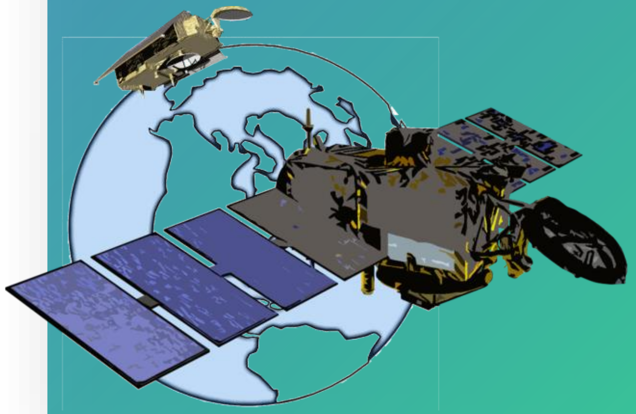
Final review 24/04/2024



Scientific Activities: CalVal Ocean

E. Cadier, B. Courcol, P. Prandi, V. Quet, T. Moreau, C. Maraldi, F. Bignalet-Cazalet, S. Dinardo, C. Martin-Puig, C. Donlon

Objectives

➔ Based on results obtained during CNES/EUMETSAT commissioning activities, during GPP project and MPS project with CNES.

Thanks to the long duration of Sentinel-6MF/Jason-3 tandem phase (12months+), a large amount of spatially and temporally collocated data have been collected. It allows to :

- perform a precise evaluation of Sentinel-6MF performance with respect to Jason-3,
- investigate, understand and correct any discrepancies/differences between Jason-3 and LR Sentinel-6A.

This goal is met thanks to residuals between Sentinel-6MF and Jason-3 datasets computed after interpolation on a same location (reference orbit). Residuals are analyzed globally over ocean but also over specific geographical areas, specific atmospheric and sea state conditions to highlight any source of dependency.

Paper

Submitted to Advances in Space Research

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research xx (2024) xxx-xxx

ADVANCES IN SPACE RESEARCH
(a COSPAR publication)
www.elsevier.com/locate/asr

Assessment of Sentinel-6MF low resolution numerical retracker over ocean: continuity on reference orbit and improvements

Emeline Cadier[a,*], Bastien Courcol[b], Pierre Prandi[c], Victor Quet[d], Thomas Moreau[e], Claire Maraldi[f], François Bignalet-Cazalet[g], Salvatore Dinardo[h], Cristina Martin-Puig[i], Craig Donlon[j]

The following slides present a summary.

Data

S6-MF

PDAP Processing Baseline F08 LR dataset

J3

GDR-F MLE4

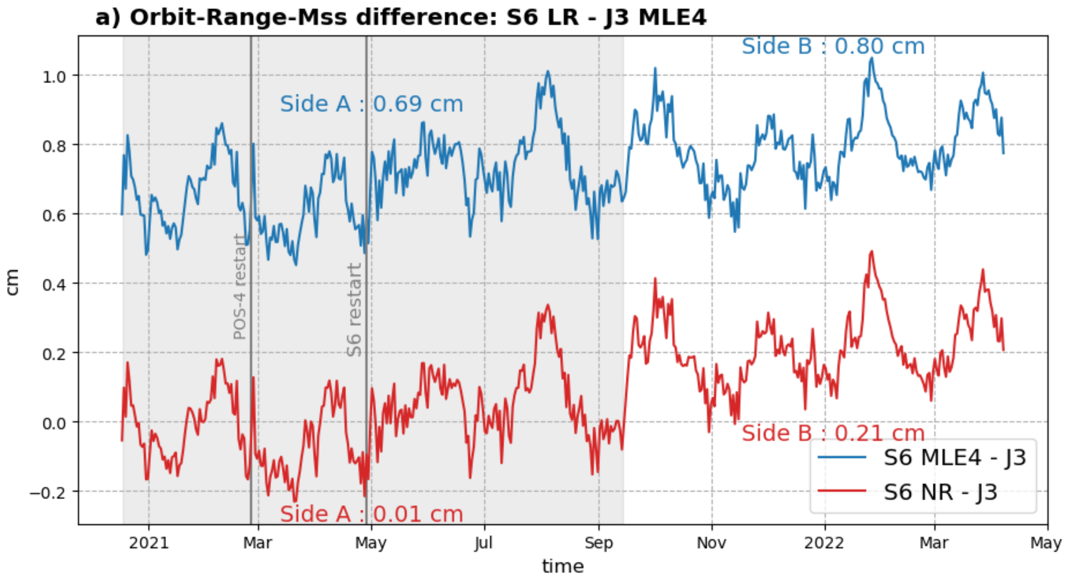
Period

17/12/2020 → 04/10/2023 (i.e. S6-MF cycles 4 to 106)

Assessment of the NR retracker outputs

Range

S6/J3 Range:

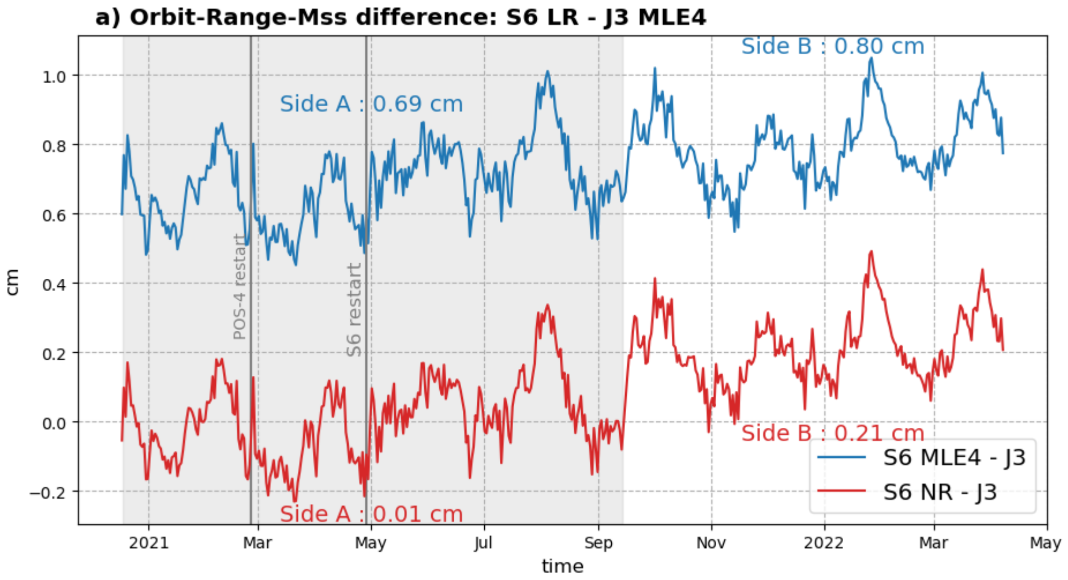


Bias between the two missions below the cm.
Reduced average bias with NR

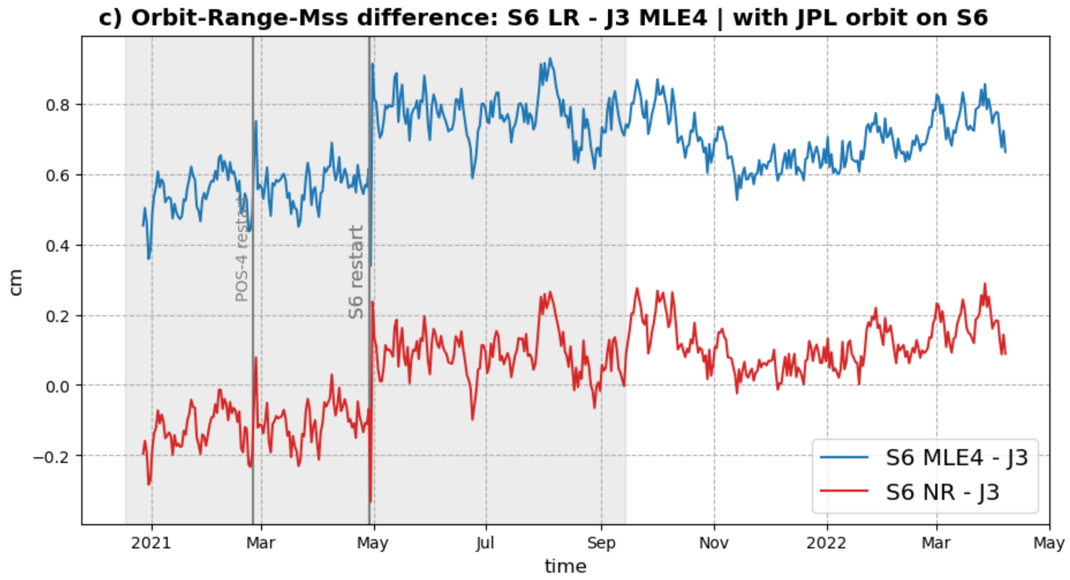
Oscillations: amplitude of 3 to 4 mm and 60-day period, correlated with beta-prime angle

Range

S6/J3 Range:



