PROGRAMME OF THE EUROPEAN UNION

Copernicus Europe's eyes on Earth

EUMETSAT NASA NOAA esa cnes CENTRE NATIONAL D'ÉTUDES SPATIALES

S6 MPWG Cal/Val Activities Status and Roadmap

Cristina Martin-Puig (EUMETSAT) on behalf of:

Rob Cullen (ESA)
Jean Damien Desjonqueres (NASA/JPL)
Eric Leuliette (NOAA)
Claire Maraldi (CNES)
Marco Meloni (EUMETSAT)

OSTST 2023, San Juan, Puerto Rico

The Mission Performance Working Group (MPWG)

What is the MPWG:

- The MPWG is a body composed of experts from EUMETSAT, NASA, ESA, NOAA and CNES.
- The group meets on a regular basis, and it is aiming at monitoring the Sentinel-6MF overall altimetry mission performance.
- The group assesses on mission and payload performance budgets, data products quality, algorithm development, new processor verification and validation performance, calibration and validation planning, as well as provides scientific support to the reprocessing calibration and validation, key mission instrument meetings and mission performance meetings.
- The MPWG activities are similar to those done by the MSEs as per previous Jason mission.

Cyclic monitoring

- S6 MF **NTC Altimeter products** cyclic Cal/Val reports are available to the user community
- S6 **POS4 Instrument Calibration** report is also made available per cycle to the user community
- https://eumetsatspace.atlassian.net/wiki/spaces/PQ/pages/1773928450/Sentinel-6+cyclic+reports
- Specifications of the Sentinel-6 processors are available here:
  - https://www.eumetsat.int/altimetry-resources

Important differences between missions

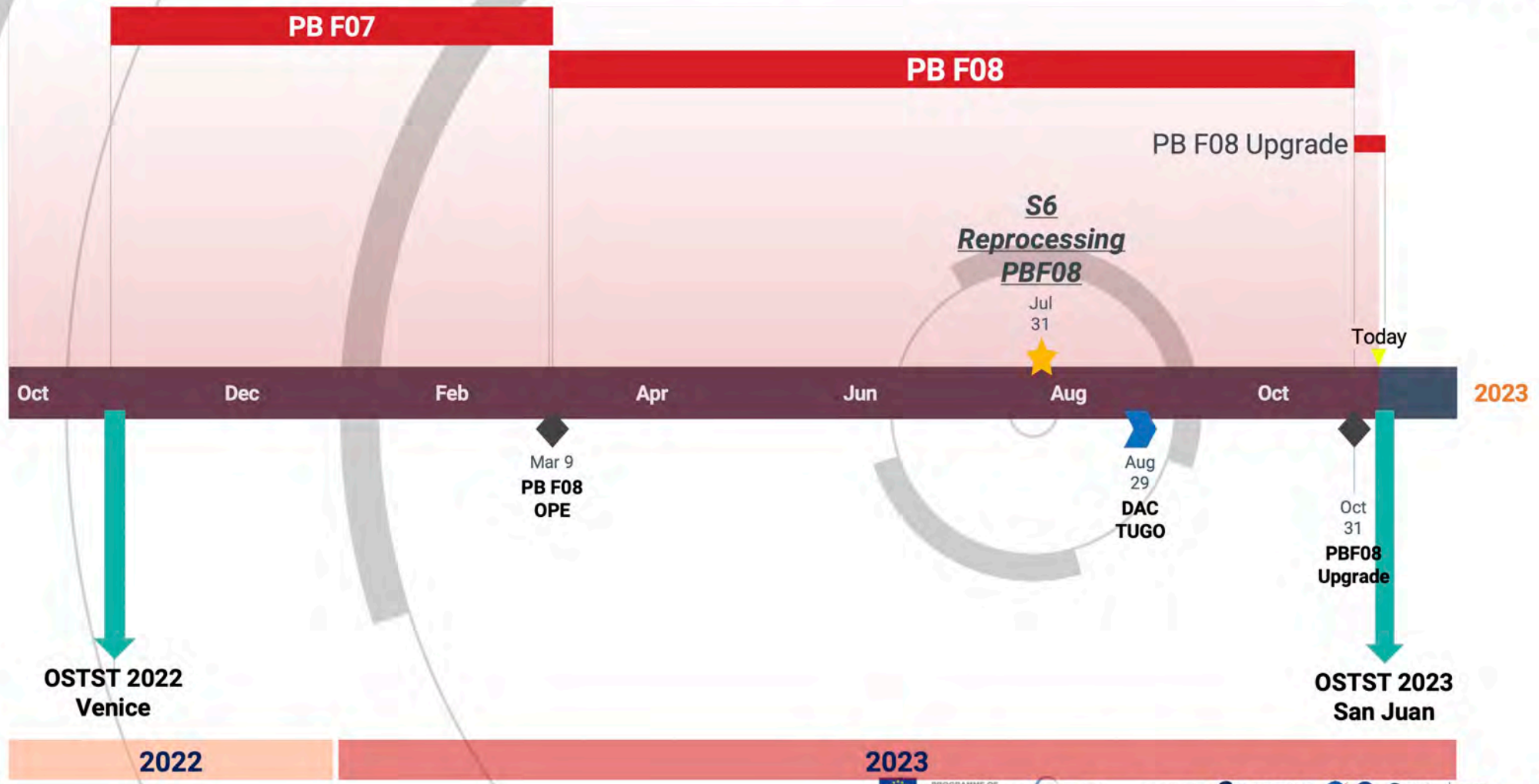
What	Jason-3	Sentinel-3	Sentinel-6
Delay/Doppler altimeter	N/A	Closed Burst (1/3 time we are tx while 2/3 time we are rx)	Open Burst
Reception pattern, and what is available in a radar cycle	90 Ku and 15 C band echoes	64 * 4 Ku band echoes 2 * 4 C band echoes	64 * 7 Ku band echoes 1 * 7 C band echoes
Calibration	Traditional calibration over specific areas CAL1, CAL2, other	Traditional calibration over specific areas CAL1, CAL2, other	ECHO CAL CAL1 Calibration along the orbit only for Ku band + traditional calibration
For modellers	deramp BW_Rx = sampling frequency	deramp BW_Rx = sampling frequency	Match filtering BW_Rx diff to sampling frequency
Radiometer	AMR	AMR	AMR-C • Supplemental Calibration System (SCS) – *maintain mm/yr stability* • High Resolution Microwave Radiometer (HRMR) – *provide coastal path delay to 1cm at 5km from land*

