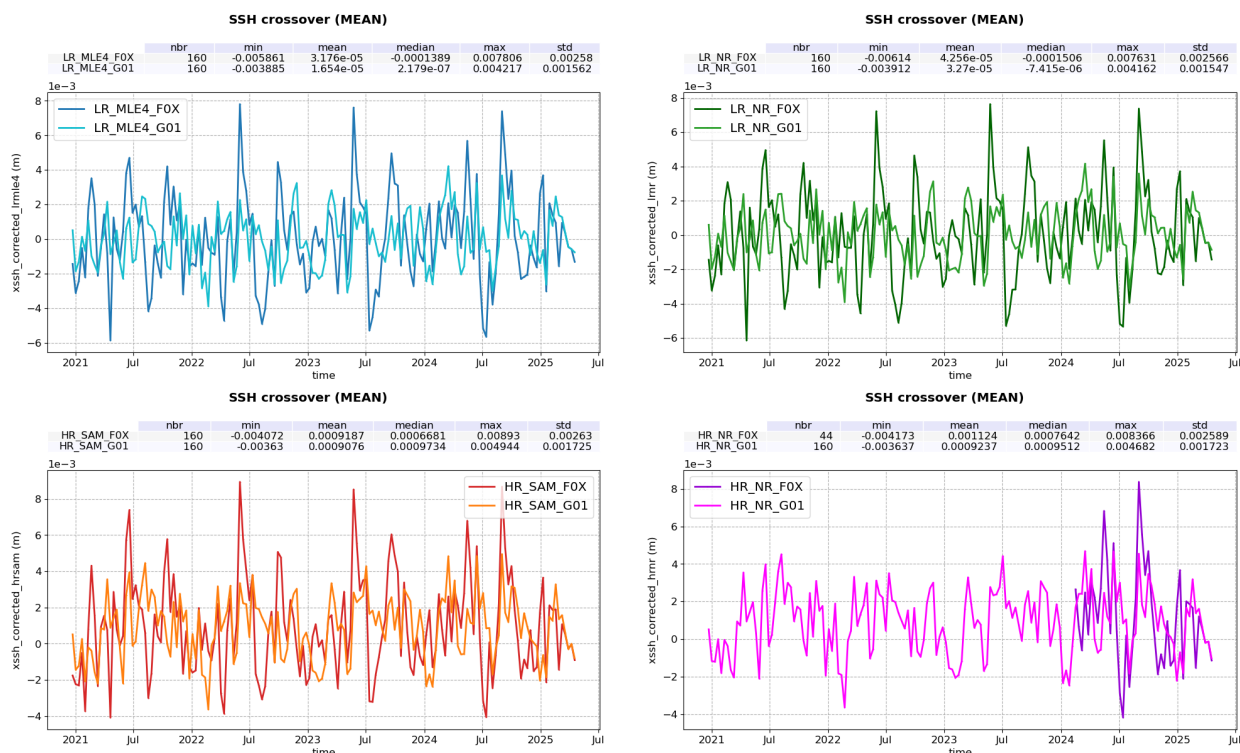


Figure 88: Monitoring of the mean SSH crossover difference per cycle (in meters). Top left: LR MLE4. Top right: LR NR. Bottom left: HR SAMOSA. Bottom right: HR NR.

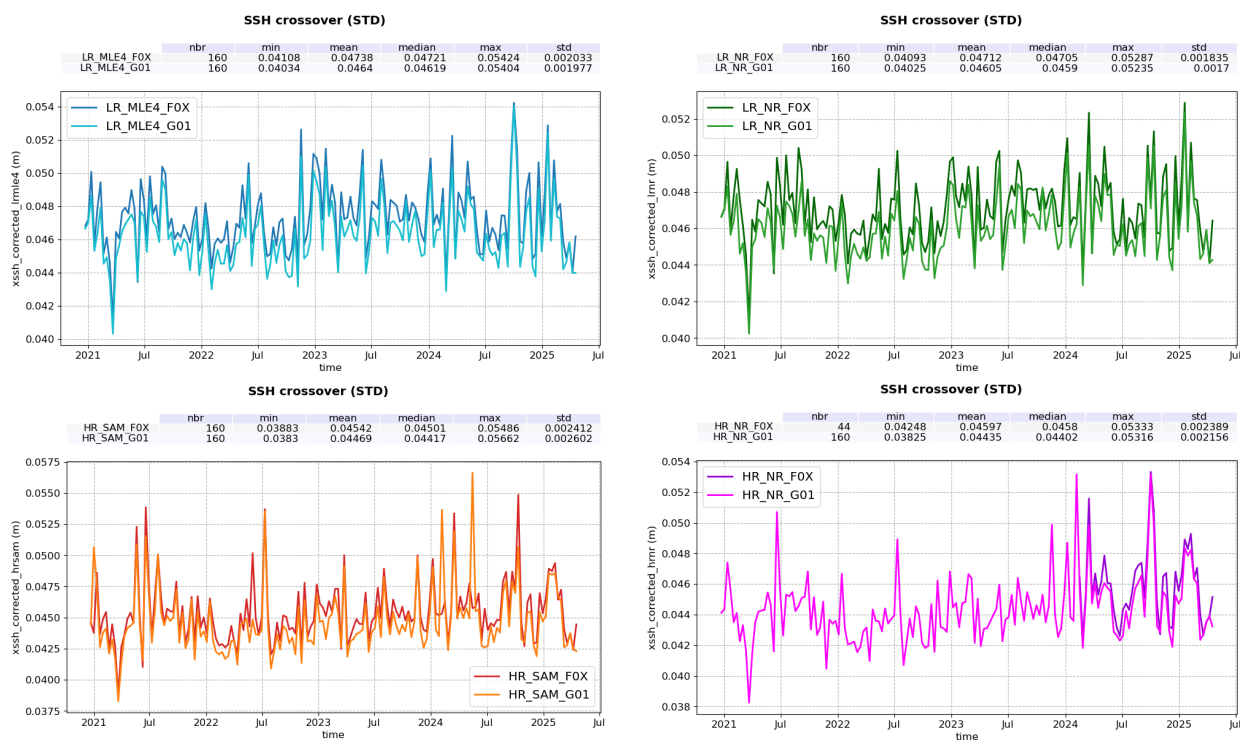


Figure 89: Monitoring of the standard deviation of SSH crossover differences per cycle (in meters). Top left: LR MLE4. Top right: LR NR. Bottom left: HR SAMOSA. Bottom right: HR NR.

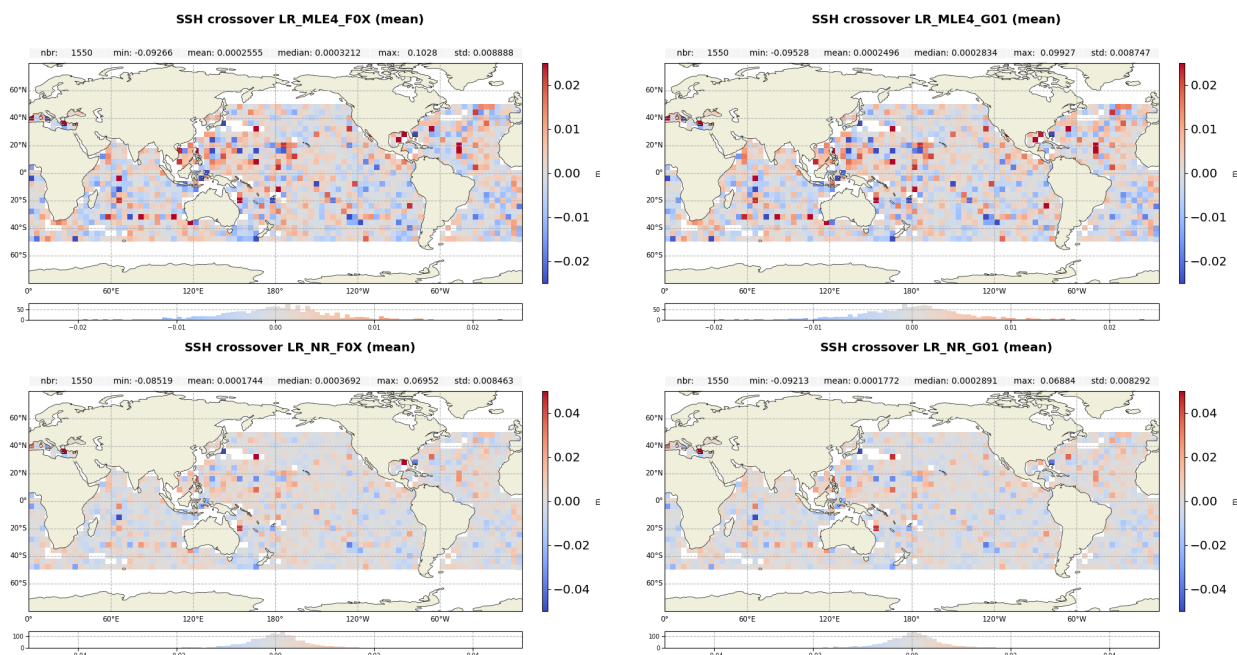


Figure 90: Mean LR SSH crossover differences for Sentinel-6 MF. Top: MLE4. Bottom: NR. Left: operational dataset. Right: reprocessed dataset. Computed over the full reprocessing period.

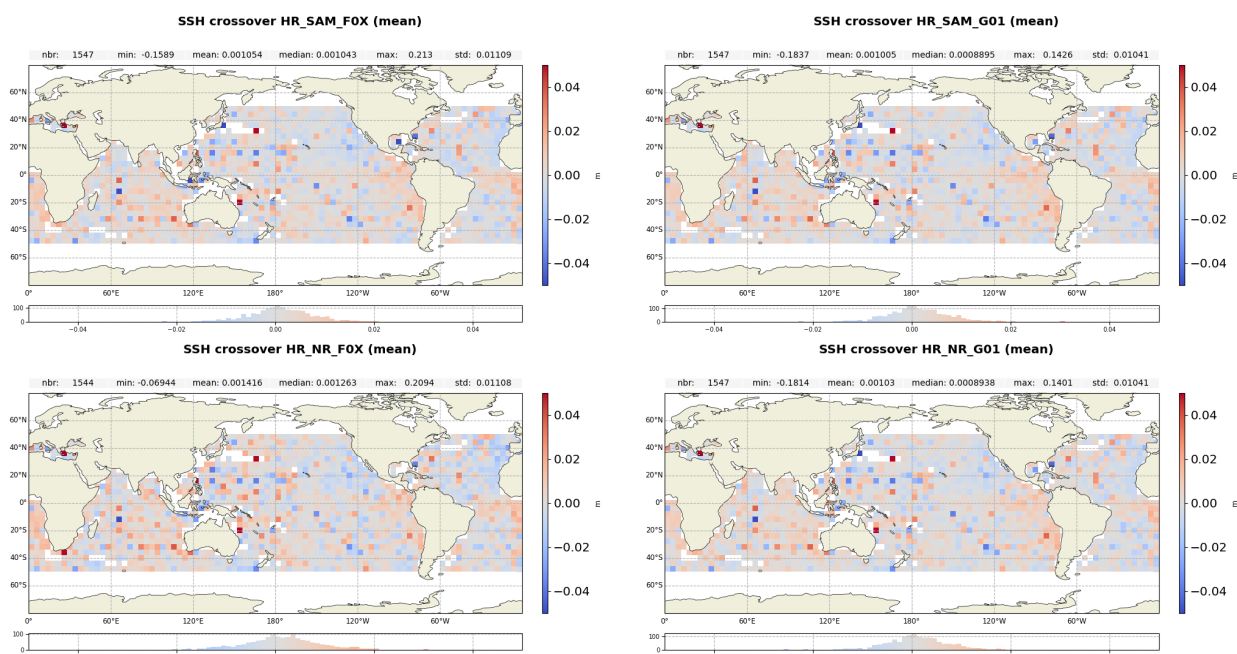


Figure 91: Mean HR SSH crossover differences for Sentinel-6 MF. Top: SAMOSA. Bottom: NR. Left: operational dataset. Right: reprocessed dataset. Computed over the full reprocessing period.

7.3. 1Hz noise

The 1-Hz noise is another metric used to assess mission performance. It is computed for the range, backscatter coefficient and SWH using the standard deviation of the 20-Hz measurements, divided by the square root of the number of valid measurements.

7.3.1. Range

Table 11 presents the 1-Hz range noise at 2-m SWH for all retrackerers, for both operational and reprocessed datasets. 1-Hz noise is presented for PB G01 on figure 96. HR noise is significantly lower than LR noise, as expected. No significant change arises from the reprocessing. Similarly, when plotting the difference between datasets as a function of model SWH (figure 93), the magnitude of the differences remains below 0.1 mm, except for HR NR (computed over a much shorter period) and at very low SWH (based on a much smaller number of measurements).

Retracker	OPE [cm]	REP [cm]
LR MLE4	1.45	1.45
LR NR	1.45	1.45
HR SAMOSA	0.81	0.81
HR NR	0.82	0.81

Table 11: 1-Hz range noise at 2-m SWH.

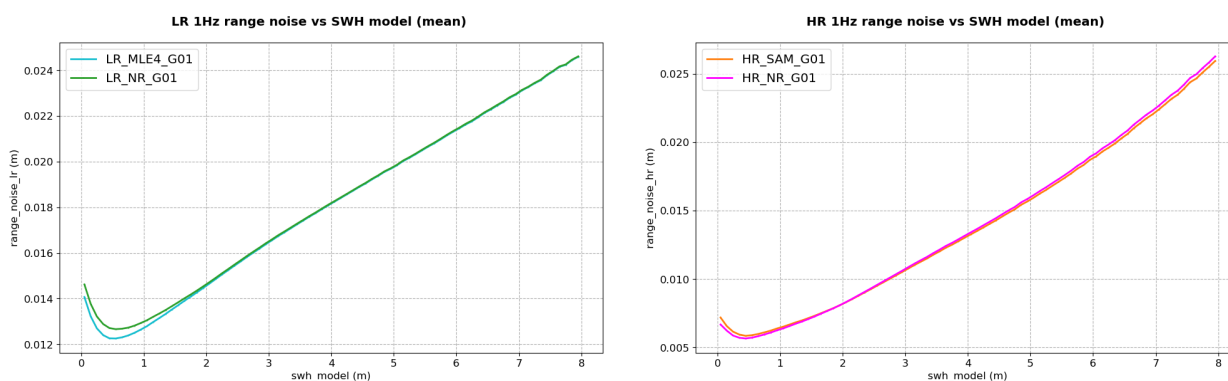


Figure 92: 1Hz range noise for PB G01 as a function of ERA 5 model SWH for LR (left) and HR (right)

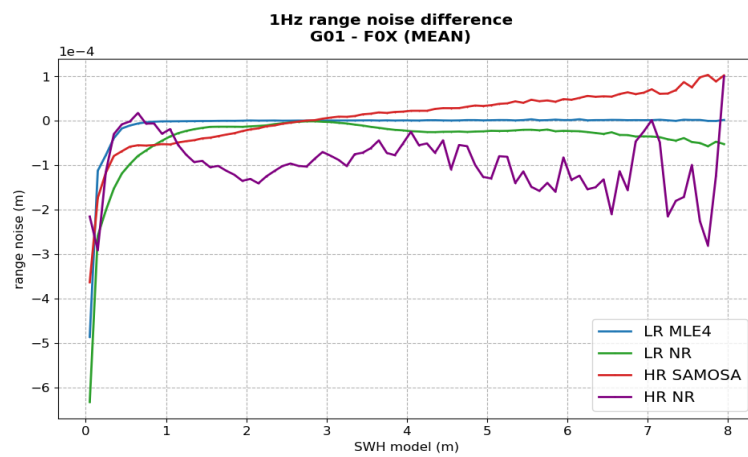


Figure 93: 1-Hz range noise reprocessed minus operational difference as a function of ERA-5 model SWH.

7.3.2. Sigma0

Table 12 presents the 1-Hz sigma0 noise at 2-m SWH for all retrackers, for both datasets. HR noise is significantly lower than LR noise, as expected. 1-Hz noise is presented for PB G01 on figure 96. No significant change is introduced by the reprocessing. When examining the differences as a function of model SWH (figure 95), all datasets are consistent, except for LR NR, which shows a small improvement of about 0.001 dB in the reprocessed dataset. This may be linked to the improvement of the LR NR retracker for peaky waveforms introduced in PB F09.

Retracker	OPE [dB]	REP [dB]
LR MLE4	0.066	0.066
LR NR	0.067	0.066
HR SAMOSA	0.019	0.019
HR NR	0.019	0.020

Table 12: 1-Hz sigma0 noise at 2-m SWH.

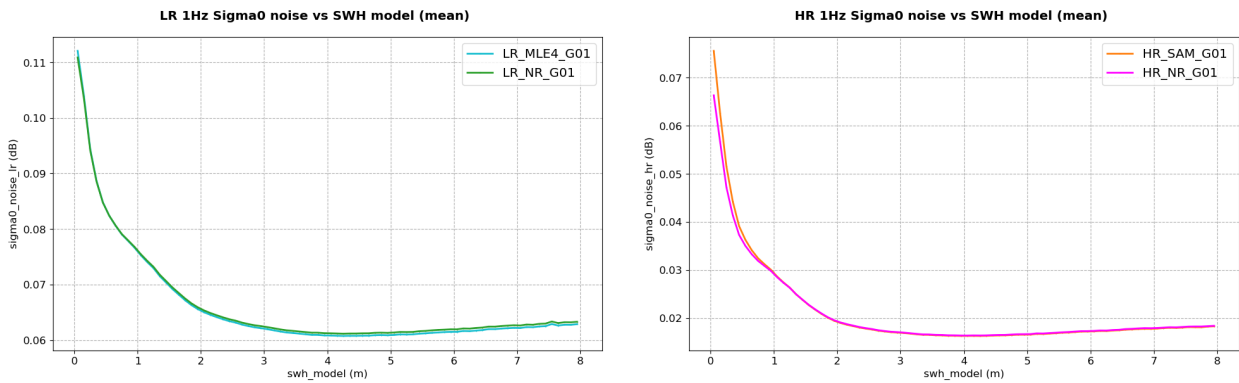


Figure 94: 1Hz sigma0 noise for PB G01 as a function of ERA 5 model SWH for LR (left) and HR (right)

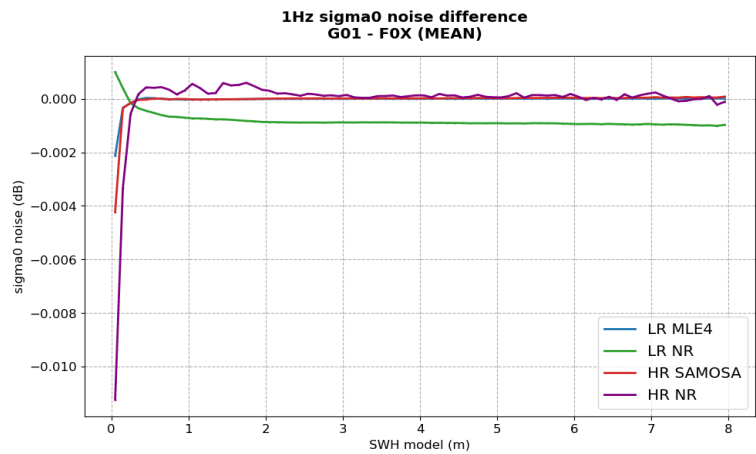


Figure 95: 1Hz sigma0 noise reprocessed minus operational difference as a function of ERA 5 model SWH

7.3.3. SWH

Table 13 presents the 1-Hz SWH noise level at 2-m SWH for all retrackers, for both the operational and reprocessed datasets. 1-Hz noise is presented for PB G01 on figure 96. As expected, HR noise is significantly lower than LR noise. There is no notable change in LR noise with the reprocessing; however, the improvement is significant in HR (about 0.6 cm for both SAMOSA and NR). This improvement is consistent with the application of the VWM correction at 20 Hz.

Figure 97 shows that the improvement is stable for all SWH values above 1 m, and appears larger at low SWH, although these bins contain fewer measurements. We also note that the LR NR (green curve) exhibits an apparent “degradation” of the noise below 1.5-m SWH. This is not a real degradation, but rather the expected effect of correcting the small-waves anomaly in the patched version of PB F08. In the original PB F08, negative 20-Hz SWH values were mapped to their positive counterparts, artificially reducing the noise.

Retracker	OPE [cm]	REP [cm]
LR MLE4	9.46	9.45
LR NR	9.12	9.10
HR SAMOSA	5.76	5.19
HR NR	5.54	4.98

Table 13: 1Hz SWH noise at 2m-SWH.

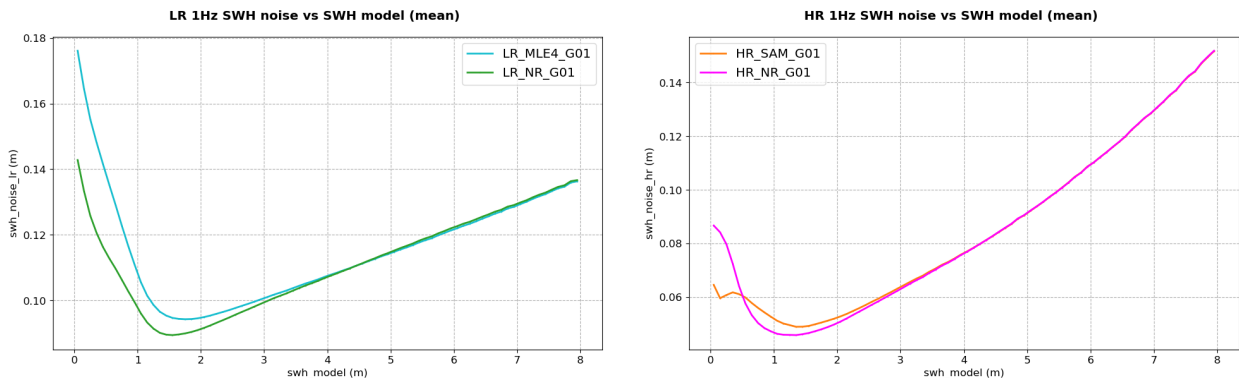


Figure 96: 1Hz SWH noise for PB G01 as a function of ERA 5 model SWH for LR (left) and HR (right)

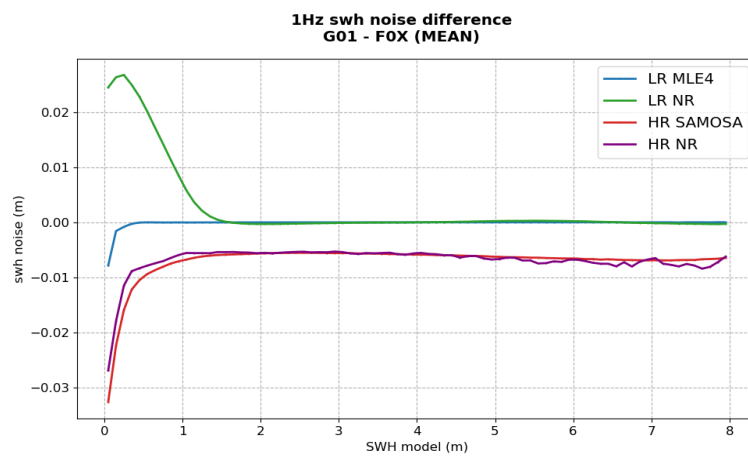


Figure 97: 1Hz SWH noise reprocessed minus operational difference as a function of ERA 5 model SWH

8 Analysis of the tandem flight with Jason-3

Between 2020-12-17 and 2022-04-07 (Sentinel-6 MF cycles 4 to 51), Sentinel-6 MF and Jason-3 were flying in tandem formation on the same ground track with only 30 seconds apart, Jason-3 ahead of Sentinel-6 MF. This section is dedicated to the precise comparison between Sentinel-6 MF and Jason-3 data over this tandem flight.

To perform such analysis, Sentinel-6 MF and Jason-3 data are co-located by interpolation onto their common theoretical ground-track. This allows to perform point to point differences over the complete tandem flight period and thus to provide precise comparison metrics.

In this section, we focus on the parameters involved in the SSHA computation. For this analysis, only MLE4 Jason-3 data are considered.

8.1. Radiometer parameters

The WTC derived from radiometer are compared between Sentinel-6 MF (AMR-C and HRMR) and Jason-3 (AMR). In average, the bias between the two retrievals is well centred around 0 (below 1mm bias). Differences range between -3 and 1 mm with clear correlation to wet troposphere content itself (figure 98).

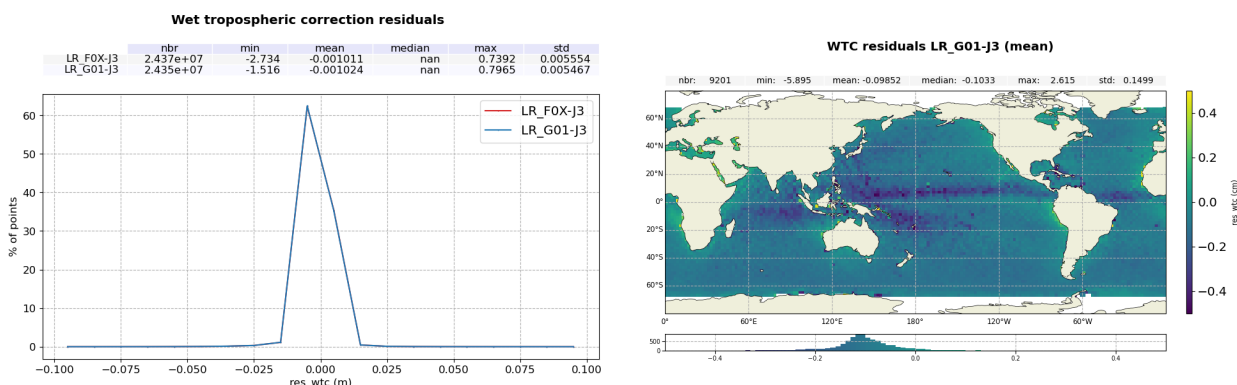


Figure 98: Radiometer WTC difference : Sentinel-6 MF AMR-C/HRMR minus Jason-3 AMR. Histogram (left) and gridded map (right) computed over the complete tandem period.

Looking at time monitoring of Sentinel-6 MF versus Jason-3 bias, two events can be observed (figure 99):

- On 27-28 April 2021 (cycle 17), a jump of -4 mm is observed in the bias, preceded by a progressive increase of the bias (from beginning of March 2021) by the same amplitude. The same behaviour was observed on Sentinel-6 MF radiometer WTC comparison to ECMWF model (see section 6.2.). The jump visible on 27-28 April 2021 is concomitant with a satellite restart. The potential link between the satellite restart and this jump is under investigation. The AMR-C jump is between two calibration sequences and will therefore be difficult to remove. Note that, while having similar amplitudes, the jump on the reprocessed dataset is shifted by about -0.5mm compared to the operational dataset.
- From the beginning of 2022, Sentinel-6 MF and Jason-3 radiometer WTC drifted from each other to reach -3.1 mm bias around mid-February. The origin of this behaviour is for the moment unknown and cannot be attributed to neither Sentinel-6 MF AMR-C nor to Jason-3 AMR.

Generally, Sentinel-6 MF and Jason-3 AMR are being calibrated completely independently of each other for

operational processing, so such a bias is possible. Sentinel-6 MF AMR-C calibration shall be superior to the Jason-3 AMR since Sentinel-6 MF is calibrated using the SCS (Supplemental Calibration System), while Jason-3 AMR is calibrated using the historical vicarious references. For the Sentinel-6 MF AMR-C, each calibration brings the radiometer back to a nominal baseline with an uncertainty of about 2mm (1-sigma).

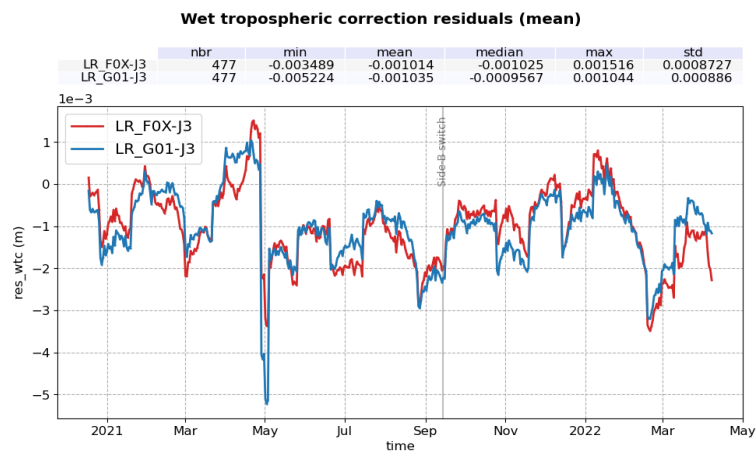


Figure 99: Time monitoring of Radiometer WTC difference : Sentinel-6 MF AMR-C/HRMR minus Jason-3 AMR. Mean per day for the operational (red) and reprocessed (blue) datasets, computed over the complete tandem period.