JPL orbit on S6



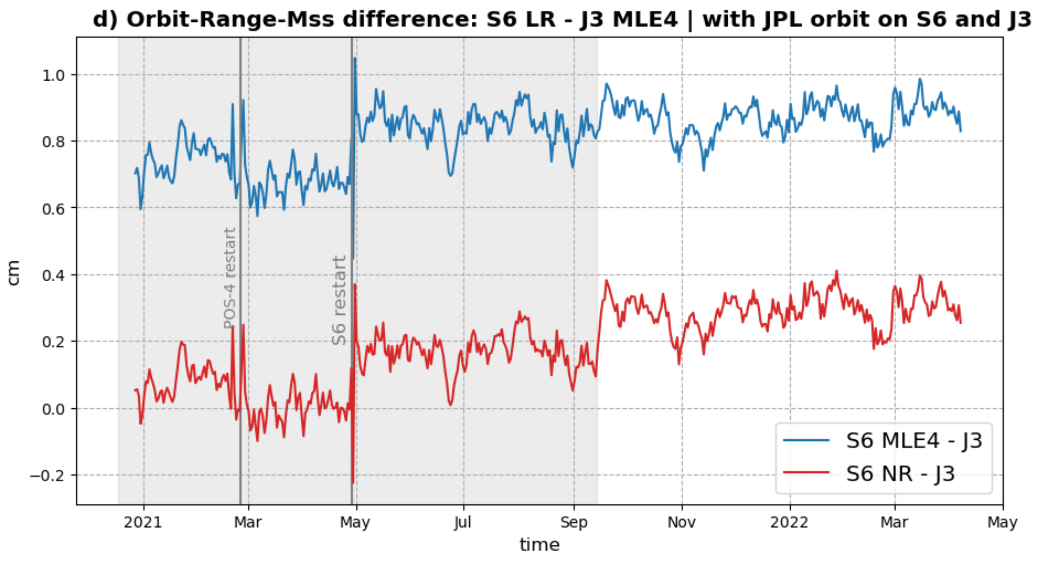
Bias between the two missions below the cm.
Reduced average bias with NR

Oscillations: amplitude of 3 to 4 mm and 60-day period, correlated with beta-prime angle

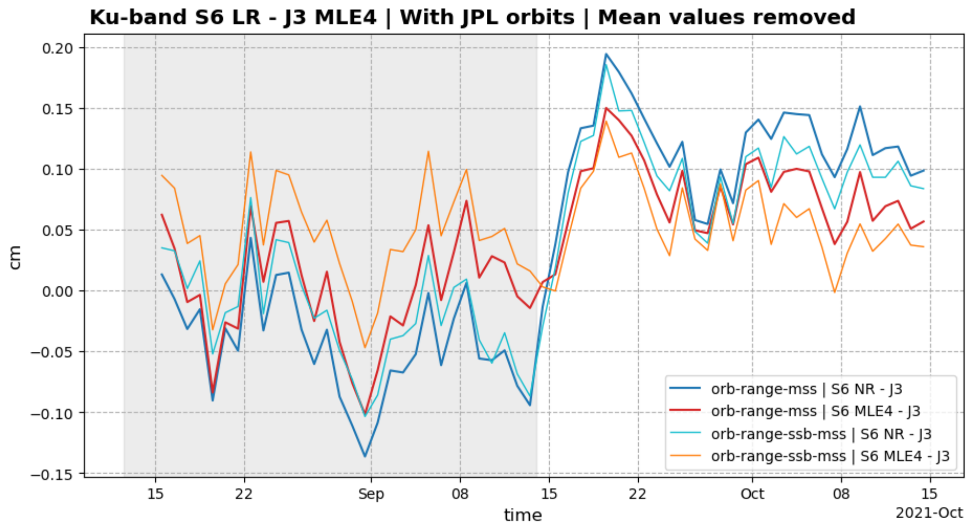
Due to S6-MF product orbit (POE-F from CNES POD)

Range

S6/J3 Range:



Zoom around the switch to POS-4B
Warning : inversion of the colors !



Some events impact the time series stability :

- Punctual impact of POS-4 restarts (ex: 2021/02/25)
- More permanent impact of **S6 full platform restart** occurring the 27-28 April 2021 : + 2 mm on NR and MLE4 range.

- Impact **switch to POS-4B** on 2021/09/14 : -1 mm on MLE4 range and -2 mm on NR range

Linked to external group delay update at the switch : increase by 2 mm for POS-4B data. This value is based on MLE4 SSHA monitoring around the switch. Analysis was performed on 2 weeks of data prior and 2 weeks after the switch, updated in PB F04 and not re-assessed since.

→ Jump on NR range artificially created.

S6/J3 Range:

Strong **improvement** of the range bias correlation to SWH with NR.

Correlation on MLE4 : due to the mis-fit of the instrumental LUT applied on MLE4 range.

Remaining effect on NR : Linked to pulse-to-pulse correlation effect on S6 (+2 mm) and some small latitudinal signal linked to the orbit.

Equatorial band + band at 40°S
→ due to J3

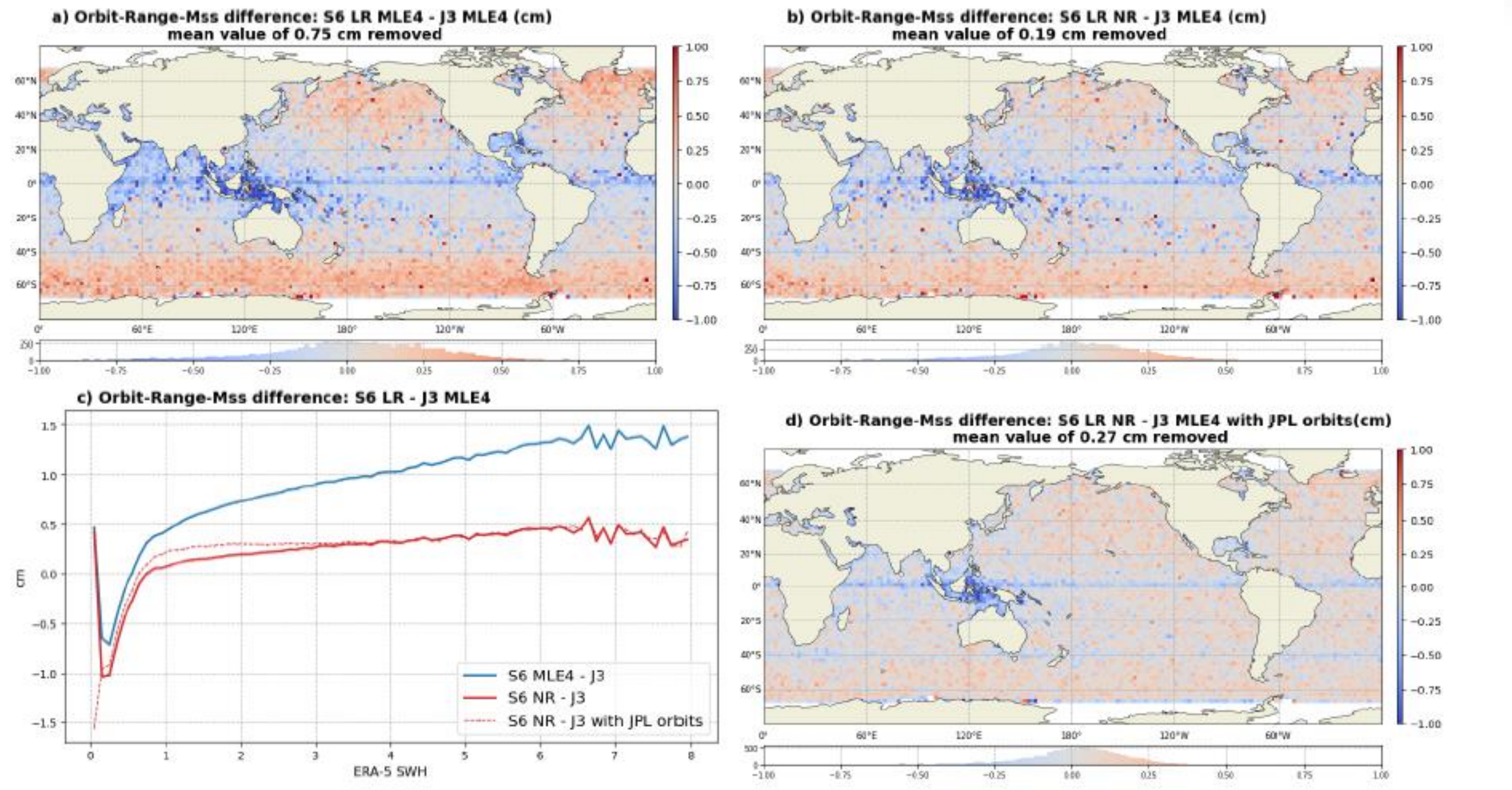
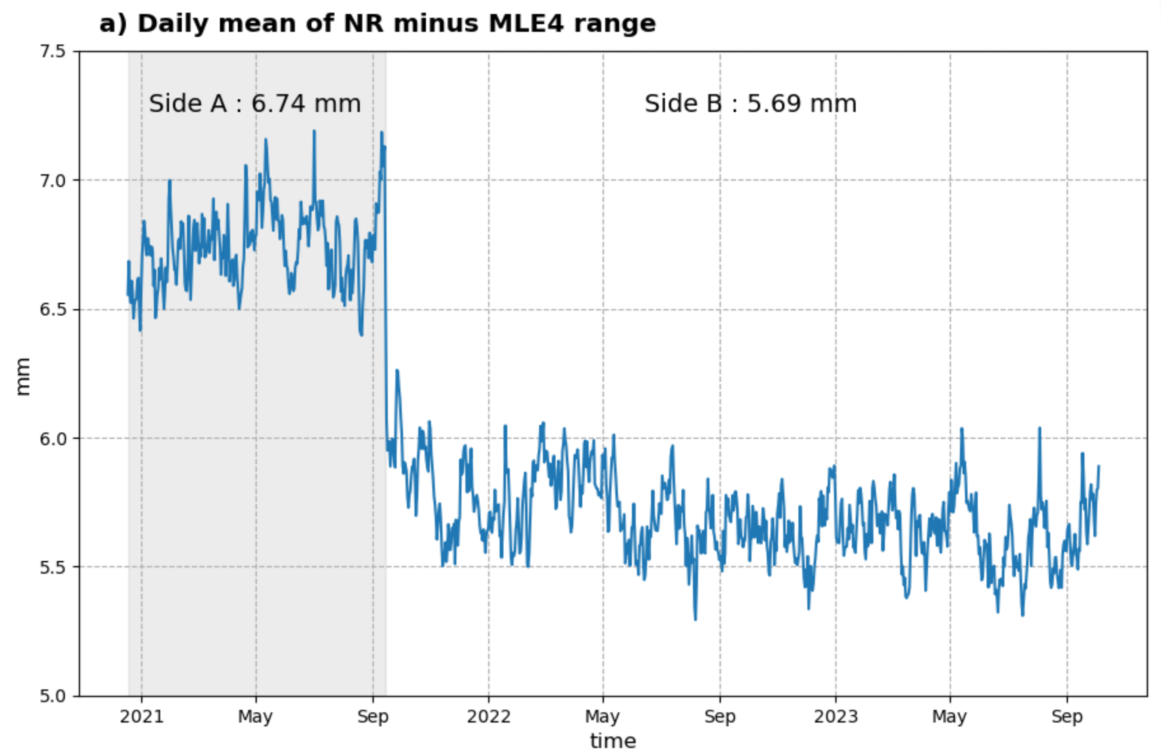