PB evolutions from OSTST 2022 to OSTST 2023

PB	Evolution
PB F08	• upgrade of the **Poseidon-4 antenna beamwidth** value from 1.33 to 1.34 degrees based on in-flight cal/val results. • Update of the **total electron content (TEC) computation** with a more appropriate scaling factor (0.881 instead of 0.925) to align the altimeter-derived TEC with the GPS-derived JPL GIM model • The availability of retrievals from the **Low Resolution Numerical Retracker** that better accounts from instrument drifts
PB F08 upgrade	• All LR NR SWH measurements will sustain some loss of significance because of wrong 20Hz to 1Hz compression. • Negative measurements of LR NR SWH are mapped to their absolute value. Impact on SWH estimates and all geophysical variables derived from them

See presentation from *F. Bignalet-Cazelet et al.on Improvements of S6 MF performanc over ocean thanks to F08 LR numerical retracker*

Timeline from OSTST 2022 to OSTST 2023



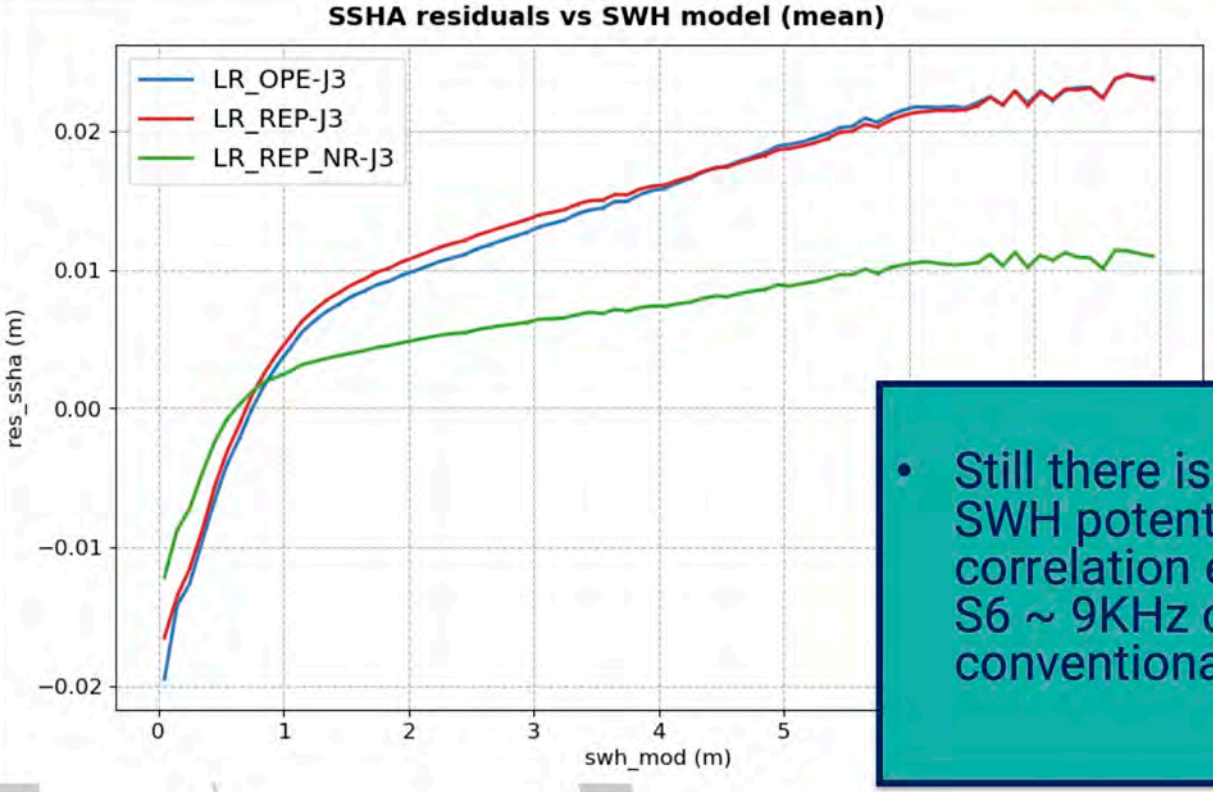
Performance Assessment vs Requirements - LR

LR Requirement	Status
[SRD] R-S-00270 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.*	**Altimeter NTC LR range noise** ([1.2, 1.5, 2.4, 3.2] cm at [1, 2, 5, 8] m SWH): Side-A: [1.25, 1.44, 1.93, 2.41] Side-B: [1.24, 1.45, 1.94, 2.41]

WAY FORWARD

Since 31 Oct 2023 thanks to the upgrade in PB F08 this requirement can be re-assed soon

What remains in LR → Pulse-to-pulse correlation



- Still there is a SSHA residual dependency with SWH potentially attributed to pulse-to-pulse correlation effects induced by the higher PRF of S6 ~ 9KHz compared to predecessor conventional altimeters ~ 2KHz.