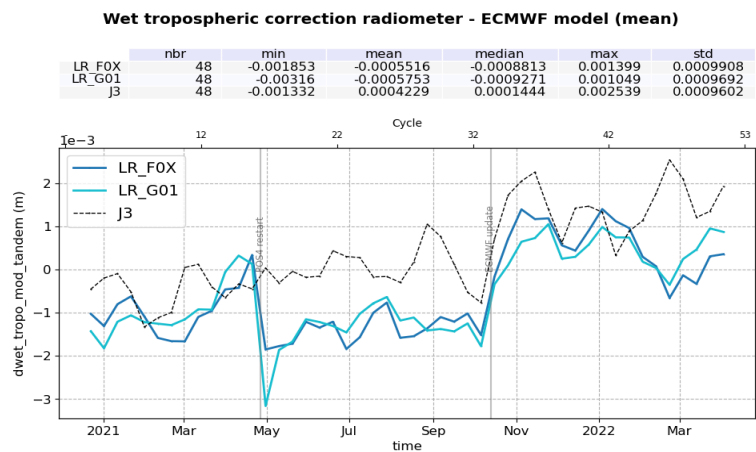


Figure 100: Time monitoring of Radiometer minus ECMWF model WTC difference. Mean per cycle for the operational (red) and reprocessed (blue) datasets as well as Jason 3 (dashed black), computed over the complete tandem period.

8.2. Ku-band LR

8.2.1. SWH

Ku-band MLE4 SWH bias between Sentinel-6 MF LR and Jason-3 is closer to zero with the reprocessing, from -1.1 cm to 0.1 cm (figure 101), and a stable time series (figure 102). The mean bias between Sentinel-6 MF LR NR and Jason-3 MLE4 is also smaller with the reprocessing, from 2.0 cm to 0.4 cm and a stable time series.

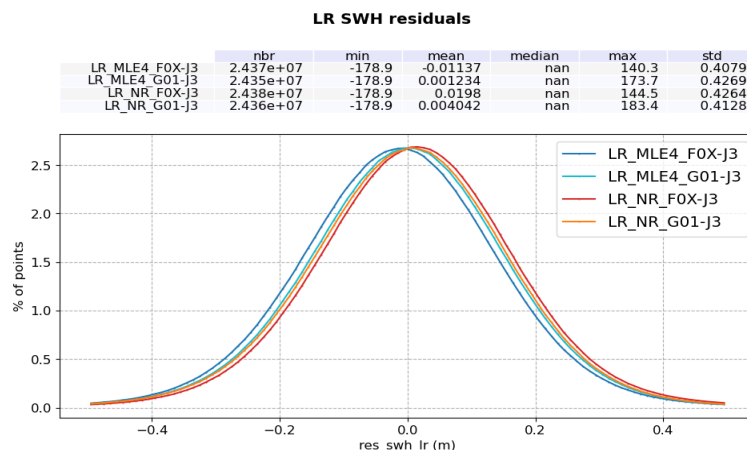


Figure 101: Histogram of Ku-band SWH difference: Sentinel-6 MF LR minus Jason-3. Computed over the complete tandem period.

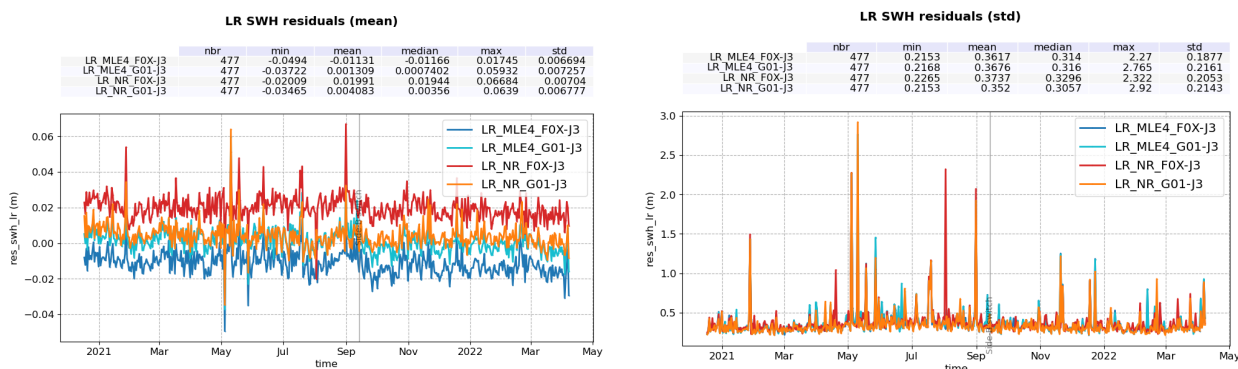


Figure 102: Time monitoring of Ku-band SWH difference: Sentinel-6 MF LR minus Jason-3. Mean per day (**left**) and standard deviation per day (**right**) computed over the complete tandem period.

Maps of SWH difference (figure 103 left panel) mainly shows a good consistency between the two missions, except in small waves areas where the bias is higher. The root cause of this higher bias is the improved handling of low wave heights in Sentinel-6 MF Level 2 processing, as already explained in section 6.1.1.: Sentinel-6 MF processing allows negative SWH values while it is not the case for Jason-3 GDR-F. It can lead to differences up to -5 cm for very low SWH (below 0.5m), see bottom panel. For SWH > 1m, Sentinel-6 MF LR and Jason-3 SWH are in line, with differences within 2cm in absolute value.

In LR NR, the reprocessing drastically improved the bias at small SWH, now aligned with MLE4. This is due to the correction of a small NR small wave anomaly (AR2620) presented in section 3.1. and impacting data up to 1m-wave.

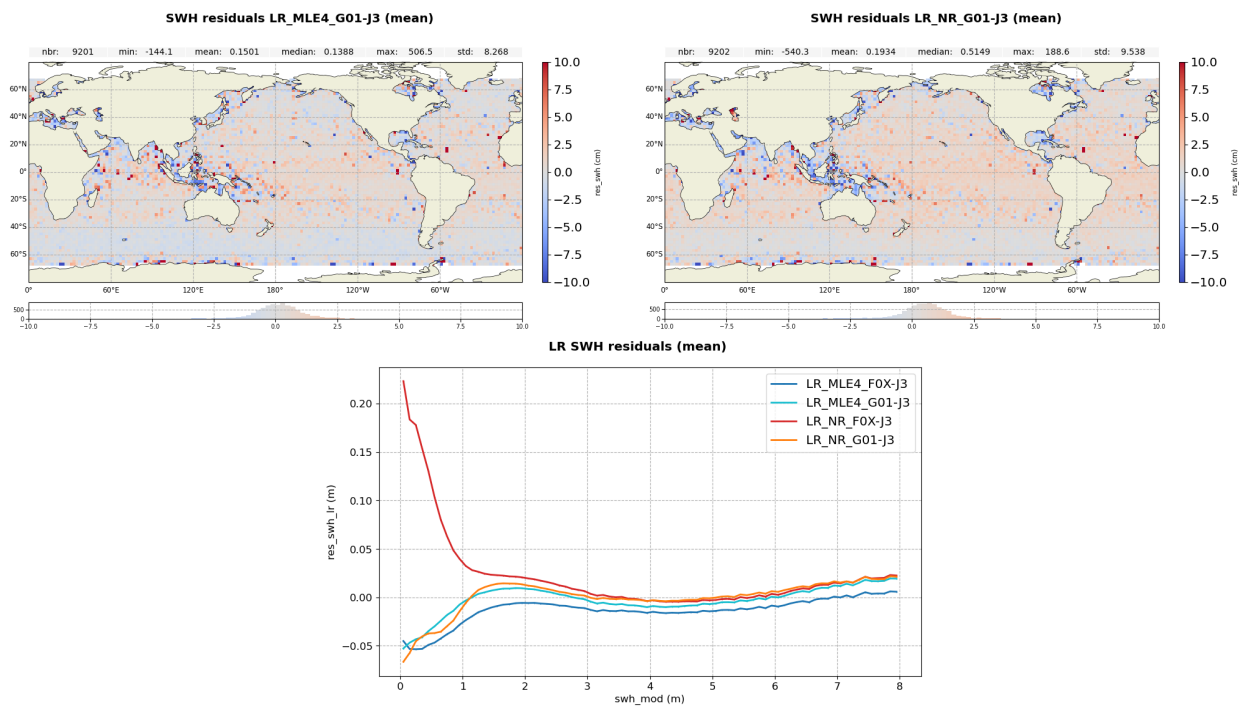


Figure 103: Ku-band SWH difference: Sentinel-6 MF LR minus Jason-3 computed over the complete tandem period. Gridded maps for S6 MF MLE4 (**left**) and NR (**right**), and differences function of ERA 5 model SWH (**bottom**).

8.2.2. Range

To compare ranges between the two missions, we do not compute a direct difference of the two ranges, because of their strong variation in time that would cause significant interpolation errors. Instead, we compare (orbit - range - MSS).

Figure 104 highlights the consistency between the two satellites with an average bias of 0.2 cm in MLE4 and NR. In MLE4, the operational dataset showed a poorer agreement with Jason-3 with a 0.7 cm global bias. The time monitoring of the difference shows a significant improvement of the reprocessing with the disappearance of 60 days oscillations. This is linked to the improved POE-G orbital solution for Sentinel-6 MF. The 2 mm bias has also been linked to the POE-G update ([11]). Note that a small jump is still visible in April 2021 after the satellite restart.

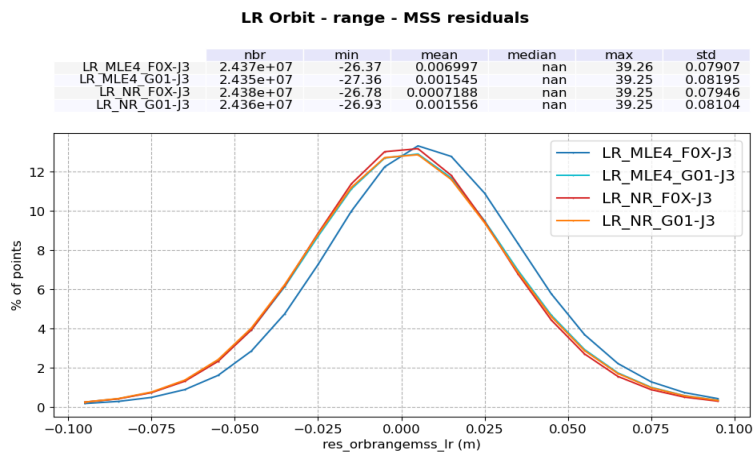


Figure 104: Histogram of Orbit - Ku-band range - MSS difference : Sentinel-6 MF LR minus Jason-3. Computed over the complete tandem period.

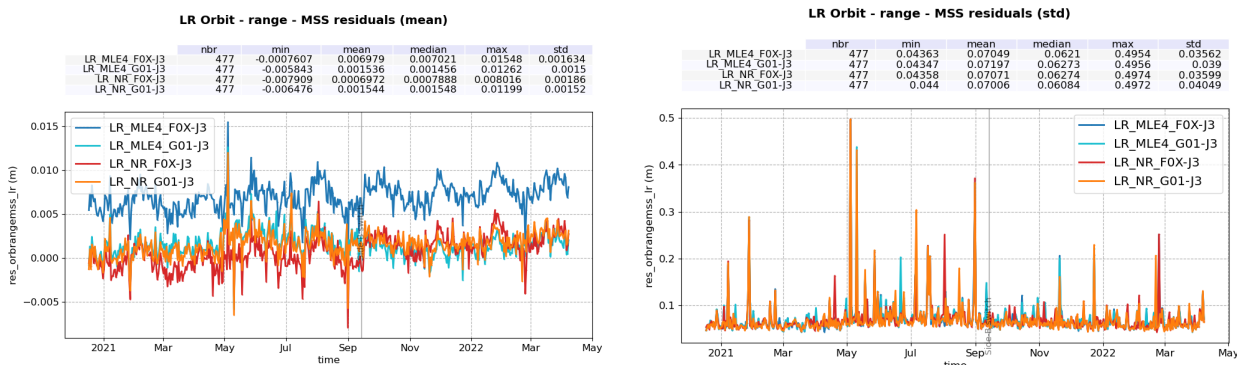


Figure 105: Time monitoring of Orbit - Ku-band range - MSS difference: Sentinel-6 MF LR minus Jason-3. Mean per day (left) and standard deviation per day (right) computed over the complete tandem period.

The maps of the difference presented in figure 106 show a small correlation to SWH. In MLE4, the reprocessing drastically reduced the correlation thanks to the LUT update to align to NR. The bias increases between 1 and 8m-SWH is of 0.5cm. The residual correlation can be linked in part to pulse-to-pulse correlation effect, not taken into account in the processing yet. As the difference presented does not only contain ranges, part of the residual correlation could also originate from the orbit as well as the MSS that are in GDR-F standards in Jason-3. See section 5.1.2. for more details on the difference between GDR-F and GDR-G MSS and [11] for more details on the differences between POE-F and POE-G orbital solutions.

An equatorial band of 5 mm amplitude is also clearly visible on both maps. Investigations have shown that this behaviour is coming from Jason-3 and will be corrected in Jason-3 GDR-G.

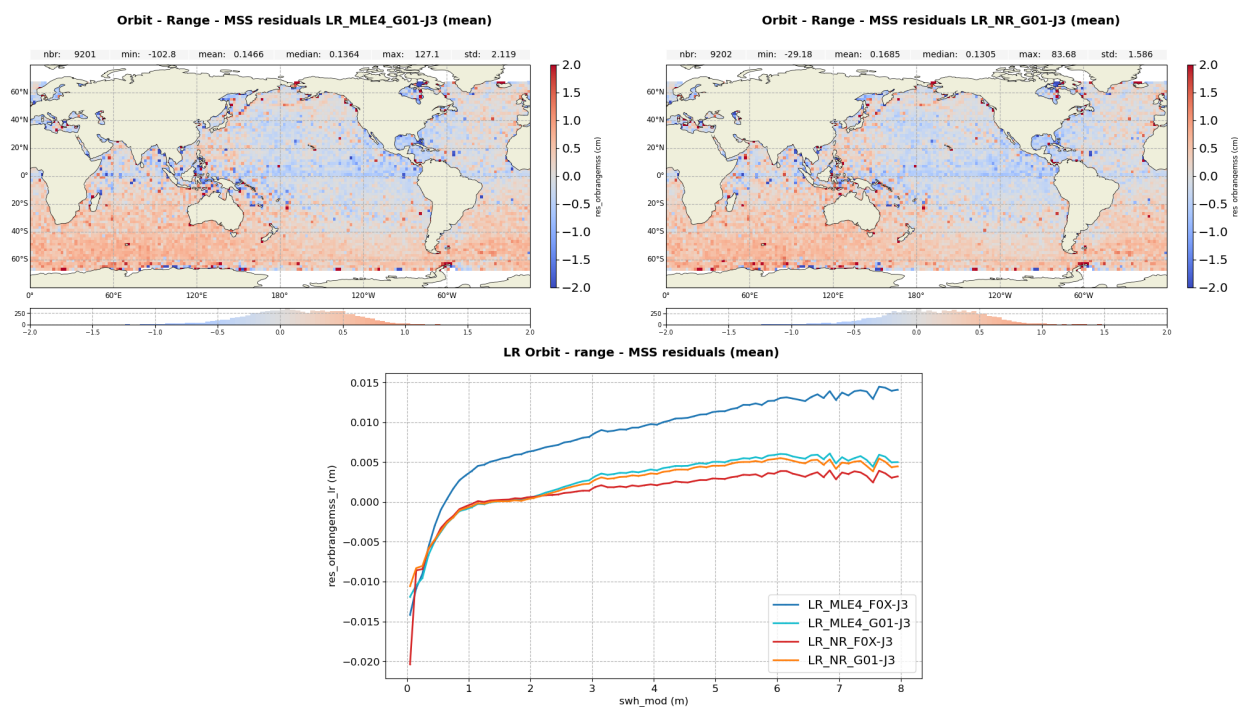


Figure 106: Orbit - Ku-band range - MSS difference: Sentinel-6 MF LR minus Jason-3 computed over the complete tandem period. Gridded maps for reprocessed MLE4 (**left**) and NR (**right**) and difference as function of ERA 5 model SWH (**bottom**).

8.2.3. Backscatter coefficient

Figure 107 shows the monitoring of the difference in sigma0. Thanks to the g-scaling update in G01 between sides A and B, jumps are no longer present in the time series. Global biases are of -0.48 dB in MLE4 and -0.49 dB in NR.

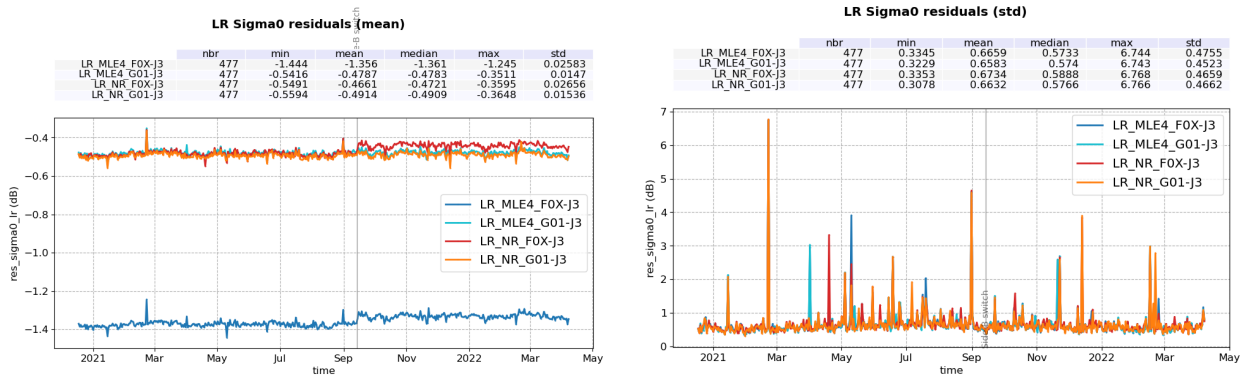


Figure 107: Time monitoring of Ku-band backscatter coefficient difference: Sentinel-6 MF LR minus Jason-3. Mean per day (**left**) and standard deviation per day (**right**) computed over the complete tandem period.

The maps of the sigma0 difference for reprocessed MLE4 and NR are presented in figure 108, top panels. As confirmed with the difference plot as function of SWH on the bottom panel, we observe a small SWH dependency : +0.11dB between 1 and 8m-SWH.

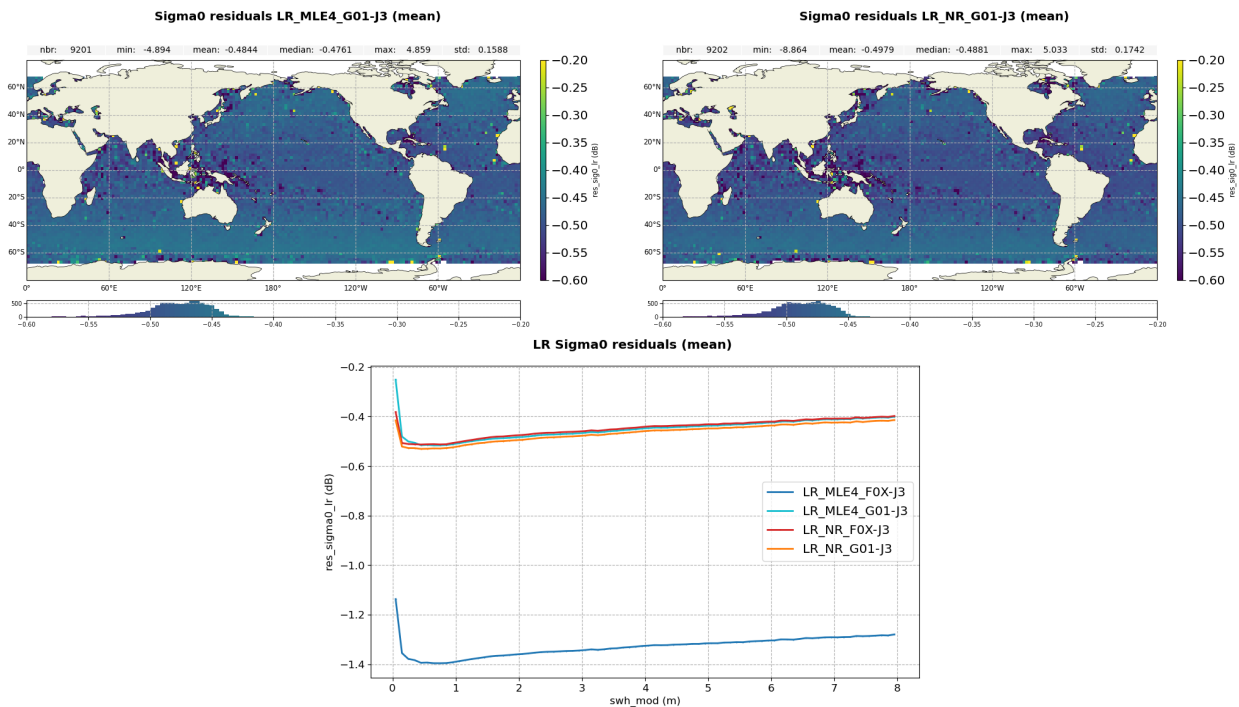


Figure 108: Ku-band backscatter coefficient difference: Sentinel-6 MF LR minus Jason-3 computed over the complete tandem period. Gridded map for reprocessed MLE4 (**left**) and NR (**right**) and difference as function of ERA 5 model SWH (**bottom**).

8.2.4. Altimeter Wind-Speed

Sentinel-6 MF wind speed is computed with Collard algorithm, as for Jason-3. Sentinel-6 MF sigma0 in input of the computation should then be calibrated the same way as Jason-3. As can be seen on the histogram in figure 109, the differences in wind speed for the reprocessed dataset are not perfectly centred around 0 (-11 cm/s in MLE4 and NR). While Sentinel-6 MF wind speed could be closer to reality than its Jason-3 counterpart (its bias to the model is only 6 to 7 cm/s as seen on figure 61), because Jason-3 SSB table is applied to Sentinel-6 MF, wind speed should be aligned between the two missions for a more precise SSB correction and therefore SSHA. This is why calibration bias applied on sigma0 for the wind speed computation should be adjusted.

For Jason-3, the sigma0 calibration bias equals to 0.06 dB. Sentinel-6 MF sigma0 calibration should be calculated as the sum of J3/Sentinel-6 MF sigma0 bias and Jason-3 sigma0 calibration bias (0.06 dB). For Sentinel-6 MF LR wind speed computation, the calibration bias applied on sigma0 should be +0.55 dB (= +0.49 + 0.06), which is very close to the current values in PB G01 (+0.57 dB for MLE4 and +0.58 dB for LR NR). We recommend using these new values for the next Sentinel-6 MF reprocessing campaign. Note that thanks to the sigma0 alignment between sides A and B in PB G01, reprocessed datasets do not show a jump at the side switch anymore in the time series (figure 110).

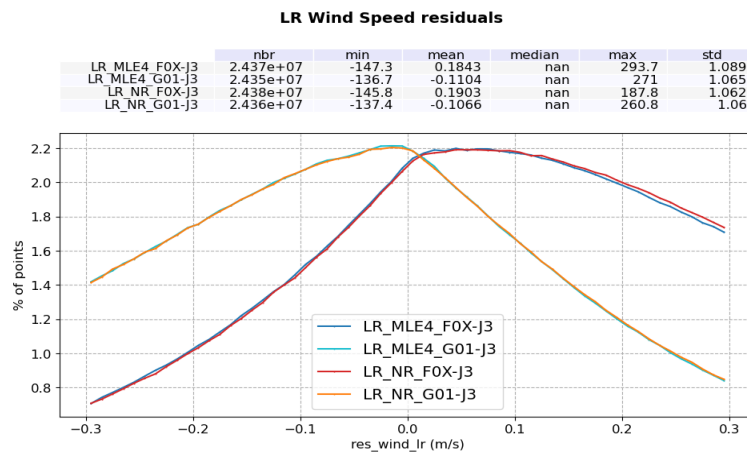


Figure 109: Histogram of altimeter wind speed difference: Sentinel-6 MF LR minus Jason-3. Computed over the complete tandem period.

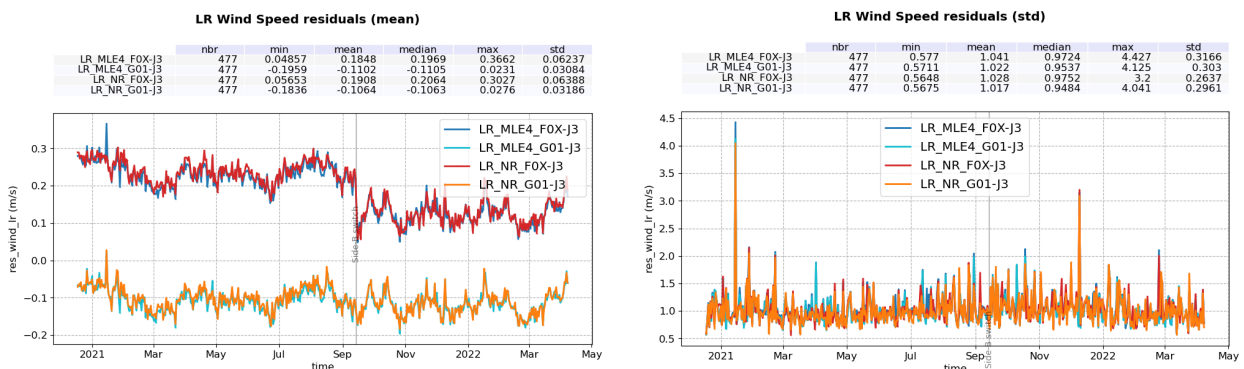


Figure 110: Time monitoring of Ku-band wind speed difference: Sentinel-6 MF LR minus Jason-3. Mean per day (left) and standard deviation per day (right) computed over the complete tandem period.

The maps of reprocessed altimeter wind speed difference are presented in figure 111, top panels. As

confirmed with the difference plot as function of SWH on the bottom panel, we observe a SWH correlation : -50 cm/s between 1 and 8m-SWH.

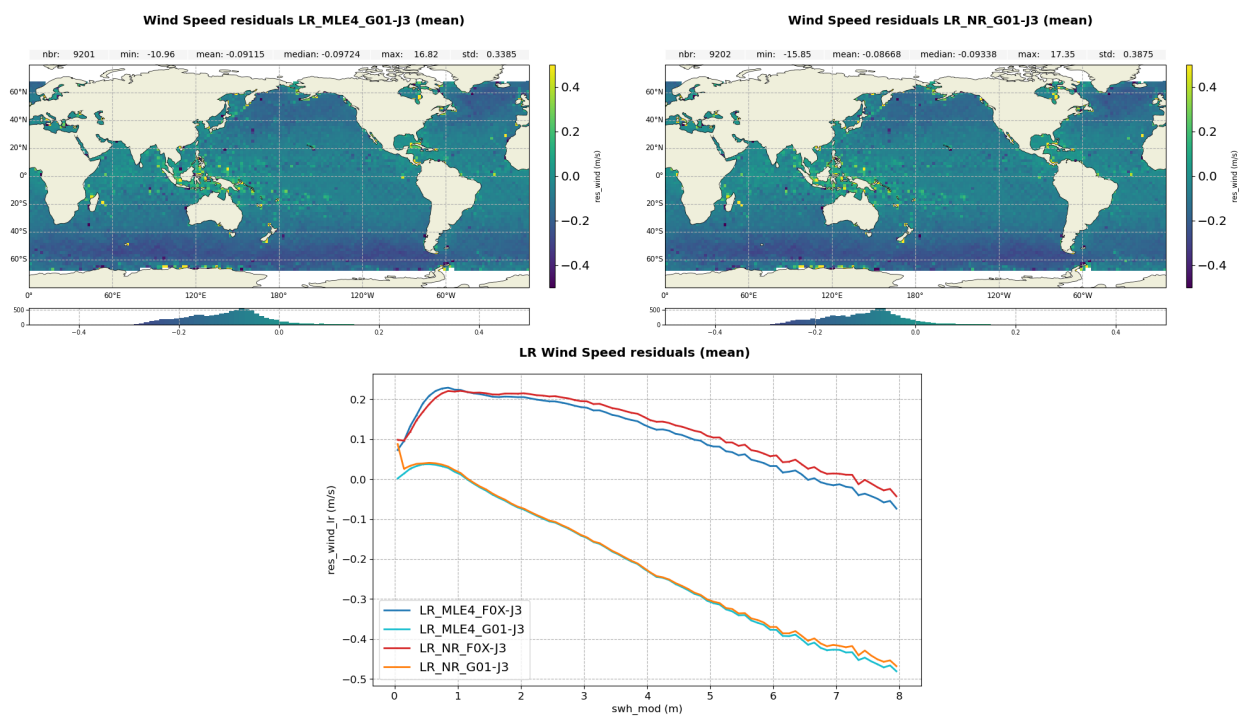


Figure 111: Altimeter wind speed difference: Sentinel-6 MF LR minus Jason-3 computed over the complete tandem period in m/s. Gridded map for reprocessed MLE4 (left) and NR (right) and difference as function of ERA 5 model SWH (bottom).