Fig. 5. S6-MF LR minus J3 MLE4 difference of the SSHA without geophysical corrections (i.e. orbit minus range minus MSS), computed over POS-4B tandem phase. Gridded mean maps for S6-MF MLE4 with product orbits (a), S6-MF NR with product orbits (b) and S6-MF NR with JPL orbits on both S6-MF and J3 (d). The corresponding curves function of ERA-5 SWH is presented on panel c.

Range

NR/MLE4 Range:



Improvement brought by NR on long term stability : cannot be assessed on the studied period as no significant drift is observed between NR and MLE4 ranges on POS-4B period.

Due to the stability of POS-4B altimeter : the effects of the PTR evolution (dissymmetric evolution between left and right side, and main lobe width evolution) compensate themselves on POS-4B (whereas they add up on POS-4A)

Range

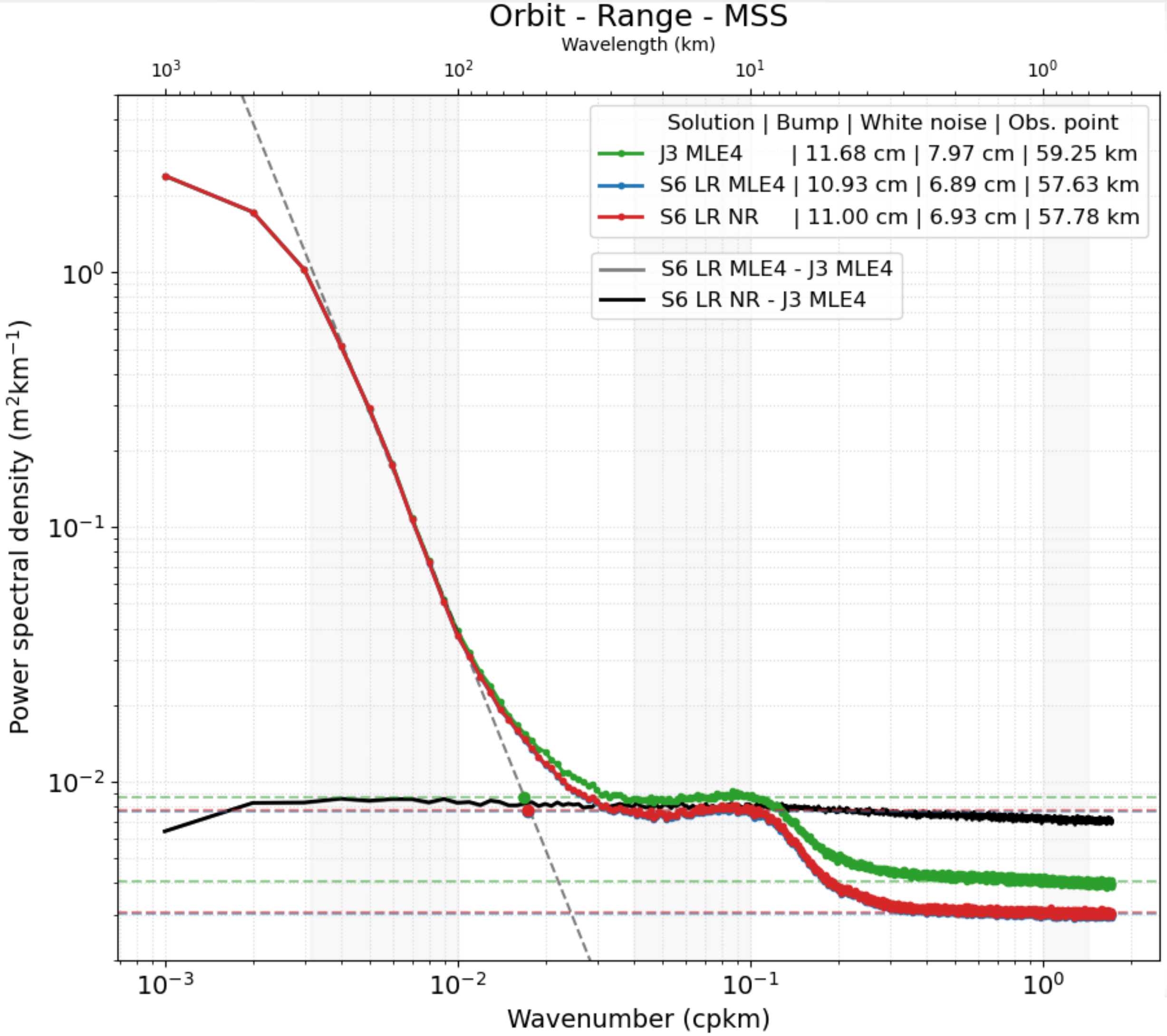
Spectral analysis:

Computed on “orbit – range – MSS” for 1 month of data during tandem phase (October 2021)

S6-MF MLE4 and NR spectrum are superimposed for all wavelengths.

Noise plateau higher for J3 than for S6 by almost 1 cm (due to altimeter and satellite design).

S6/J3 difference flat for all wavelength > 7 km: Same oceanic slope and same bump amplitude thanks to L2 processing resulting in the same radar altimeter footprint size.

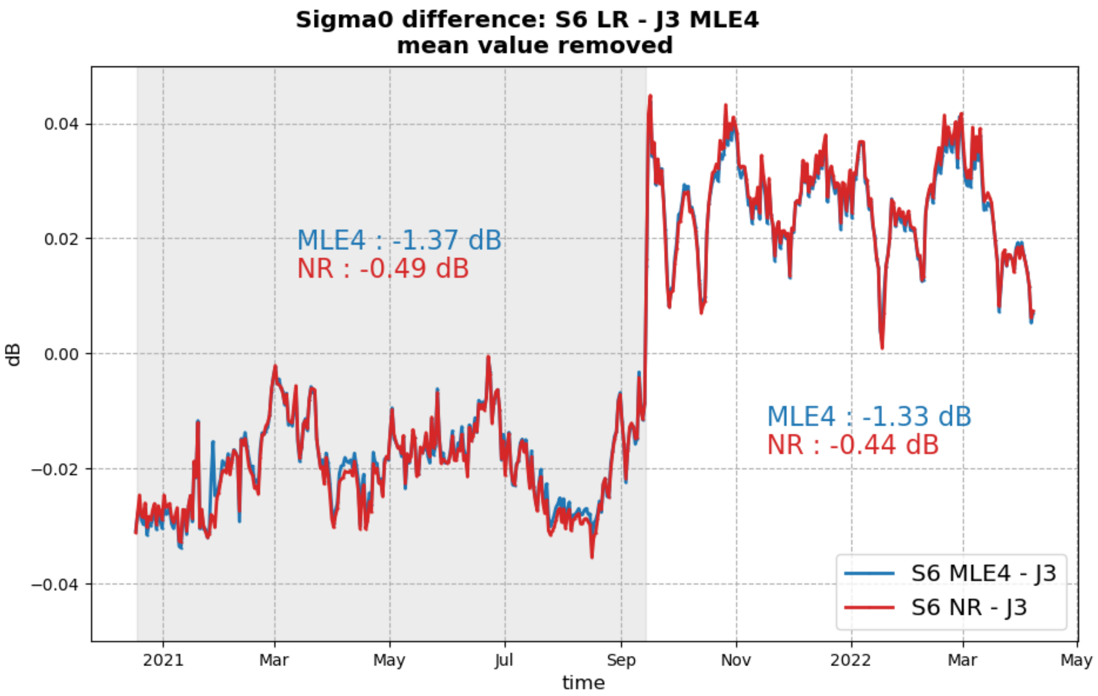


Sigma0

S6/J3 Sigma0:

Different average values between POS-4A and POS4B: Tuned in processing with external group biases (antenna and duplexer losses)
Remaining biases seen here. Taken into via calibration bias for wind speed computation.