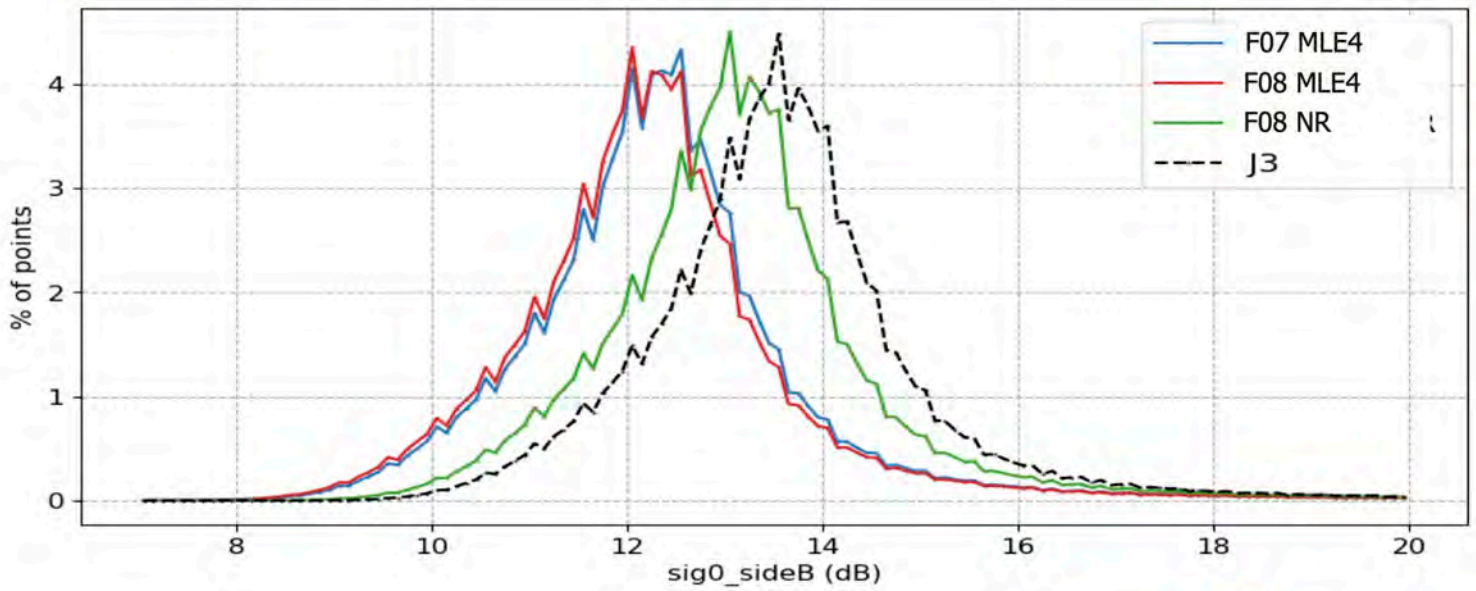
- To mitigate this effect MPWG is proposing specific science activities in the context of S6 MF Tandem Phase with S6B

LR NR Sig0 biases → to be improved in next reprocessing

- LR NR sig0 closer to J3, still some diff.

Sigma0 in Ku band for S6A side B

	nbr	min	mean	med	max	std
LR_OPE	27798524	7	12.39	nan	23.79	1.581
LR_REP	27803387	7	12.3	nan	23.73	1.579
LR_REP_NR	27878996	7	13.19	nan	24.6	1.604
J3	41026002	7.15	13.64	nan	25.01	1.613



- The source of the remaining difference is mostly attributed to the wrong computation of calibration total power. The formula is now corrected and the correction will be available in PB F09

Performance Assessment vs Requirements – HR (I)

HR Requirement	Status
[SRD] R-S-00690 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.*	**Altimeter NTC HR range noise** ([0.7, 0.8, 1.3, 2.0] cm at [1, 2, 5, 8] m SWH): Side-A: [0.62, 0.75, 1.46, 2.42] Side-B: [0.61, 0.77, 1.45, 2.41]
WAY FORWARD	
We need a new PB including HR upgrades to re assess this requirement	

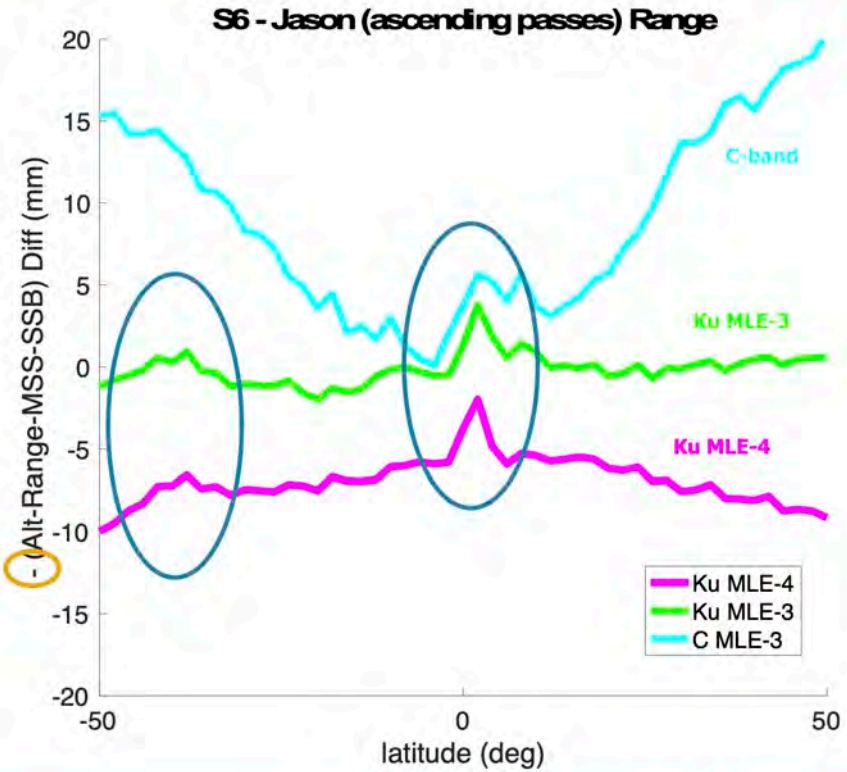
Performance Assessment vs Requirements – HR (II)

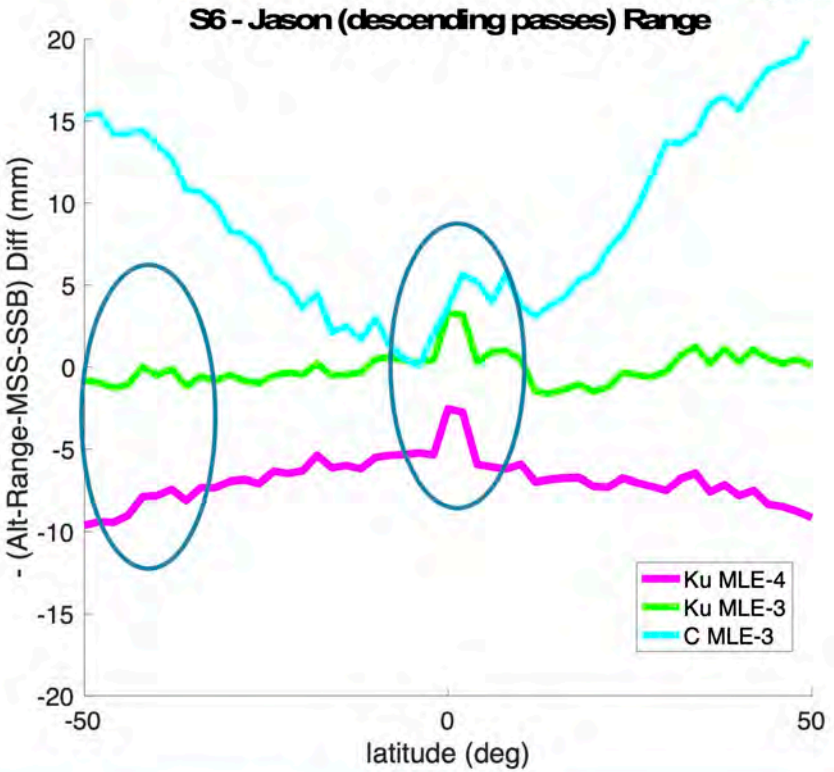
HR Requirement	Status
[SRD] R-S-00760 For high-resolution ALT-NTC products, the uncertainty of 1-second along-track averaged high-resolution measurements of significant wave height in the range 0.5 to 8 m shall be less than 15 cm plus 5% of significant wave height. *Note: This is based on the combination of noise and systematic error.* *Note: A goal is 10 cm plus 5% of significant wave height.*	**Altimeter NTC HR uncertainty** Not met yet

