Summary of the S6VT Outcomes

Sentinel-6 Project Scientists
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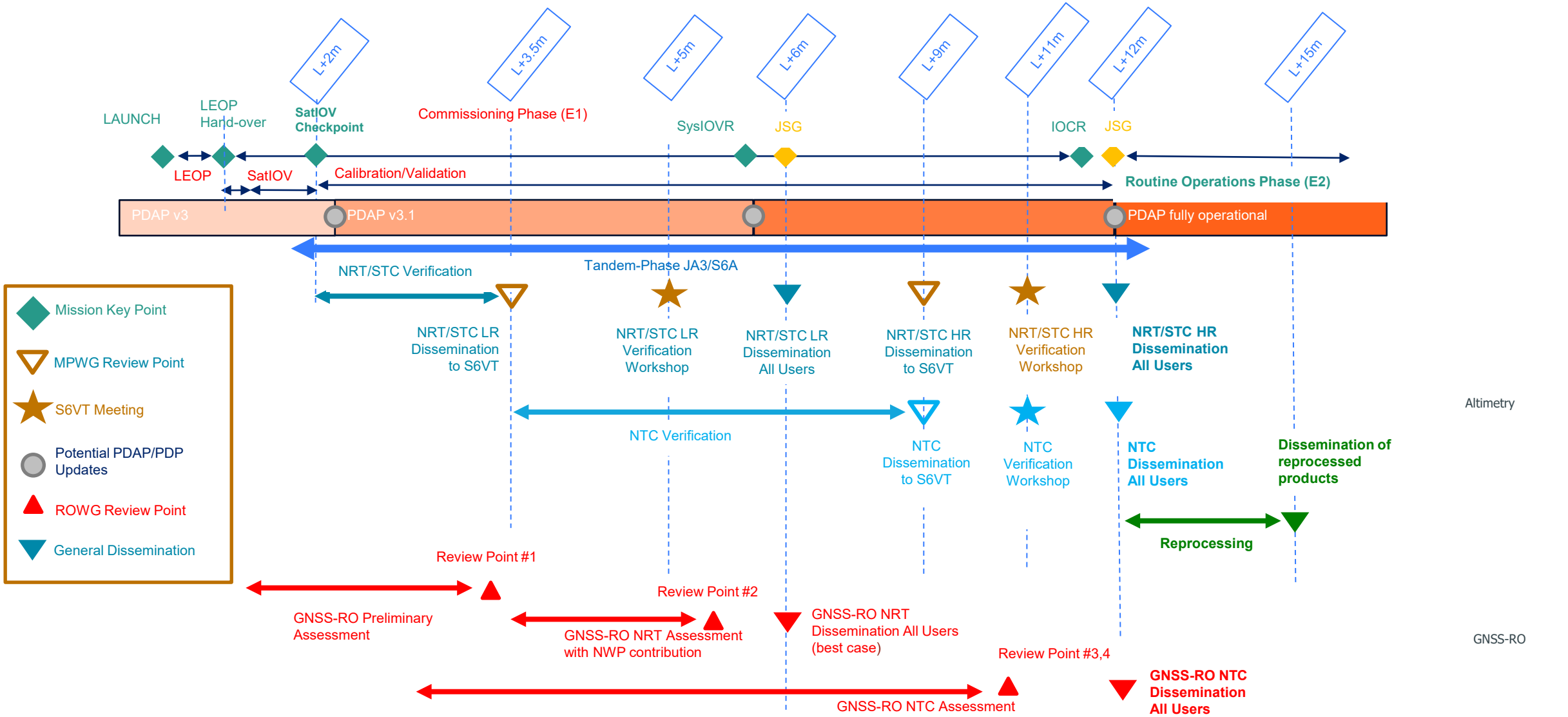
OSTST Meeting – 21 March 2022

Planning From Launch to Now



Altimetry and Radiometry Products Baseline

Product	Latency	Format	Distributed since June	Distributed since Nov	Expected 2022 Q2
ALT Low Resolution (LRM)	**NRT**	BUFR	L2 (GTS since Sep 2021)		
		NetCDF	L2		L2P, L3
	STC	NetCDF	L1B, L2		
	NTC	NetCDF		L1B, L2	L2P, L3
ALT High Resolution (SAR)	**NRT**	BUFR		L2	
		NetCDF		L2	L2P
	STC	NetCDF		L1A, L1B, L2	L2P, L3
	NTC	NetCDF		L1A, L1B, L2	L2P, L3
MWR	**NRT**	NetCDF	L2		
	STC	NetCDF	L2		
	NTC	NetCDF		L2	