But remaining jump observed on derived wind speed (-10 cm/s) and on SSB (+0.3 mm)
→ Sigma0 calibration biases and/or external-group biases between side-A and side-B need to be further refined to improve the transition between the 2 altimetric chains.



M-shape patterns on the time series, correlated to sun beta-prime angle. Small amplitude but stronger impact on POS-4B (0.02 to 0.04 dB).

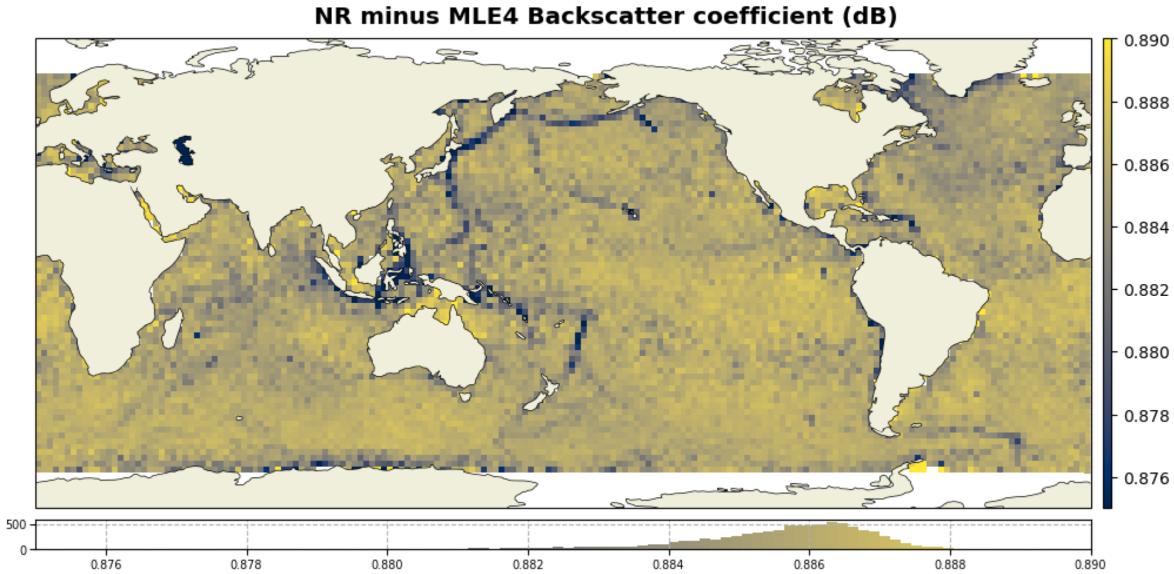
Sigma0

NR/MLE4 Sigma0:

Unexpected pattern on the difference: larger value (0.01 dB) over zones of sudden changes in the bathymetry.

→ Different sensitivity to sea surface slopes between the 2 retrackers that remains to be understood.

Note: MLE4 sigma0 will be updated in PB F09 (correction of an anomaly in the definition of the total power) → MLE4 sigma0 increased by 0.91 dB, bringing it closer to NR and to J3.

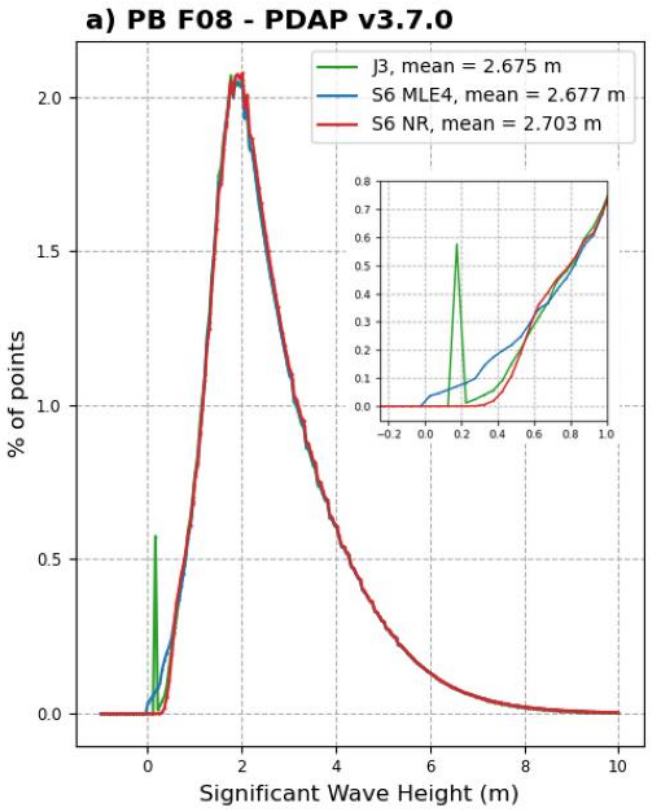


SWH

Difference between S6-MF MLE4 and J3 at small SWH: No negative value allowed on J3 while negative value allowed for S6 → different histogram shape.

S6-MF NR SWH

Anomaly detected during F08 pre-operational validation : negative NR 20 Hz SWH mapped to their absolute values. Mainly impact NR SWH < 1m but impact is visible up to 3 m wave.

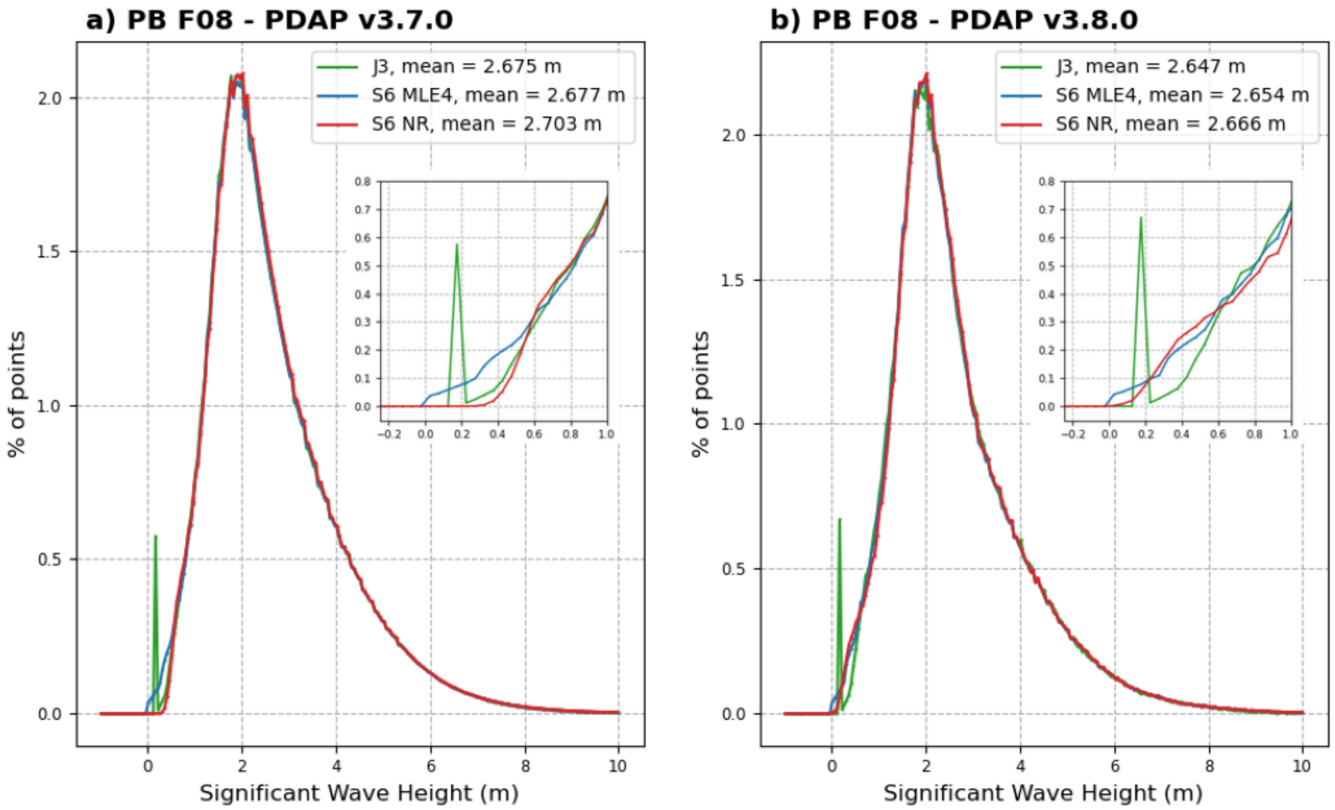


Difference between S6-MF MLE4 and J3 at small SWH:
No negative value allowed on J3 while negative value allowed for S6 → different histogram shape.