WAY FORWARD

We need a new PB including HR upgrades to re assess this requirement

S6 – J3 Range differences vs Latitude [under investigation]



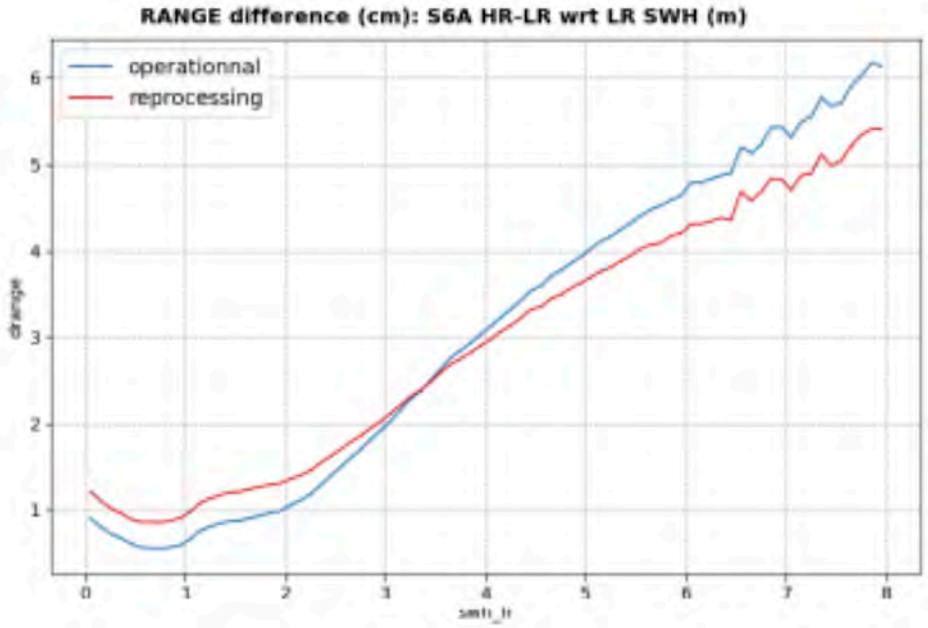


Range for Ku MLE-4 presents significant V-shape discrepancy
Range for C presents large V-shape discrepancy
For all, bump at the equator is present → this has been attributed to Jason-3
Ku MLE-4 and MLE-3 present slight differences around lat = -40 deg (~1mm)

J. D. Desjonqueres , OSTST 2022 – OSTST 2023

Range for HR compared to LR

- We still observe a dependency of S6 LR-HR as a function of SWH → this was diminished by means of reducing the number of Doppler beams in the Stack (PB F06 used for reprocessing #1), but
- Still there is a residual dependency



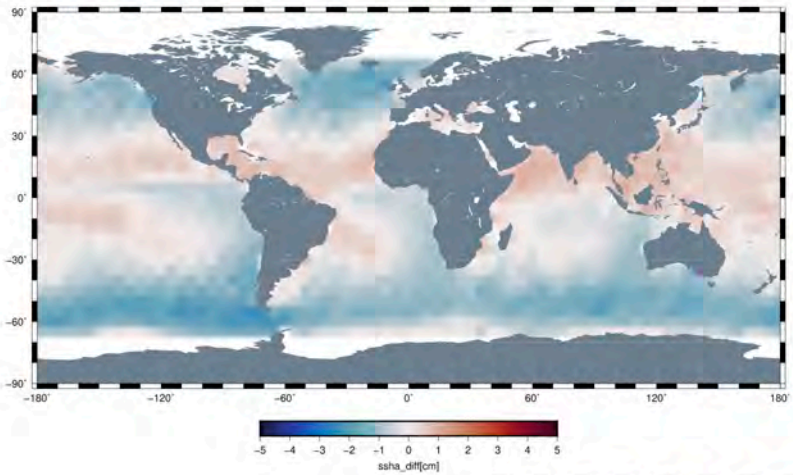
WHY?

- Skewness, range walk in HR, or meridional winds or all combined?

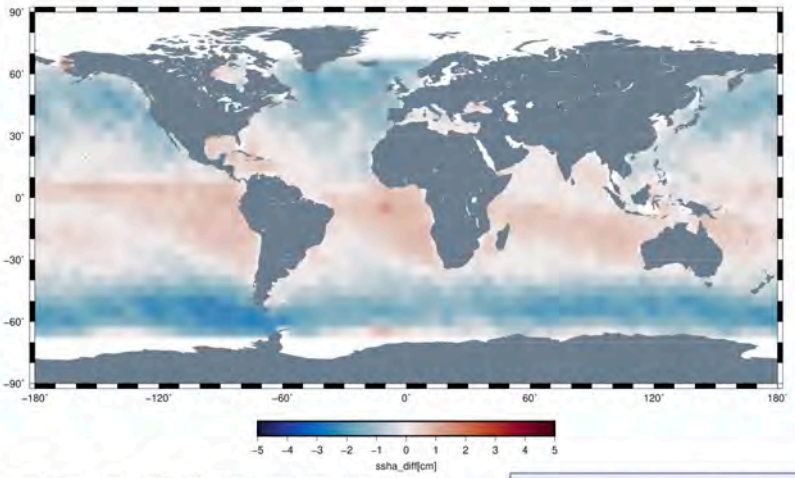
- *An effective/fast solution for range walk is available thanks to the CZT Transform (Dinardo et al., 2023)*
- *Skewness could be introduced if HR NR was implemented.*
- *Unfortunately there is no solution for meridional winds effect yet*