8.2.5. Ku-band Sea State Bias

Figure 112 shows the distribution of the differences in SSB over the complete period, with a bias of less than 0.2 mm in reprocessed MLE4 and 0.1 mm in NR. The time monitoring of these differences is presented in figure 113. The jump of about +0.3 mm, visible in the operational datasets at the switch to POS4-B due to the change in wind speed, is no longer present in the reprocessed time series.

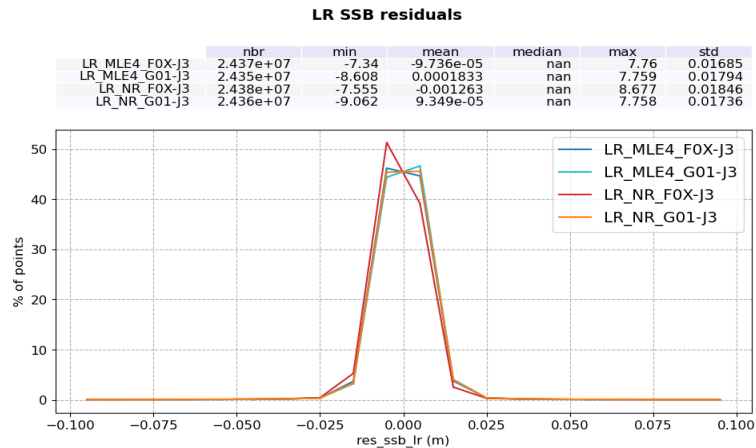


Figure 112: Histogram of Ku-band SSB difference: Sentinel-6 MF LR minus Jason-3. Computed over the complete tandem period.

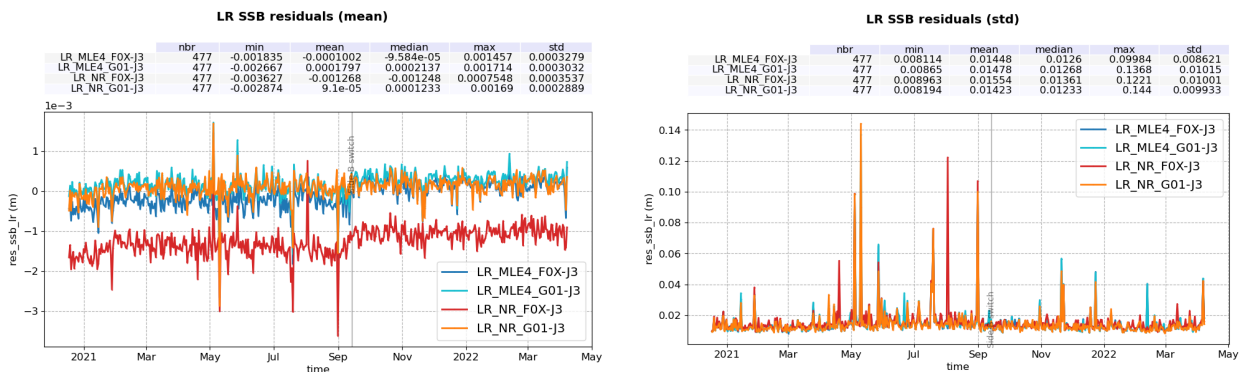


Figure 113: Time monitoring of Ku-band SSB difference: Sentinel-6 MF LR minus Jason-3. Mean per day (**left**) and standard deviation per day (**right**) computed over the complete tandem period for operational MLE4 (blue), reprocessed MLE4 (red) and NR (green). Means have been centred on 0 for better visibility.

The maps of the SSB difference are presented in figure 114, top panels. The differences are mostly located in low SWH areas. It is in line with what is observed for SWH differences in Figure 103 and is due to the difference in low SWH management between Sentinel-6 MF and Jason-3 processing.

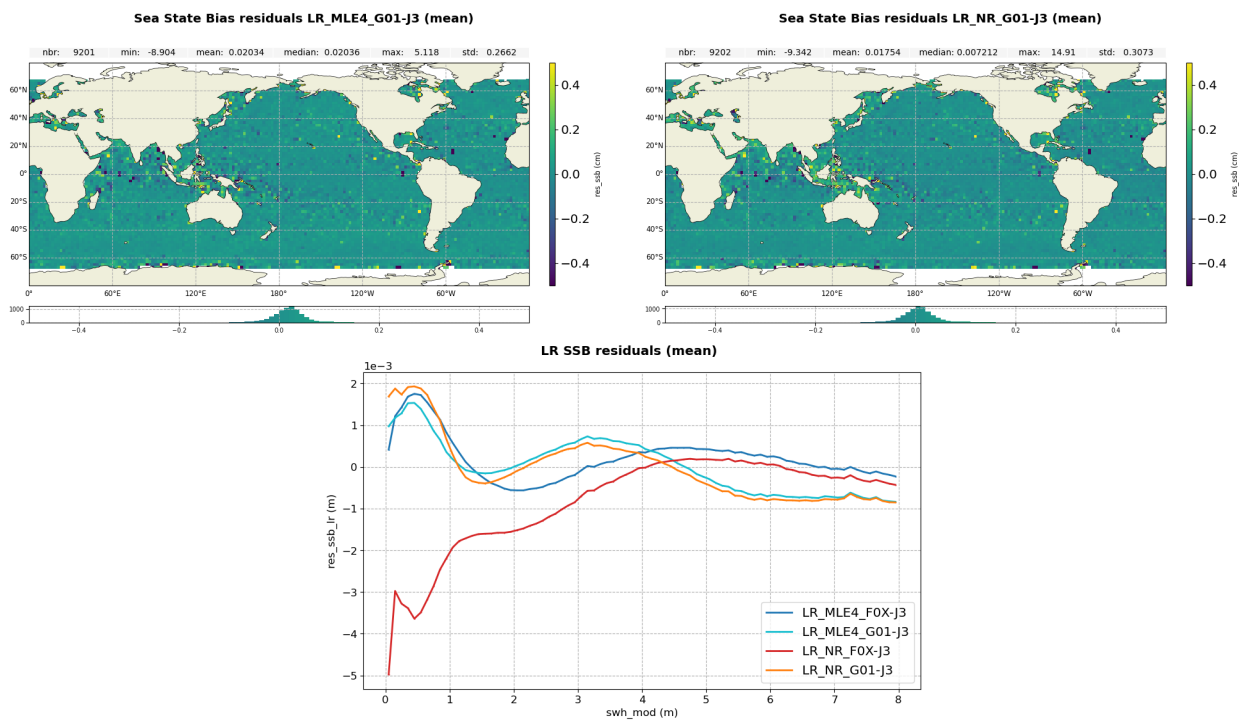


Figure 114: Ku-band SSB difference: Sentinel-6 MF LR minus Jason-3 computed over the complete tandem period. Gridded map for reprocessed MLE4 (**left**) and NR (**right**) and difference as function of ERA 5 model SWH (**bottom**).

8.2.6. Mispointing

In this paragraph, the difference of the square of the off-nadir angles derived from the waveform retracking from LR datasets are compared between Jason-3 and Sentinel-6 MF. Biases of 0.0041 and 0.0042 degree² for reprocessed MLE4 and NR respectively are detected (figure 115). Analysis presented in section 6.1.7. shows that this bias is coming from Sentinel-6 MF, as Jason-3 off-nadir angle is well centred around 0. There is a slight mispointing improvement after the 2021-01-18 star-tracker rotation matrix alignment ([16]), after which these biases are stable in time (figure 116). Manoeuvres performed on Sentinel-6 MF during the commissioning activities are visible on both the time monitorings and the maps (figure 117).

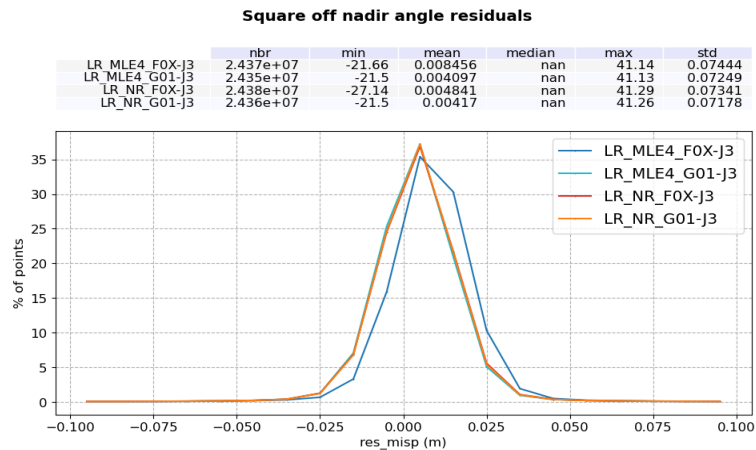


Figure 115: Histogram of mispointing difference: Sentinel-6 MF LR minus Jason-3. Computed over the complete tandem period.

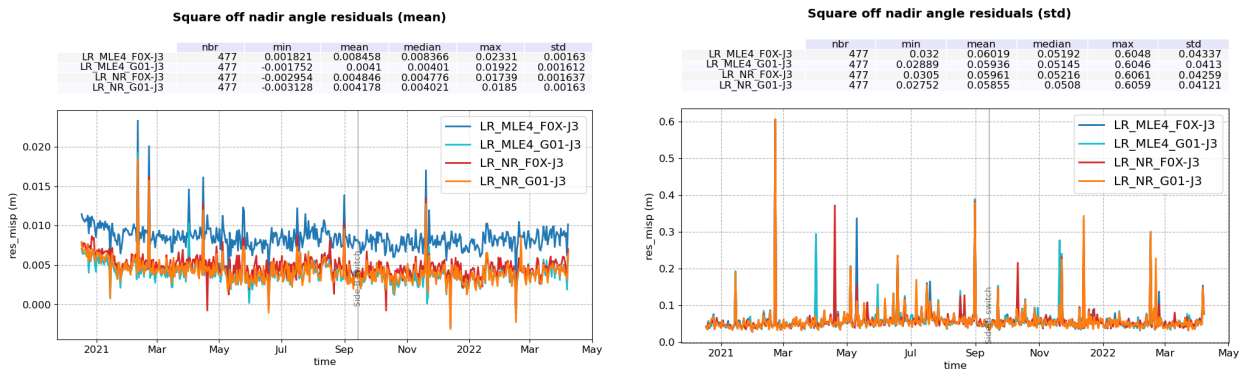


Figure 116: Time monitoring of mispointing difference: Sentinel-6 MF LR minus Jason-3. Mean per day (**left**) and standard deviation per day (**right**) computed over the complete tandem period for operational MLE4 (blue), reprocessed MLE4 (red) and NR (green).

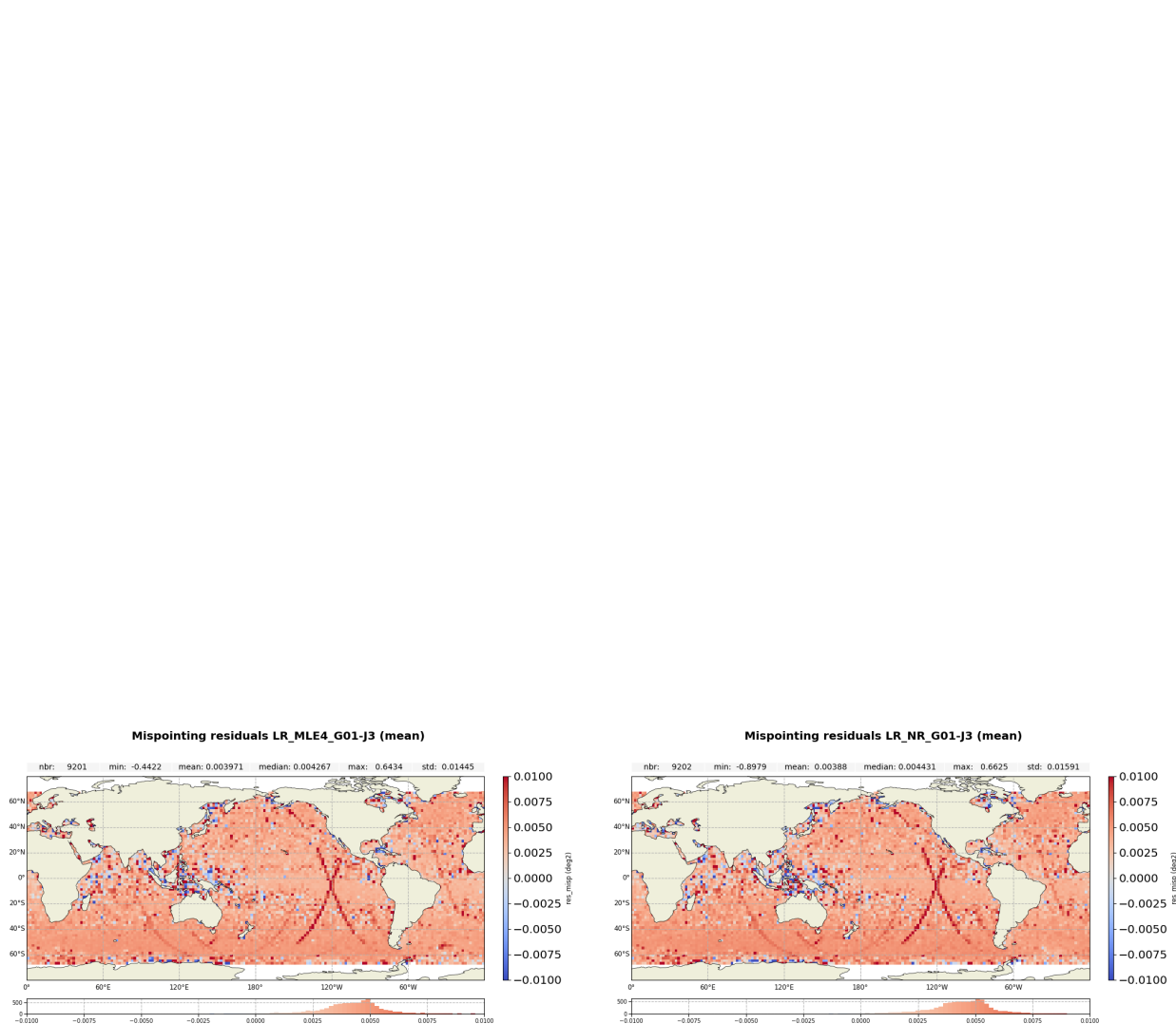


Figure 117: Mispointing difference: Sentinel-6 MF LR minus Jason-3 computed over the complete tandem period. Gridded map for reprocessed MLE4 (**left**) and NR (**right**).

8.3. Ku-band HR

8.3.1. SWH

SAMOSA SWH bias between Sentinel-6 MF HR and Jason-3 (figure 118) is closer to zero with the reprocessing, from 21 cm in operational SAMOSA to -2 mm in reprocessed SAMOSA and 5.2 cm in NR (see section 6.1.1.3.). This is thanks to the use of vertical wave motion correction. Time series are stable (figure 119) and the standard deviation is of 22 cm in SAMOSA and 18 cm in NR.

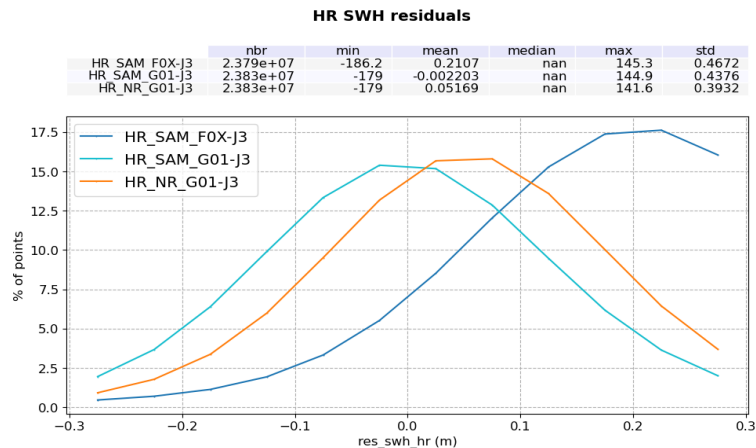


Figure 118: Histogram of Ku-band SWH difference: Sentinel-6 MF HR minus Jason-3. Computed over the complete tandem period.

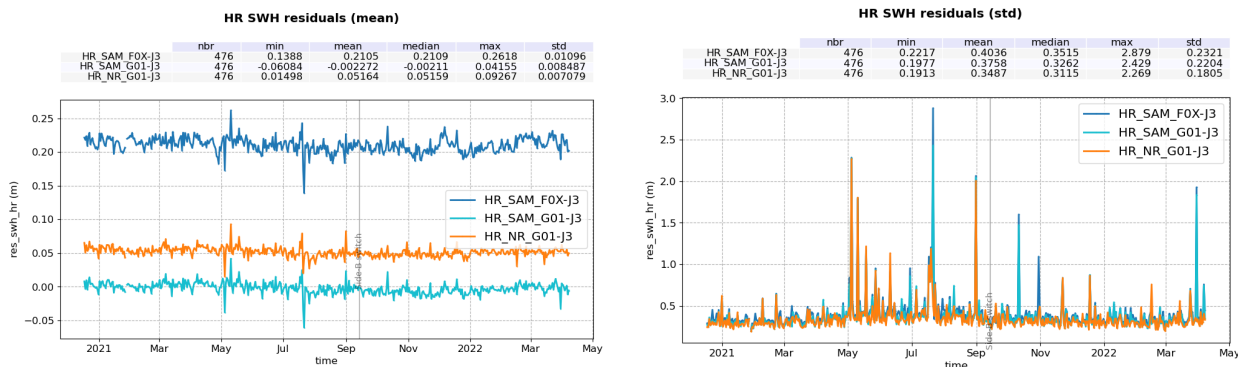


Figure 119: Time monitoring of Ku-band SWH difference: Sentinel-6 MF HR minus Jason-3. Mean per day (**left**) and standard deviation per day (**right**) computed over the complete tandem period.

Maps of SWH difference and differences as a function of model SWH (figure 120) show that, despite the 5 cm bias, NR is better aligned to Jason-3 than SAMOSA (+8 cm between 1 m and 8 m SWH vs +16 cm). This could be linked to the residual doppler ambiguities better handled with the HR NR retracker than with the SAMOSA retracker. Both retrackerers are not aligned with Jason-3 for small SWH due to small waves management differences between the two missions.

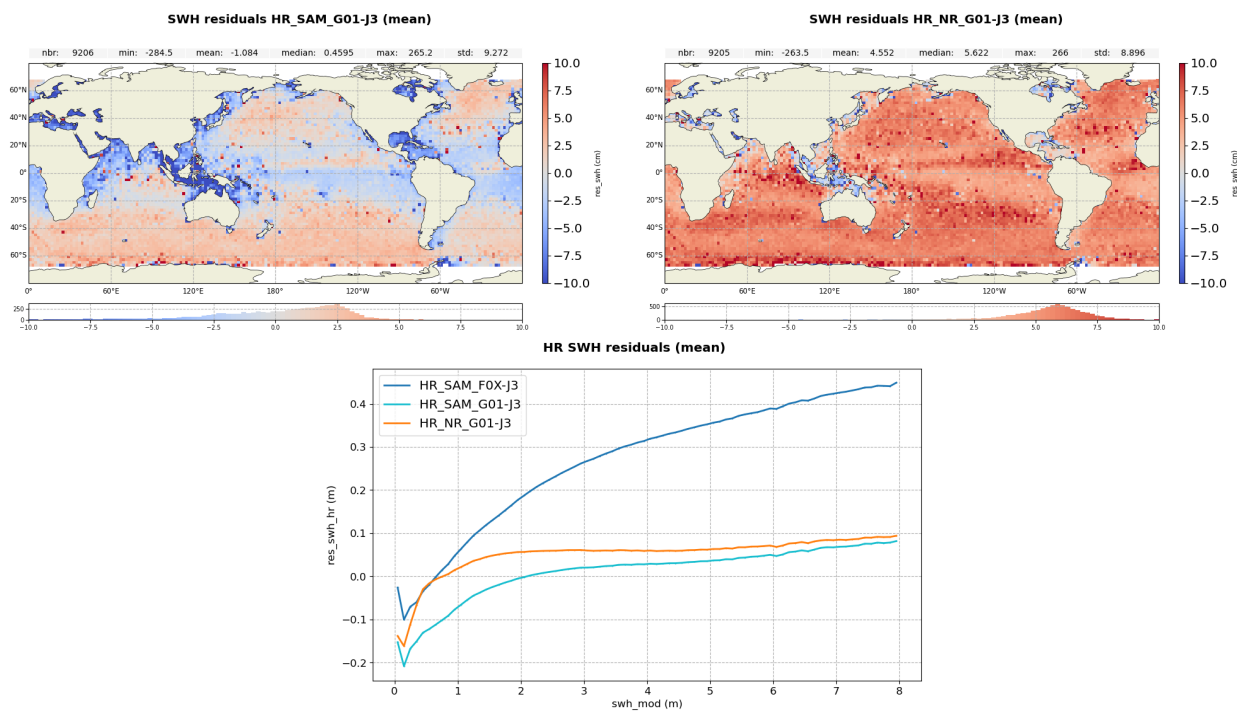


Figure 120: Ku-band SWH difference: Sentinel-6 MF HR minus Jason-3 computed over the complete tandem period. Gridded maps for S6 MF SAMOSA (*left*) and NR (*right*), and differences function of ERA 5 model SWH (*bottom*).

8.3.2. Range

To compare ranges between the two missions, we do not compute a direct difference between the two ranges, because of their strong variation in time that would cause significant interpolation errors. Instead, we compare (orbit - range - MSS).

Figure 121 highlights the consistency between HR NR and Jason-3 with an average bias of 0.2 cm. This bias is consistent with the POE-G update ([11]). Due to the absence of skewness parameter in SAMOSA, the bias is larger at -1.3 cm. In MLE4, the operational dataset showed a poorer agreement with Jason-3 with a 0.7 cm global bias. The time monitoring of the difference (figure 122) shows a significant improvement of the reprocessing with the disappearance of 60 days oscillations. This is linked to the improved POE-G orbital solution for Sentinel-6 MF. Note that a small jump is still visible in April 2021 after the satellite restart.

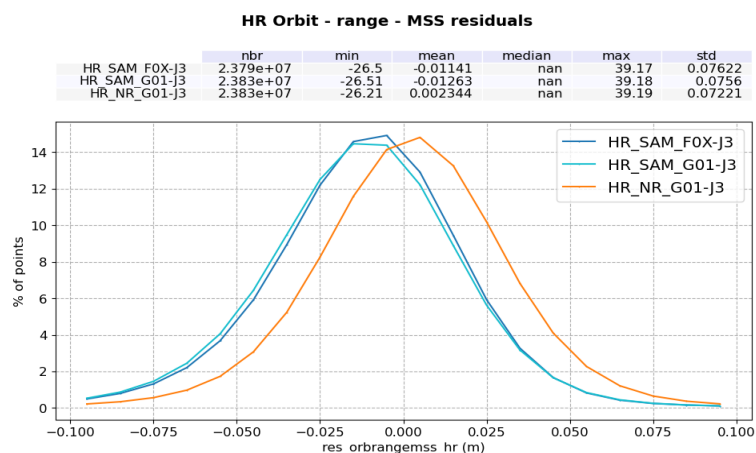


Figure 121: Histogram of Orbit - Ku-band range - MSS difference : Sentinel-6 MF HR minus Jason-3. Computed over the complete tandem period.

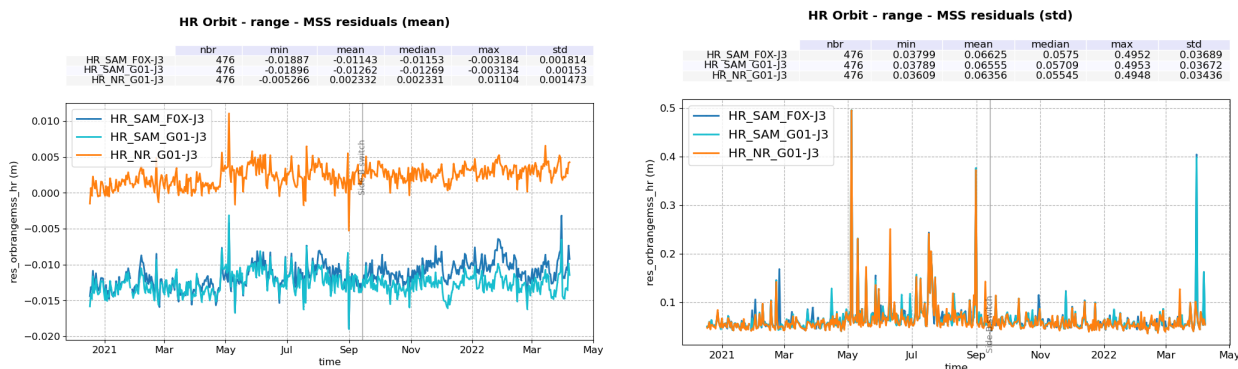


Figure 122: Time monitoring of Orbit - Ku-band range - MSS difference: Sentinel-6 MF HR minus Jason-3. Mean per day (left) and standard deviation per day (right) computed over the complete tandem period.

The maps of the difference presented in figure 123 show a significant correlation to SWH. The bias increase between 1 and 8m-SWH is of -3.4 cm in SAMOSA and -1.8 cm in NR.

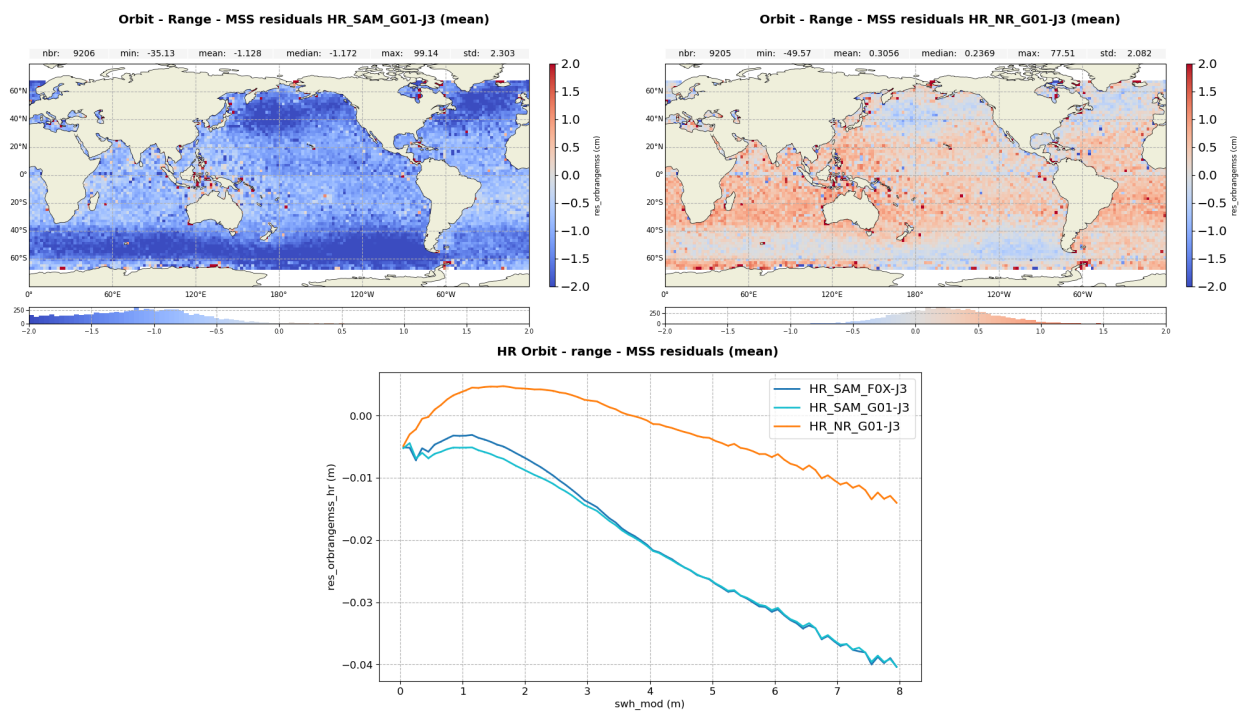


Figure 123: Orbit - Ku-band range - MSS difference: Sentinel-6 MF HR minus Jason-3 computed over the complete tandem period. Gridded maps for reprocessed SAMOSA (left) and NR (right) and difference as function of ERA 5 model SWH (bottom).

8.3.3. Backscatter coefficient

Figure 124 shows the distribution of the difference in sigma0, with a -1.82dB bias in SAMOSA and a -1.96 dB bias in NR. The sigma0 bias between the two missions is stable in time (figure 125, left panel) with a standard deviation of 0.40 dB in reprocessed SAMOSA and 0.39 dB in reprocessed NR (right panel).

