Sentinel-6 MF validation and cross calibration activities

2024 Executive Summary

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1 Executive Summary

Sentinel-6 MF onboard altimeter (POS4) allows for simultaneous low and high resolution observations due to its innovative design. This is referred as **interleaved mode** in which hence the instrument acquires data at same time in :

- Low Resolution Mode, hereafter "LR", which is the historical mode used by previous altimeters in the Topex/Jason satellites.
- High Resolution Mode, hereafter "HR", commonly called Synthetic Aperture Radar (SAR) or Delay Doppler Altimetry (DDA), already used on Cryosat-2 and on the Sentinel-3 satellites.

Over the year 2024, POS4 altimeter operated in Range Migration Correction and open loop tracking for most of the globe.

In April 2024, Sentinel-6 MF Processing Baseline was updated from F08 to F09 version. A detailed product notice on the changes between baselines is available at EUMETSAT's product release note. F09 major improvements benefited the HR processing, with the addition of:

- a **Numerical Retracking (NR) in HR mode**, which includes skewness parameter set at 0.1 (similar to Jason-3 and Sentinel-6 MF processings),
- the **range walk correction** in ALT L1 HR processing, improving the two HR retrackers retrievals (SAMOSA and NR),
- a **Vertical Wave Motion (VWM) correction** in ALT L2 HR products applied to NR Significant Wave Heights (SWH).

During each cycle, missing measurements were monitored, spurious data were edited, and relevant parameters derived from instrumental measurements and geophysical corrections were analysed. Please note that these analyses are done **over ocean** only, no assessment is done over hydrological targets. This summary focuses on the performances over the year 2024.

1/ Data availability

In 2024, data availability over ocean was excellent for both Sentinel-6 MF LR and HR products (figure 1), with respectively 99.99 % and 99.81 % of available data. Over this year, **no important event impacting data availability occurred.**

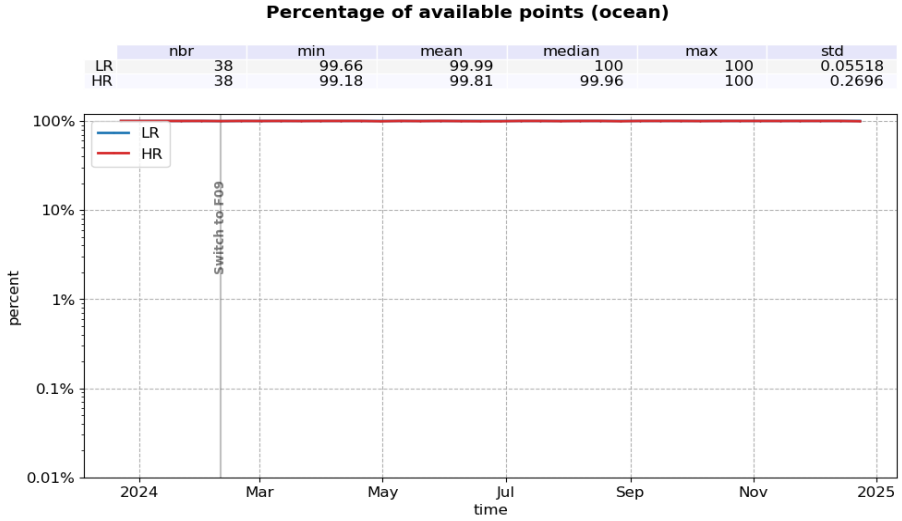


Figure 1: Percentage of available data over ocean for NTC Sentinel-6 MF LR (blue) and HR (red) per cycle over the year 2024.

2/ Sea Level Anomalies

In 2024 Sentinel-6 MF and Jason-3 SSHA followed identical seasonal cycles and variations (figure 2), with mean values of 5.9 cm for Sentinel-6 MF LR MLE4, 5.5 cm for LR NR, 4.7 cm for HR SAMOSA, 5.7 cm for HR NR and 3.6 cm for Jason-3. Excluding the Caspian Sea, Sentinel-6 MF SSHA daily standard deviation shows to be similar between all datasets.