SSHA (HR – LR) Asc – Des Orbit differences

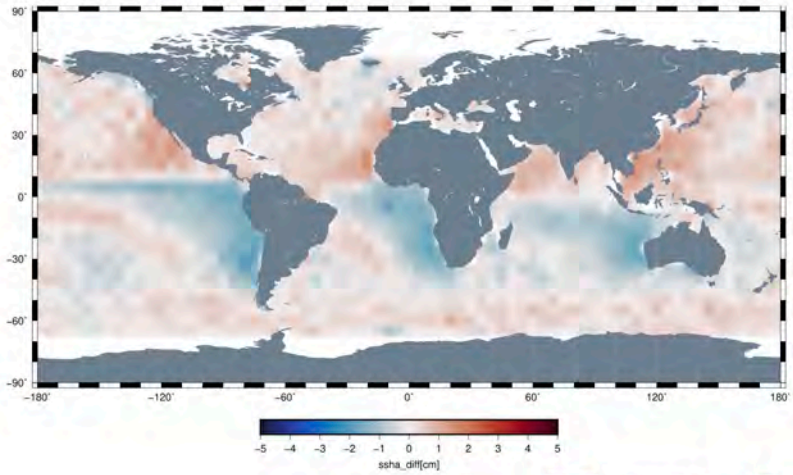
HR - LR SSHA difference - Ascending



HR - LR SSHA difference - Descending



HR - LR SSHA difference – Ascending - Descending



Geographical distribution of SSHA biases between asc. and des. orbits for HR data are correlated with **meridional winds patterns**.

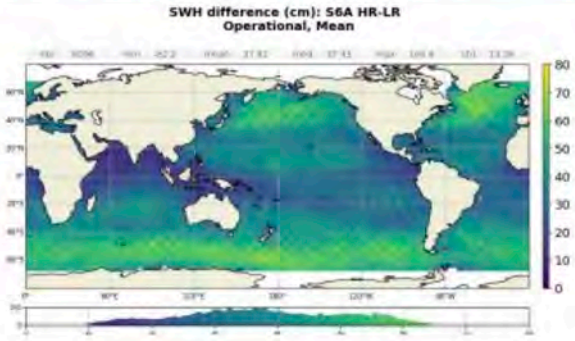
- There is a solution available to resolve this effect'
- The solution is available in the S6 L2 PGS v5A soon to be released thanks to NOAA – EUMETSAT collaboration.

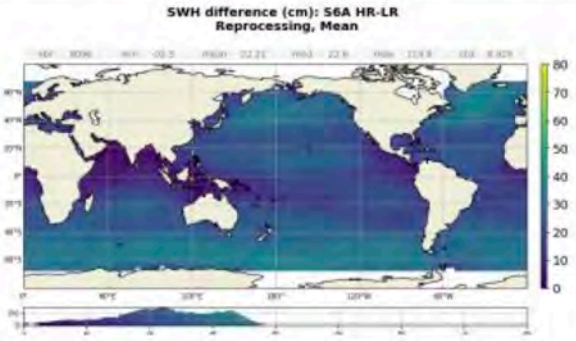
A. Egido et al., OSTST 2022

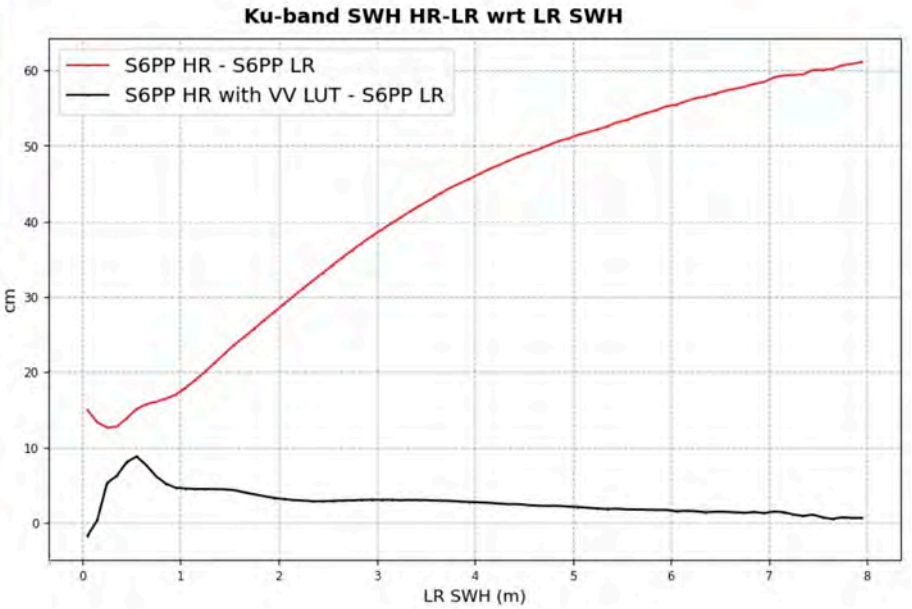
SWH LR vs HR only S6

- The difference between SWH was considerably reduced after F06
- Remaining differences are understood and linked to range walk and Vertical Velocity Motion (VVM)

- There is a solution for Range Walk thanks to CZT transform
- There is a solution for VVM correction