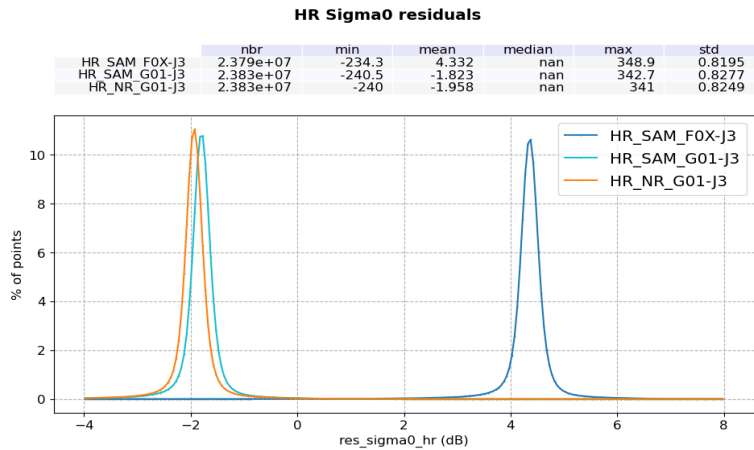


Figure 124: Histogram of Ku-band backscatter coefficient difference: Sentinel-6 MF HR minus Jason-3. Computed over the complete tandem period.

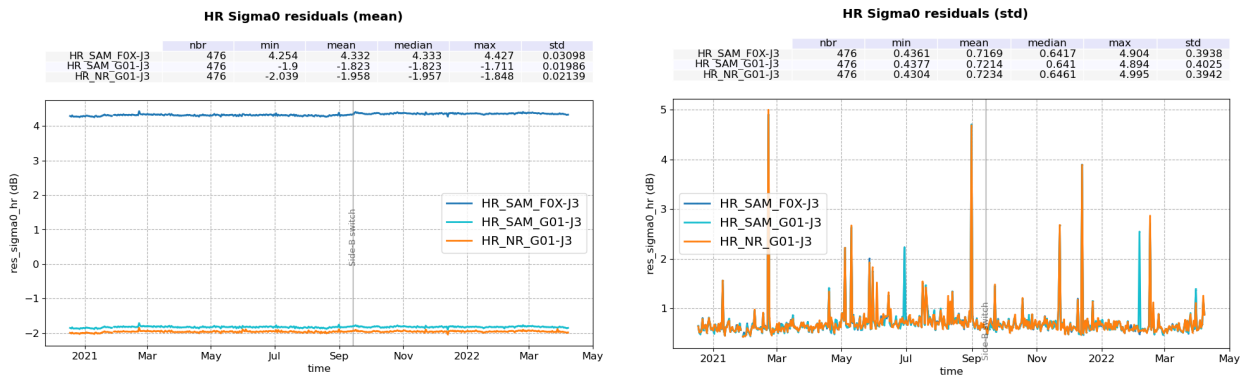


Figure 125: Time monitoring of Ku-band backscatter coefficient difference: Sentinel-6 MF HR minus Jason-3. Mean per day (left) and standard deviation per day (right) computed over the complete tandem period.

Map of the sigma0 difference for reprocessed HR datasets are presented in figure 126, top panels. As confirmed with the difference plot as function of SWH on the bottom panel, we observe a significant SWH dependency : +0.26dB between 1 and 8m-SWH. This correlation is identical in the operational dataset.

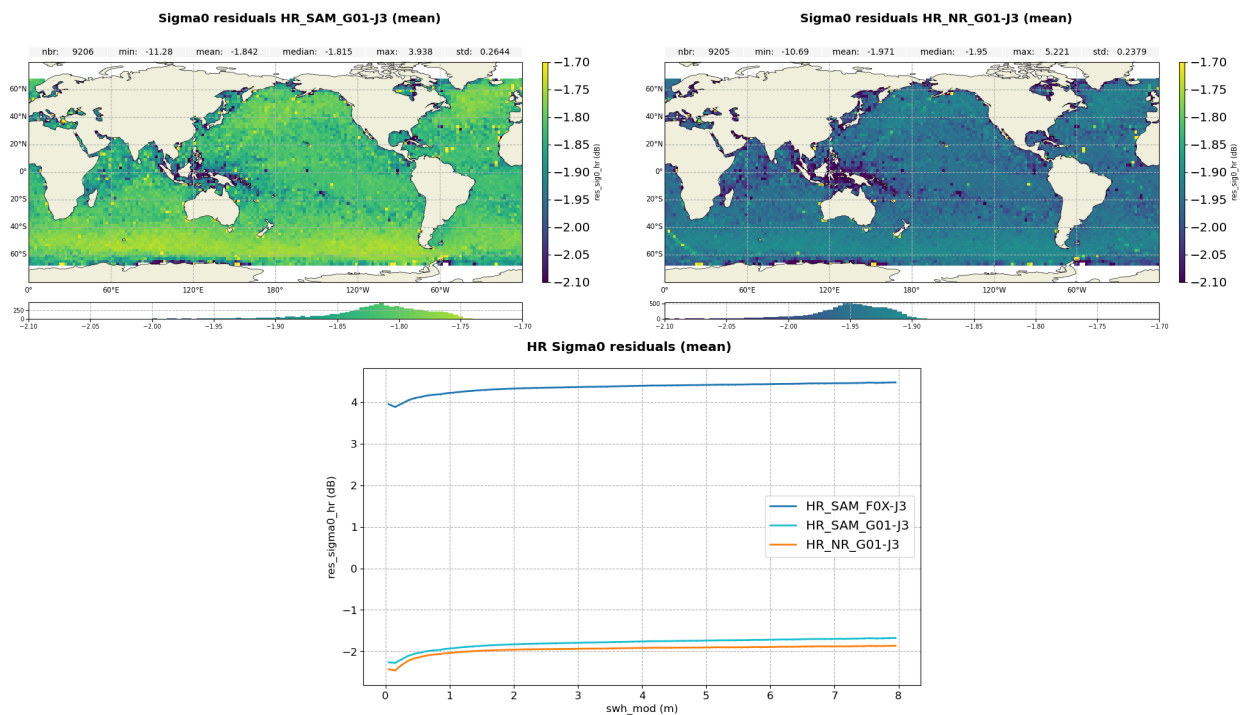


Figure 126: Ku-band backscatter coefficient difference: Sentinel-6 MF HR minus Jason-3 computed over the complete tandem period. Gridded map for SAMOSA reprocessed dataset (top left), NR (top right) and difference as function of ERA 5 model SWH (bottom).

8.3.4. Altimeter Wind-Speed

Sentinel-6 MF wind speed is computed with Collard algorithm, as for Jason-3. Sentinel-6 MF sigma0 in input of the computation should then be calibrated the same way as Jason-3. As can be seen on the histogram in figure 127, the differences in wind speed are not perfectly centred around 0 (-10.5 cm/s for the SAMOSA reprocessed dataset and -9.5 cm/s for HR NR). As Jason-3 SSB table is applied to Sentinel-6 MF, wind speed should be aligned between the two missions for a more precise SSB correction and therefore SSHA. Calibrations biases applied on sigma0 for the wind speed computation should therefore be adjusted. For Jason-3, the sigma0 calibration bias equals to 0.06 dB. Sentinel-6 MF sigma0 calibration should be calculated as the sum of J3/Sentinel-6 MF sigma0 bias and Jason-3 sigma0 calibration bias (0.06 dB). For Sentinel-6 MF HR wind speed computation, the calibration bias applied on sigma0 should be : +1.88 dB (= +1.82 + 0.06) in SAMOSA and +2.02 dB (= +1.96 + 0.06) in NR. We recommend using these values for the next Sentinel-6 MF reprocessing campaign. Note that current PB G01 wind system biases applied for HR is 1.89 dB for SAMOSA and 2.02 dB for HR NR. These biases have been computed to align altimetry wind speed to ECMWF wind speed.

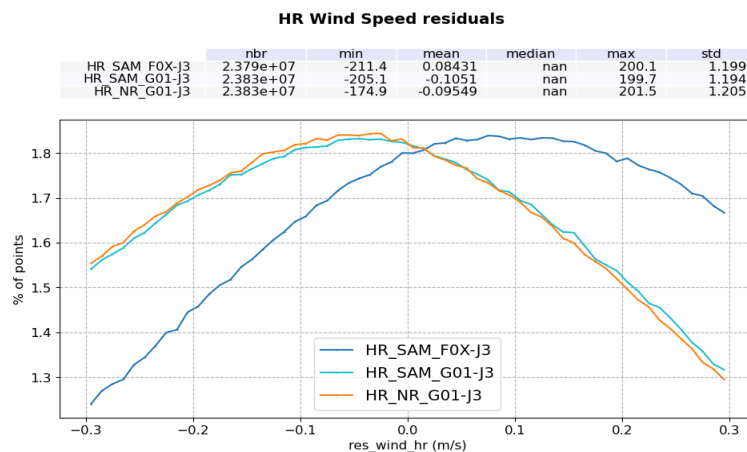


Figure 127: Histogram of altimeter wind speed difference: Sentinel-6 MF HR minus Jason-3. Computed over the complete tandem period.

Time monitoring of the wind speed difference is presented in figure 128. A jump is visible around 18 Jan 2021 after the star-tracker rotation matrix update on board.

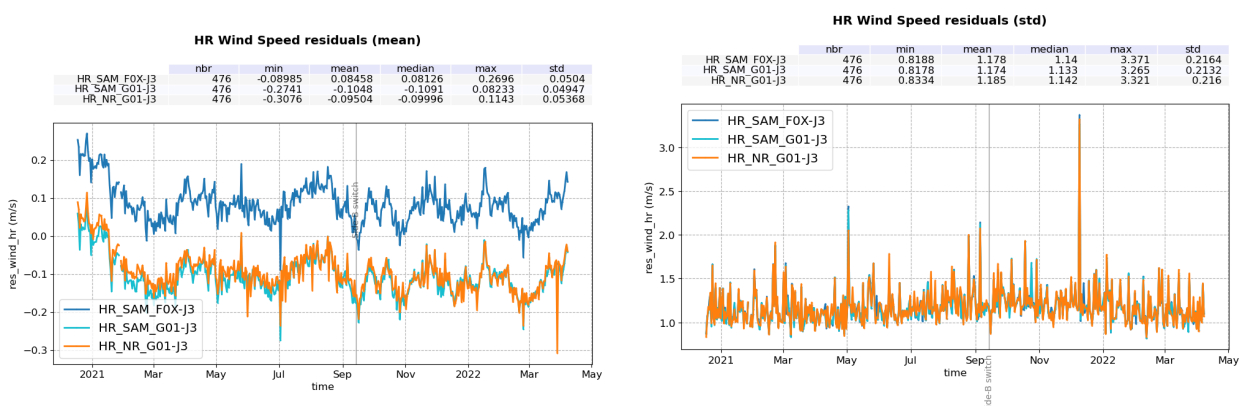


Figure 128: Time monitoring of Ku-band wind speed difference: Sentinel-6 MF HR minus Jason-3. Mean per day (left) and standard deviation per day (right) computed over the complete tandem period.

The maps of reprocessed altimeter wind speed difference are presented in figure 129, top panels. As

confirmed with the difference plot as function of SWH on the bottom panel, the SWH dependency is significantly reduced in NR compared to the reprocessed SAMOSA : -52 cm/s instead of -80 cm/s between 1 and 8m-SWH.

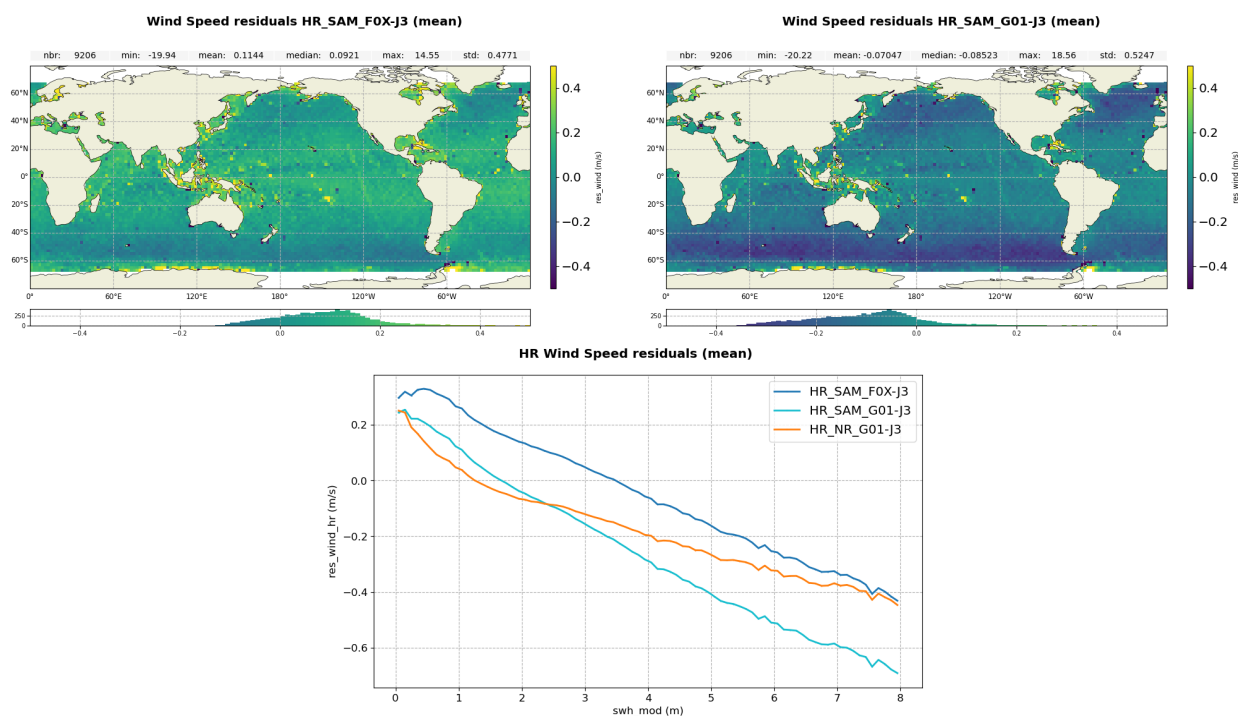


Figure 129: Altimeter wind speed difference: Sentinel-6 MF HR minus Jason-3 computed over the complete tandem period in m/s. Gridded map for operational (**left**) and reprocessed (**right**) datasets and difference as function of ERA 5 model SWH (**bottom**).

8.3.5. Ku-band Sea State Bias

Figure 130 shows the distribution of the differences in SSB over the complete period, with a bias of less than 0.3 mm in reprocessed SAMOSA and 1.6 mm in NR. The time monitoring of these differences, presented in figure 131, is stable.

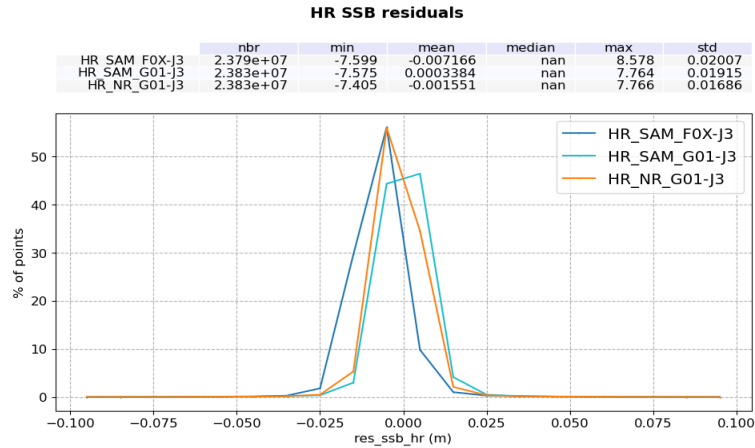


Figure 130: Histogram of Ku-band SSB difference: Sentinel-6 MF HR minus Jason-3. Computed over the complete tandem period.

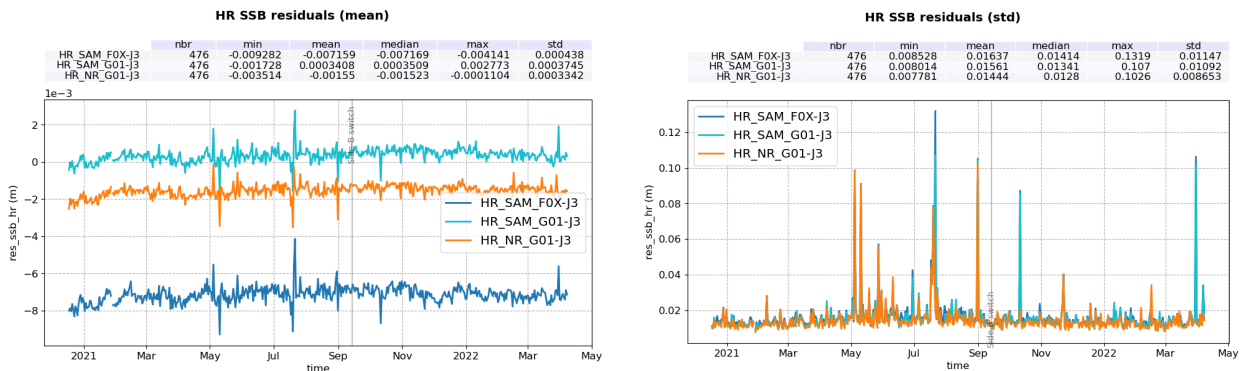


Figure 131: Time monitoring of Ku-band SSB difference: Sentinel-6 MF LR minus Jason-3. Mean per day (**left**) and standard deviation per day (**right**) computed over the complete tandem period.

The maps of the SSB difference are presented in figure 132, top panels. In SAMOSA, the reprocessing drastically reduced the SWH correlation (-5 mm between 1 and 8 m SWH in the reprocessed dataset). The curve for HR NR is essentially flat for SWH larger than 1 m.

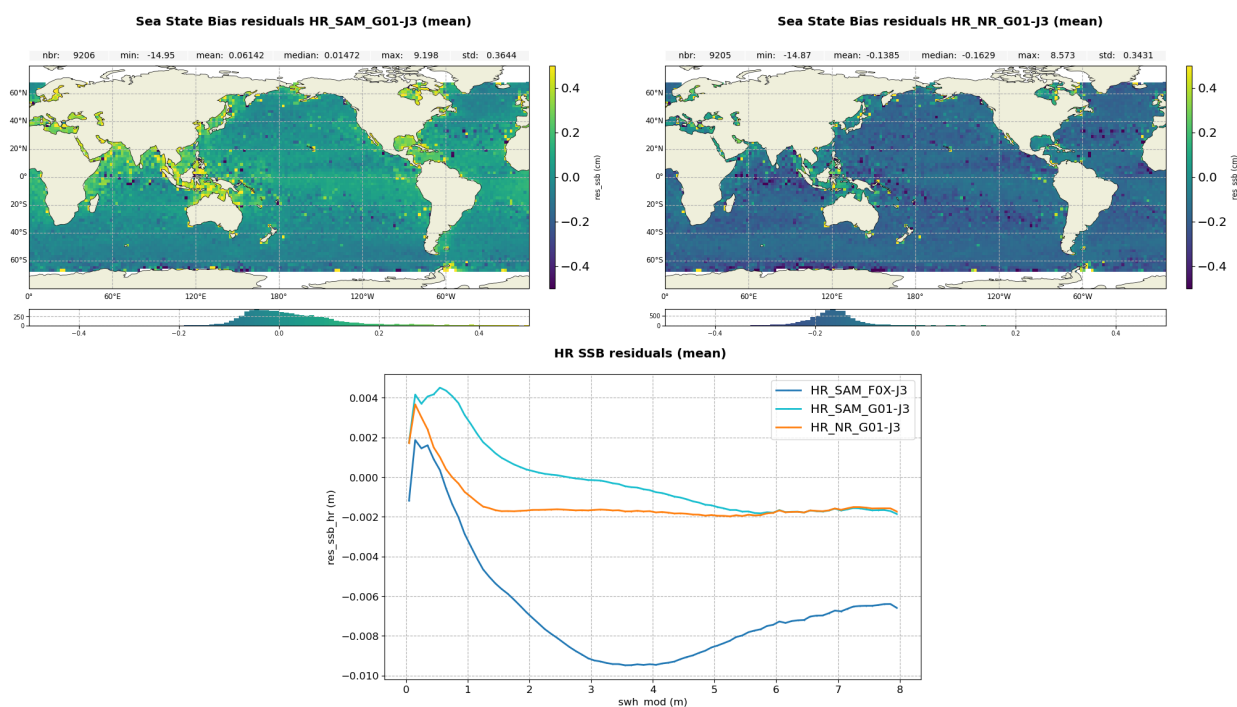


Figure 132: Ku-band SSB difference: Sentinel-6 MF HR minus Jason-3 computed over the complete tandem period. Gridded map for reprocessed SAMOSA (**left**) and NR (**right**) and difference as function of ERA 5 model SWH (**bottom**).

8.4. C-band

8.4.1. C-band SWH

Please note that the C-band SWH is not used in the SSHA computation process.

C-band SWH difference between Sentinel-6 MF LR and Jason-3 shows a large bias of -17 cm (figures 133 and 134), that has been reduced to 9 cm in the reprocessed dataset thanks to the LUT update.

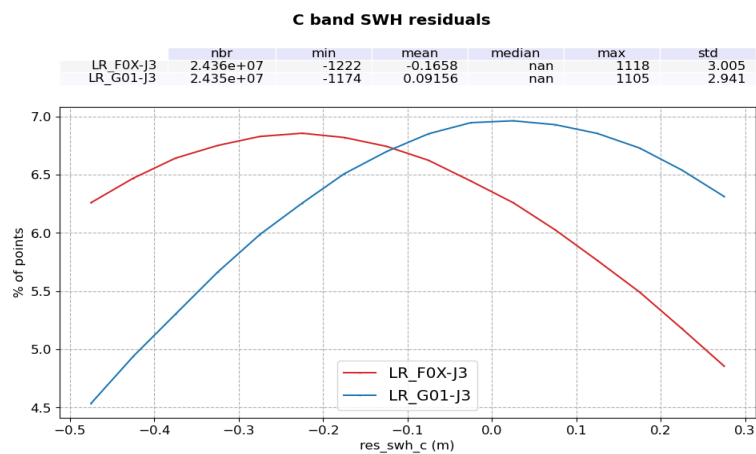


Figure 133: Histogram of C-band SWH difference: Sentinel-6 MF LR minus Jason-3. Computed over the complete tandem period.

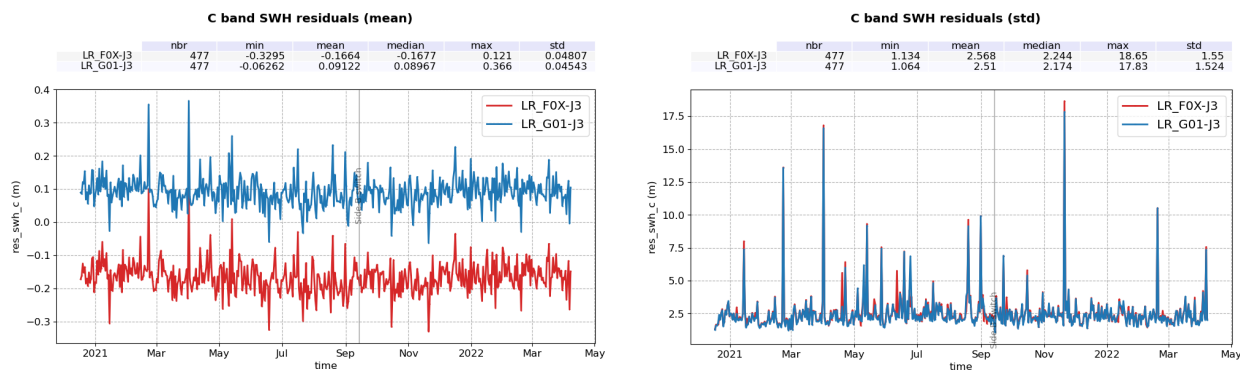


Figure 134: Time monitoring of C-band SWH difference: Sentinel-6 MF LR minus Jason-3. Mean per day (**left**) and standard deviation per day (**right**) computed over the complete tandem period.

The map of the C-band SWH differences for the reprocessed dataset and difference plotted function of ERA-5 SWH are presented in figure 135. The correlation to SWH is still very significant but has been reduced with the reprocessing to about +10 cm between 2 and 8 m SWH.

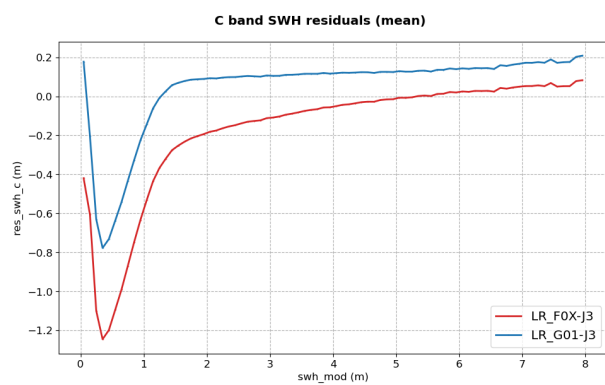
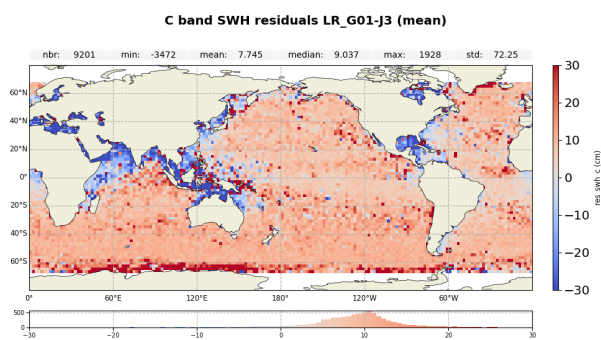


Figure 135: C-band SWH difference: Sentinel-6 MF LR minus Jason-3 computed over the complete tandem period. Gridded map for the reprocessed dataset (**left**) and difference as function of ERA5 SWH (**right**).

8.4.2. C-band Range

C-band range difference highlights the consistency between the two satellites with a bias of only -2.1 cm in average, which is higher than the MLE4 Ku-band range bias (0.2 cm). Additionally, the standard deviation of the difference is higher for C-band: 74 cm versus 8 cm in MLE4 Ku-band. This behaviour is expected and due to the reduced number of pulses in C-band.

The time monitoring of this difference, presented in figure 137, is stable.

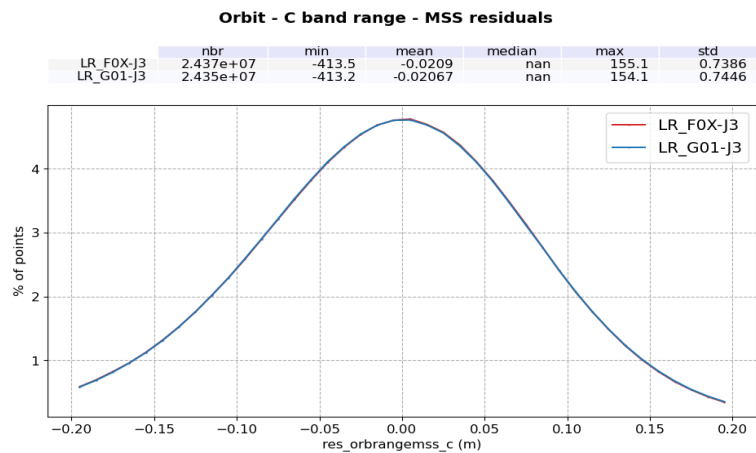


Figure 136: Histogram of Orbit - C-band Range - MSS difference: Sentinel-6 MF LR minus Jason-3. Computed over the complete tandem period.

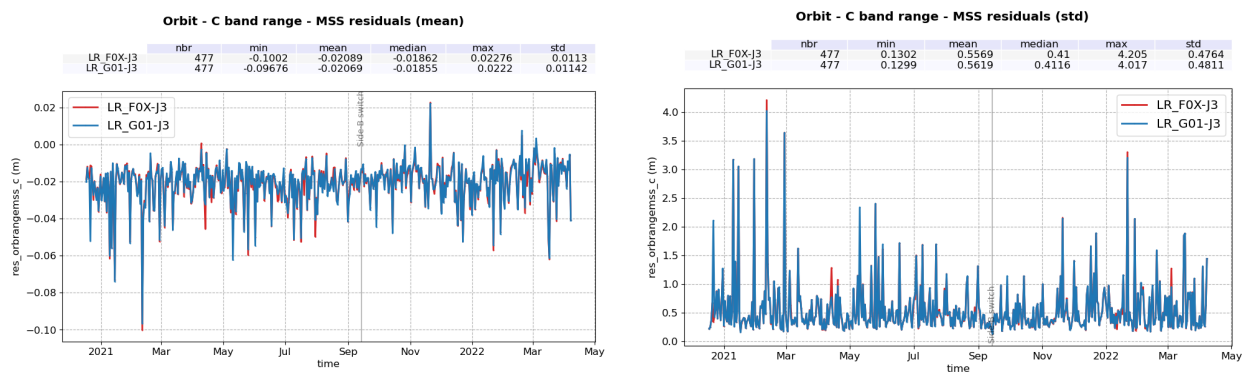


Figure 137: Time monitoring of Orbit - C-band Range - MSS difference: Sentinel-6 MF LR minus Jason-3. Mean per day (left) and standard deviation per day (right) computed over the complete tandem period.