Note: ALT Level 2 NetCDF products: reduced (1-Hz only) and standard (1-Hz and 20-Hz)

Product Validation Process

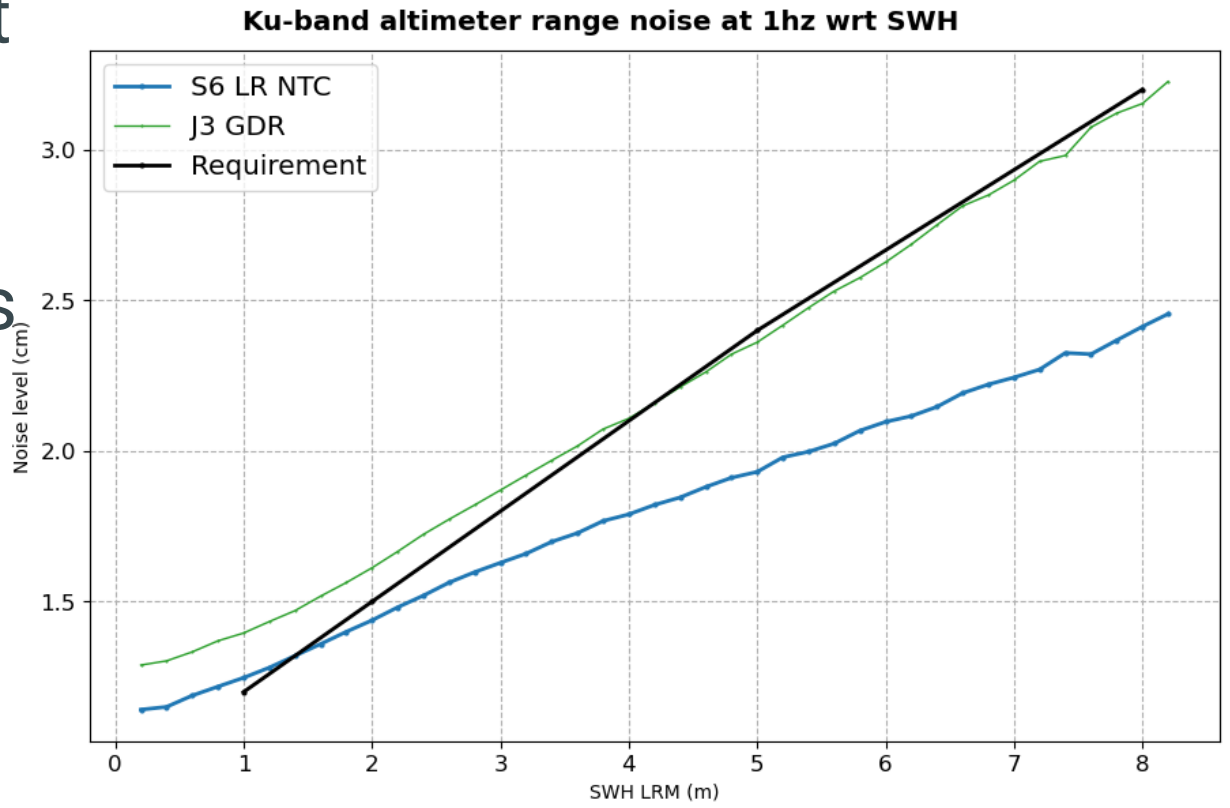
- Sentinel-6 Validation Team
  - ~100 researchers from ~40 institutes
  - S6VT Meeting #2 (May) to review ALT LR (NRT/STC) and AMR-C (NRT/STC) products
    - Already covered in SysIOV-R with updates provided during IOCR
  - S6VT Meeting #3 (Oct) to review ALT LR (NTC), ALT HR (NRT/STC/NTC) and AMR-C (NTC) products
- Mission Performance Working Group
  - EUM, ESA, NOAA, NASA/JPL, CNES. Chaired by EUM
  - Work Packages defined in the Cal/Val Implementation Plan