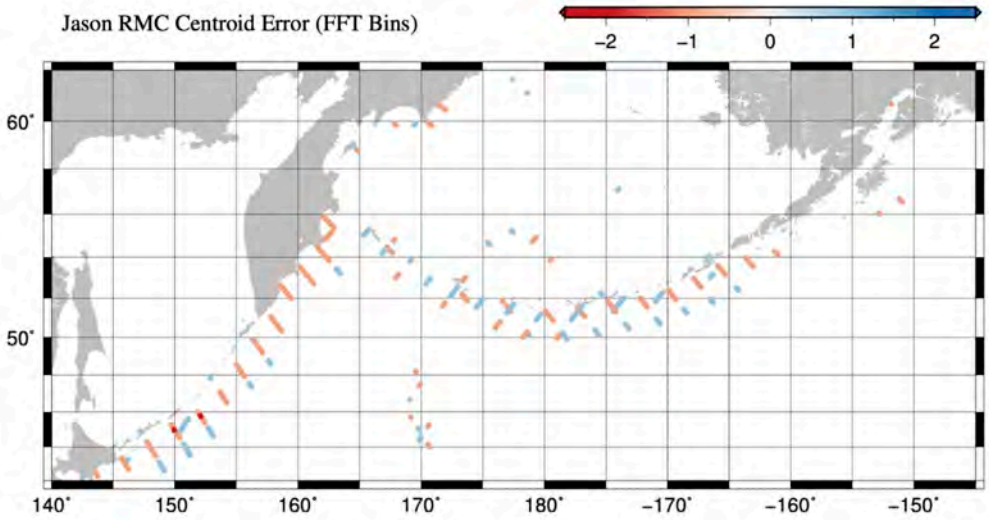


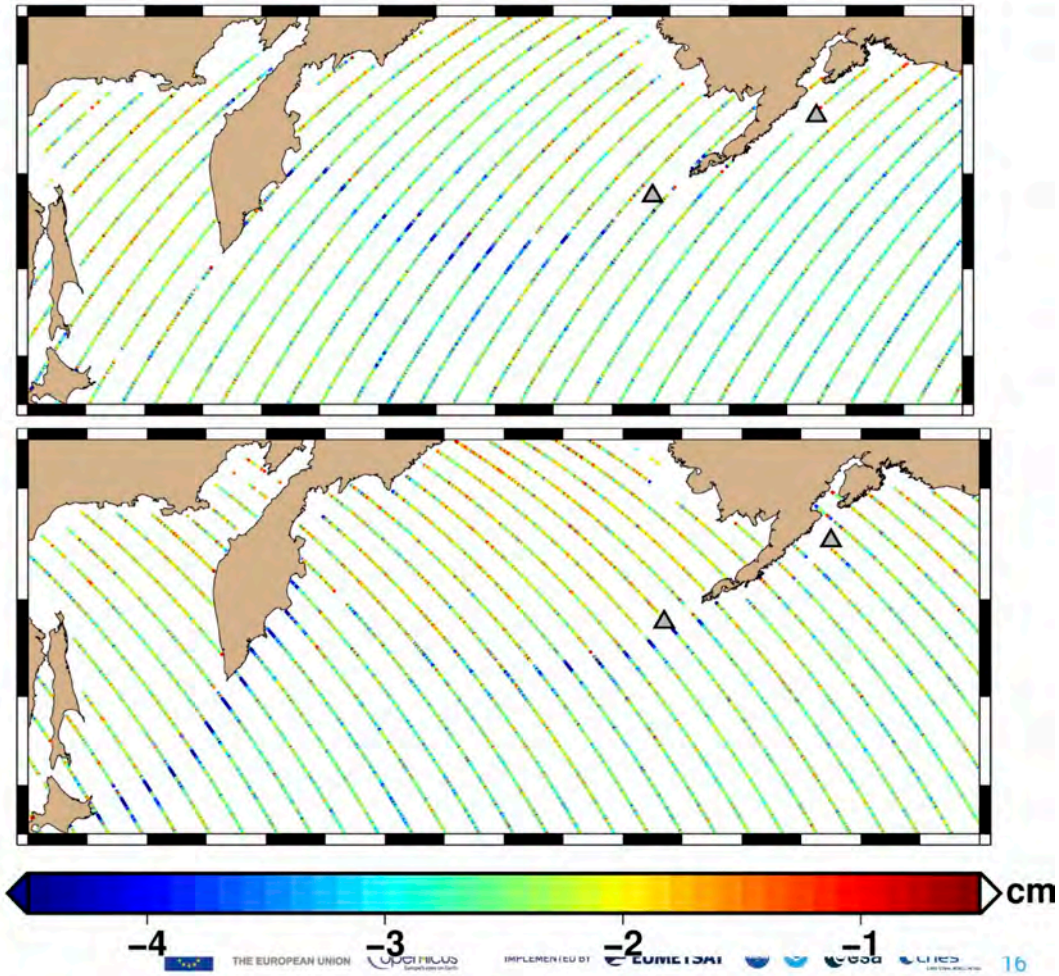




Sentinel-6MF HR – Jason-3 intermission bias: slope dependence

North Pacific Trenches and Seamounts





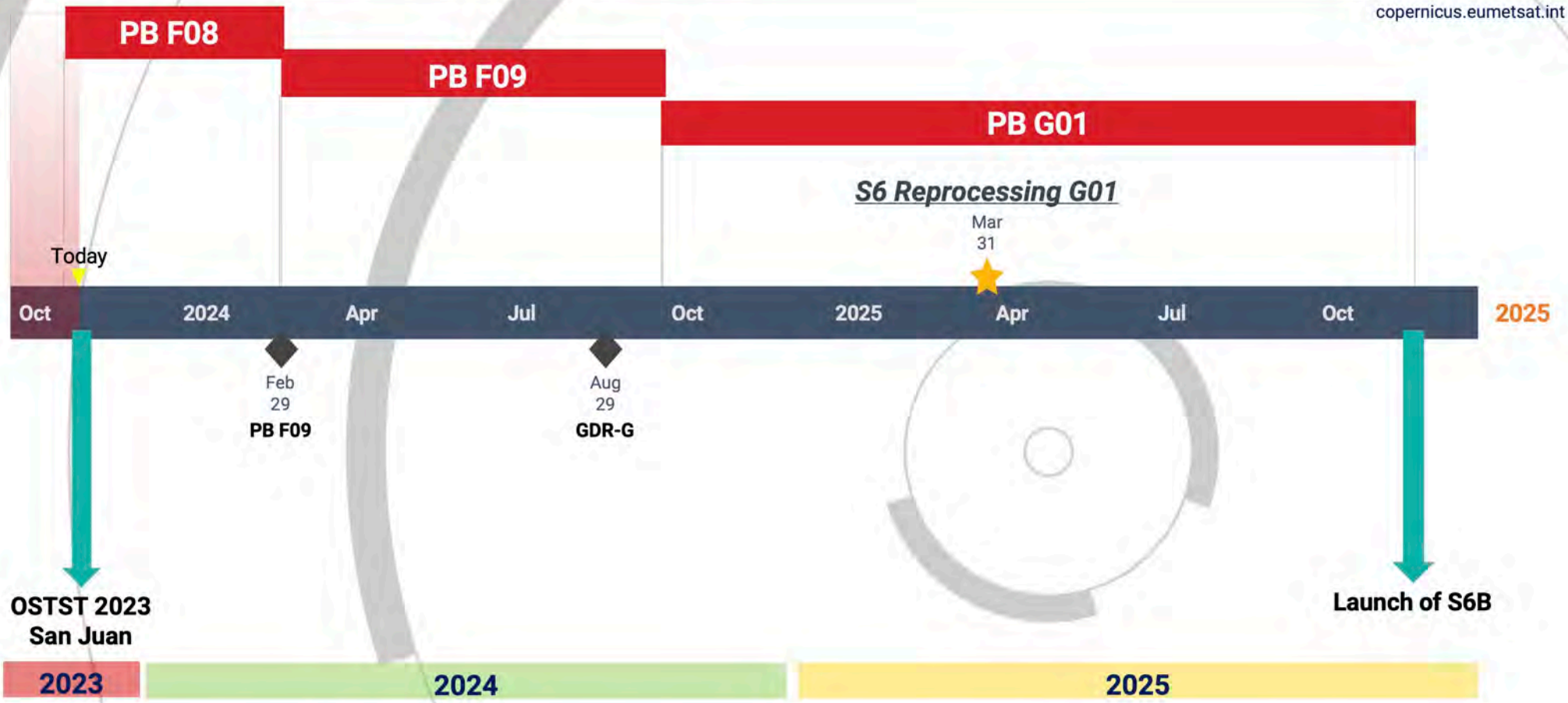
1-2 cm bias over areas over trenches

Courtesy of E. Leuliette, OSTST 2022

PB evolutions from OSTST 2023 to S6B launch

PB	Evolution
PB F09	1. Numerical Re-tracking in ALT L2 HR processing 2. Range Walk in ALT L1 Processing 3. Improvement of SWH estimates cancelling vertical wave motion effect in ALT L2 HR, and addition of wave parameters f(rom Meteo-France) in the L2 products 4. Addition of HRMR data into L2 products 5. Addition of rain_flag_nr and rain_attenuation_nr in L2 products 6. Use of variable range_cor_att_cal_delay in L2 processing 7. L1A Chunking size changed as recommended by NOAA team 8. Sig0 biases understood and corrections applied
G01	• Working towards multi-mission standards

Tentative PDP evolutions timeline



After the S6B launch the S6 PDP will be freeze for the whole commissioning. NO EVOLUTIONS till 2027.

Conclusions

- S6 MF data quality is showing high quality, and ensures continuity with Jason-3.
- Altimetry products are within requirements with a few marginal exceptions.
- Evolutions and studies are defined and planned to reassess marginal non-compliant requirements.
- Multi-mission standards are under discussion and Agencies are working hard to implement them before the launch of S6B.
- The S6 PDP will be frozen one year before launch until end of commissioning. During this time period no evolutions can be implemented, only bugs/anomalies.

Thank you!

Questions are welcome.

For questions or findings please contact us at:
ops@eumetsat.int

Now more on preparatory activities for S6B Mode Mask

Introduction

DISCLAIMER

- The Mission Performance Working Group is currently preparing the recommendation for POS4 altimeter measurement modes during commissioning activities (S6 MF vs S6 B tandem) to benefit the execution of all activities described in the Calibration and Validation Implementation Plan.
- The information available in the next slides **is not final**, it is under discussion and when a final draft is ready it must be evaluated by the mission analysis team.
- We are sharing this info with the OSTST for transparency and to hear from you what boxes are of interest to the science community to work on Sentinel-6 research.
- During tandem S6 MF will be operated as now. No changes on S6 MF mask are possible. Boxes to operate S6B in different measurement modes are under discussion to allow for cal/val and scientific work.
- After tandem S6 B will be operated as S6 MF. RMC all over the Globe.
- Each slide includes the scientific justification for the definition of the box