The map of C-band range differences is presented in figure 138, left panel. The main correlation is with the total electron content of the ionosphere, which can be explained by the C-band frequency difference between Sentinel-6 MF (5.41 GHz) and Jason-3 (5.3 GHz) (the ionosphere impact depends on band frequency). Additionally, these differences might also be correlated to the sea state bias.

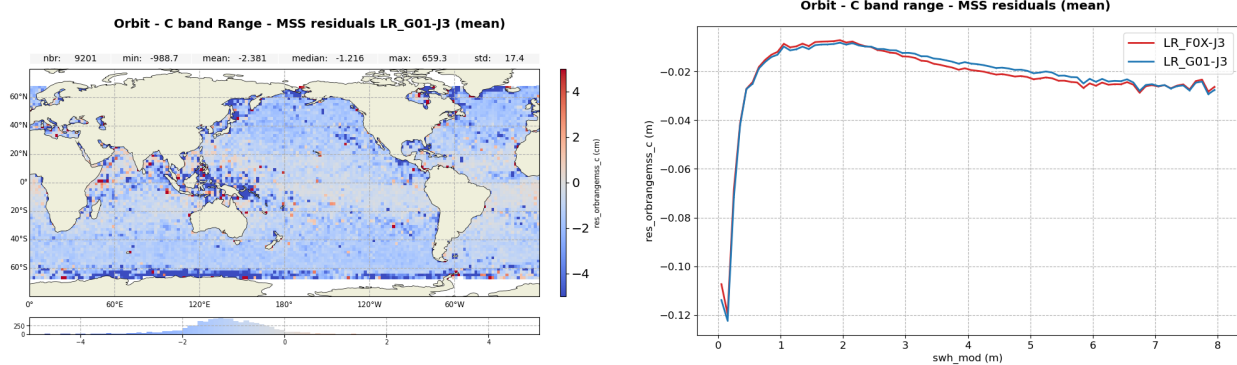


Figure 138: Orbit - C-band Range - MSS difference: Sentinel-6 MF LR minus Jason-3 computed over the complete tandem period. Gridded map (left panel) and difference as function of ERA 5 model SWH (right panel).

8.4.3. C-band Backscatter coefficient

Please note that the C-band sigma0 is not used in the SSHA computation process.

Figure 139 (left panel) shows the distribution of the differences in C-band sigma0 over the complete period, with a bias of -1.64 dB before and -0.73 dB after reprocessing. The time monitoring of these differences is presented in figure 140, with a drift mostly visible before the POS4 switch to B-side.

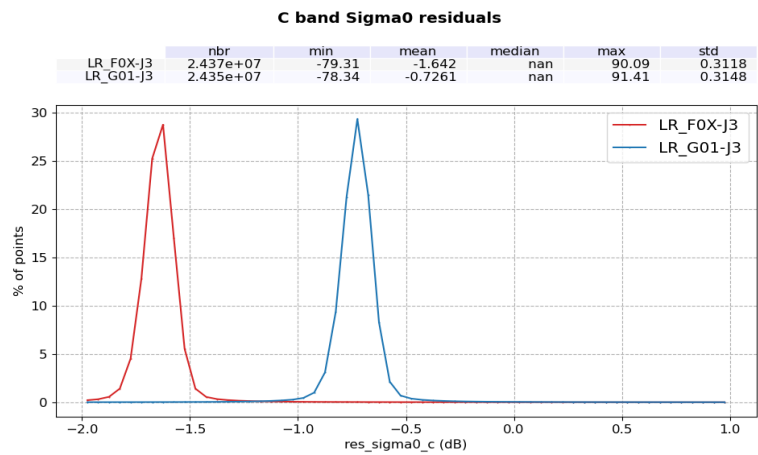


Figure 139: Histogram of C-band backscatter coefficient difference: Sentinel-6 MF LR minus Jason-3. Computed over the complete tandem period.

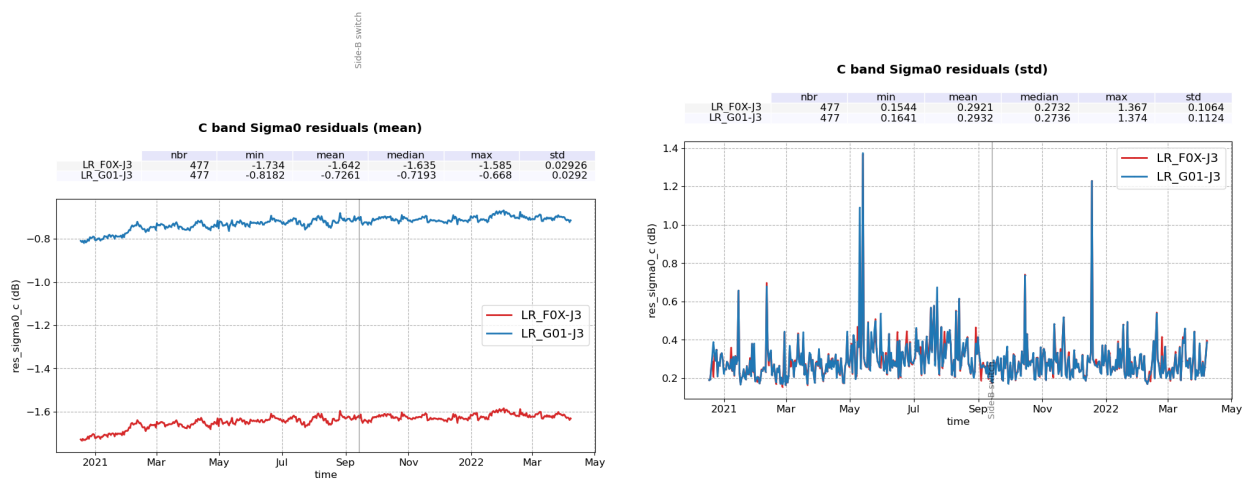


Figure 140: Time monitoring of C-band backscatter coefficient difference: Sentinel-6 MF LR minus Jason-3. Mean per day (left) and standard deviation per day (right) computed over the complete tandem period.

The map of C-band sigma0 difference is presented in figure 141, left panel. The differences are mostly located in low SWH areas.

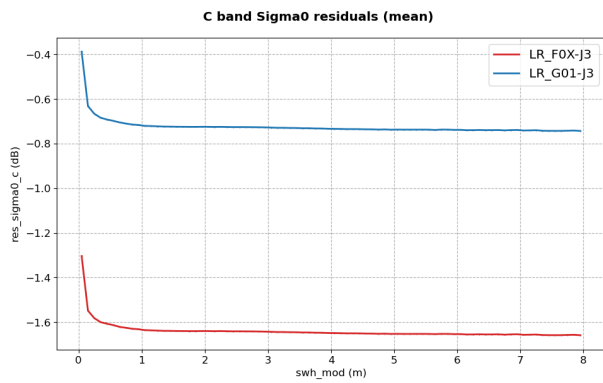
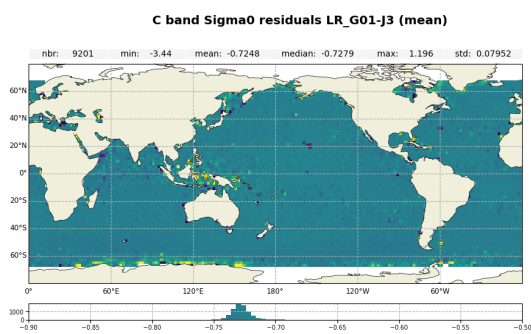


Figure 141: C-band backscatter coefficient difference: Sentinel-6 MF reprocessed LR minus Jason-3 computed over the complete tandem period. Gridded map (left) and difference as function of ERA 5 model SWH (right).

8.4.4. C-band Sea State Bias

Sentinel-6 MF C-band SSB are computed using Jason-3 GDR-F C-band SSB table with Sentinel-6 MF LR Ku-band SWH and altimeter wind speed derived from LR Ku-band measurements as inputs. Sentinel-6 MF and Jason-3 C-band SSB are perfectly in line between the operational and reprocessed datasets, with a bias below the mm (figure 142). The time monitoring of the SSB difference (figure 143) highlights a jump of 0.5 mm at the POS4 B-side switch in operational datasets, no longer present in reprocessed datasets due to the g scaling update.

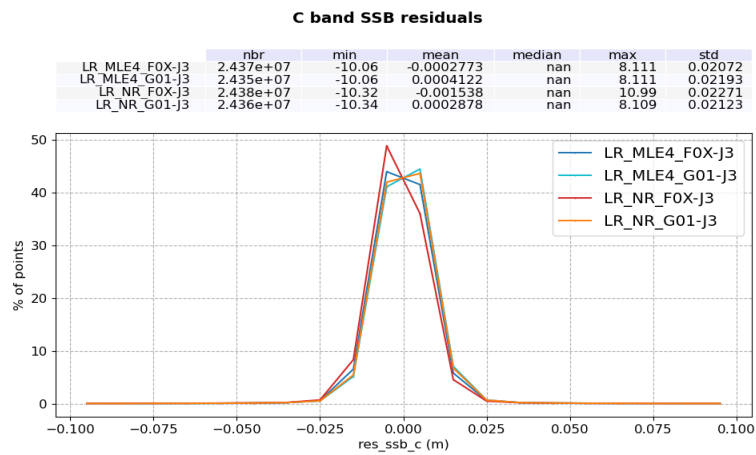


Figure 142: Histogram of C-band SSB difference: Sentinel-6 MF LR minus Jason-3. Computed over the complete tandem period.

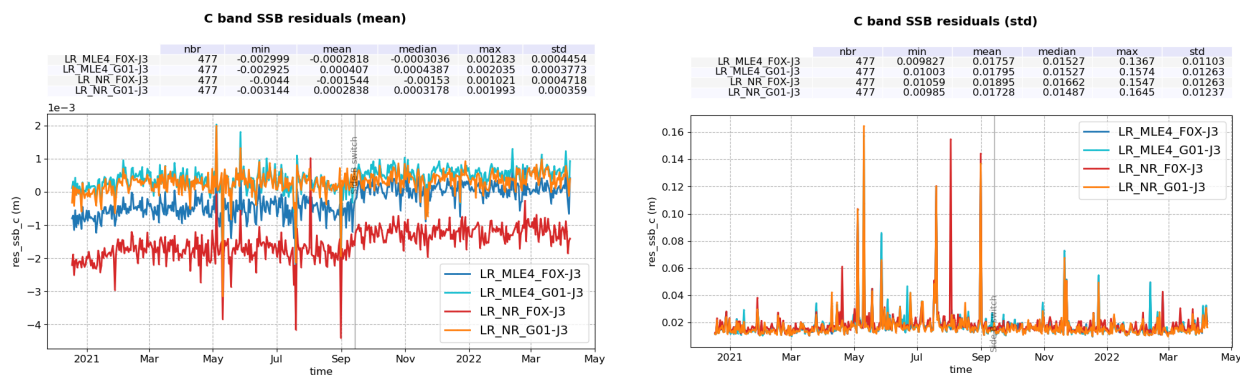


Figure 143: Time monitoring of C-band SSB difference: Sentinel-6 MF LR minus Jason-3. Mean per day (left) and standard deviation per day (right) computed over the complete tandem period.

The corresponding maps (figure 144, top panels) show a small correlation to SWH for very small waves. It is in line with what is observed for SWH differences in Figure 103 and is due to the difference in low SWH management between Sentinel-6 MF and Jason-3 processing.

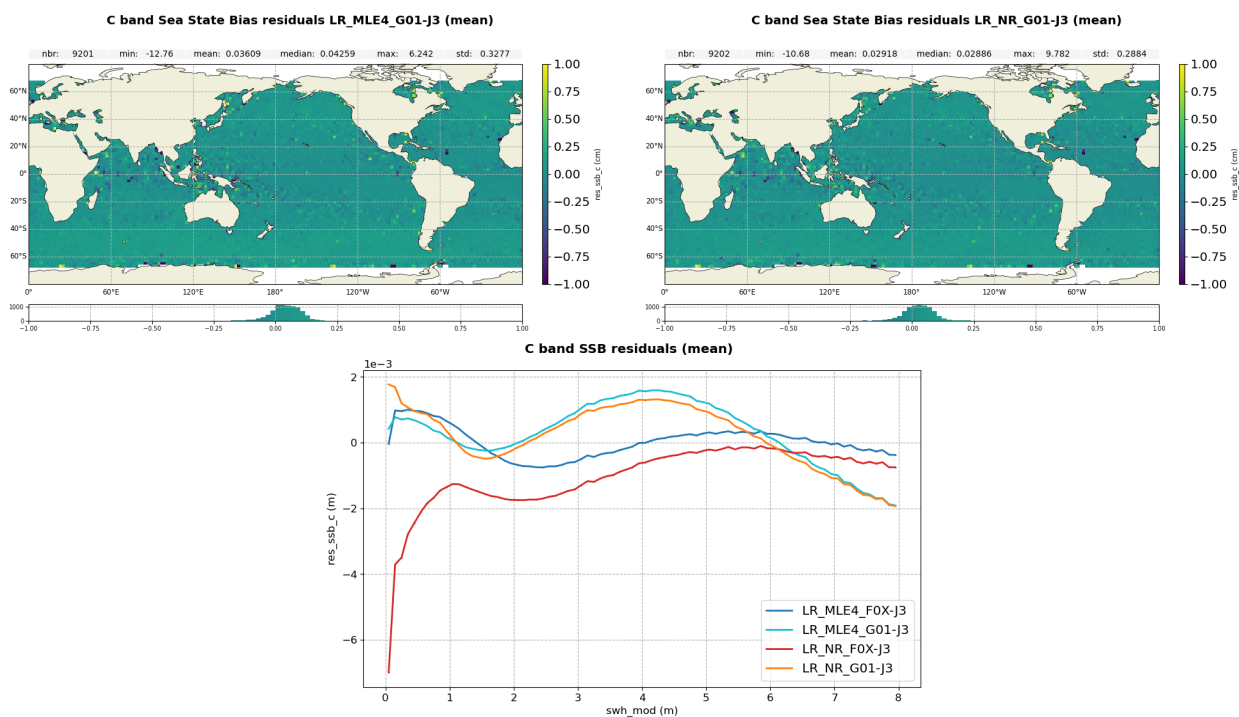


Figure 144: C-band SSB difference: Sentinel-6 MF LR minus Jason-3 computed over the complete tandem period. Gridded map for reprocessed MLE4 (**left**), NR (**right**) and difference as function of ERA 5 model SWH (**bottom**).

8.5. Altimeter ionosphere correction

In this section, the filtered altimeter ionosphere corrections from Sentinel-6 MF and Jason-3 are compared. Sentinel-6 MF altimeter ionosphere correction is derived from LR data, in Ku and C band, and more precisely from ranges corrected from SSB.

Over the complete tandem phase, the bias between the two solutions is centred around -0.2 cm in reprocessed MLE4 and NR.

The time monitoring of this bias (figure 146) shows a clear jump at the POS4-B switch in all datasets. This value is smaller for reprocessed datasets (about 0.5 mm in MLE4 and 0.7 mm in NR). The fact that these jumps appear in the reprocessed ionospheric corrections but not in its components (Ku and C band range and SSB) is still under investigation.

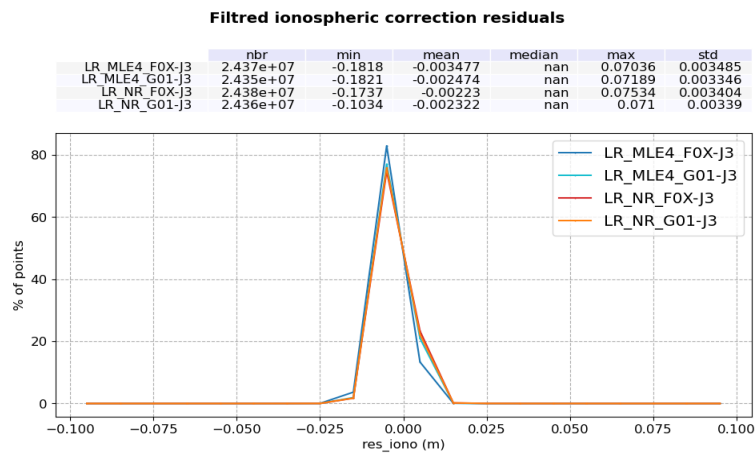


Figure 145: Histogram of Filtered Altimeter Ionosphere correction difference: Sentinel-6 MF LR minus Jason-3. Computed over the complete tandem period.

The maps of the filtered ionosphere correction differences are presented in figure 147, top panels. We observe a correlation with ERA-5 model SWH (bottom panel) : -0.6 cm between 1 and 8m-SWH.

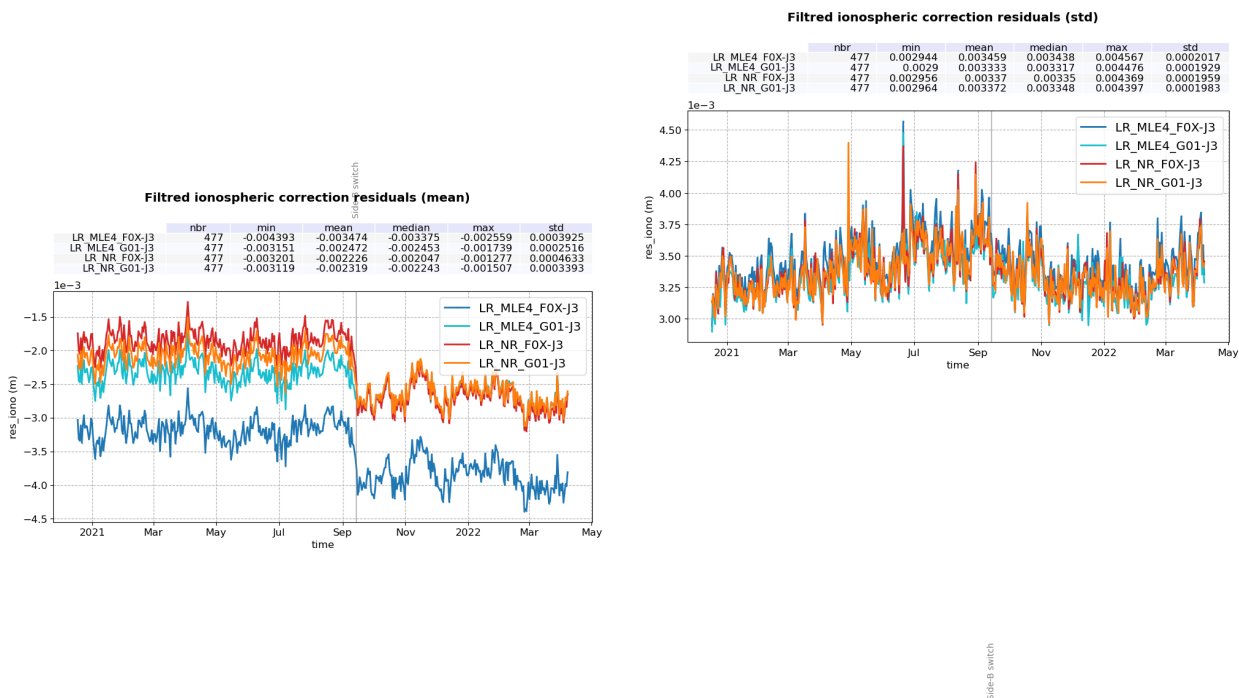


Figure 146: Time monitoring of Filtered Altimeter Ionosphere correction difference: Sentinel-6 MF LR minus Jason-3. Mean per day (**left**) and standard deviation per day (**right**) computed over the complete tandem period.

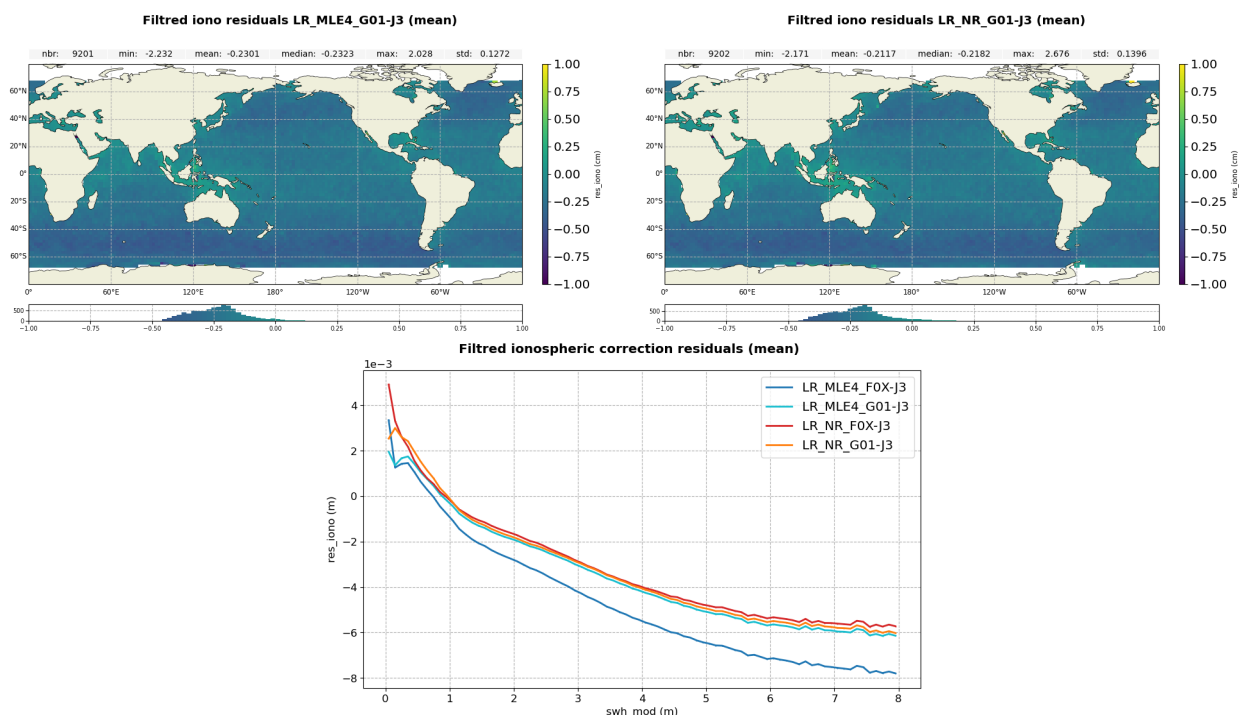


Figure 147: Filtered Altimeter Ionosphere correction difference: Sentinel-6 MF LR minus Jason-3 computed over the complete tandem period. Gridded map for reprocessed MLE4 (**left**) and NR (**right**) and difference as function of ERA 5 model SWH (**bottom**).

8.6. SSHA

8.6.1. LR SSHA

In this section, Sentinel-6 MF LR and Jason-3 MLE4 SSHA are compared over the complete tandem flight. The average bias is of 0.5 cm in reprocessed MLE4 and NR. As summarized in table 14, the ionosphere correction accounts for about half of this bias. This is because the Sentinel-6 MF C band SSB uses Jason-3 table despite their difference in frequency. Next biggest contributor is the Orbit - range - MSS, with about 2 mm, due to the POE-G orbit update on Sentinel-6 MF.

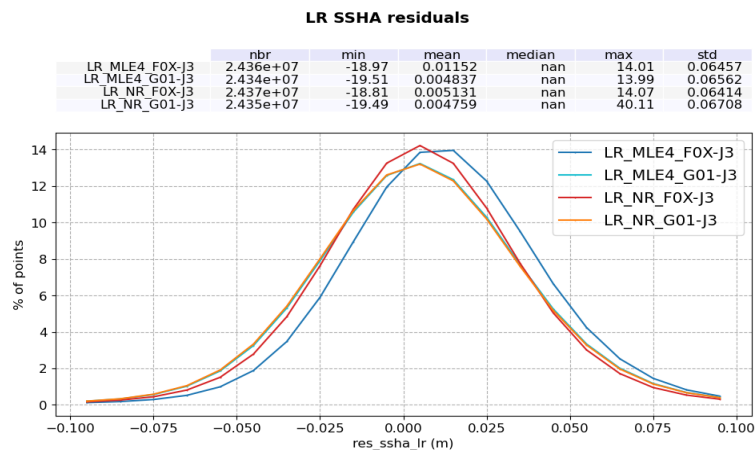


Figure 148: Histogram of product SSHA difference: Sentinel-6 MF LR minus Jason-3. Computed over the complete tandem period.

Parameter	S6 MF LR - J3 bias	
	MLE4	NR
Orbit - Ku-band range - MSS	0.15 cm	0.16 cm
Ku-band SSB	0.02 cm	-0.01 cm
Altimeter filtered ionosphere correction	-0.25 cm	- 0.23 cm
AMR-C/HRMR WTC	-0.10 cm	
Sum	0.48 cm	0.51 cm

Table 14: Summary of the Sentinel-6 MF LR minus Jason-3 biases for the parameters used in the SSHA computation. Computed over the complete tandem flight. The sum is performed as [bias on orbit-range-mss] minus [the sum of the bias on the geophysical correction], as in the SSHA computation.

The time monitoring of this difference (figure 149, left panel) shows a jump of about +5 mm after the satellite restart of 27-28 April 2021. This is partly caused by the jump in WTC (cf figure 99) of similar amplitude. Figure 150 presents only the reprocessed time series.

We cannot definitely conclude on the existence of a jump in the monitoring at POS4 switch to B-side on September 14th 2021. It is because the SSHA difference has a standard deviation stronger than the jumps observed on the ionospheric corrections. This standard deviation is stable in time and is centred around 6.2 cm in reprocessed MLE4 and 6.1 cm in NR (figure 149, right panel).

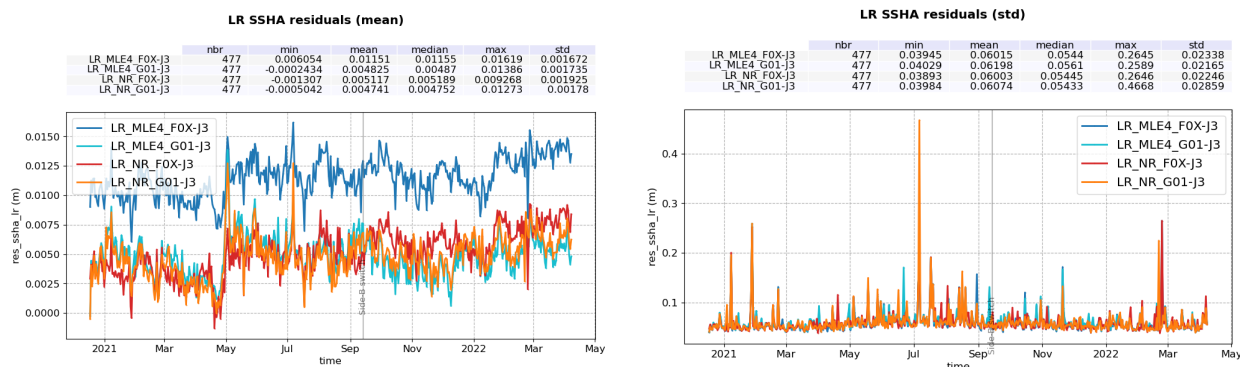


Figure 149: Time monitoring of product SSHA difference: Sentinel-6 MF LR minus Jason-3. Mean (**left**) and standard deviation (**right**) per day computed over the complete tandem period.

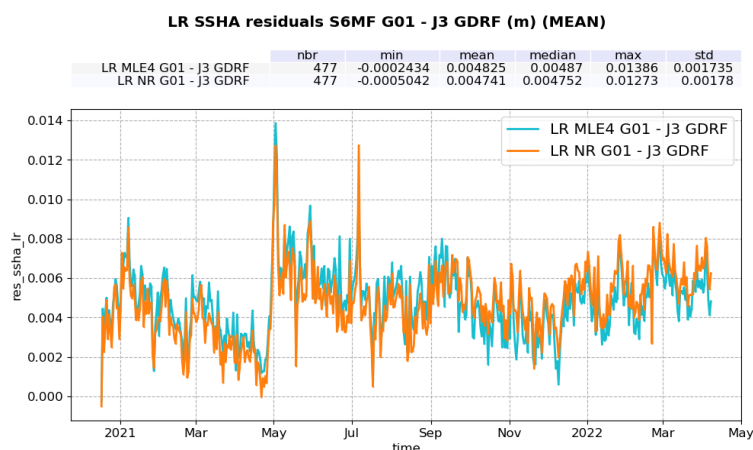


Figure 150: Time monitoring of product SSHA difference: Sentinel-6 MF LR G01 minus Jason-3 GDR-F per day computed over the complete tandem period.