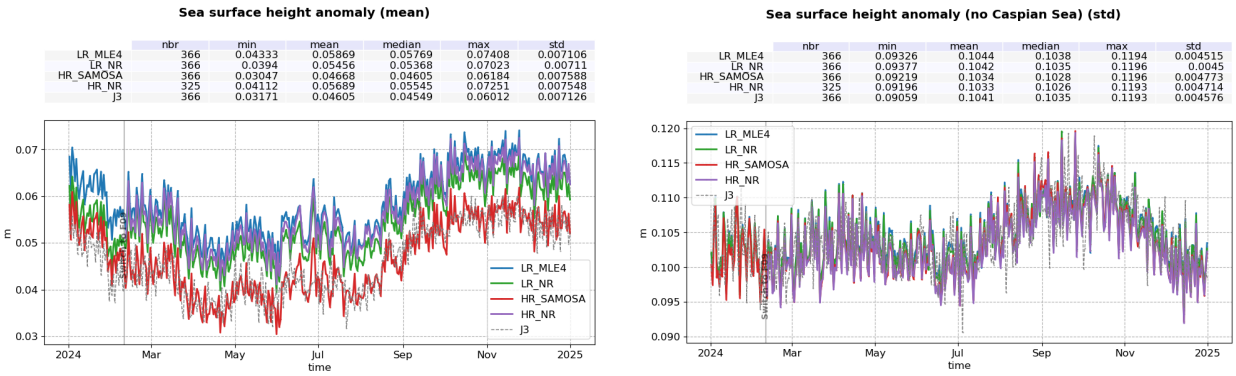


Figure 2: Mean (left) and standard deviation (right) SSHA by day for LR MLE4 (blue), LR NR (green), HR SAMOSA (red), HR NR (purple) and Jason-3 (black). Computed over the year 2024.

The comparison between LR MLE4 and LR NR SSHA, as shown in figure 3, confirms that the numerical retracker delivers notable improvements, as already cited in the previous annual report (thanks to PB F08 addition of LR NR). Still, there is a clear correlation with SWH visible in both the spatial map and the SWH-dependent curve. Unlike MLE4, the NR's outputs do not rely on instrumental LUTs. As a result, the NR results are not affected by any inaccuracies that might arise from LUT approximations, making its retrievals more robust to SWH variations.

In PB F09, HR retrievals were improved thanks to range walk and the addition of the NR. The availability of NR allows for better accountability of instrumental aging through the use of the in-flight point target response (PTR). The improvement of HR long-term stability will require further data and is not possible with 2024 results alone. In the meantime, HR NR SSHA comparison to HR SAMOSA highlights a strong correlation to sea state, and inital investigations indicate that this may be due to the absence of skewness parameter in SAMOSA. This is under investigation.