S6-MF NR SWH

Anomaly detected during F08 pre-operational validation : negative NR 20 Hz SWH mapped to their absolute values. Mainly impact NR SWH < 1m but impact is visible up to 3 m wave.
Corrected in a patch version of F08 (PDAP v3.8.0), not used in the reprocessing. → not corrected in the data used for this study.

Remaining bias between NR and MLE4 SWH : ~ 2 cm



Mispointing

Stable in time after star tracker update on the 18/01/2021.

Small oscillations on S6-MF time series: 0.001 deg² amplitude and 120-days period, correlated to the sun beta-prime angle.
→ Confirms the impact of beta-prime angle on S6-MF retrackers outputs, already seen on sigma0.

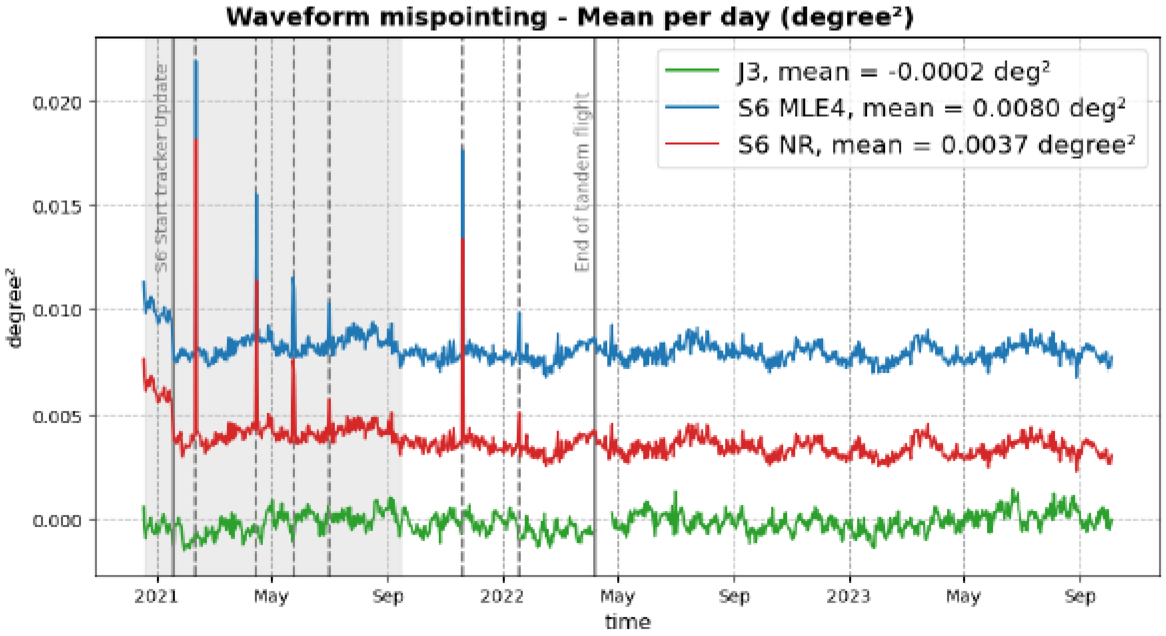


Fig. 14. Daily monitoring of the waveform mispointing for S6-MF MLE4 and NR and for J3. Grey range: POS-4A period.

Ionospheric correction

Ionospheric correction

S6/J3 iono:

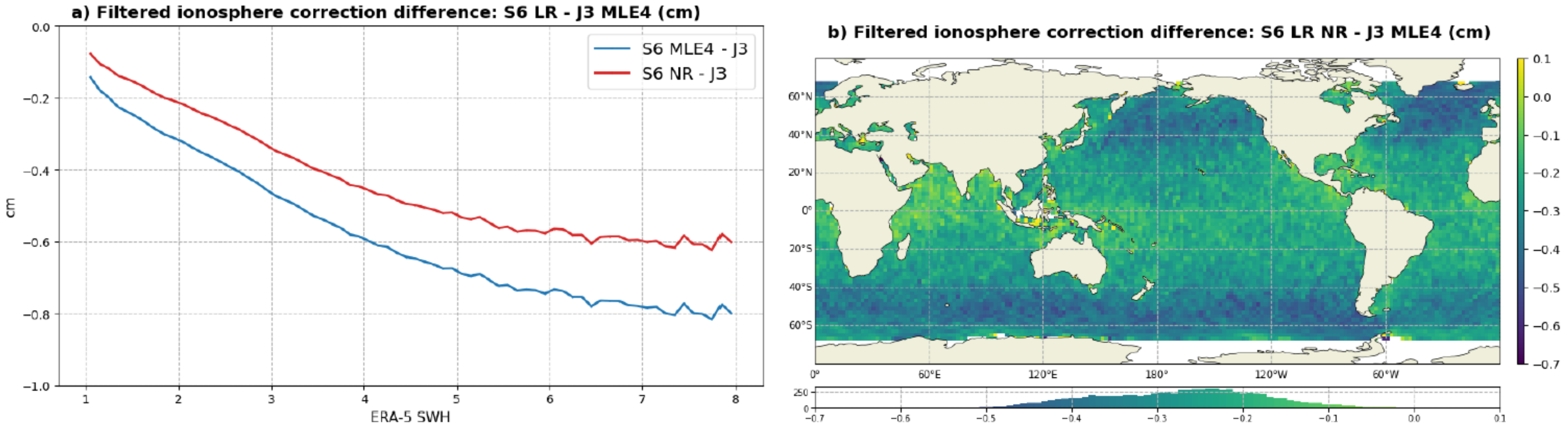


Fig. 15. Difference of collocated filtered ionospheric correction: S6-MF LR minus J3 MLE4, computed over POS-4B tandem phase and for ERA5 SWH greater than 1 m. a) Function of ERA5 SWH. b) Gridded map for S6-MF LR NR minus J3.

Strong correlation to SWH in the S6/J3 bias.
Only small improvement with NR (thanks to Ku-band range improvement). Remaining correlation in NR is of the order of -4.5 mm between 1 and 5 m wave.

→ Cannot come from Ku-band range and SSB as their bias wrt J3 is too small.
→ Main hypothesis : C-band. But difference in C-band frequencies between the 2 missions prevent from performing direct differences between the C-band ranges.

Ionospheric correction

Check on C-band SSB:

In PDAP: J3 GDR-F C-band table used, while C-band frequencies are not identical.

We defined SSB proxies using GIM model: $$SSB_C \approx SSB_{C\text{proxy}} = (Range_{Ku} + SSB_{Ku}) - Range_C - \frac{\text{Iono}_{\text{GIM}}}{\delta f}$$

S6/J3 differences between proxies and C-band SSBs shows that J3 C-band SSB is not suitable to correct S6-MF C-band range.

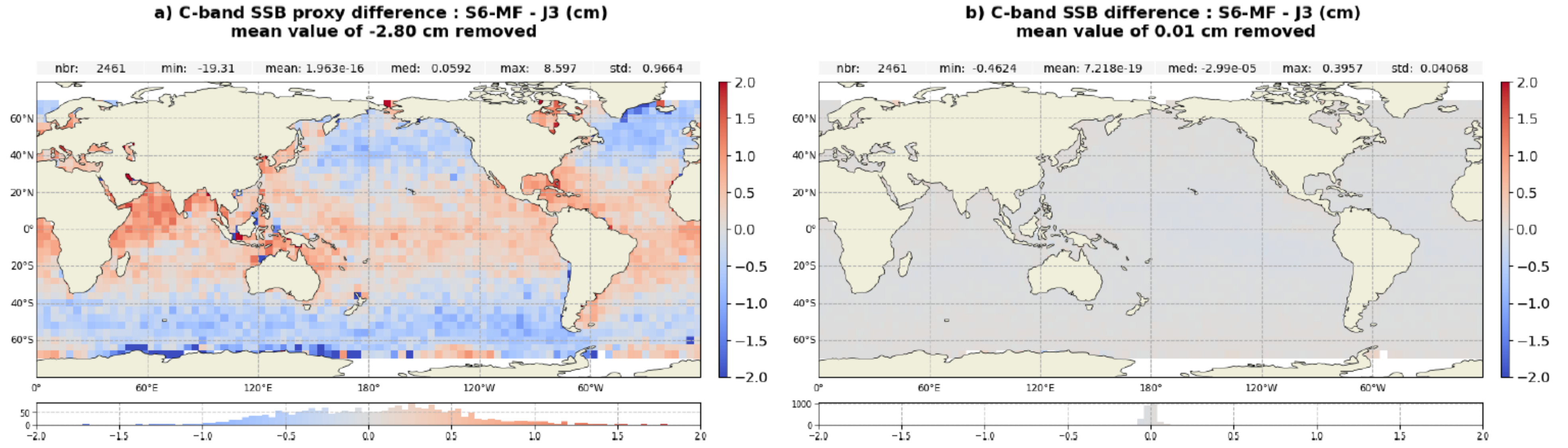


Fig. 17. Gridded mean map of collocated C-band SSB difference: S6-MF LR minus J3, computed over POS-4B tandem phase and for ERA5 SWH greater than 1 m. a) Independent GIM-derived proxies. b) Product C-band SSBs.