L2 LR Product Performances

	NRT 3 hours	STC 36 hours	NTC 60 days	Observed
Altimeter noise (Ku)	[1.2, 1.5, 2.4, 3.2] cm at [1, 2, 5, 8] m SWH			[1.25, 1.44, 1.93, 2.41] cm
Altimeter noise (C)	[4.5, 5.7, 9.1, 12.0] cm at [1, 2, 5, 8] m SWH			[4.5, 5.2, 7.9, 10.1] cm
Ionosphere	0.5 cm			0.1 cm
Sea State Bias	2.0 cm			0.6 cm (compared to JA3)
Dry troposphere	0.8 cm	0.7 cm	0.7 cm	Based on historical analysis
Wet troposphere	1.2 cm	1.2 cm	1.0 cm	0.2 cm (compared to JA3) 0.8 cm (compared to ECMWF)
Altimeter range RSS	2.93 cm	2.90 cm	2.83 cm	< 2.5 cm with bias < 1 cm
RMS Radial Orbit	5 cm	2 cm	1.5 cm	NRT/STC/NTC: < 2 cm / ~1 cm / ~0.8 cm
Total RSS sea surface height	5.79 cm	3.53 cm	3.20 cm	NRT/STC/NTC: 3.3 cm / 2.8 cm / 2.5 cm
Significant wave height	15 cm + 5%			Far below 15 cm + 5%
Wind speed	1.5 m/s			0.5 m/s
Sigma naught	0.3 dB			0.18 dB

L2 LR Product Performances

- Requirement on altimeter noise
  - **Marginal** overrun of requirement at low wave height
  - Requirement (drawn from the Mission Performance Budget) is now recognised to be unnecessarily/overly restrictive
  - Noise level much lower than Jason-3 across the board



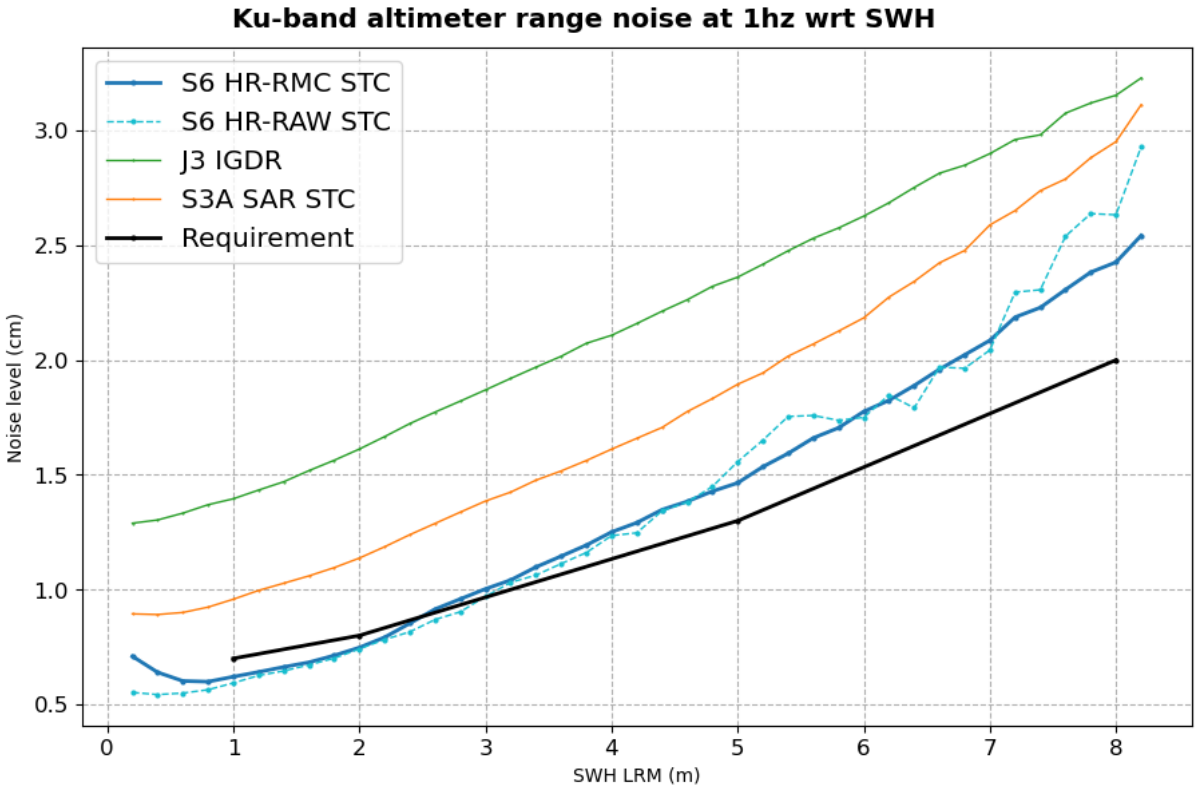
L2 HR Product Performances

	NRT 3 hours	STC 36 hours	NTC 60 days	Observed
Altimeter noise (Ku)	[0.7, 0.8, 1.3, 2.0] cm at [1, 2, 5, 8] m SWH			[0.62, 0.75, 1.46, 2.42] cm Sensitivity to swell at higher SWH
Sea State Bias	2.0 cm			< 0.5 cm
Altimeter range RSS	2.64 cm	2.61 cm	2.53 cm	Fulfilled in STC and NTC (NRT to be assessed)
Total RSS sea surface height	5.65 cm	3.29 cm	2.94 cm	NRT/STC/NTC: 3.84 cm / 2.18 cm / 2.15 cm
Significant wave height	15 cm + 5%			NOK but way forward identified (correction for vertical waves velocity to be implemented)
Wind speed	1.5 m/s			0.5 m/s
Sigma naught	0.3 dB			< 0.15 dB