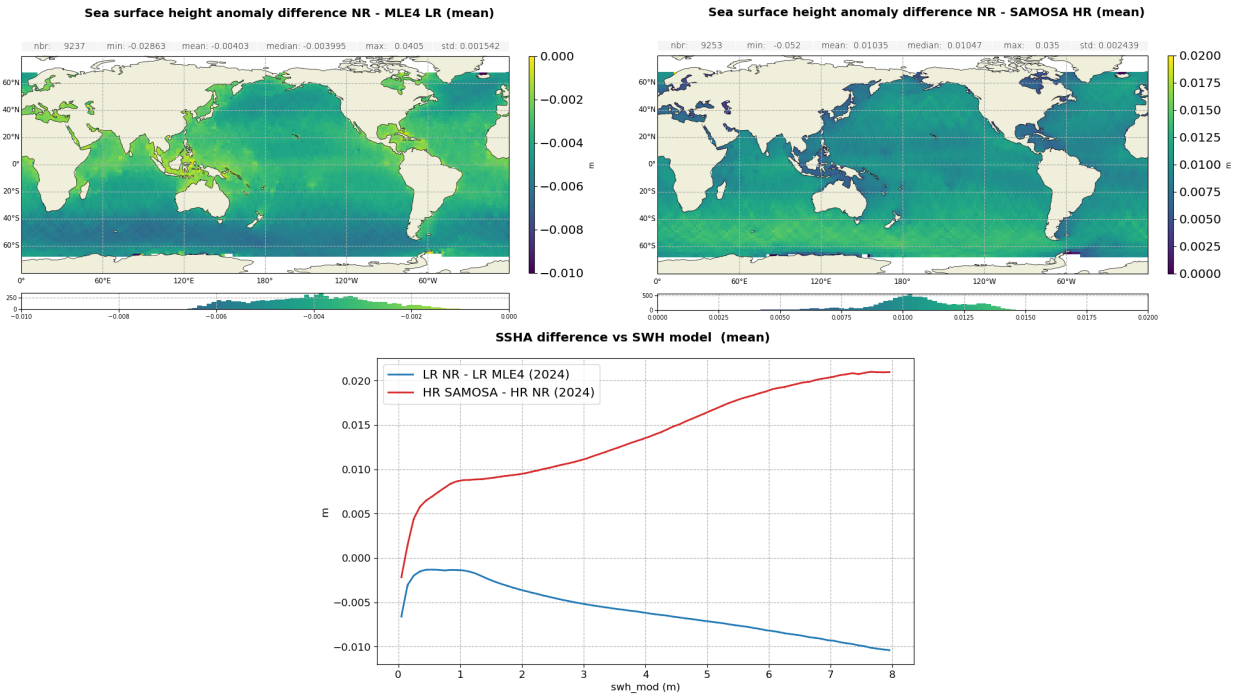
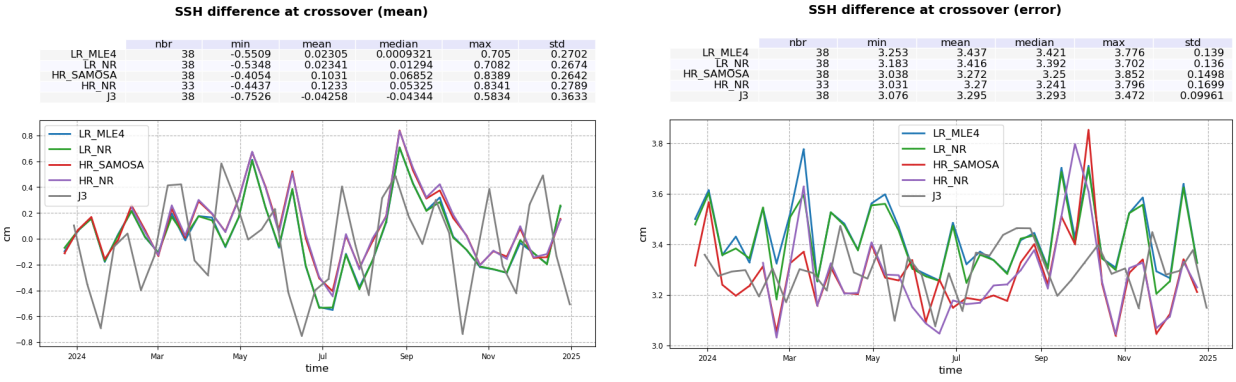


Figure 3: Maps of Sentinel-6 MF SSHA difference for LR NR - LR MLE4 (top left) and HR NR - HR SAMOSA (top right), and the corresponding mean as a function of ERA 5 model SWH (bottom).

3/ Performance at crossover points

Looking at SSH difference at mono-mission crossovers, mean values are well centred around 0 for all modes and retrackers (figure 4 left panel).
Concerning the SSH error at mono-mission crossovers ($STD\ /\ \sqrt{2}$), Sentinel-6 MF shows very good and stable performance with an error of 3.4 cm in LR and 3.3 cm in HR, which is similar to Jason-3 error (figure 4 right panel). A slight increase is observed for Sentinel-6 MF from mid-September to mid-October due to punctual crossover points with higher SSH difference.



	nbr	min	mean	median	max	std
LR_MLE4	38	-0.5509	0.02305	0.0009321	0.705	0.2702
LR_NR	38	-0.5348	0.02341	0.01294	0.7082	0.2674
HR_SAMOSA	38	-0.4054	0.1031	0.06852	0.8389	0.2642
HR_NR	33	-0.4437	0.1233	0.05325	0.8341	0.2789
J3	38	-0.7526	-0.04258	-0.04344	0.5834	0.3633

	nbr	min	mean	median	max	std
LR_MLE4	38	3.253	3.437	3.421	3.776	0.139
LR_NR	38	3.183	3.416	3.392	3.702	0.136
HR_SAMOSA	38	3.038	3.272	3.25	3.852	0.1498
HR_NR	33	3.031	3.27	3.241	3.796	0.1699
J3	38	3.076	3.295	3.293	3.472	0.09961

Figure 4: Monitoring of SSH difference at mono-mission crossover for Sentinel-6 MF LR MLE4 (blue), LR NR (green), HR SAMOSA (red), HR NR (purple) and Jason-3 (black). Mean (left) and error (right) per cycle are computed over the year 2024. Only data with |latitude| < 50 °, bathymetry < -1000 m and low oceanic variability were selected.

