Sentinel-6A validation and cross calibration activities

2022 Executive Summary

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By succeeding to TOPEX/Poseidon, Jason-1, Jason-2 and Jason-3 on their primary ground track, Sentinel-6 MF has extended the high-precision ocean altimetry data record.

Sentinel-6 MF was launched on November 21st 2020. Its onboard altimeter (POS4) operates simultaneously in two acquisition modes in a so-called **interleaved mode**. These modes are:

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

HR data can be telemetred on ground either on RAW mode, i.e. with the full range window of the HR waveform, or in RMC mode, that transmits a truncated waveform thanks to on-board processing, to cut data volume in half. More information on the different telemetry configurations can be found in the L1 Product Generation Specification[1].
Sentinel-6 MF POS4 operates in LR plus HR-RMC mode globally since cycle 32 (2021/09/21). This configuration is called LRMC. Before 2021/09/21, several configurations have been tested via predefined mode masks, mainly in order to validate to HR-RMC performance versus HR-RAW.

During Sentinel-6 MF tandem phase with Jason-3 (2020/12/17 to 2022/04/07), both satellites were on the same ground-track (with only 30 seconds delay), which was a unique opportunity to precisely assess parameter discrepancies between both missions and detect geographically correlated biases, jumps or drifts. In order to calibrate both altimeters, POS4 was switched to its redundant side (POS4-B) on 2021/09/14. It remains in this configuration from this date onwards.
Thanks to this tandem phase, Sentinel-6 MF has been precisely calibrated leading to a seamless transition between Jason-3 and Sentinel-6 MF LR as reference mission in the DUACS system.

In July 2022, the **first Sentinel-6 full mission reprocessing** was distributed. LR and HR data were reprocessed using **Processing Baseline F06** (see F06 product notice for details[2]). This reprocessing was the first opportunuity to assess Sentinel-6 MF performance with an homogenuous processing. This assessment is available in the associated reprocessing Cal/Val report[3].
The reprocessed period spanned from the beginning of the mission till 2022/04/28 (NTC sensor time). PB F06 has then been used to produce F06 data operationaly until 2022-08-15 (NTC sensor time). **Processing baseline F07** was then used see F06 product notice for details[4].

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 analysis are done **over ocean** only, no assessment is done over hydrological targets.

[1] https://www.eumetsat.int/media/48261
[2] https://www.eumetsat.int/media/48237
[3] https://www-cdn.eumetsat.int/files/2022-10/S6A_F06_Reprocessing_Calval_Assesment_v2_draft4.pdf
[4] https://www.eumetsat.int/media/50079

1/ Data availability

Data availability over ocean is excellent for Sentinel-6 MF LR products, with 99.45% of available data over the complete mission lifetime. It is only impacted by few events, occuring during Sentinel-6 MF commissioning phase, represented with grey lines on figure 1 and listed below.

Sentinel-6 MF HR requirements on data availability are met, with a slightly reduced percentage of available data compared to LR at 97.9 %. From cycle 4 to 31 (i.e. from 2021/02/05 to 2021/09/21, in red on the figure), different mode masks were activated on POS-4. Over these cycles, HR data were not always available globally. From cycle 32, the average percentage of available HR data is of 99.1 %, which is still lower than LR. This difference is mainly due to a known anomaly impacting HR data recovery: the Fairbanks Ground Station key hole effect.

The following events impacts data availability in both LR and HR products:

- POS4 restart on 2021/01/26
- POS4 restart on 2021/02/25
- POS4 restart on 2021/04/22
- Satellite switch off for satellite software patch from 2021/04/27 03:35 to 2021/04/28 17:07
- POS4 restart on 2021/08/26
- Switch from POS4-A to POS4-B on 2021/09/14.

No important event occured over 2022.