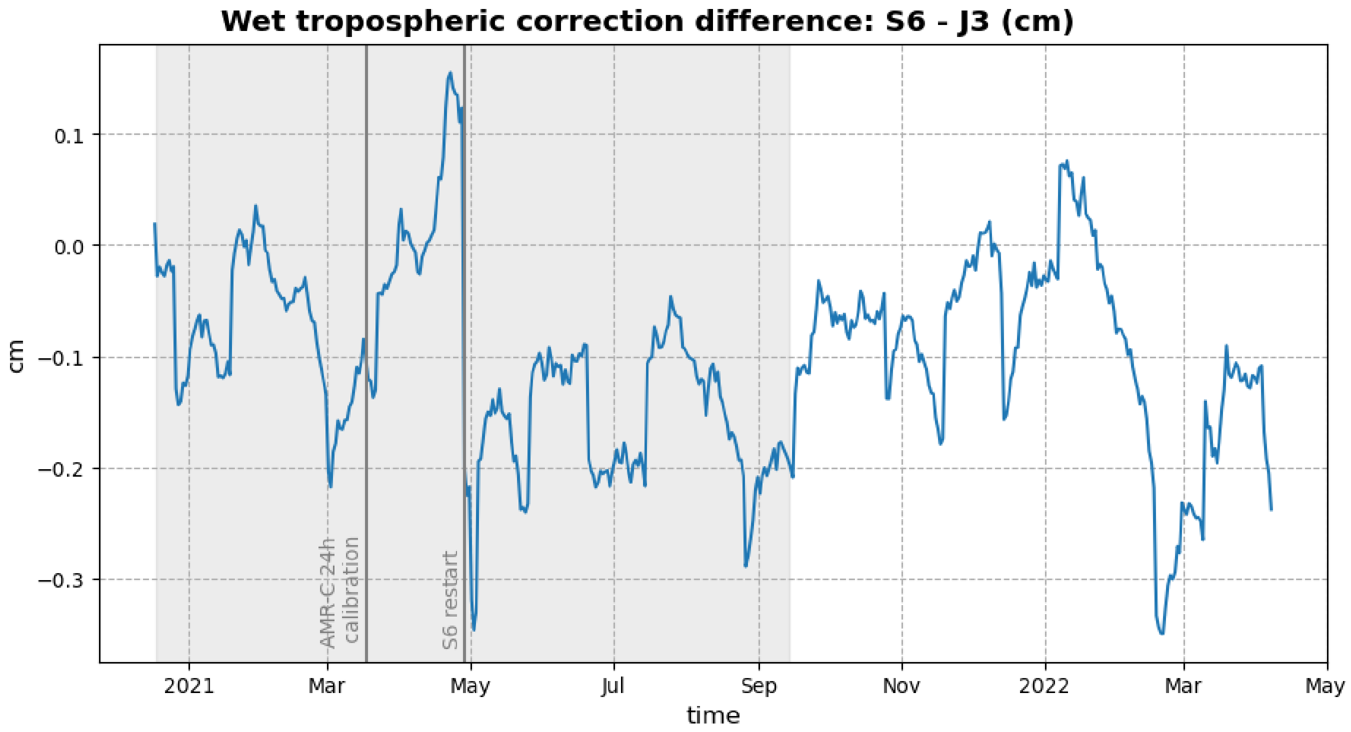
Wet troposphere correction

Radiometer Wet Tropospheric Correction

S6/J3 WTC:

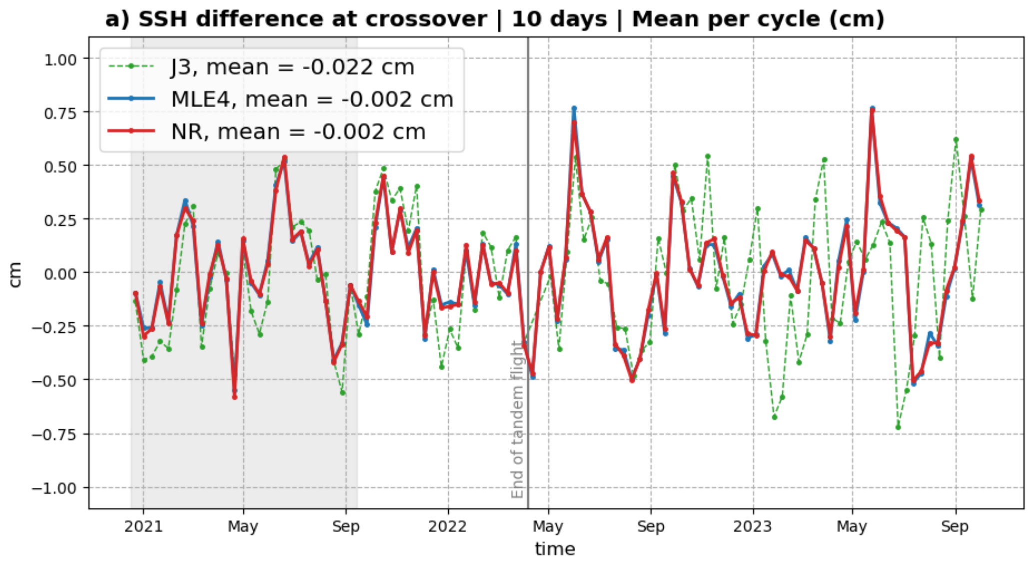
Several jumps of various amplitude (between 1 and 3 mm).
→ Non-negligeable impact on SSHA and GMSL comparison between the 2 missions.

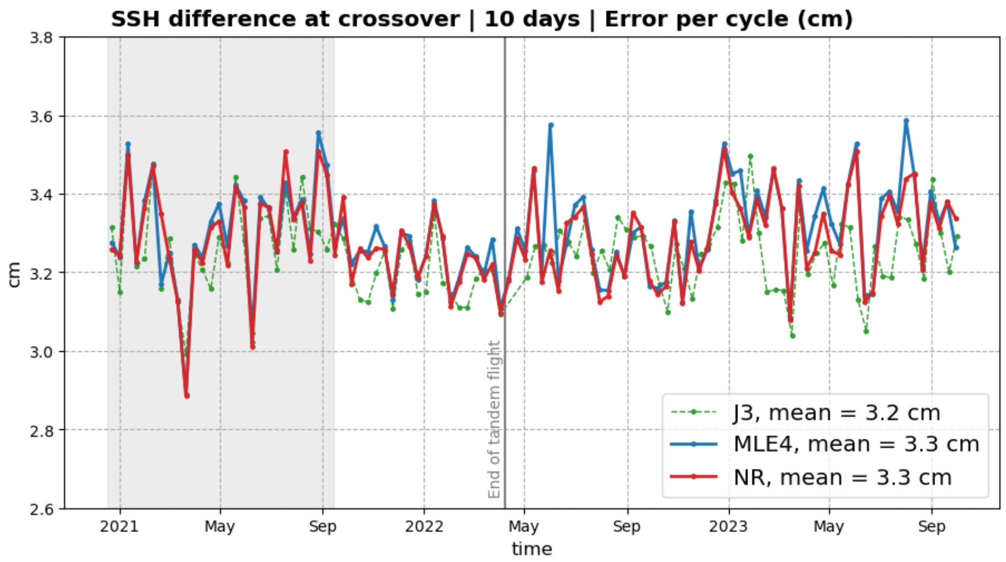
Main hypothesis : changes in radiometer calibration coefficients on S6-MF and/or J3 (except for the jump on 28/04 linked to S6-MF platform restart)



SSHA

Performance at crossovers:





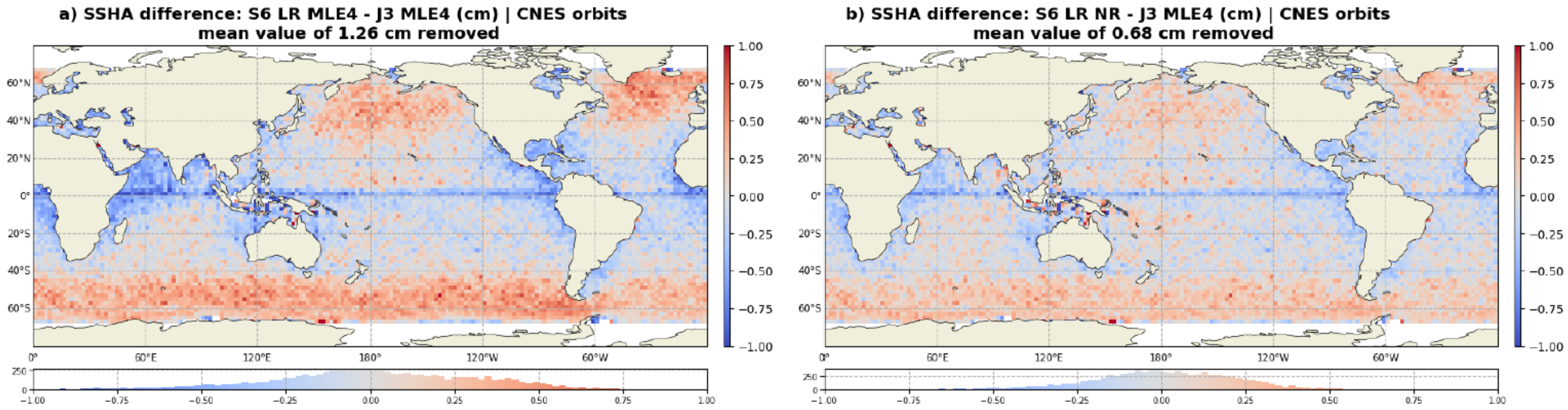
Excellent performance at xovers with a null mean difference and an error of 3.3 cm (error= sqrt(std))
In line with J3
Identical for S6 MLE4 and NR