As shown in figure 4, the mean differences in sea surface height (SSH) at Sentinel-6 MF and Jason-3 crossover points exhibit consistent behavior across all four Sentinel-6 MF retrieval types throughout 2024. There is no evidence of drift or recurring patterns over the year. The observed mean SSH differences are

minimal: -1.3 cm for LR MLE4, -0.9 cm for LR NR, -0.1 cm for HR SAMOSA, and -1.2 cm for HR NR. No significant regional pattern can be seen on the corresponding maps for LR MLE4, LR NR and HR NR (figure 5 top and middle right panels). The HR SAMOSA map (middle left panel) highlights the absence of skewness parameter in the HR SAMOSA processing, leading to correlation with sea state conditions in the comparison with Jason-3. Thanks to the addition of this parameter to the HR NR processing, such patterns are not visible on the HR NR SSH comparison to Jason-3.

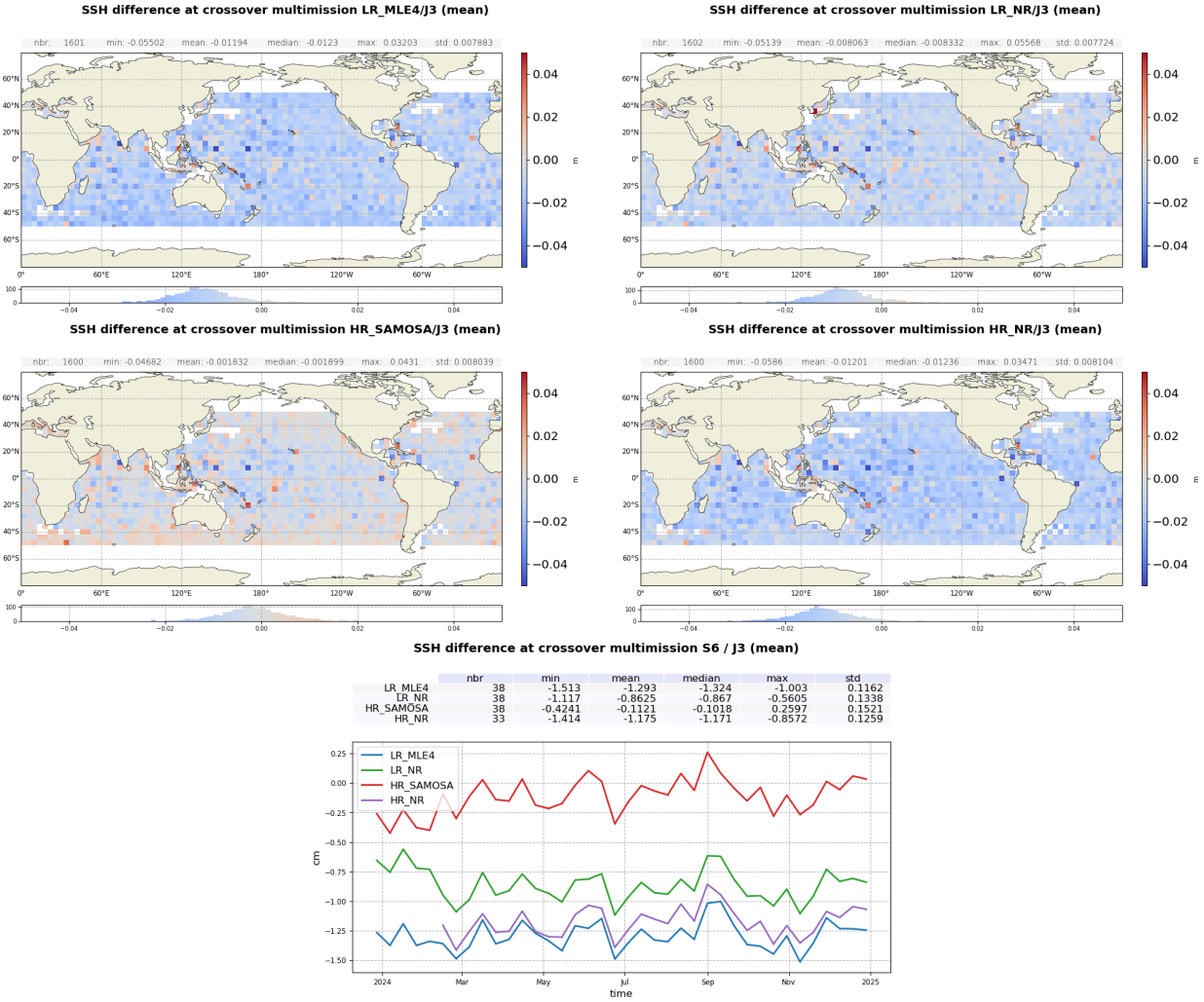


Figure 5: Sentinel-6 MF - Jason-3 SSH difference at crossover: maps over year 2024 for LR MLE4 (top left), LR NR (top right), HR SAMOSA (middle left) and HR NR (middle right), and corresponding cyclic monitoring (bottom). Only data with |latitude| < 50 °, bathymetry < -1000 m and low oceanic variability were selected.