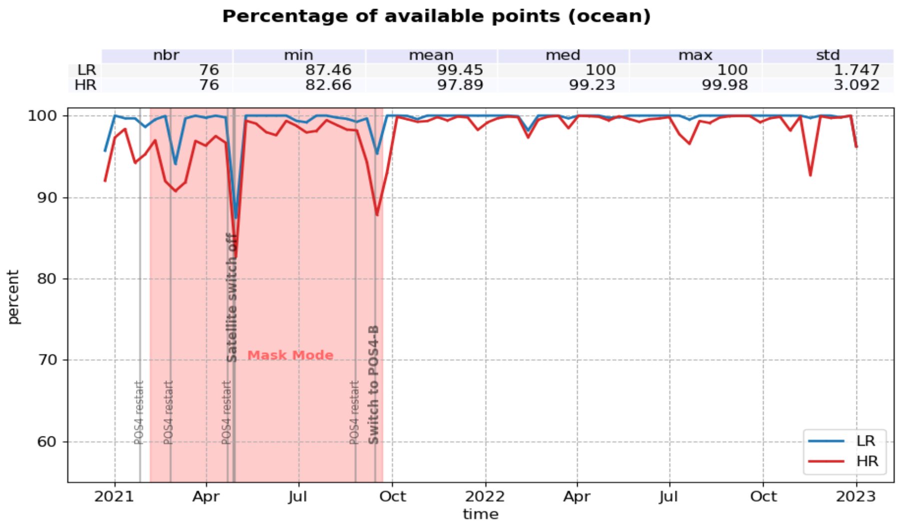

Figure 1 – Percentage of available data over ocean for NTC Sentinel-6 MF LR (blue) and HR (red) per cycle.

2/ Sea Level Anomalies

Sentinel-6 MF and Jason-3 SSHA follow identical seasonal cycles and variations, with mean value of 4.7 cm for Sentinel-6 MF LR, 3.5 cm for Sentinel-6 MF HR and 3.4 cm for Jason-3. The curves diverge from Jason-3 between october and december 2022. This is due to an anomaly in Sentinel-6 MF radiometer calibration, causing a drift of -2 mm/month of Sentinel-6 MF wet tropospheric correction. Sentinel-6 MF SSHA cyclic standard deviation is lower for Sentinel-6 MF LR and HR than Jason-3 by about 6mm up until the update to processing baseline F07 on 2022-08-15. With this update, ionospheric correction was made available over the Caspian Sea, enabling SSHA computation and subsequently increasing the standard deviation of the entire dataset to levels consistent with Jason-3. The drop in April 2022 in Jason-3 SSHA standard deviation is due to missing measurements during Jason-3 move to the interleaved orbit.

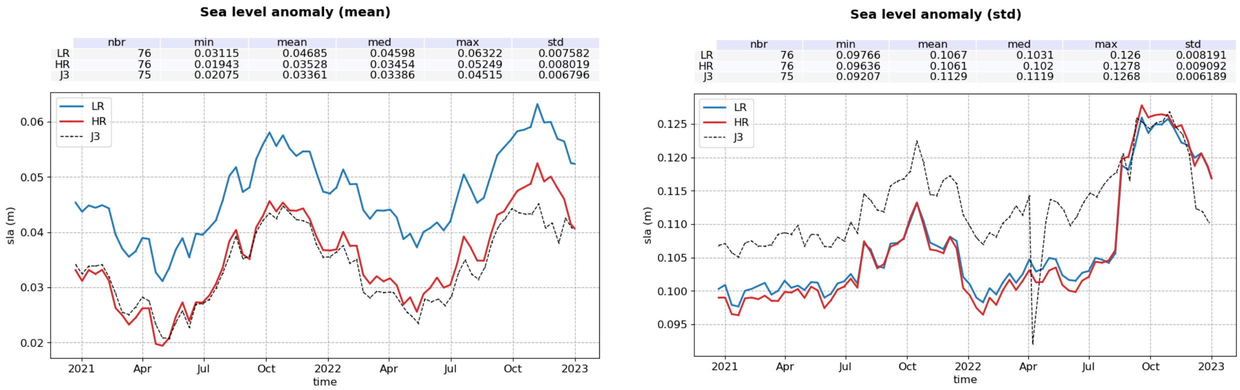

Figure 2 – Mean (left) and standard deviation (right) SSHA by cycle for LR (red), HR (red) and Jason-3 (black).

Over the tandem phase, the mean SLA differences between Sentinel-6 MF and Jason-3 per cycle is centred around 1.17 cm for Sentinel-6 MF LR and -0.05cm for Sentinel-6 MF HR. The time monitoring of this difference (figure 3) highlights two events of similar amplitudes in LR and HR:

- a jump of about +5 mm is visible after the satellite restart of 27-28 April 2021. This is partly caused by a strong variation in radiometer WTC.
- a jump of about +2.5 mm is visible around the 20 January 2022.