The maps of the SSHA differences (figure 151 top panels) highlight a clear correlation to SWH, as confirmed by the plot of the difference function of ERA-5 SWH (figure 151 bottom panel). Note that these maps are also impacted by the difference in standard between Jason-3 and Sentinel-6 MF, Jason-3 still uses GDR-F standards (see section 5) and POE-F orbital solutions [11]. The SSHA bias increases by 1.3 cm between 1 and 8m-SWH in reprocessed datasets.

The equatorial band visible on the orbit-range-mss difference map (figure 106) due to Jason-3 is still observed on the SSHA difference map, with the same amplitude.

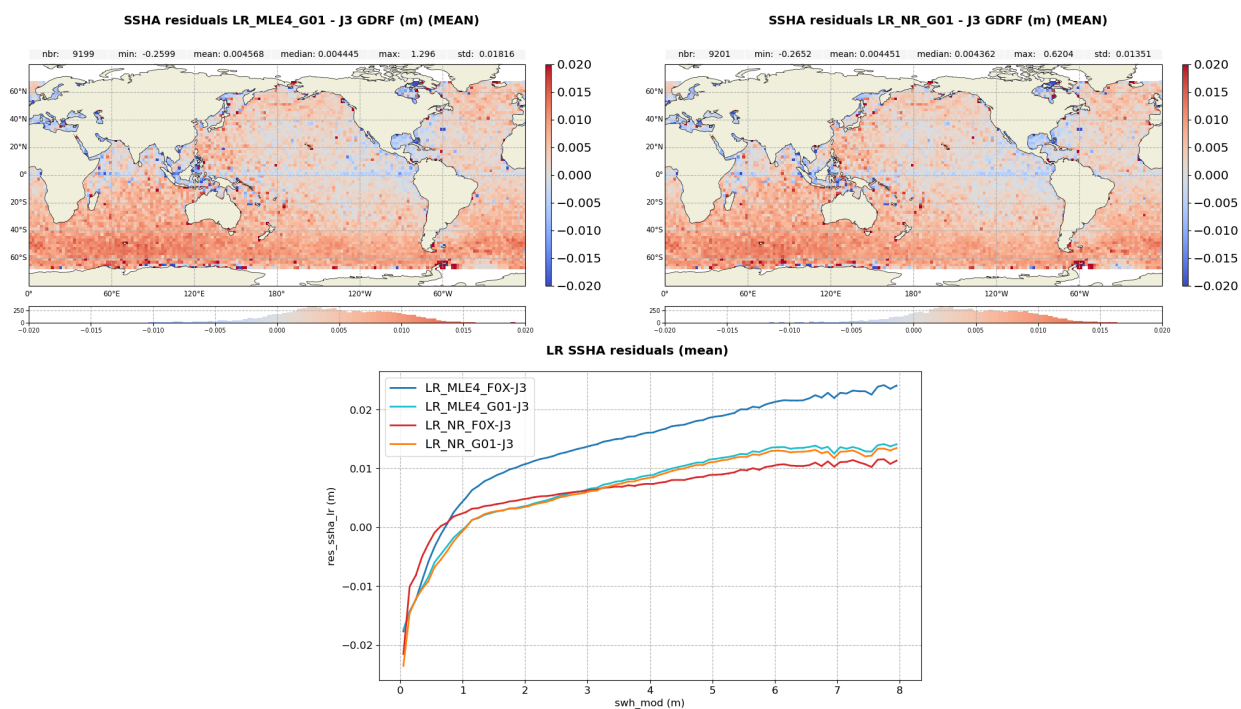


Figure 151: SSHA difference: Sentinel-6 MF LR minus Jason-3 computed over the complete tandem period. Gridded map for reprocessed MLE4 (**left**) and NR (**right**) and difference as function of ERA 5 model SWH (**bottom**).

8.6.2. HR SSHA

In this section, Sentinel-6 MF HR and Jason-3 MLE4 SSHA are compared over the complete tandem flight. The average bias is of -0.9 cm in SAMOSA and 0.7 cm in NR (figure 152). Main contributors are shown in table 15.

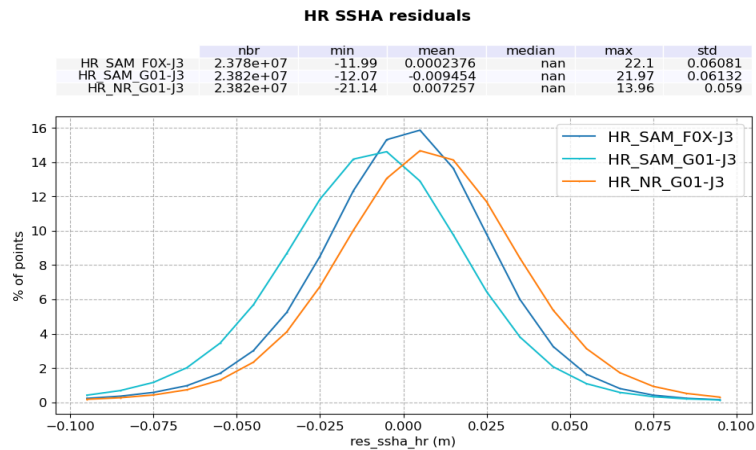


Figure 152: Histogram of product SSHA differences: Sentinel-6 MF HR minus Jason-3. Computed over the complete tandem period.

Parameter	S6 MF HR - J3 bias	
	SAMOSA	NR
Orbit - Ku-band range - MSS	-1.26 cm	0.23 cm
Ku-band SSB	0.03 cm	-0.16 cm
Altimeter filtered ionosphere correction	-0.25 cm	-0.23 cm
AMR-C/HRMR WTC	-0.10 cm	
Sum	-0.95 cm	0.73 cm

Table 15: Summary of the Sentinel-6 MF HR minus Jason-3 biases for the parameters used in the SSHA computation. Computed over the complete tandem flight. The sum is performed as [bias on orbit-range-mss] minus [the sum of the bias on the geophysical correction], as in the SSHA computation.

The time monitoring of this difference (figure 153, left panel) highlights the same event as in LR mode in the previous section: a jump of about +5 mm after the satellite restart of 27-28 April 2021. Both curves follow identical evolution but with a +1.6 cm bias due to the absence of skewness parameter in SAMOSA. Standard deviations (right panel) are similar with 5.7 cm for reprocessed SAMOSA and 5.6 cm for NR. Figure 154 presents only the reprocessed time series.

The maps of the SSHA differences (figure 155 top panels) highlight a clear correlation to SWH, as confirmed by the plot of the difference function of ERA-5 SWH (figure 151 left panel). Note that these maps are also impacted by the difference in standard between Jason-3 and Sentinel-6 MF, Jason-3 still uses GDR-F standards (see section 5) and POE-F orbital solutions [11]. The SSHA bias decreases by 2.6 cm in SAMOSA and 1 cm in NR between 1 and 8m-SWH. The higher value in SAMOSA reflects the skewness differences with Jason-3.

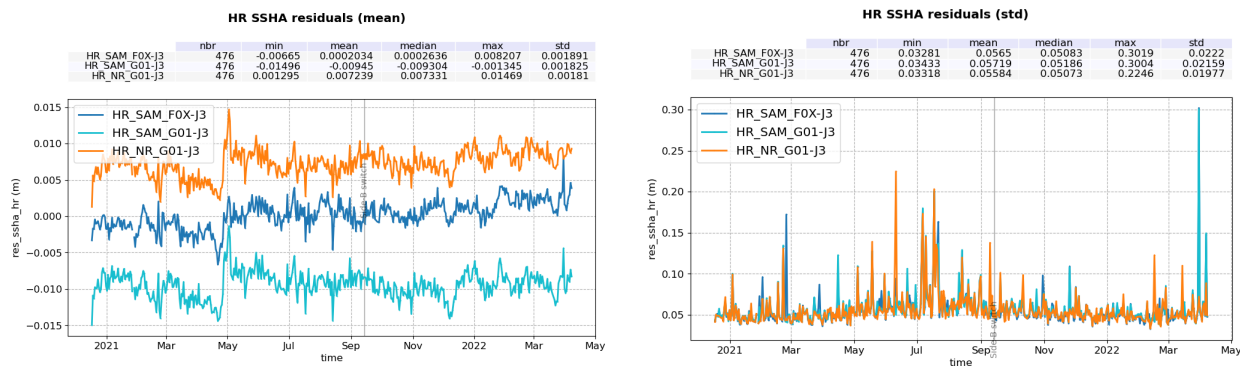


Figure 153: Time monitoring of product SSHA difference: Sentinel-6 MF HR minus Jason-3. Mean (**left**) and standard deviation (**right**) per day computed over the complete tandem period.

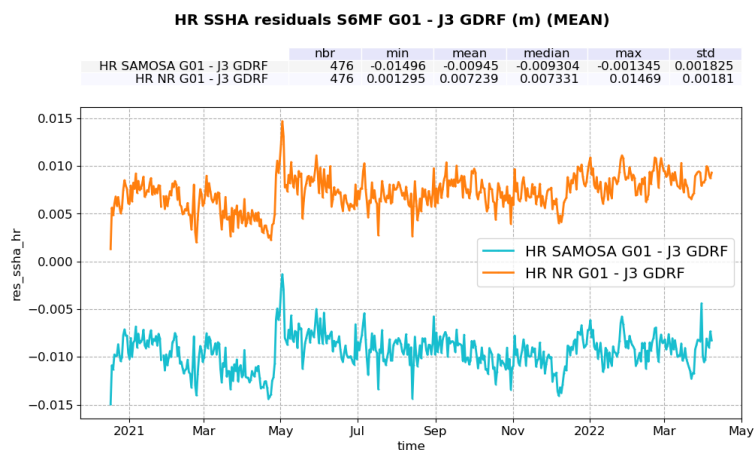


Figure 154: Time monitoring of product SSHA difference: Sentinel-6 MF HR G01 minus Jason-3 GDR-F per day computed over the complete tandem period.

The equatorial band already observed in LR is also visible here, with a similar amplitude, as it is expected since this behaviour comes from Jason-3.

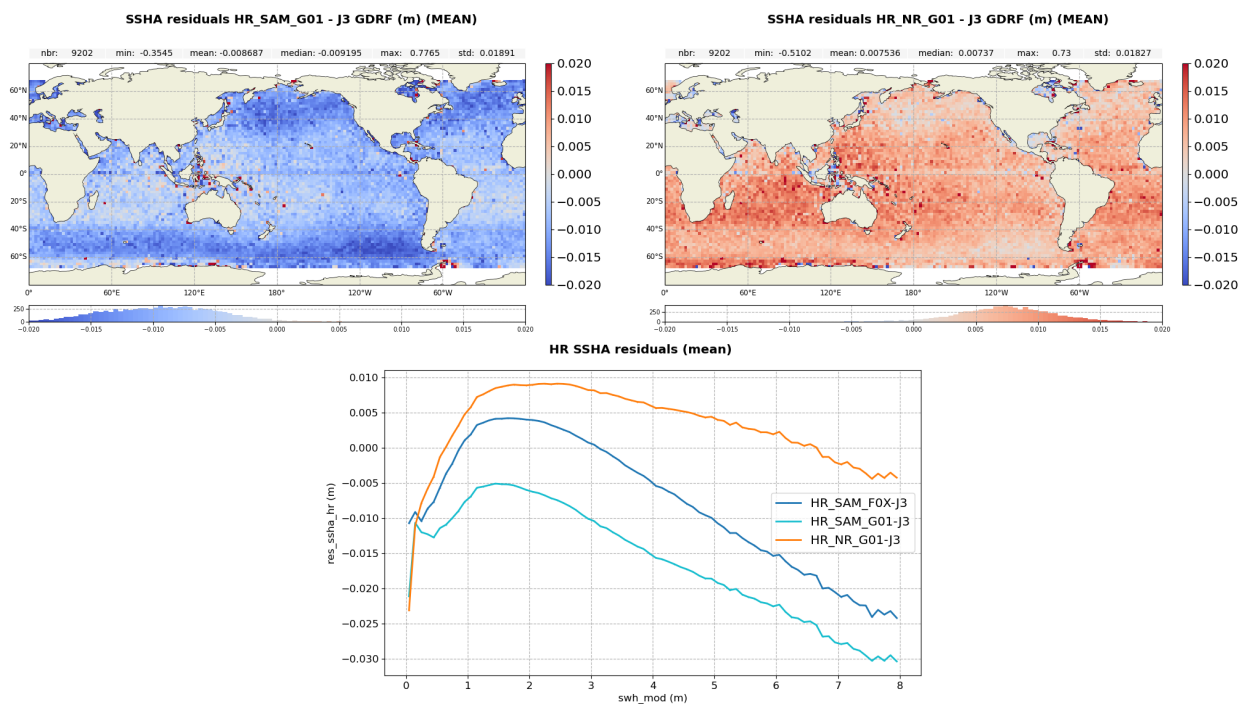


Figure 155: SSHA difference: Sentinel-6 MF HR minus Jason-3 computed over the complete tandem period. Gridded map for reprocessed SAMOSA (**left**) and NR (**right**) datasets and difference as function of ERA 5 model SWH (**bottom**).

Sentinel-6MF satellite is taking over the responsibility as the reference mission to continue the long-term record of sea-surface height measurements started in January 1993 by the Topex-Poseidon satellite and then by the Jason series. The role of Copernicus Sentinel-6 MF is not only to extend the so-called Global Mean Sea Level (GMSL) climate record, but also to monitor the changing height of the sea surface with greater precision than before. At first, dedicated tandem phase with previous satellite Jason-3 ensure precise calibrations of the GMSL Sentinel-6 MF record.

9.1. Uncertainty between Jason-3 and Sentinel-6MF

In this section, we present the derivation of the GMSL offset and its uncertainty between Jason-3 and Sentinel-6MF for its LR mode only, over the tandem phase. We also discuss the behaviour of the GMSL difference time series between the two satellites to highlight potential residuals discrepancies. Both MLE4 and Numerical retracking algorithms are analysed in this part of the report.

For this analysis, Jason-3 GDR-F MLE4 data has been used with the AVISO Level2 Plus vDT2024 standards (see [17]).

9.1.1. Side A

Figure 156 presents the GMSL over POS4-A period for the reprocessed dataset, for LR MLE4 (left panel) and LR NR (right panel) retrievals. The GMSL evolution is identical for the two retracking outputs over this period (green curves in the middle panels). The differences with respect to Jason-3 (bottom plots) also show the same evolution in time: it is stable in time, with two jumps : one at cycle 14 and one at cycle 17. This jump at cycle 17 is concomitant with Sentinel-6MF restart occurring on the 27-28 April 2021 that impacted the range. This jump is also visible on Sentinel-6 MF SSHA and WTC comparison to Jason-3 (see sections 6.2., 8.1. and 8.6.1. for more details). The anomaly measured during cycle 14 is probably from Jason-3 measurements as a small jump is seen on the Jason-3 time series (black) and not on the Sentinel-6 MF time series (green).

The GMSL offset between Jason-3 and reprocessed Sentinel-6MF dataset is estimated to $-50 \pm 0.5 \text{ mm}$ (68.2 % C.L.) for LR MLE4. It is estimated at $-51 \pm 0.4 \text{ mm}$ (68.2 % C.L.) for LR NR (see right panels of figure 157). Please note that these offsets differ from bias estimates given in section 8.6.1. as Jason-3 data contain L2P biases in the present analysis, unlike previously. The GMSL offset derivation and its uncertainty estimation is based on [14].

From figure 157 (left panel), we still observed a significant GMSL drift between Jason-3 and Sentinel-6MF ($4.6 \pm 3.8 \text{ mm.yr}^{-1}$ (90 % C.L.) for LR MLE4 and $4.2 \pm 3.8 \text{ mm.yr}^{-1}$ (90 % C.L.) LR NR) that is mostly due to the jump at cycle 17 mentioned above. This behaviour was already observed with PB F08 data (see [7]) and did not change with the reprocessing.

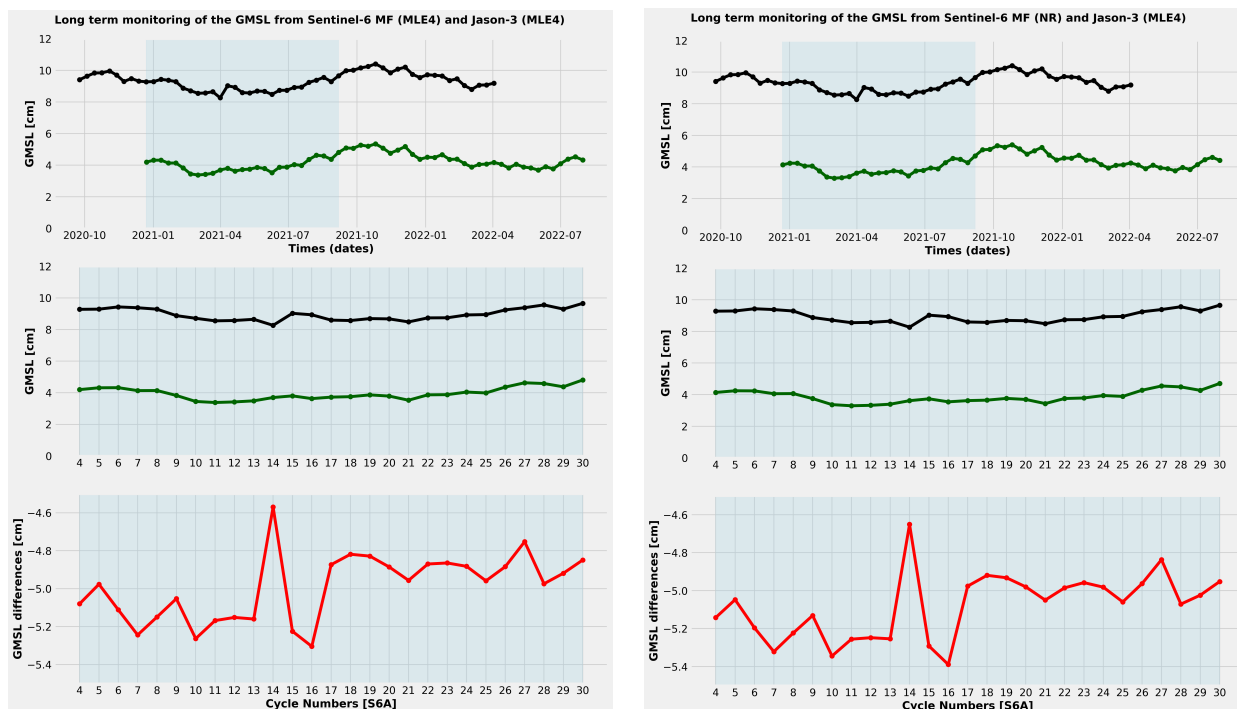


Figure 156: Jason-3 (black) and Sentinel-6 MF (green) GMSL time series (top panel), the tandem phase over the side-A tandem phase (middle panel) and their differences (bottom panel), for Sentinel-6 MF reprocessed dataset, LR MLE4 on the left and LR NR on the right.

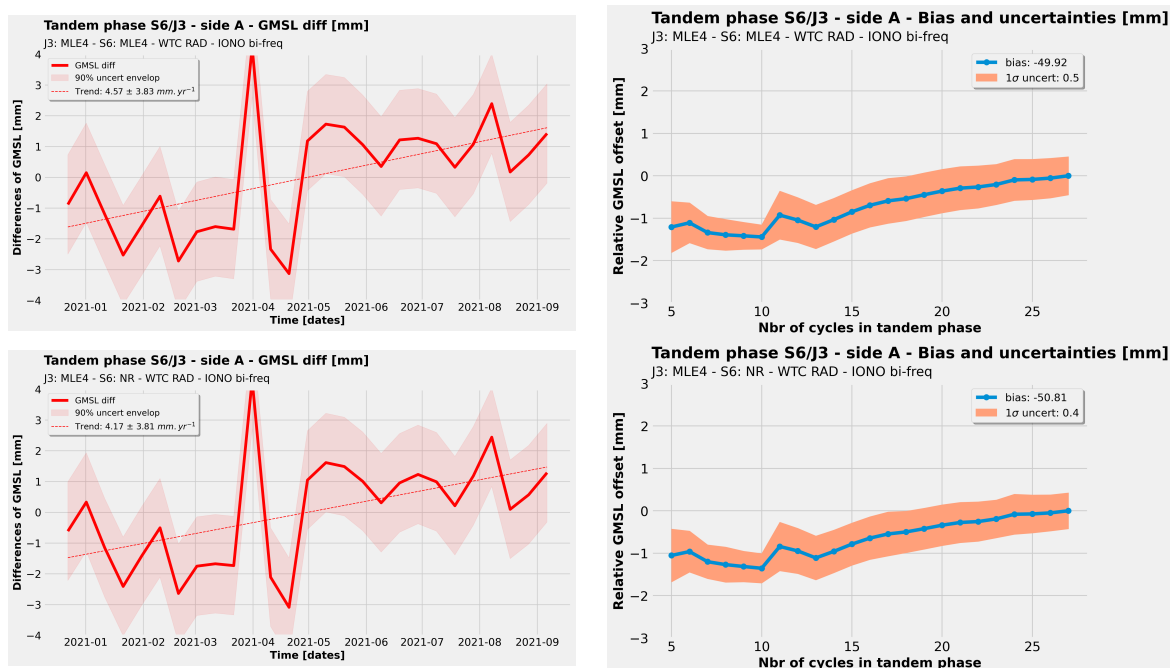


Figure 157: Time series of GMSL difference between Jason-3 and Sentinel-6 MF over the side A tandem phase (left) and relative GMSL offset and its uncertainty between Jason-3 and Sentinel-6 MF as a function of the number of cycle used for the computation (right). Top: Sentinel-6MF LR MLE4; Bottom: Sentinel-6MF LR MLE4

9.1.2. Side B

Figures 158 and 159 present the GMSL over the side B for the reprocessed dataset, as well as the GMSL differences with respect to Jason-3 and their relative offset over the tandem phase. The stability between Jason-3 and Sentinel-6MF has been improved after the switch (from $4.6 \pm 3.8 \text{ mm.yr}^{-1}$ to $0.3 \pm 2.1 \text{ mm.yr}^{-1}$ (90 % C.L.) in LR MLE4). No significant drift is observed between Jason-3 and Sentinel-6MF side-B GMSL (despite the large uncertainty due to the short time period). The uncertainty on the GMSL offset has also been slightly improved from 0.5 mm to 0.4 mm (68.2 % C.L.). On the monitoring of the difference of GMSL with Jason-3, a change of behaviour can be seen during February 2022, which origin is under investigation. This behavior was also observed in the tandem phase analysis (see section 6.2., 8.1. and 8.6.1. for more details).

The metrics are of the same order for the two retracker outputs. The only difference can be observed on the GMSL offset between Jason-3 and reprocessed Sentinel-6MF dataset. As for POS4-A period, it is estimated at $50.4 \pm 0.4 \text{ mm}$ (68.2 % C.L.) with LR MLE4 and $49.8 \pm 0.4 \text{ mm}$ (68.2 % C.L.) with LR NR. Please note that these offsets differ from bias estimates given in section 8.6.1. as Jason-3 data contain L2P biases in the present analysis, unlike previously.

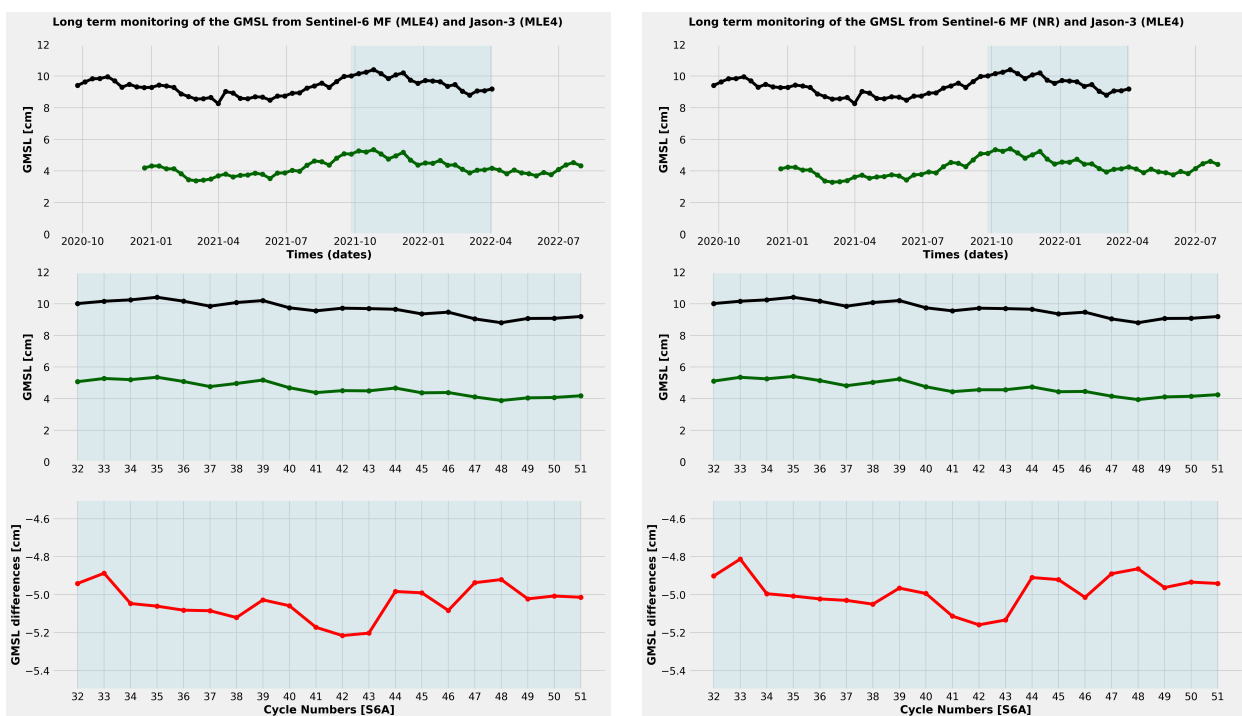


Figure 158: Jason-3 (black) and Sentinel-6 MF (green) GMSL time series (top panel), the tandem phase over the side-B tandem phase (middle panel) and their differences (bottom panel), for Sentinel-6 MF reprocessed dataset, LR MLE4 on the left and LR NR on the right.

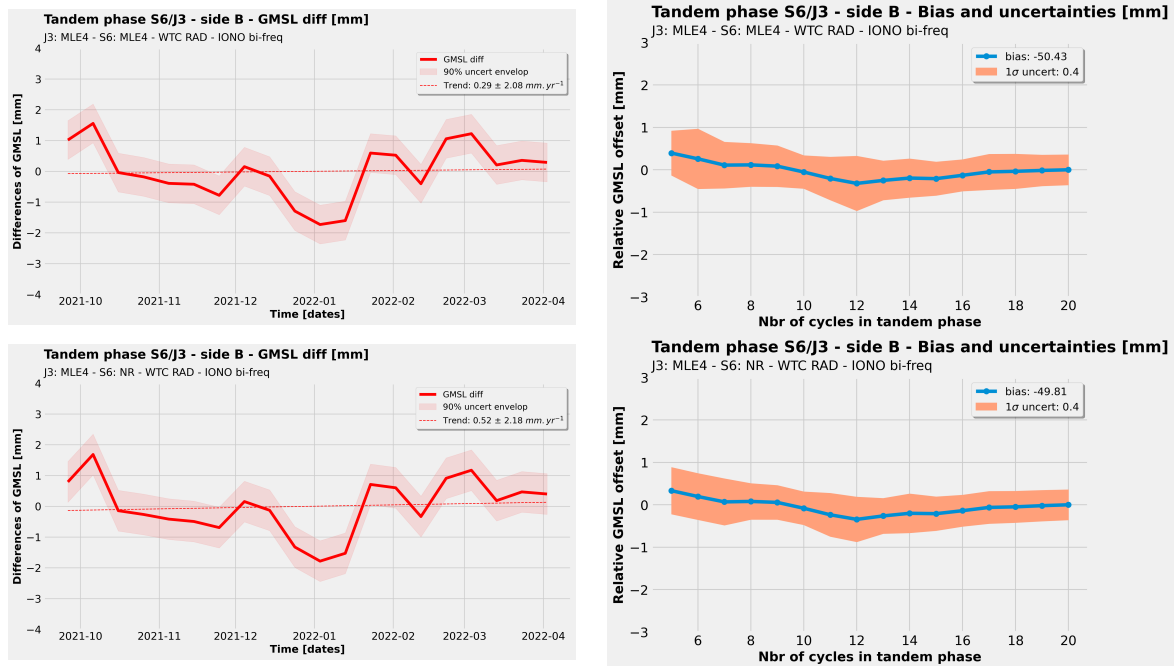


Figure 159: Time series of GMSL difference between Jason-3 and Sentinel-6 MF over the side B tandem phase (left) and relative GMSL offset and its uncertainty between Jason-3 and Sentinel-6MF as a function of the number of cycle used for the computation (right). Top: Sentinel-6 MF LR MLE4; Bottom: Sentinel-6 MF LR MLE4

9.2. Comparison between MLE4 and NR

To compare the LR MLE4 and LR NR retracers in terms of GMSL, two GMSL have been estimated over the complete Sentinel-6 MF reprocessed time period. Figure 160 shows the resulting GMSL difference (MLE4 - NR). Over the two periods (POS4-A and POS4-B), a significant drift of $-0.52 \pm 0.16 \text{ mm.yr}^{-1}$ at the 90% confidence level is detected during the side A period. Regarding the side B period, a change of behaviour is observed in differences between NR and MLE4 retracking algorithms. This evolution is discussed in the Cal/Val section of this report. The relative drift of $-0.05 \pm 0.01 \text{ mm.yr}^{-1}$ at the 90% confidence level observed for POS4-B can be attributed to this change.