Poseidon-4 operates in interleave mode, but it handles several science measurement modes that basically define the data that is downlinked:

- **LRM_CL** interleaved chronogram in Closed Loop tracking mode with only LR data.
- **LX_CL** interleaved chronogram in Closed Loop tracking mode with LR + HR RAW.
- **LRMC_CL** interleaved chronogram in Closed Loop tracking mode with LR + HR RMC data.
- **LX2_CL** interleaved chronogram in Closed Loop tracking mode with LR + HR RAW + HR RMC data.
- The previous repeats for all except for LX2 with the Open Loop tracking mode, and thus Poseidon-4 includes the next three additional modes: **LRM_OL, LX_OL and LRMC_OL.**

Tandem Phase MPWG Recommendation

Tandem phase duration

- In order to minimize the errors on the intermission biases that are fundamental to the stability of the long-term sea level record derived by the satellite reference altimeter mission, the MPWG recommends that during commissioning Sentinel-6B should execute a tandem phase with S6MF of at least 12 complete cycles during nominal operations for each redundant side of POSEIDON 4.

- Therefore the total duration should be: max 1 month drift (including SatIOV activities during the drift) + 12 cycles side A (~4 months) + 12 cycles side B (~4 months) + overhead (2 cycles of potential overhead due to needed special operations activities ~ 1 additional month) = total of 10 months commissioning.

Pulse-to-Pulse Correlation effects

- It has been observed by MPWG during Sentinel-6A Cal/Val analysis that Pulse-to-pulse correlation effects is still present in the PDAP and S6PP for LR due to the much higher pulse repetition frequency implemented in this mission.

- **What is recommended:**
  - Implement the summation on-board at 2 KHz in LRM (OL or CL) for one cycle to be compared to the nominal configuration at 9 KHz of the reference mission during tandem phase.
  - This cycle should not be part of the cross calibration between each side of the POS4 of Sentinel-6B with the reference mission.
  - To be implemented upon the satellite reaches the reference orbit.

- **Challenges:**
  - RDB patch needed to allow for this functionality.
  - this activity shall be carefully planned in the commissioning timeline to avoid any potential issues at system and/or satellite level.
  - The scientific challenge is to derive a P2P LUT for users, based on numerical retracking to allow the mitigation of P2P effect (after reprocessing).

C-Band Degraded Performance

- During Sentinel-6A Cal/Val phase, MPWG has observed a degraded performance of the C-Band retrievals, with different impacts depending on latitude in particular affecting the ionospheric correction.
- No violation of requirements has been observed, but only a discrepancy w.r.t. previous missions such as Jason-3.