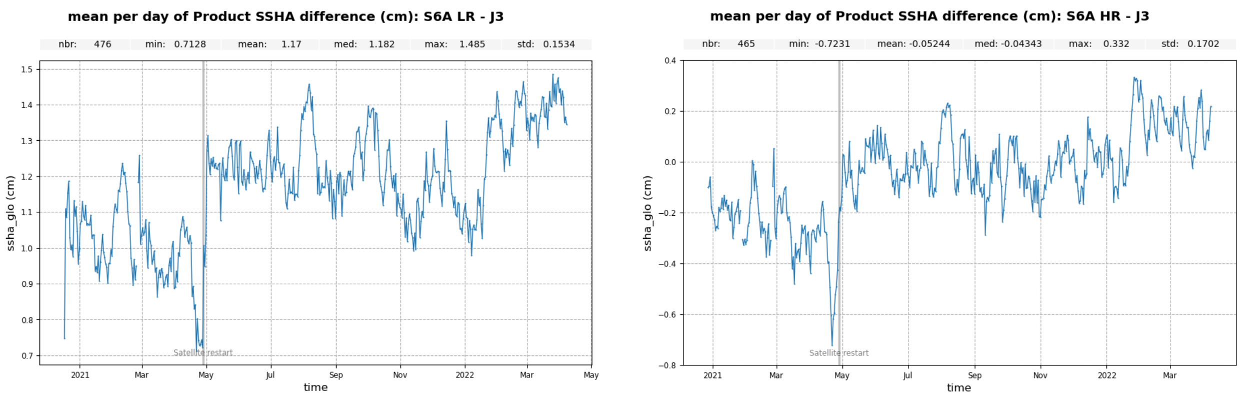

Figure 3 – Time monitoring of product SSHA difference: Sentinel-6 MF LR (left) and HR (right) minus Jason-3. Mean per day computed over the complete tandem period.

The map of the SSHA residuals between Sentinel-6 MF LR and Jason-3 (figure 4 left panel) highlights a clear correlation to SWH (+1.3 cm between 2 and 7 m wave). It is linked to range and ionosphere correction bias as well as pulse-to-pusle correlation effects, as Sentinel-6 MF uses a 9kHz PRF while Jason-3 uses a 2kHz PRF. LR numerical retracker implemented in PB F08 should improve this behavior.
In HR (figure 4 right panel), the map of SSHA differences highlights a strong correlation to sea state condi-

tion, mainly due to the usage of different skewness coefficient in the Jason-3 and Sentinel-6 HR retracking but also to the remaining impact of ocean vertical velocity on HR data [**?**]. Both should be corrected in PB F09 thanks to HR numerical retracking.
An equatorial band of 5 mm amplitude is visible on both maps. Investigations have shown that this behavior is most likely coming from Jason-3. The root cause is still to be identified.

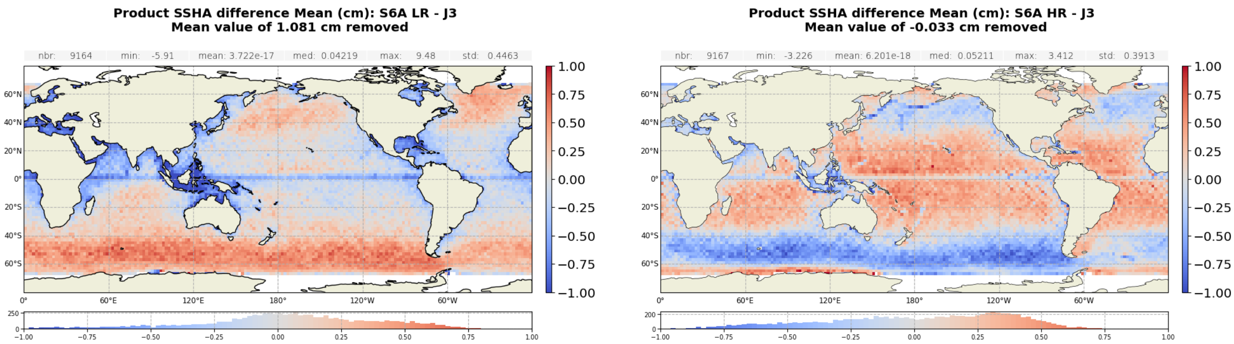

Figure 4 – Gridded map of product SSHA difference: Sentinel-6 MF LR (left) and HR (right) minus Jason-3 computed over the complete tandem period. To better compare the results, the mean value (1.081cm for the left graph, -0.033cm for the right graph) between differences have been subtracted.

3/ Performance at crossover points

Looking at SSH difference at mono-mission crossovers, mean values are well centred around 0 for both LR and HR data (figure 5 left panel). A small 120 day signal similar to Jason-3 is visible with amplitude below 1.5 cm. Prior Sentinel-6 MF launch, the origin of this signal was linked to Jason-3 platform. As the two satellites do not have the same platform, this hypothesis seems not to be the right one. Further investigations are required to fully understand this behavior.