The offset observed between side A and side B is linked to ranges. As seen in section 6.1.2.1., range difference between LR NR and LR MLE4 shows a jump of 1 mm at the switch to POS4-B. It results in a jump of 1.5 mm in the SSHA difference (figure 160), which is in line with the jump seen here. The culprit of this jump is supposed to be MLE4 since the same MLE4 Look Up Table is used for both side-A and side-B whereas the PTR from each side is known to be different.

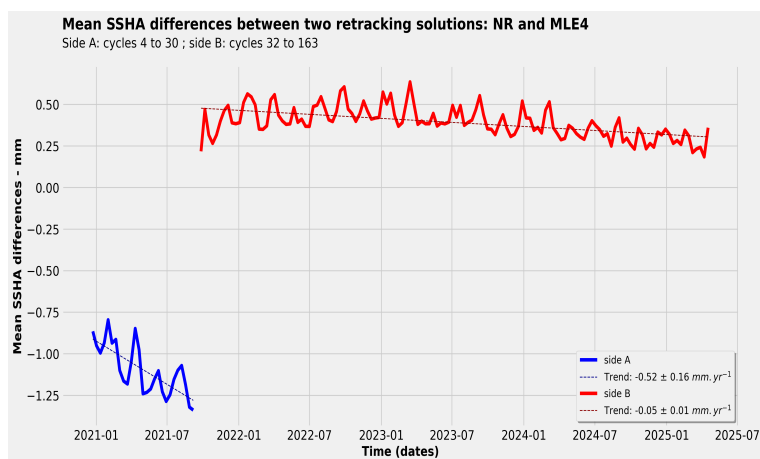


Figure 160: GMSL difference MLE4 - NR SLAs over the reprocessed period. Slope errors are given at 90 % C.L.

10 System Requirements

In this section, the system requirements are verified for reprocessed data, for all retrackers.

10.1. LR

10.1.1. R-S-00260

Requirement	Status
For low-resolution ALT-NTC products, the standard deviation of the 1-second along-track averaged corrected low-resolution altimeter range measurements shall be less than 2.83 cm. Note: This requirement is based on the apportionment given in the table of the Sentinel-6 low-resolution altimetry error budget at the end of the document. Note: Like all performance requirements on the altimeter, unless specified otherwise, this specifies the maximum global RMS error over open ocean. Note: A goal is 1.73 cm.	Not addressed in this report

Table 16: R-S-00260

10.1.2. R-S-00270

Requirement	Status
For low-resolution ALT-NTC products, the noise of the 1-second along-track average of the low-resolution Ku-band altimeter range measurements shall be less than 1.5 cm at 2 m significant wave height. Note: the requirement is applicable after ground re-tracking. Note: The upper limit depends on SWH: 1.2 cm at 1 m SWH, 1.5 cm at 2 m SWH, 2.4 cm at 5 m SWH, and 3.2 cm at 8 m SWH. Note: A goal is 1.0 cm at 2 m SWH	OK

Table 17: R-S-00270

To estimate the noise of 1-second along-track average of the LR Ku-band altimeter range, we analyse "data_01/ku/range_ocean_rms" variable from LR products. It contains the standard deviation of 20 Hz measurements used for the compression to 1Hz. To retrieve 1 Hz level of noise, this value is divided by $\sqrt{\text{range_ocean_number}}$.

The resulting 1 Hz level of noise averaged over the complete period is plotted function of SWH on figure 161, left panel. Noise levels are similar for MLE4 and NR except at very low SWH. As expected, Sentinel-6 MF LR noise level is well below Jason-3 level and below the system requirement (purple curve) over almost all the SWH spectrum. For 1 m wave, the level of noise is slightly above the note in the requirement with a value of 1.24 cm / 1.26 cm in MLE4/NR and an upper limit at 1.2 cm. Please note that the requirement itself, i.e. the 2 m SWH limit, is met. Table 18 reports the level of noise for the stated SWH values.

This noise level is stable in time, as shown on the cyclic monitoring of figure 161, right panel.

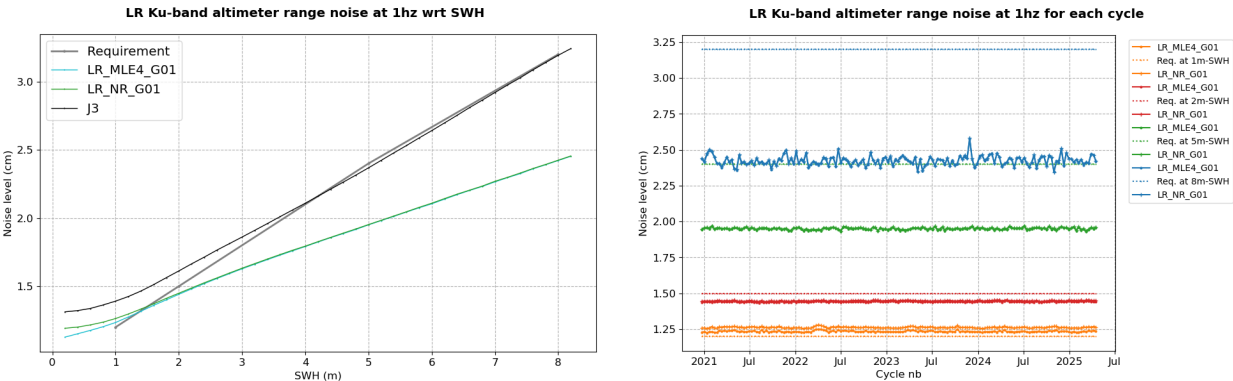


Figure 161: 1 Hz noise of LR Ku-band altimeter range. Left panel: noise function of SWH for Sentinel-6 MF LR MLE4 (blue for MLE4, green for NR) and Jason-3 (black); the purple line represents the requirement thresholds. Right panel : noise level computed for each cycle and at 1, 2, 5 and 8 m-wave (solid lines for MLE4, dashed lines for NR) and the corresponding requirement levels (dotted lines).

SWH	Requirement	Noise level MLE4	Noise level NR
1 m	1.2 cm	1.24 cm	1.26 cm
2 m	1.5 cm	1.44 cm	1.45 cm
5 m	2.4 cm	1.95 cm	1.95 cm
8 m	3.2 cm	2.42 cm	2.43 cm

Table 18: 1 Hz noise of LR Ku-band altimeter range at 1, 2, 5 and 8 m-wave.

10.1.3. R-S-00280

Requirement	Status
For low-resolution ALT-NTC products, the noise of the 1-second along-track average of the C-band altimeter range measurements shall be less than 5.7 cm at 2 m significant wave height.	OK
Note: the requirement is applicable after ground re-tracking.	
Note: The upper limit depends on SWH: 4.5 cm at 1 m SWH, 5.7 cm at 2 m SWH, 9.1 cm at 5 m SWH, and 12.0 cm at 8 m SWH	

Table 19: R-S-00280

Similarly to Ku-band, we analyse "data_01/c/range_ocean_rms" variable from LR products to estimate the noise of 1-second along-track average of the LR C-band altimeter range.

The resulting 1 Hz level of noise averaged over the complete period is plotted as a function of SWH on figure 162, left panel. Sentinel-6 MF LR noise level is below the system requirement (purple curve) over all the SWH spectrum. Table 20 reports the level of noise for the stated SWH values.

This noise level is stable in time, as shown on the cyclic monitoring of figure 162, right panel.

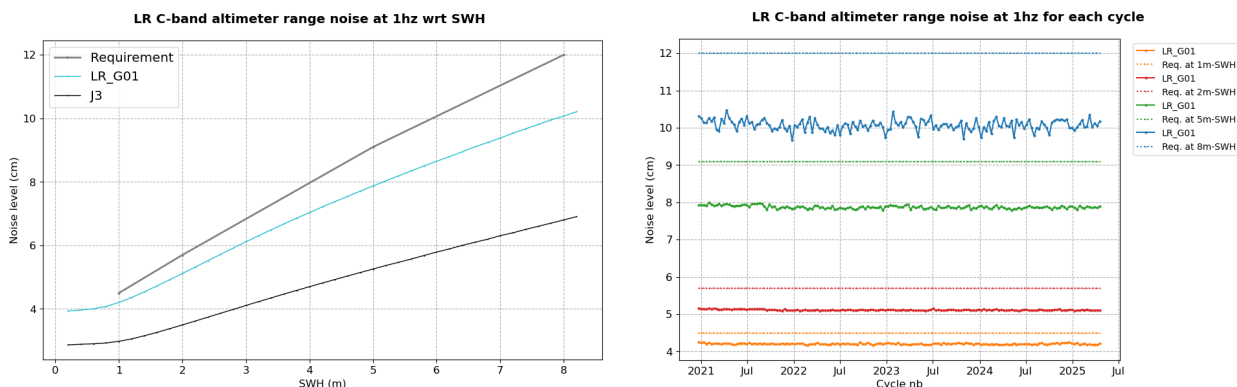


Figure 162: 1 Hz noise of LR C-band altimeter range. Left panel: noise function of SWH for Sentinel-6 MF LR and Jason-3; the purple line represents the requirement thresholds. Right panel : noise level computed for each cycle and at 1, 2, 5 and 8 m-wave (solid lines) and the corresponding requirement levels (dashed lines).

SWH	Requirement	Noise level
1 m	4.5 cm	4.20 cm
2 m	5.7 cm	5.12 cm
5 m	9.1 cm	7.87 cm
8 m	12 cm	10.07 cm

Table 20: 1 Hz noise of LR C-band altimeter range at 1, 2, 5 and 8 m-wave.

10.1.4. R-S-00290

Requirement	Status
For low-resolution ALT-NTC products, the contribution of the ionosphere correction error to the standard deviation of the 1-second along-track averaged corrected low-resolution altimeter range measurements shall be less than 0.5 cm. Note: Derived from C and Ku band and averaged over 200 km. Note: Like all performance requirements on the altimeter, unless specified otherwise, this specifies the maximum global RMS error over open ocean. Note: A goal is 0.3 cm	OK

Table 21: R-S-00290

To quantify the contribution of the ionosphere correction error to the standard deviation of 1 Hz corrected LR range, several metrics are checked.

A first estimation of filtered ionosphere correction error is performed by checking the noise between consecutive measurements. The results show a very low level of noise, way below the mm (figure 164), except for a single pass (cycle 15 pass 1), for which rapid ionosphere variations near the equator caused significant jumps between land masses around Indonesia. Even this extreme case is compliant with requirements.

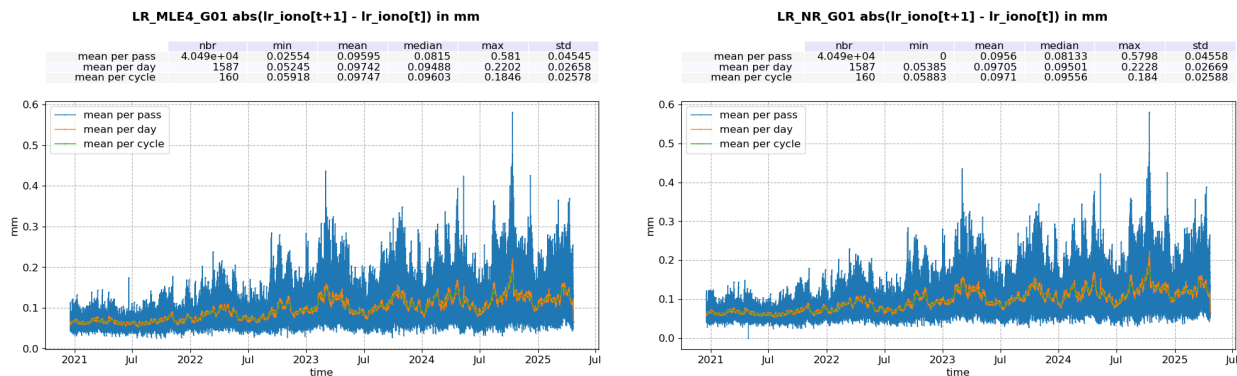


Figure 163: Absolute value of consecutive filtered ionosphere correction measurement for MLE4 (left) and NR (right). Mean per pass (blue), mean per day (orange) and mean per cycle (green).

Comparison to Jason-3 filtered ionosphere correction highlights a standard deviation ranging between 2 and 4.5 mm (figure 164) for both retrackings. And finally, comparison to ionosphere correction derived from GIM model shows a standard deviation ranging between 3 mm and 2 cm (figure 165) for both retrackings. These values are all within the requirement.

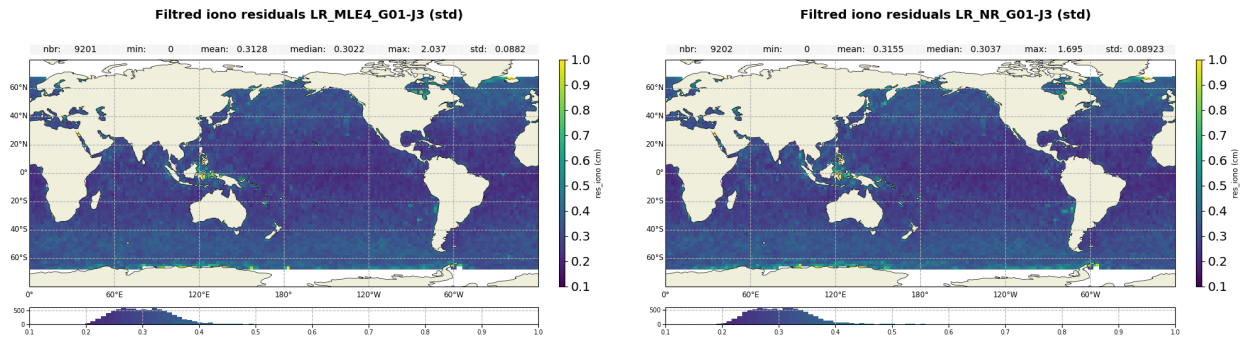


Figure 164: Standard deviation gridded map of Altimeter Filtered Ionosphere correction Sentinel-6 MF-Jason-3 difference (cm) for MLE4 (left) and NR (right). Computed over the tandem phase.

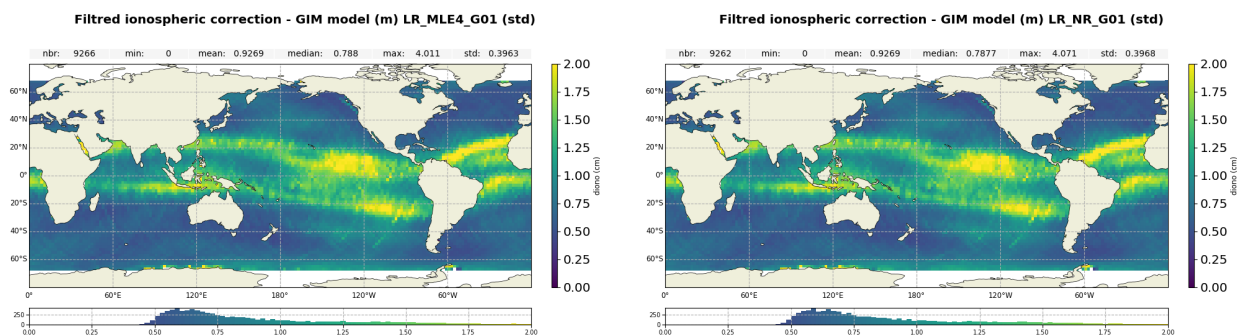


Figure 165: Standard deviation gridded map of the difference between Altimeter Filtered Ionosphere correction and GIM model (cm) for MLE4 (left) and NR (right). Computed over the entire reprocessing period.

10.1.5. R-S-00300

Requirement	Status
For low-resolution ALT-NTC products, the contribution of the sea state bias error to the standard deviation of the 1-second along-track averaged corrected low-resolution altimeter range measurements shall be less than 2.0 cm. Note: Like all performance requirements on the altimeter, unless specified otherwise, this specifies the maximum global RMS error over open ocean. Note: A goal is 1.0 cm	OK

Table 22: R-S-00300

As for ionosphere correction, a first estimation of the SSB error is performed by checking the noise between consecutive measurements. The results show a low level of noise, below the cm (figure 166) for both LR retracers.

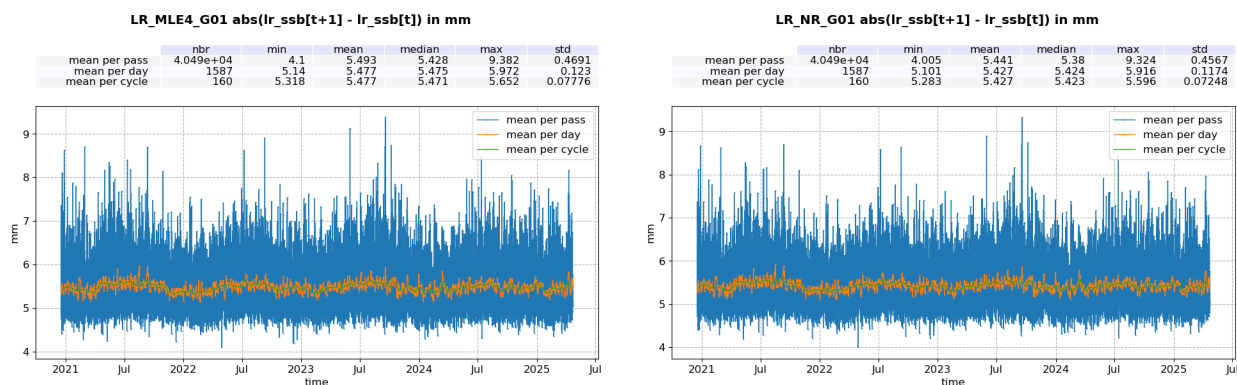


Figure 166: Absolute value of consecutive LR sea state bias measurement for LR MLE4 (left) and NR (right). Mean per pass (blue), mean per day (orange) and mean per cycle (green).

Comparison to Jason-3 SSB highlights a standard deviation ranging between 4.5 mm and 1.5 cm (figure 167) for both retrackings. These values are within the requirement.

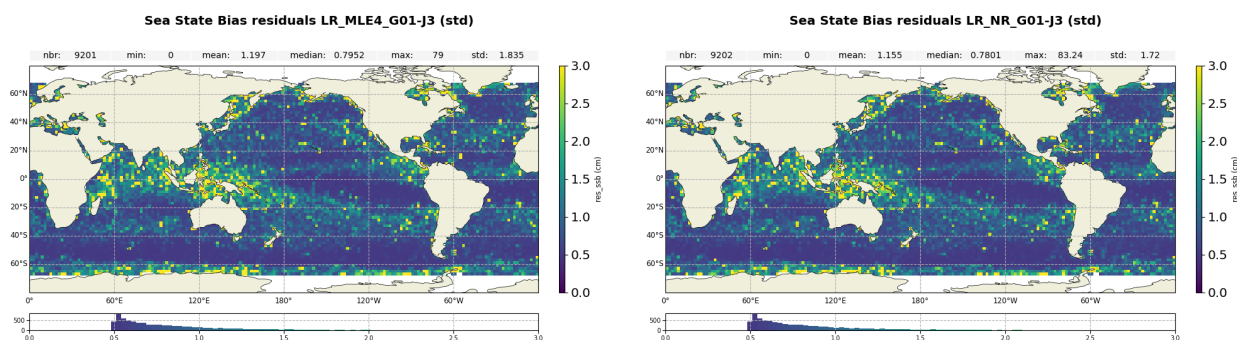


Figure 167: Standard deviation gridded map of Ku-band SSB difference: Sentinel-6 MF LR minus Jason-3 computed over the complete tandem period for MLE4 (left) and NR (right).

10.1.6. R-S-00310

Requirement	Status
For low-resolution ALT-NTC products, the contribution of the dry tropospheric correction error to the standard deviation of the 1-second along-track averaged corrected low-resolution altimeter range measurements shall be less than 0.7 cm. Note: this requirement applies to the model to be used to calculate the dry troposphere model. Note: Like all performance requirements on the altimeter, unless specified otherwise, this specifies the maximum global RMS error over open ocean. Note: A goal is 0.5 cm	OK

Table 23: R-S-00310

The dry troposphere correction model is identical between Jason-3 and Sentinel-6 MF products: same model and same estimation from model.

Analysis has shown that the two retrievals are indeed perfectly in line (see figure 168).

System requirement for Jason-3 dry troposphere correction is the same as Sentinel-6 MF present requirement, and it has been shown that Jason-3 dry troposphere correction is compliant.

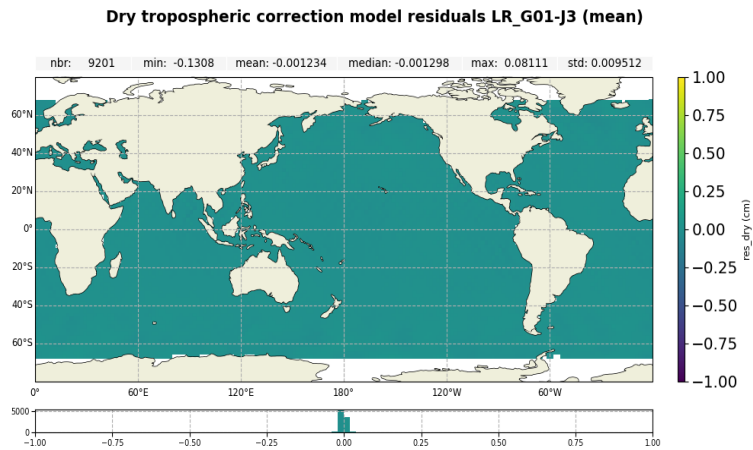


Figure 168: Mean gridded map of dry tropospheric correction difference: Sentinel-6 MF LR minus Jason-3. Computed over cycles 4 to 51.

10.1.7. R-S-00320

Requirement	Status
For low-resolution ALT-NTC products, the contribution of the wet tropospheric correction error to the standard deviation of the 1-second along-track averaged corrected low-resolution altimeter range measurements shall be less than 1.0 cm. Note: Like all performance requirements on the altimeter, unless specified otherwise, this specifies the maximum global RMS error over open ocean. Note: A goal is 0.8 cm	OK

Table 24: R-S-00320

A first estimation of AMR-C WTC error is performed by checking the noise between consecutive measurements. The results show a very low level of noise, below 2 mm (figure 169).

Comparison to Jason-3 AMR WTC highlights a standard deviation below 1 cm (figure 170). These values are within the requirement.

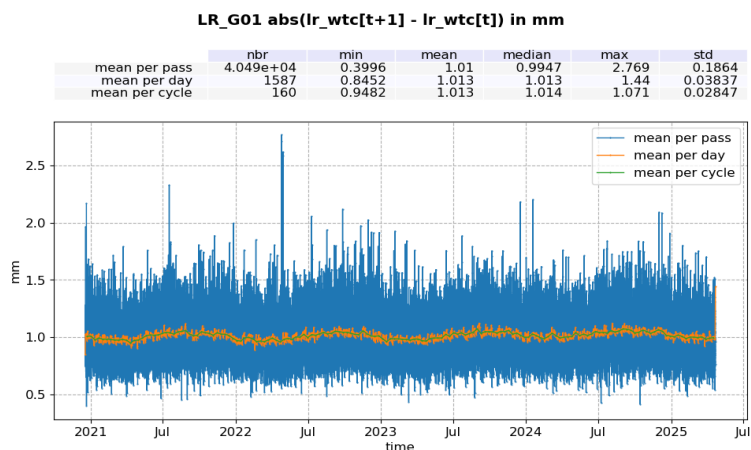


Figure 169: Absolute value of consecutive AMR-C WTC measurement in mm. Mean per pass (blue), mean per day (orange) and mean per cycle (green).

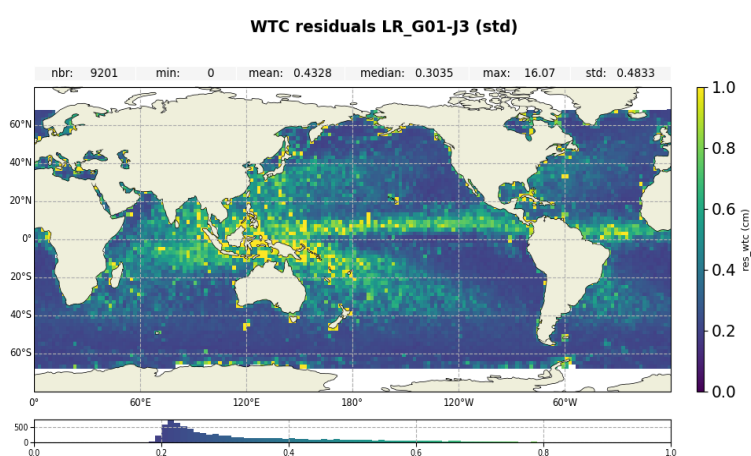


Figure 170: STD gridded map of AMR WTC difference: Sentinel-6 MF LR minus Jason-3, in m. Computed over cycles 4 to 51.

10.1.8. R-S-00330

Requirement	Status
For low-resolution ALT-NTC products, the standard deviation of the determination of the radial component of the orbit shall be less than 1.5 cm. Note: This requirement is applicable to the orbital solution derived from the combined set of data from DORIS, GNSS-POD and LRA. Note: Orbit errors have a larger than 1000 km length scale, significantly different from the 1 Hz altimetry noise. Nevertheless, the orbit error is added in a RSS sense, presuming that the error is uncorrelated from cycle to cycle at the same location. Note: a goal is 1.0 cm	Not addressed in this report

Table 25: R-S-00330

10.1.9. R-S-00340

Requirement	Status
For low-resolution ALT-NTC products, the standard deviation of the 1-second along-track averaged corrected low-resolution measurements of sea surface height shall be less than 3.20 cm. Note: This requirement is based on the apportionment given in the table of the Sentinel-6 low-resolution altimetry error budget at the end of the document. Note: Like all performance requirements on the altimeter, unless specified otherwise, this specifies the maximum global RMS error over open ocean. Note: A goal is 1.99 cm	OK

Table 26: R-S-00340

To verify this requirement, the crossover analysis presented in section 7.2. is used. The standard deviation of corrected LR SSH difference is centred around 4.6 cm (see figure 89) in both MLE4 and NR. It means that the error is of 3.25 cm (standard deviation divided by $\sqrt{2}$). This value is slightly above the requirement. However, looking at a region with low variability, for example the pacific patch, the error is of 2.2 cm in average. On a cyclic basis, this error is always below the requirement limit of 3.2 cm as shown on figure 171.

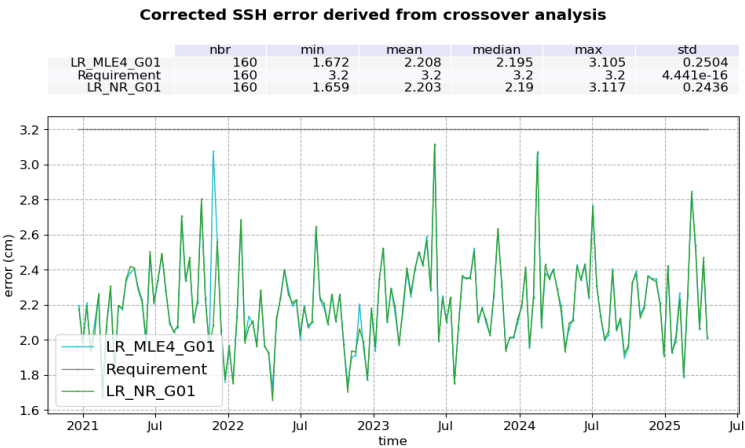


Figure 171: Corrected LR SSH error derived from crossover analysis with a selection over Pacific patch (latitude in [-24.5°N; -3°N] and longitude in [220°E; 246°E]), in cm for MLE4 and NR. The error equals to the standard deviation of the SSH difference divided by $\sqrt{2}$. Computed on a cyclic basis.

10.1.10. R-S-00350

Requirement	Status
For low-resolution ALT-NTC products, the uncertainty of 1-second along-track averaged low-resolution measurements of significant wave height in the range 0.5 to 8 m shall be less than 15 cm plus 5% of significant wave height. Note: This is based on the combination of noise and systematic error. Note: A goal is 10 cm plus 5% of significant wave height	OK

Table 27: R-S-00350

LR Ku-band SWH uncertainties are computed as the quadratic sum of the systematic error (difference to ERA-5 model) and the noise (as defined in section 7.3.3.). The result (figure 172) shows a good consistency between the two datasets, the uncertainty being below the requirement limit over the complete SWH spectrum.