- Orbit, wet and dry tropospheric corrections, as well as ionospheric correction are already covered in L2 LR table.

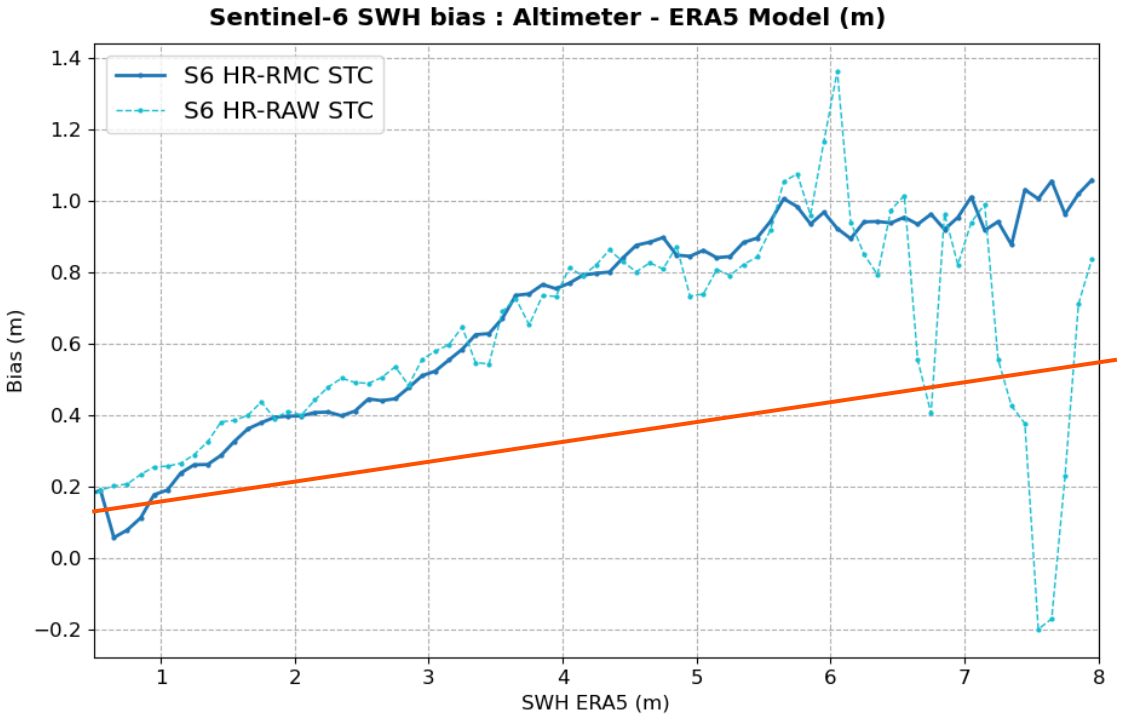
L2 HR Product Performances

- Requirement on altimeter noise
  - Overrun of requirement at higher wave heights
  - Due to larger sensitivity of HR altimetry to swell than considered when writing the requirement
  - Noise level much lower than Jason-3 and Sentinel-3 across the board



L2 HR Product Performances

- Requirement on Significant Wave Height
  - Overrun of requirement over entire range
  - Presently understood: general issue with HR altimetry, an impact of vertical wave velocity, more prominent in S6A than lower flying S3
  - For S3, issue is only now recognised to exist; similarly was not considered when specifying retrieval algorithms
  - To be fully corrected by PDAP evolution: look-up table driven by SWH and modelled mean wave period