Concerning SSH error at mono-mission crossovers ($STD\ /\ \sqrt{2}$), Sentinel-6 MF shows very good and stable performance with an error of 3.32 cm for Sentinel-6 MF LR, which is in line with Jason-3 (3.28 cm) (figure 5 right panel). The error for Sentinel-6 MF HR SSH is even lower (3.18 cm).

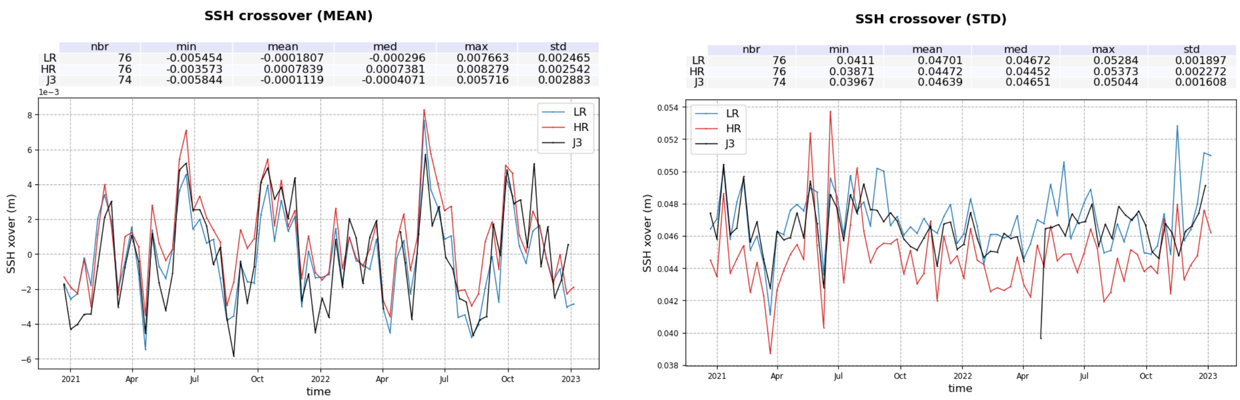

Figure 5 – Monitoring of SSH difference at mono-mission crossover for Sentinel-6 MF LR (blue), Sentinel-6 MF HR (red) and Jason-3 (black), mean (left) and std (right) per cycle. Only data with |latitude| < 50 °, bathymetry < -1000m and low oceanic variability were selected.

The mean SSH differences at Sentinel-6 MF/Jason-3 crossovers is following the same variations for LR and HR, with means of -1.3cm and 0.1cm respectively (figure 6 top panel). A downward drift is visible.

It might be caused by different PTR shape degradation between both satellites, and in HR mode by the omission of the range walk application in the baseline currently deployed in operation. Between October and December 2022, the Sentinel-6 MF/Jason-3 differences at crossover increase in absolute value. This is due to an anomaly in Sentinel-6 MF radiometer calibration, causing a drift of -2 mm/month of Sentinel-6 MF wet tropospheric correction from 2022/10/01 to 2022-12-14.

No significant regional pattern can be seen in the Sentinel-6 MF LR/Jason-3 SSH crossovers differences (figure 6 bottom panel). The map of Sentinel-6 MF HR/Jason-3 SSH differences at crossover highlight the absence of skewness parameter in the HR processing, leading to correlation to sea state conditions in the comparison to Jason-3.