Small oscillations on S6 and J3 mean differences : due to the orbits (120-day signal linked to beta prime angle)

SSHA

S6/J3 SSHA:

With NR : strong improvement in terms of correlation to SWH (reduced by 60 %)



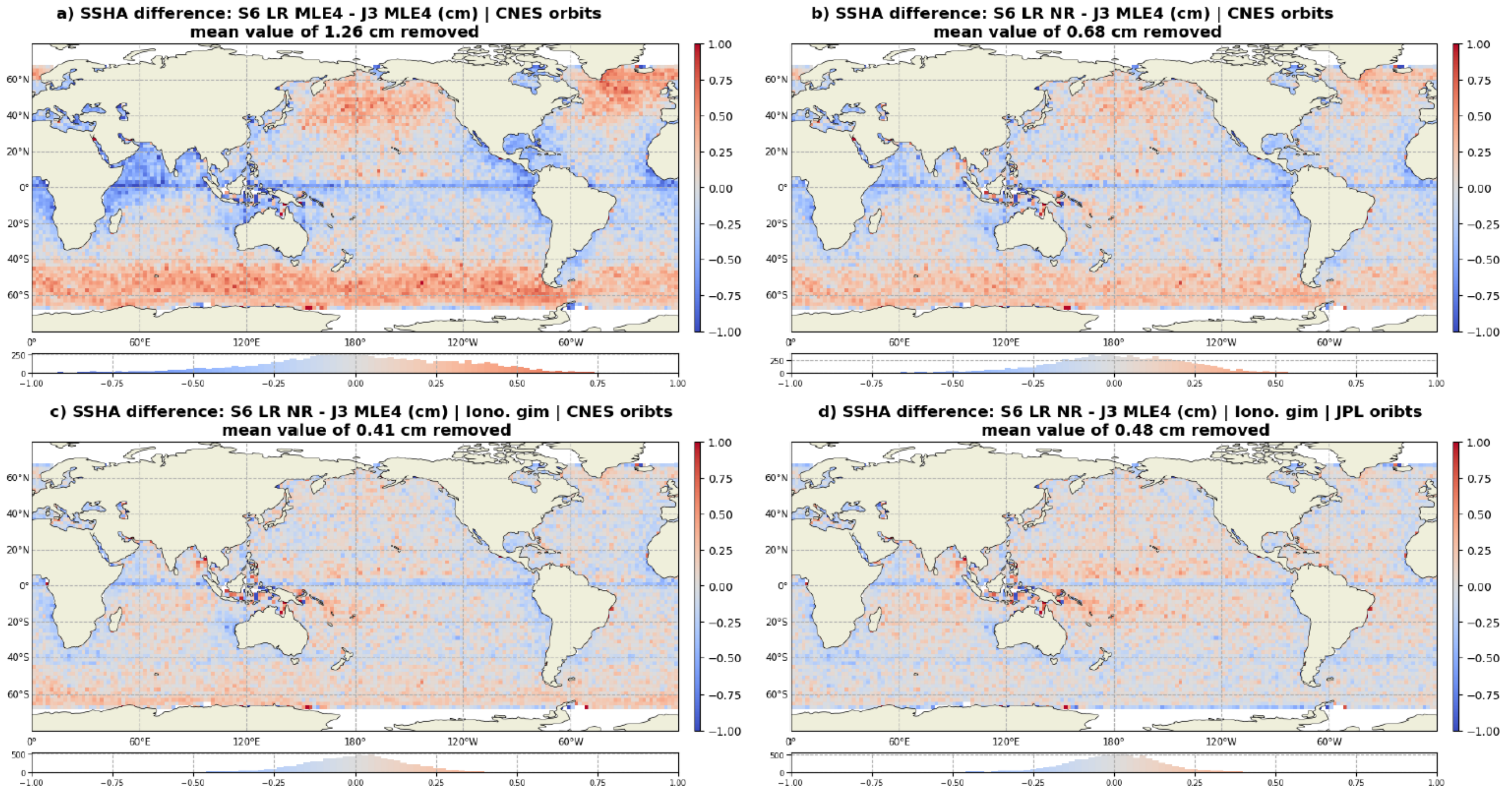
SSHA

S6/J3 SSHA:

With NR : strong improvement in terms of correlation to SWH (reduced by 60 %)

Remaining effects linked to :

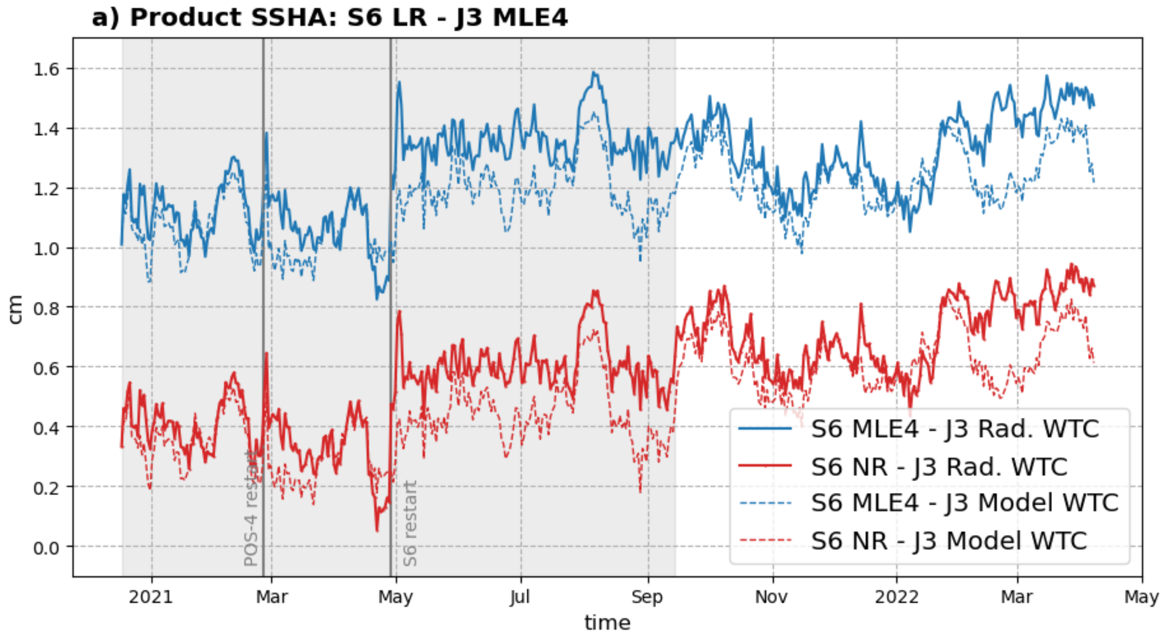
1. Ionosphere correction
2. P2P correlation effect
3. Orbit



S6/J3 SSHA:

Temporal stability of S6/J3 SSHA bias strongly impacted by rad. WTC → divide the time series into several regimes.

With the use of model WTC : 60-day period oscillations linked to S6-MF orbits (as observed on range).



SSHA

S6/J3 SSHA:

With Model WTC and JPL orbits

Some events remains and impact the time series stability :

- 2021/02/25: POS-4 restart (punctual impact)

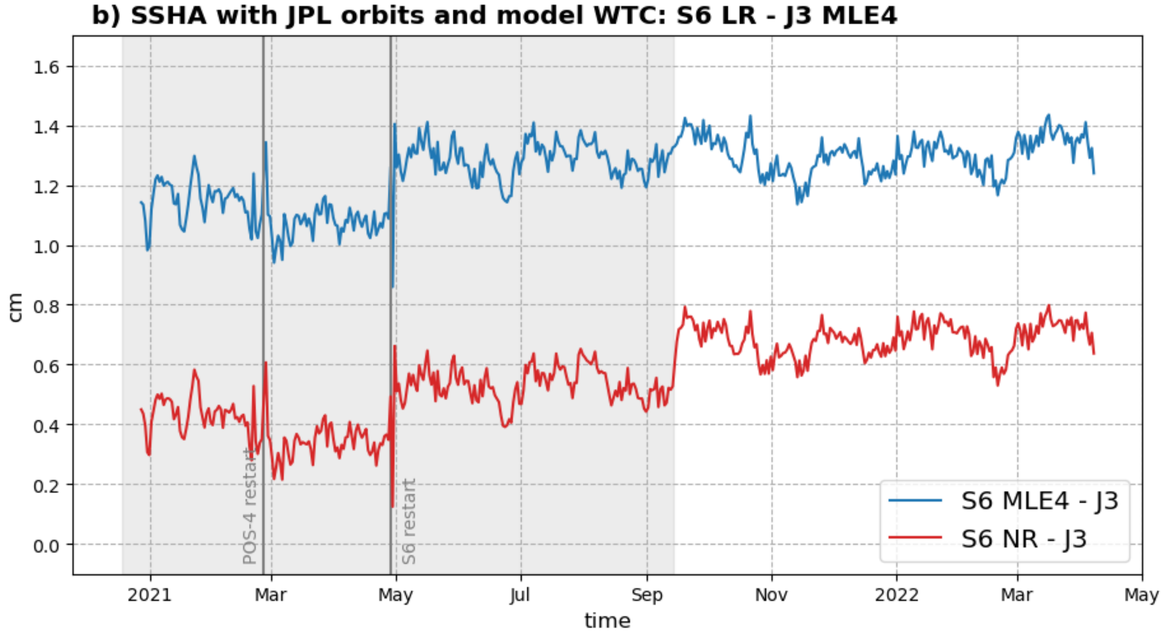
- 2021/04/27-28: S6-MF platform restart
  - -3 mm on WTC relative bias
  - -2 mm on Ku-band ranges
  - → +5 mm on SSHA for both MLE4 and NR