- **What is recommended:**
  - RAW acquisition box which covers open ocean and extends from -60 to +60 deg latitudes, in order to analyse the C-Band performance over different ionospheric conditions; Or few passes with full lat coverage in LX allowing for RAW data.
  - In case of a box, the width of the box (i.e. longitude wise) can be opportunely tuned based on the system availability.
- **Challenges:**
  - The major operational challenge in analyzing the C-Band degraded performance is the sizing of the RAW acquisition box based on the available system margin.
  - The scientific challenge is the use of the complex echoes in L1A to properly characterize the C-Band degradation and find a way to improve the C-Band processing (i.e. evolution of L1 PGF) and ionospheric correction retrievals.
  - Already known evolution: add in the L1A products the C-band complex echoes when available, and C band NR.
- **Discussion:**
  - Atlantic or Pacific ocean? Minimum Box Extension in Longitude?

Swell and Slope

- The user community observed that the presence of swell lowers the quality of the geophysical parameters which can be retrieved from the delay/Doppler radar altimeter data.
- RAW mode is showing potential to see waves better than RMC, resulting on increasing ground resolution in the range direction with increasing incident angle.

- **What is recommended:**
  - Small boxes in collocated areas with side-looking SAR imagers (Sentinel-1A / 1C) and SWOT, dominated by swells, such as Pacific. Size of the boxes in the order of 100-200km along-track.
  - Hawaiian Islands (NDBC-NOAA buoys, all simultaneously active).
  - Madeira Island is a very interesting case study with no across track ambiguity. Recommendation to acquire one small RAW box in this region so that we can investigate the RAW (almost) unambiguous spectra for the first time.
- **Challenges:**
  - The major operational challenge is the data volume derived from the sizing of the different boxes defined.
  - Potentially better understanding of the SAR altimeter responses by comparing with another SAR system, identify crossovers with a variety in directionality of swell waves and estimate the swell direction exploiting the phase shifts analyzing the tandem phase data.
  - This would maybe allow improving algorithms at either Level-1 or Level-2, in turn producing higher quality altimeter products.
  - Swell Wave Spectra from fully-focused SAR (FFSAR) altimetry processed data, and demonstrate that SAR altimetry can serve as a source for swell monitoring.
- **Discussion:**
  - Precise Box extension/location needed. Need to check against System availability.

Polar Ocean and Sea Ice

- RAW acquisition would be precious to support R&D activities, such as leads detection, AMR-C performance over sea ice, etc. This work would strongly benefit future altimeter missions as the CRISTAL mission.
- In addition, FFSAR over sea ice retrievals reveals high potential and could be better exploited during Sentinel-6B commissioning.

- **What is recommended:**
  - For this application, the RAW boxes defined during the Sentinel-6A commissioning phase can be reused:
    - BOX 3N: a box covering the Arctic Ocean (sea ice – depending on the season, the marginal ice zone between a 55S and 66S latitude band), choosing the cycle to observe different types of sea ice.
    - BOX 3S: a box covering the Antarctic Ocean (sea ice – depending on the season, the marginal ice zone between a 55S and 66S latitude band), choosing the cycle to observe different types of sea ice.
- **Challenges:**
  - The major operational challenge is the sizing of the RAW acquisition boxes based on the available system margin.
  - The required RAW boxes shall be activated for one cycle based on season to observe different type of sea ice and improve the leads detection algorithm eventually exploiting the FFSAR capability.
- **Discussion:**
  - Confirm that we can reuse S6A boxes. If not, define updated boxes to be checked against system margins.

Inland Waters

- Inland waters applications can be also exploited during Sentinel-6B commissioning phase, by analysis of targeted RAW acquisitions and analyze the properties of the backscattering in different conditions such as summer/winter, impacts of the snow etc. In addition, FFSAR can be exploited.

- **What is recommended:**
  - For this application, the RAW boxes defined during the Sentinel-6A commissioning phase can be reused:
    - BOX 4: a box covering the West of Europe for the inland water analysis, choosing the cycle to observe different types of continental inland water conditions (summer / winter, impact of the snow, ...).
- **Challenges:**
  - The major operational challenge is the sizing of the RAW acquisition boxes based on the available system margin.
  - This R&D study will benefit from the new OLTC tables (V1.3) uploaded on board in May 2023 allowing for better monitoring of waters targets.
  - In order to enhance the retrievals over the inland waters areas, FFSAR is particularly suited (enhanced along track resolution). FFSAR can be also used to map lake extents.
- **Discussion:**
  - Better understand why RAW is needed and this can not be done with RMC.
  - Confirm if S6A box can be reused. If not, define updated boxes to be checked against system margins.

Waves: extreme events and synergy with other sensors

- Satellite altimetry is suitable in observing waves over ocean and extreme events such as cyclones or extreme wave conditions.
- Targeted RAW acquisition can be exploited to understand the effects of such extreme events on altimetry retrievals.

- **What is recommended:**
  - Extreme waves:
    - Mediterranean Sea (Gulf of Lion) and the Bay of Biscay.
    - Extension of South Africa box: 40°S and 45°E.
    - Mask extension East of Australia, region of wave-current interactions.
  - Internal waves:
    - Boxes in well-known internal wave regions: synergy with SWOT will allow better characterization of internal waves and better understanding of their impact in the LR/SAR retracking.
    - Andaman Sea (Bay of Bengal), Sulu and Banda Seas, Mascarene Plateau.
  - Tropical cyclones:
    - Pick areas with varying swell systems (wavelengths, directions, SWH) to collect as much data as possible for analysis.
- **Challenges:**
  - The major operational challenge is the sizing of the RAW acquisition boxes based on the available system margin.
  - This R&D activity will address the effects of the extreme events on altimetry measurements
  - Demonstrate the capability to monitor extreme events as consequences of climate change.
- **Discussion:**
  - Precise Box extension/location needed. Need to check against System availability.

Open Ocean and Coastal Regions

- For open ocean and coastal areas we will reuse the same mask as for Sentinel-6 MF?, such as:
  - **Open Ocean:** RMC mode.
  - **Coastal:** LX mode, BOX 5 (including larger lakes)
    - BUT, It has been demonstrated that RMC performance over coastal areas are excellent with negligible differences vs RAW.
    - Thus, why would we favor RAW to RMC? At the detriment of previous slides?