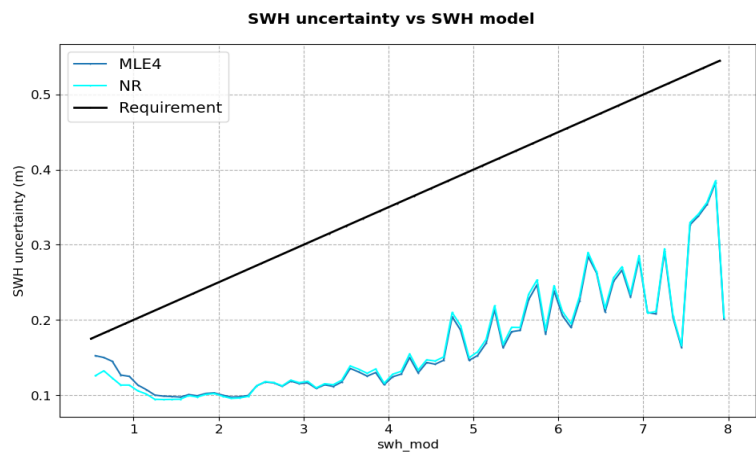


Figure 172: SWH difference between Sentinel-6 MF LR data and ERA-5 SWH, plotted function of ERA-5 SWH for MLE4 (blue) and NR (cyan). Computed over Sentinel-6 MF cycle 40. Results are identical for all cycles.

10.1.11. R-S-00355

Requirement	Status
For low-resolution ALT-NTC products, significant wave heights shall be provided up to at least 20 m. Note: The measurement performance under high sea state conditions will be determined during commissioning	OK

Table 28: R-S-00355

Figure 173 shows the maximum value per cycle of Sentinel-6 MF LR SWH. As expected, the values are above 20 m in MLE4, while they are at 20 m in NR.

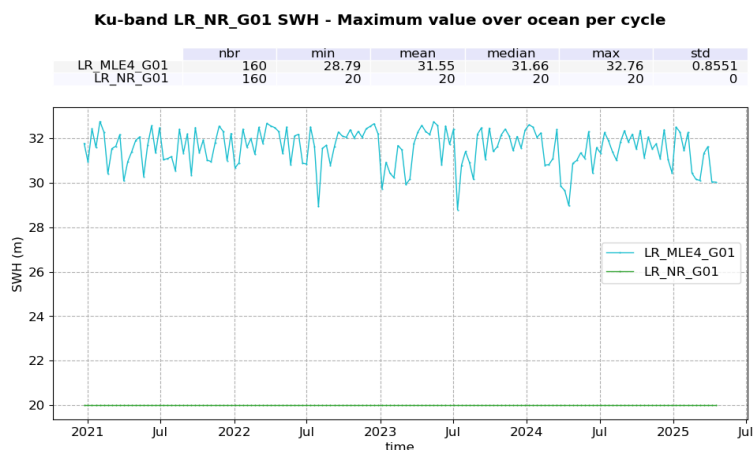


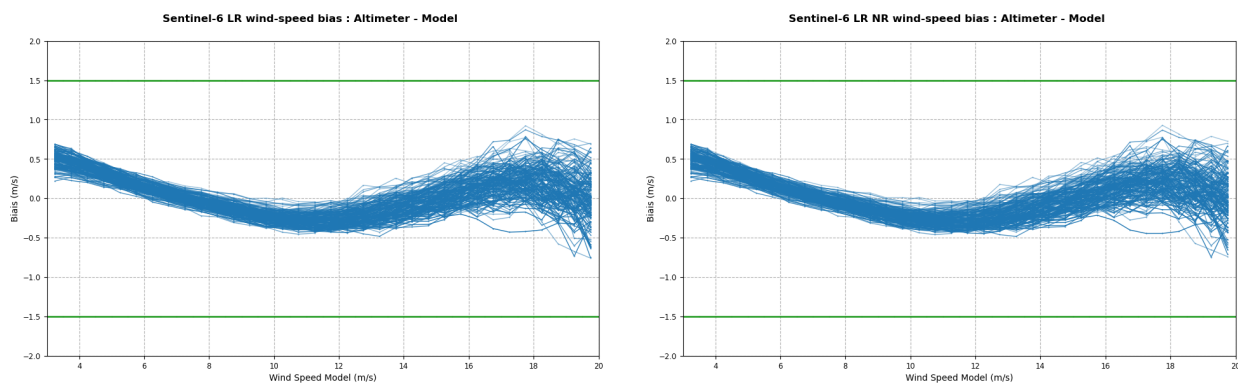
Figure 173: Maximum value of Sentinel-6 MF LR SWH per cycle for MLE4 and NR.

10.1.12. R-S-00360

Requirement	Status
For low-resolution ALT-NTC products, the uncertainty of 1-second along-track averages of 10 meter wind speed over ocean surfaces, derived from low-resolution altimeter measurements, shall be better than 1.5 m/s for wind speeds in the range 3 m/s to 20 m/s. Note: Wind speed refers to the wind (not neutral wind) speed at a reference height of 10 meters above the sea surface. Note: This wind speed accuracy requirement translates to an accuracy requirement on the backscatter. Note: A goal is 1.0 m/s	OK

Table 29: R-S-00360

To verify the uncertainty of Sentinel-6 MF LR altimeter wind-speed, a comparison to model is performed. The model wind speed used is derived from U and V components provided in L2 product ("data_01/wind_speed_mod_u" and "data_01/wind_speed_mod_v"). Difference between altimeter and model wind speed is plotted on figure 174 function of model wind speed. Values are within the requirement.



*Figure 174: Difference between Altimeter LR wind speed and model wind speed function of model wind speed, in m/s for MLE4 (**left**) and NR (**right**). Computed for all cycles. Green lines represent requirement limits.*

10.1.13. R-S-00370

Requirement	Status
For low-resolution ALT-NTC products, the absolute accuracy of 1-second along-track averaged low-resolution measurements of normalized radar cross-section at Ku-band and vertical incidence, in the range 7 to 16 dB, shall be better than 0.3 dB. Note: This value (0.3 dB) is not the value at satellite level (1 dB), but it is achieved after external in-flight calibration to ensure coherence with other missions. In other words, 0.3 dB is the global value, what allows 1 dB at satellite level, to be compensated by the ground processing. Note: This requirement also sets limits on the accuracy of sigma0 attenuation correction to be supplied by the radiometer	Not addressed in this report

Table 30: R-S-00370

The absolute accuracy of the LR sigma0 is not addressed in this report as there is currently no facility available to measure it.

10.2. HR

10.2.1. R-S-00680

Requirement	Status
For high-resolution ALT-NTC products, the standard deviation of the 1-second along-track averaged corrected high-resolution altimeter range measurements shall be less than 2.53 cm. Note: This requirement is based on the apportionment given in the table of the Sentinel-6 high-resolution altimetry error budget at the end of the document. Note: Note: Like all performance requirements on the altimeter, unless specified otherwise, this specifies the maximum global RMS error over open ocean. Note: Note: A goal is 1.49 cm.	Not addressed in this report

Table 31: R-S-00680

10.2.2. R-S-00690

Requirement	Status
For high-resolution ALT-NTC products, the noise of the 1-second along-track average of the high-resolution Ku-band altimeter range measurements shall be less than 0.8 cm at 2 m significant wave height. Note: the requirement is applicable after ground re-tracking. Note: The upper limit depends on SWH: 0.7 cm at 1 m SWH, 0.8 cm at 2 m SWH, 1.3 cm at 5 m SWH, and 2.0 cm at 8 m SWH. Note: A goal is 0.5 cm at 2m SWH	OK

Table 32: R-S-00690

Similarly to LR, we analyse "data_01/ku/range_ocean_rms" variable from HR products to estimate the noise of 1-second along-track average of the HR Ku-band altimeter range.

The resulting 1 Hz level of noise averaged over the complete period is plotted function of SWH on figure 175, left panel. Sentinel-6 MF HR noise level is above the additional note in the requirement (purple curve) for 5 m and 8 m wave upper limits for both retrackings. Please note that the requirement itself, i.e. the 2m SWH limit, is met. Table 33 reports the level of noise for the stated SWH values.

This noise level is stable in time, as shown on the cyclic monitoring of figure 175, right panel.



Figure 175: 1 Hz noise of HR Ku-band altimeter range, in cm. Left panel: noise function of SWH in m for Sentinel-6 MF HR and Jason-3; the purple line represents the requirement thresholds. Right panel : noise level computed for each cycle and at 1, 2, 5 and 8 m-wave (solid lines) and the corresponding requirement levels (dashed lines).

SWH	Requirement	Noise level SAMOSA	Noise level NR
1 m	0.7 cm	0.61 cm	0.60 cm
2 m	0.8 cm	0.78 cm	0.78 cm
5 m	1.3 cm	1.48 cm	1.50 cm
8 m	2.0 cm	2.47 cm	2.50 cm

Table 33: 1 Hz noise of HR Ku-band altimeter range at 1, 2, 5 and 8 m-wave.

10.2.3. R-S-00700

Requirement	Status
For high-resolution ALT-NTC products, the contribution of the ionospheric correction error to the standard deviation of the 1-second along-track averaged corrected high-resolution altimeter range measurements shall be less than 0.5 cm. Note: Derived from C and Ku band and averaged over 200 km. Note: Like all performance requirements on the altimeter, unless specified otherwise, this specifies the maximum global RMS error over open ocean. Note: A goal is 0.3 cm	OK, see section 10.1.4.

Table 34: R-S-00700

10.2.4. R-S-00710

Requirement	Status
For high-resolution ALT-NTC products, the contribution of the sea state bias error to the standard deviation of the 1-second along-track averaged corrected high-resolution altimeter range measurements shall be less than 2.0 cm. Note: Since the sea state bias model will have to be determined for the altimeter data itself, the error can only be evaluated based on day-2 processing. Note: Like all performance requirements on the altimeter, unless specified otherwise, this specifies the maximum global RMS error over open ocean. Note: A goal is 1.0 cm	OK

Table 35: R-S-00710

As for LR data, a first estimation of HR SSB error is performed by checking the noise between consecutive measurements. The results show a low level of noise, below the cm (figure 176) for both HR retrackers except for one pass in 2023.

Comparison to Jason-3 SSB highlights a standard deviation ranging between 4.5 mm and 1.5 cm (figure 177). These values are within the requirement.

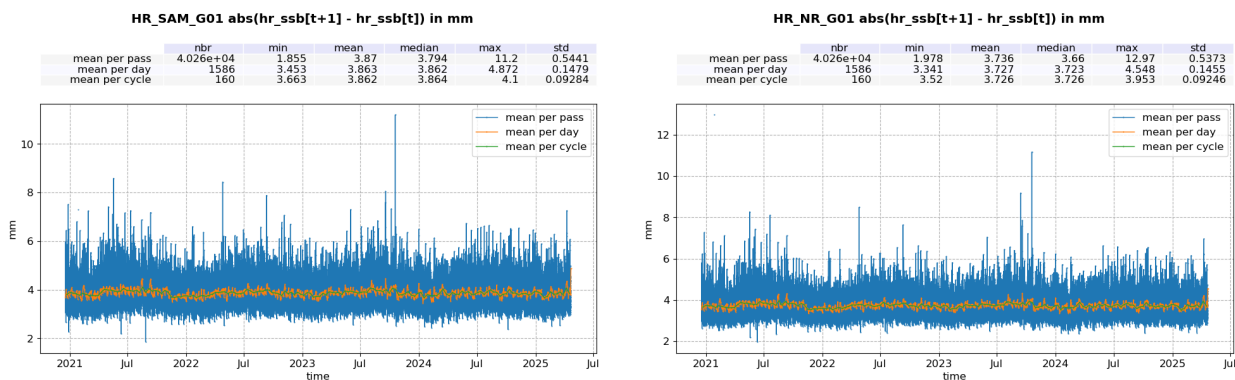


Figure 176: Absolute value of consecutive HR sea state bias measurement. Mean per pass (blue), mean per day (orange) and mean per cycle (green).

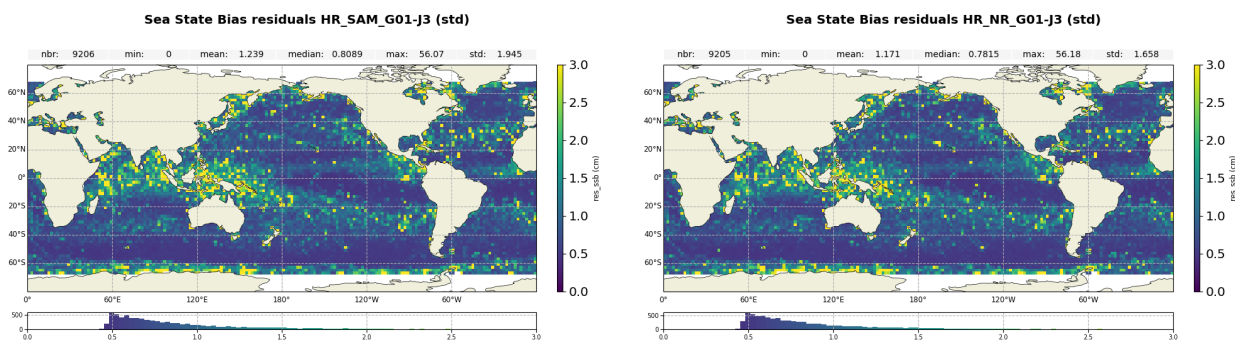


Figure 177: Standard deviation gridded map of Ku-band SSB difference: Sentinel-6 MF HR minus Jason-3 computed over the complete tandem period.

10.2.5. R-S-00720

Requirement	Status
For high-resolution ALT-NTC products, the contribution of the dry tropospheric correction error to the standard deviation of the 1-second along-track averaged corrected high-resolution altimeter range measurements shall be less than 0.7 cm. Note: this requirement applies to the model to be used to calculate the dry troposphere model. Note: Like all performance requirements on the altimeter, unless specified otherwise, this specifies the maximum global RMS error over open ocean. Note: A goal is 0.5 cm	OK, see section 10.1.6.

Table 36: R-S-00720

10.2.6. R-S-00730

Requirement	Status
For high-resolution ALT-NTC products, the contribution of the wet tropospheric correction error to the standard deviation of the 1-second along-track averaged corrected high-resolution altimeter range measurements shall be less than 1.0 cm. Note: Like all performance requirements on the altimeter, unless specified otherwise, this specifies the maximum global RMS error over open ocean. Note: A goal is 0.8 cm	OK, see section 10.1.7.

Table 37: R-S-00730

10.2.7. R-S-00740

Requirement	Status
For high-resolution ALT-NTC products, the standard deviation of the determination of the radial component of the orbit shall be less than 1.5 cm. Note: This requirement is applicable to the orbital solution derived from the combined set of data from DORIS, GNSS-POD and LRA. Note: Orbit errors have a larger than 1000 km length scale, significantly different from the 1 Hz altimetry noise. Nevertheless, the orbit error is added in a RSS sense, presuming that the error is uncorrelated from cycle to cycle at the same location. Note: A goal is 1.0 cm	Not addressed in this report

Table 38: R-S-00740

10.2.8. R-S-00750

Requirement	Status
For high-resolution ALT-NTC products, the standard deviation of the 1-second along-track averaged corrected high-resolution measurements of sea surface height shall be less than 2.94 cm. Note: This requirement is based on the apportionment given in the table of the Sentinel-6 high-resolution altimetry error budget at the end of the document. Note: Like all performance requirements on the altimeter, unless specified otherwise, this specifies the maximum global RMS error over open ocean. Note: A goal is 1.80 cm	OK

Table 39: R-S-00750

To verify this requirement, the crossover analysis presented in section 7.2. is used. The standard deviation of corrected HR SSH difference is centred around 4.4 cm (see figure 89) for both retrackers. It means that the error is of 3.1 cm (standard deviation divided by $\sqrt{2}$). This value is slightly above the requirement. However looking at a region with low variability, for example the pacific patch, the error is of 1.99 cm in average for both retrackers. On a cyclic basis, this error is always below the requirement limit of 3.2 cm as shown on figure 171, except for one cycle in SAMOSA (cycle 19).

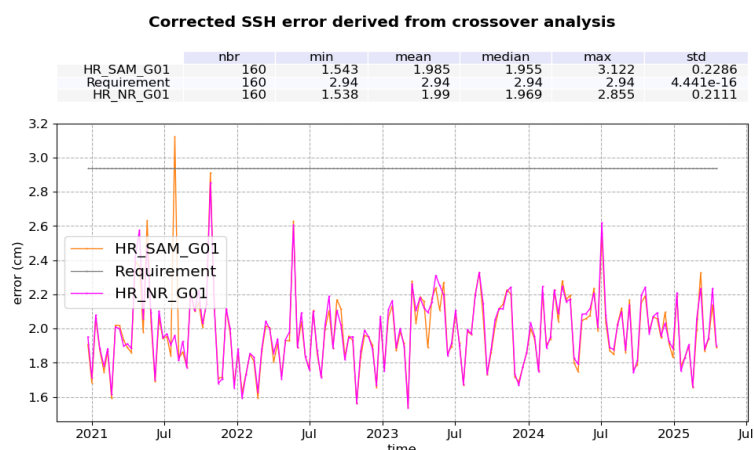


Figure 178: Corrected HR SSH error derived from crossover analysis with a selection over Pacific patch (latitude in $[-24.5^{\circ}\text{N}; -3^{\circ}\text{N}]$ and longitude in $[220^{\circ}\text{E}; 246^{\circ}\text{E}]$), in cm. The error equals to the standard deviation of the SSH difference divided by $\sqrt{(2)}$. Computed on a cyclic basis.

10.2.9. R-S-00760

Requirement	Status
For high-resolution ALT-NTC products, the uncertainty of 1-second along-track averaged high-resolution measurements of significant wave height in the range 0.5 to 8 m shall be less than 15 cm plus 5% of significant wave height. Note: This is based on the combination of noise and systematic error. Note: A goal is 10 cm plus 5% of significant wave height	OK

Table 40: R-S-00760

HR SWH uncertainties are computed as the quadratic sum of the systematic error (difference to ERA-5 model) and the noise (as defined in section 7.3.3.). Sentinel-6 MF HR SWH are compliant with requirement for both SAMOSA and NR (figure 179). Note that this requirement was not met for F08 and earlier processing baselines. This is now the case thanks to the vertical wave motion correction introduced in F09 for HR NR and G01 for HR SAMOSA.

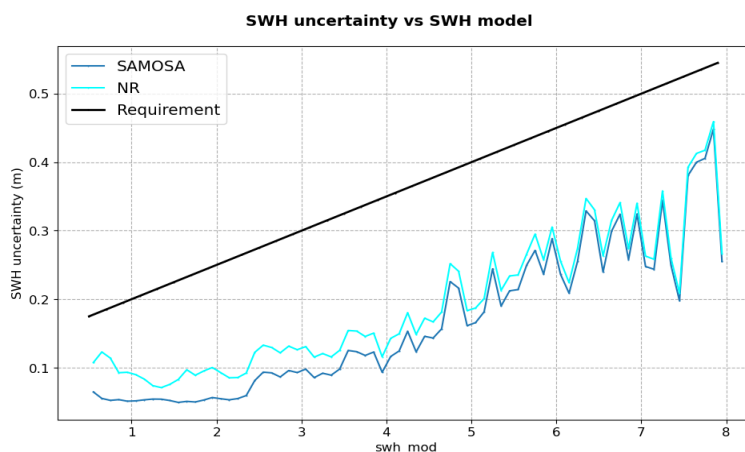


Figure 179: SWH uncertainties plotted as function of ERA-5 SWH. Computed over Sentinel-6 MF cycle 40. Results are identical for all cycles.

10.2.10. R-S-00765

Requirement	Status
For high-resolution ALT-NTC products, significant wave heights shall be provided up to at least 20 m. Note: The measurement performance under high sea state conditions will be determined during commissioning	OK

Table 41: R-S-00765

Figure 180 shows the maximum value per cycle of Sentinel-6 MF HR SWH. It is slightly lower than 20 m. However, this is because of the vertical wave motion correction that lower HR SWH maximum values by about 40 cm. Maximum uncorrected SWH (not available in 1Hz NTC products) is equal to 20 m for all cycle for both retrackers.

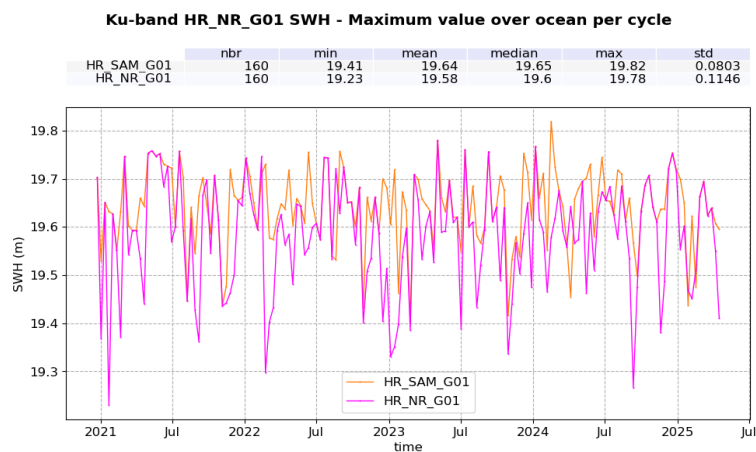


Figure 180: Maximum value of Sentinel-6 MF HR SWH per cycle.

10.2.11. R-S-00770

Requirement	Status
For high-resolution ALT-NTC products, the uncertainty of 1-second along-track averages of 10 meter wind speed over ocean surfaces, derived from high-resolution altimeter measurements, shall be better than 1.5 m/s for wind speeds in the range 3 m/s to 20 m/s. Note: Wind speed refers to the wind (not neutral wind) speed at a reference height of 10 meters above the sea surface. Note: This wind speed accuracy requirement translates to an accuracy requirement on the backscatter Note: A goal is 1.0 m/s	OK

Table 42: R-S-00770

As for LR, a comparison to model is performed to verify the uncertainty of Sentinel-6 MF HR altimeter wind-speed. Difference between altimeter and model wind speed is plotted on figure 181 function of model wind speed. Values are within the requirement.

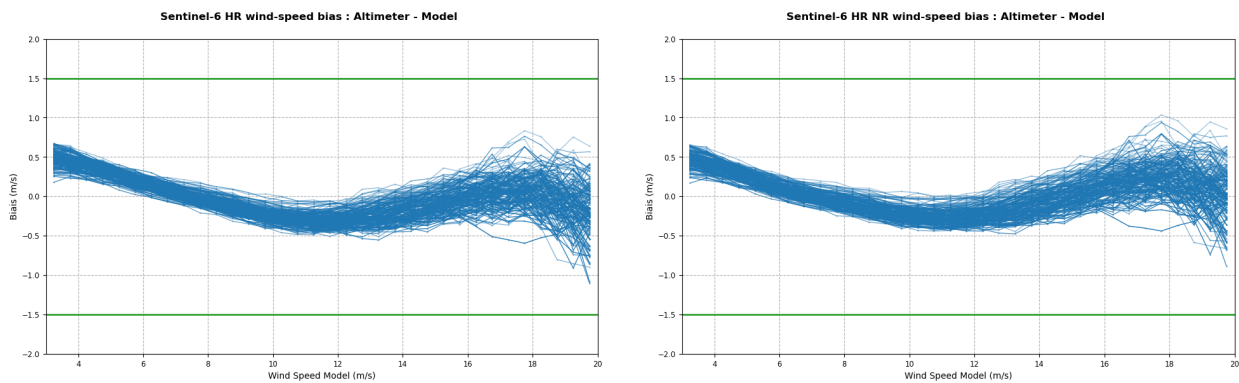


Figure 181: Difference between Altimeter HR wind speed and model wind speed function of model wind speed, in m/s. Computed over Sentinel-6 MF for all cycles for HR SAMOSA (left) and HR NR (right). Green lines represent requirement limits.

10.2.12. R-S-00780

Requirement	Status
For high-resolution ALT-NTC products, the absolute accuracy of 1-second along-track averaged high-resolution measurements of normalized radar cross-section at Ku-band and vertical incidence, in the range 7 to 16 dB, shall be better than 0.3 dB. Note: This value (0.3 dB) is not the value at satellite level (1 dB), but it is achieved after external in-flight calibration to ensure coherence with other missions. In other words, 0.3 dB is the global value, what allows 1 dB at satellite level, to be compensated by the ground processing. Note: This requirement also sets limits on the accuracy of sigma0 attenuation correction to be supplied by the radiometer	Not addressed in this report

Table 43: R-S-00780

The absolute accuracy of the HR sigma0 is not addressed in this report. This would require a dedicated study using corner reflectors.

11 Conclusion

An overview of the impact of Sentinel-6 MF G01 reprocessing over ocean has been presented in this report. The Processing Baseline G01 used for this reprocessing brought major improvements:

- The update from GDR-F to GDR-G standards on MDT, MSS, ocean and load tide models, as well as from POE-F to POE-G on the orbital solution.
- LUT updates for LR MLE4 retracker in Ku-band and MLE3 retracker in C-band computed to align LR MLE4 values on LR NR.
- The application of the vertical wave motion correction at 20Hz on both SAMOSA and HR NR.

This reprocessing also includes improvements brought by the patch of the PB F08 that corrected an anomaly impacting small waves in LR NR up until 2023-10-05, as well as PB F09 on data before 2024-02-10, with :

- The introduction of the Numerical Retracker in HR mode
- The range walk correction for both SAMOSA and NR in HR mode
- The vertical wave motion correction on HR NR.

The completeness of the dataset has been improved thanks to two new LR and eight new HR tracks. Coverage is likely at its maximum, as missing tracks could never be produced due to the lack of the corresponding L0 data.

For the first time since launch, the dataset now includes all four retrackers (MLE4 and NR for LR mode, SAMOSA and NR for HR mode) for the entire time series. Consistency between retrackers has been significantly improved, with reduced bias for range, SWH and wind speed, thanks to the updated LUTs in LR MLE4, the correction of the small waves anomaly in LR NR and the 20Hz VWM application on HR SAMOSA and HR NR. This last correction also significantly reduces the 1Hz SWH noise. However, a certain wave dependence persists on the range difference between the two HR retrackers (approximately 1 cm) and between LR and HR (approximately 2 to 4 cm).

The long-term impact of the range walk correction in HR range (approximately 1 mm/yr) is clearly visible when comparing the operational and reprocessed datasets. Compared to numerical retrackers, the impact of the uncalibrated part of the PTR evolution is clearly visible on LR MLE4 and HR SAMOSA data, with centimetric amplitudes for SWH, and submillimetric amplitudes for range on the side B time series.

The GDR-G update resulted in a small but significant decrease (0.1 cm) of the standard deviation of SSHA and SSH crossover differences in LR MLE4, LR NR and HR SAMOSA (the completeness difference biases the HR NR comparison). The standard deviation of SSH crossover differences highlights excellent stability for all retrackers, with 4.6 cm in LR mode and 4.4 cm in HR mode. Thanks to the new POE-G orbital solution, the 120-day oscillations in the monitoring of the mean SSH crossovers differences were significantly attenuated.

Thanks to external path delay and g scaling update, there is no longer any discontinuity between POS4 sides A and B, on 14/09/2021. The only exception, for the ionospheric correction (about -0.5 mm in MLE4 and -0.7 mm in NR), is under investigation. However, because of their very small amplitudes, these jumps are not visible in the SSHA monitoring.

Sentinel-6 MF and Jason-3 consistency has been improved with the reprocessing, with biases of only 5 mm in LR, due for half to the ionospheric correction and more specifically to the Sentinel-6 MF C band SSB that still uses Jason-3 parametrization despite their frequency difference. In HR, biases are of 7 mm in NR and -1 cm in SAMOSA. This latter bias, larger and of opposite sign, is due to the skewness difference between the SAMOSA retracker and Jason-3 MLE4, that has a significant impact on the range bias (-1.3 cm). Note

that thanks to the vertical wave motion correction, HR SWH consistency to Jason-3 dramatically improved with the reprocessing. The POE-G orbit update has also reduced oscillations in the time monitoring of the SSHA differences between Sentinel-6 MF and Jason-3.

Regarding the GMSL stability, results are consistent with the previous reprocessing campaign. There is no particular increase in performances regarding differences with Jason-3, but no degradation.

The compliance status to system requirements shows once again the excellent quality of Sentinel-6 MF data, especially for LR dataset for both MLE4 and NR retrackerers.

Finally, several recommendations can be formulated for the next processing baseline to further refine Sentinel-6 MF data consistency and stability :

- The Sentinel-6 MF sigma0 calibration bias for the wind speed computation should be adjusted to +1.88 dB in SAMOSA, +2.02 dB in HR NR and +0.55 dB in LR.
- The jump on the ionospheric correction at the side B switch should be investigated and corrected.
- The ice flag should be computed from Sentinel-6 MF AMR and altimeter parameters as done for Jason-3.
- The alpha-p LUT function for HR SAMOSA retracker should be updated to account for the skewness.
- The WVM correction should be computed from Sentinel-6 MF parameters instead of using model.
- Dedicated SSB parametrizations should be computed for each retracker, especially SAMOSA and C-band MLE3.

12 References

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