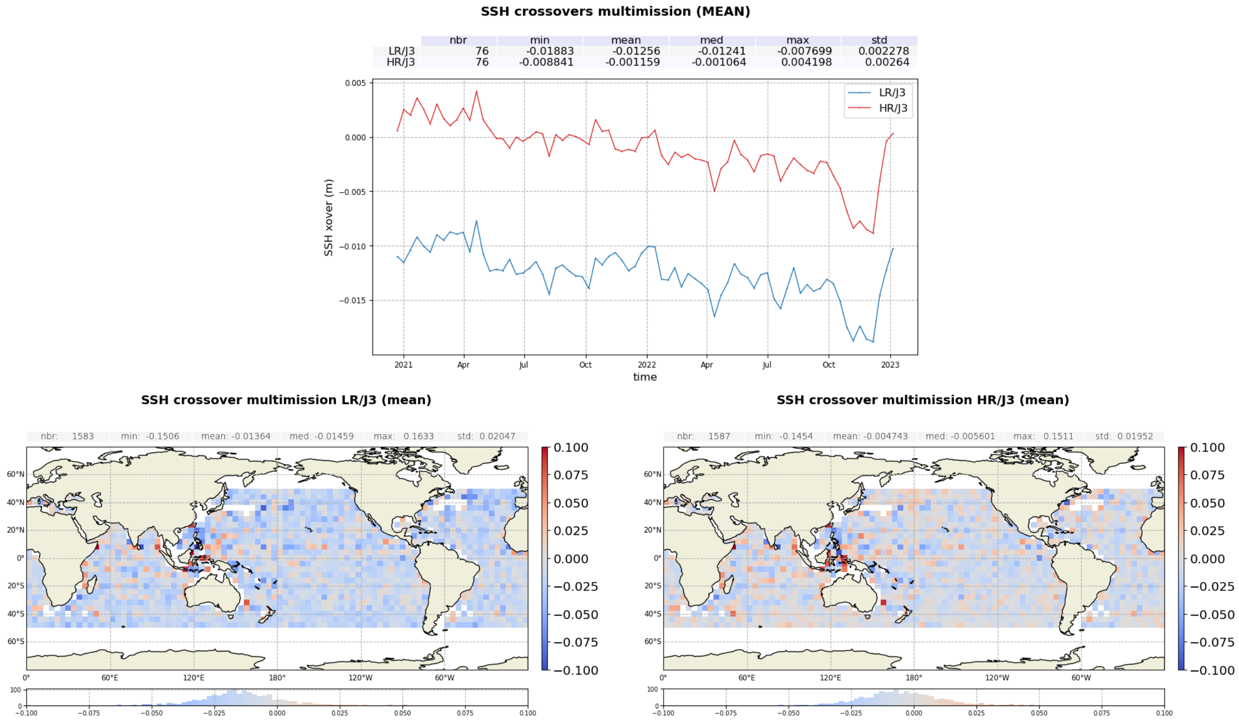

Figure 6 – Cyclic monitoring of Sentinel-6 MF - Jason-3 SSH crossover differences mean (top) and maps over cycle 42 to 79 (bottom). Only data with |latitude| < 50 °, bathymetry < -1000m and low oceanic variability were selected.

4/ Contribution to Global Mean Sea Level

Since April 2022 (Sentinel-6 MF cycle 52), Sentinel-6 MF is the reference altimetry mission to estimate the Global Mean Sea Level (GMSL), replacing Jason-3. Regional and global biases between missions have to be precisely estimated in order to ensure the quality of the reference GMSL serie as seen on Figure 7. For more precisions, see the dedicated section on AVISO+ website[5].

Sentinel-6 MF GMSL are impacted by three known effects:

- a -2 mm/month drift in the wet tropospheric correction between October and December 2022 follow by a +5 mm jump. This has been tracked to a calibration error in the radiometer. This drift will be corrected in the upcoming PDAP PB F08 upcoming update.
- the evolution of the PTR shape in the range direction. It impacts range and SWH estimates both in LR and HR. Numerical rectracker allows to account for the PTR shape evolution thanks to the use of true PTRs. Such retrackers will be implemented in the upcoming PDAP processing baseline : F08 for LR and F09 for HR.
- 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 will be available in PB F09.

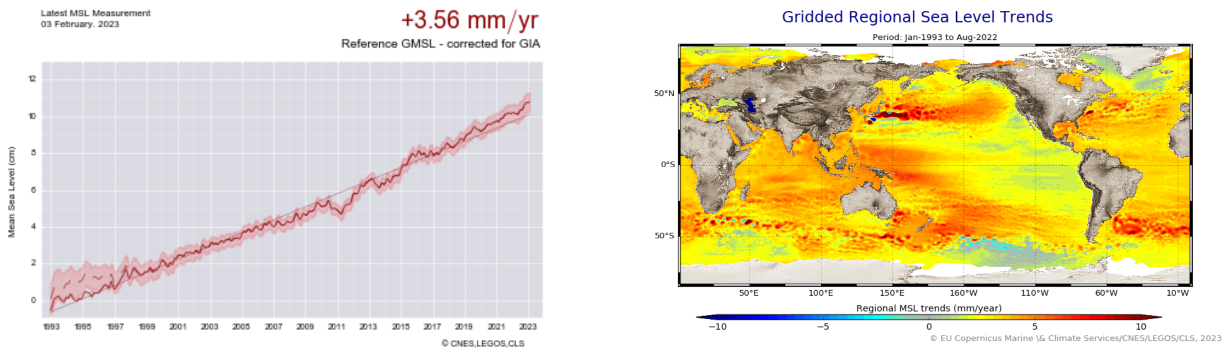

Figure 7 – Global (left) and regional (right) MSL trends from 1993 onwards.

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