- 2021/09/14: switch to POS-4B

	MLE4	NR
Ku-band range	- 1 mm	- 2 mm
Ku-band SSB	+ 0.3 mm	+ 0.3 mm
Iono.	- 0.6 mm	- 0.8 mm
Rad. WTC	+ 1 mm	
SSHA	- 0.3 mm → ~0	+ 1.5 mm

→ Due to Ku and C-band ranges

→ Not linked to the switch but relative jump on the same day



The Ku-band external group delay has been tuned for POS-4B based on MLE4 SSHA monitoring

→ POS-4A and POS-4B MLE4 SSHA are aligned. But this update absorbs the WTC jump occurring on the same day.

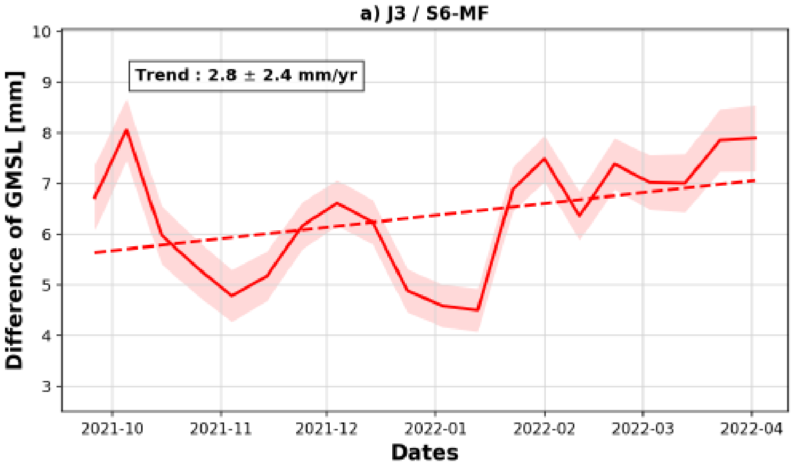
➔ A re-evaluation of the Ku-band external group delay should be performed using SSHA without geophysical correction, using NR retrievals (less impacted by Side A/B PTR shape difference), and using 60-day periods (orbits).

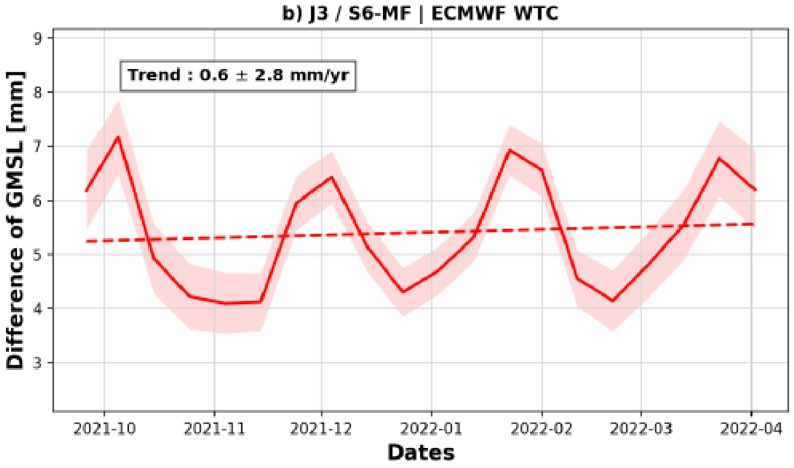
GMSL

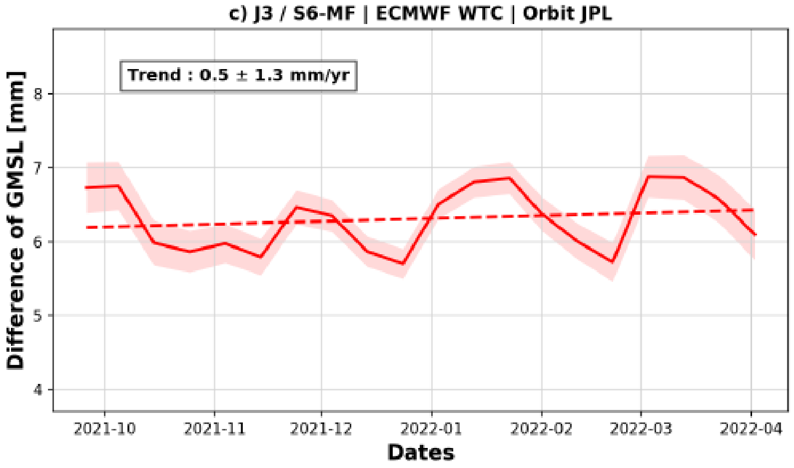
GMSL: relative drifts between S6 and J3

S6/J3 GMSL differences :

Analysis performed on POS-4B period using S6-MF LR NR data :







Impact of rad WTC → significant trend difference between the 2 missions

With Model WTC : no significant trend between S6 and J3 GMSL.
As on SSHA : oscillations linked to S6-MF orbits

With Model WTC and JPL orbit
Reduction of the oscillations.

GMSL: intermission offsets & uncertainties

Estimation of inter-mission offsets & uncertainties between J3 and S6A,
Estimators based on Guérou et al., 2023, modified to account for two-sided PDF,

Table 3. *J3 / S6-MF NR inter-mission offsets and uncertainties*

Orbit solution	WTC correction	offset [cm]	uncertainty at 1σ level [mm]
CNES	radiometer	0.63	0.5
CNES	model	0.54	0.4
JPL	model	0.63	0.1

With model WTC & JPL orbits, offset uncertainty is 0.1 mm (1 sigma level)
Slightly better than with S6 MLE4 (0.2 mm)

GMSL: uncertainty budget

Document uncertainty budget, in addition to Guérou et al., 2023, with conservative intermission offset

Table 4. *Uncertainty budget for S6-MF LR NR*

Source of uncertainties	Type of errors	Correlation scale	Uncertainty at 1σ level [mm]
Altimeter noise/geophysical corrections	Correlated errors	$\lambda = 2\ months$	1.1
Geophysical corrections/orbit	Correlated errors	$\lambda = 1\ year$	1.3
Intermissions calibration offsets	Bias		$u_\Delta = 0.5\ mm$

Results in

- 3.2 +/- 0.3 mm/yr GMSL trend
- 0.15 +/- 0.05 mm/yr² GMSL acceleration

since 1993, with L2P21 standards, will be revised with L2P24

Conclusion

Very good consistency between S6-MF LR NR and J3 retrievals (below 1 cm difference in range and below 2 cm for SWH)

Strong improvement brought by Numerical retracker in terms of sea-state related bias between S6 and J3 : reduction of 60% of the correlation to SWH in the SSHA difference.

Remaining differences:

- **Ionosphere correction** difference remains correlated to SWH.
- We recommend to build a C-band SSB dedicated to S6
- **S6/J3 WTC relative jumps** to understand (calibration updates?)
- **P2P correlation effect** on LR
- **Orbit:** 60-day signal on S6-MF
- Remaining jump at the **switch between POS4A and POS4B** :
  - Impact on NR range artificially created by the updates of the Ku-band external group delay (heritage from S6-MF commissioning)
  - → We recommend a re-evaluation of the Ku-band external group delay using SSHA without geophysical correction, using NR retrievals (less impacted by Side A/B PTR shape difference), and using 60-day periods (orbits).
  - Impact on sigma0 not totally accounted in wind speed computation
  - → We recommend a further tuning of sigma0 calibration bias and/or external-group biases
- Small impact of the sun beta-prime angle on S6-MF retracker's outputs (observed on sigma0 and mispointing)

Perspectives

2nd tandem phase between S6-MF and J3 planned for early 2025

→ Unique opportunity to re-evaluate the relative errors made between the two altimeter missions a few years after the initial tandem phase.

For altimeter and radiometer parameters :

→ Will allow us to characterize the evolution of the instrumental errors and potentially detect any parameter drifts with a very low uncertainty

→ Will allow us to investigate to what extent the agreement between S6-MF and J3 has changed over time.

→ Unique opportunity to verify our current uncertainty budget on the long-term stability of the altimeter and radiometer parameters

Will required NTC data processed with the same ground segment processing baseline