4/ Contribution to Global Mean Sea Level

Regional and global biases between missions have to be precisely estimated in order to ensure the quality of the reference GMSL series as seen on Figure 6. For more details, see the dedicated section on AVISO+ website[1].

Sentinel-6 MF GMSL may be impacted by two known effects:

- The instrumental aging consisting in the evolution of the PTR shape in range direction. It impacts both range and SWH estimates in the analytical models as is the case of LR MLE4 and HR SAMOSA. Note that numerical models account for the in-flight instrument aging and hence they are not affected at all by these impacts.
- The evolution of the PTR shape in the azimuth direction, impacting the range variations within a burst, in HR only. It is corrected thanks to the range walk correction, that is available in PB F09.

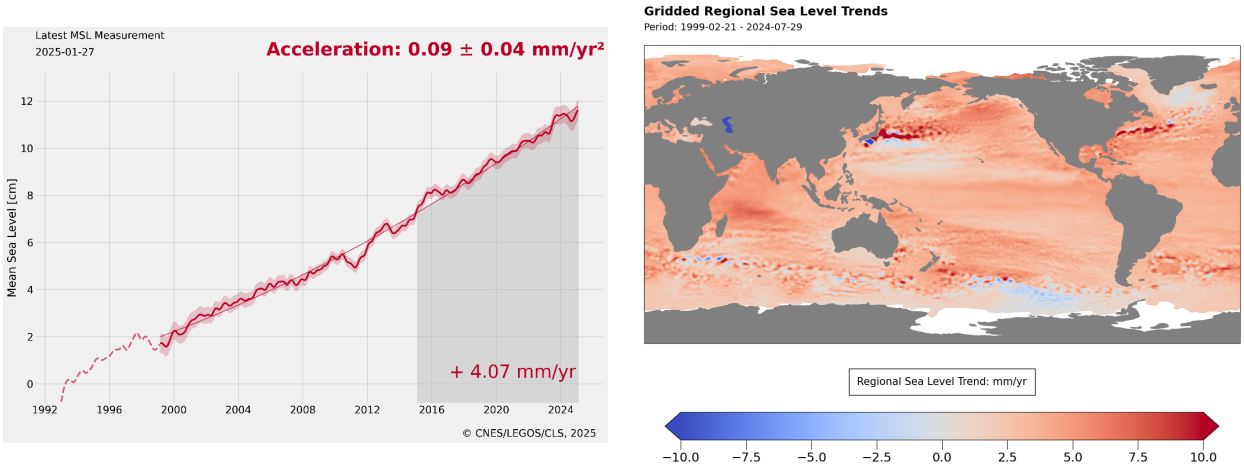


Figure 6: Global (left) and regional (right) MSL trends from 1993 onwards.

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