Summary of Altimeter Performance Requirements

- ALT LR NTC
  - All requirements met (except range noise @ 1m SWH, not significant)
- ALT HR, All latencies
  - Geophysical corrections the same as LR, so not further evaluated
  - Range noise: within requirements, except @ 5, 8 m SWH, still well below S3
  - SWH: errors out of requirements at higher wave height; understood as general SAR issue not yet treated properly in algorithm; needs correction for vertical wave velocity, which in itself could become a derived variable
  - SSB: in requirement, but can be refined in the future
  - SSH: far within requirements, major improvement over JA3, particularly in NRT
  - Wind speed: within requirements
  - Sigma0: noise within requirements
  - RMC compared to RAW over ocean
    - < 2 mm in range; slight SWH dependence absorbed by SSB
    - < 1 cm in SWH; < 0.02 dB in sigma0
  - RMC compared to RAW over Amazonia: negligible differences
- Compliant on all short-terms performance requirements, except minor details for which deviations to the requirements are being prepared

AMR Product and POD Performances

- AMR-C
  - 8 mm std difference with ECMWF; 2 mm with JA3
  - Stability to within ±1 mm with ECMWF and JA3
    - Some updates to Calibration values introduced in March ‘22
  - HRMR providing good extension to coast; to be added into combined AMR/HRMR product
  - All requirements on AMR-C met

- Precise Orbit Determination
  - Radial orbit error POE: 8 mm
  - Update of POE standards introduced in March ‘22
  - All requirements on POD met

Drift and range cross-calibration

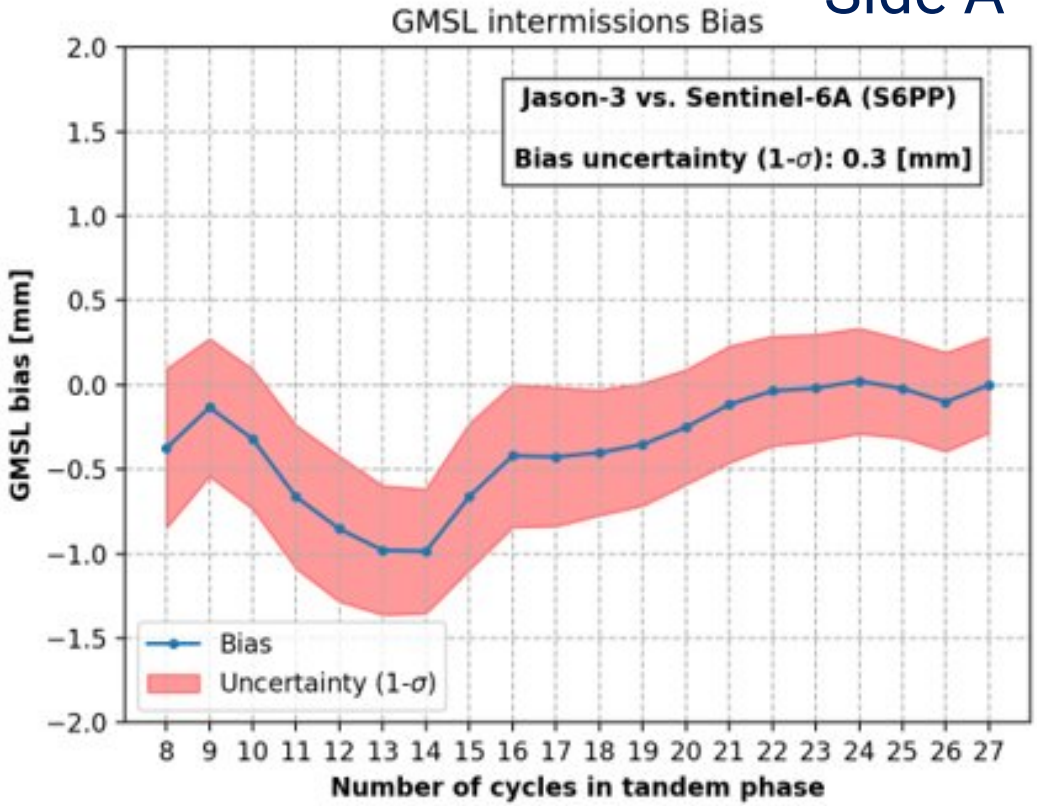
- Drift requirement (1 mm/yr) can only be properly evaluated after a minimum of 2 years
- Some points of note on stability and cross-calibration
  - Anomaly causes calibration to be used at time of processing instead of time of measurement *(fixed on 9 Nov)*
  - Use ECHO CAL to account for short-term variations in interna… delay *(approach under evaluation)*
  - HR SWH skewness to be updated (0.0… …date)
  - Range walk correction to be…
  - Account for verti… …odel and LUT)
  - Use f… …acking *(GDR-G, Q1 2023)*
    - …drift at 0.1 mm/yr level. Applies to LR and HR.
    - …be done for Jason missions as well!

"Instrument Processing: Measurement and Retacking" See Presentation on

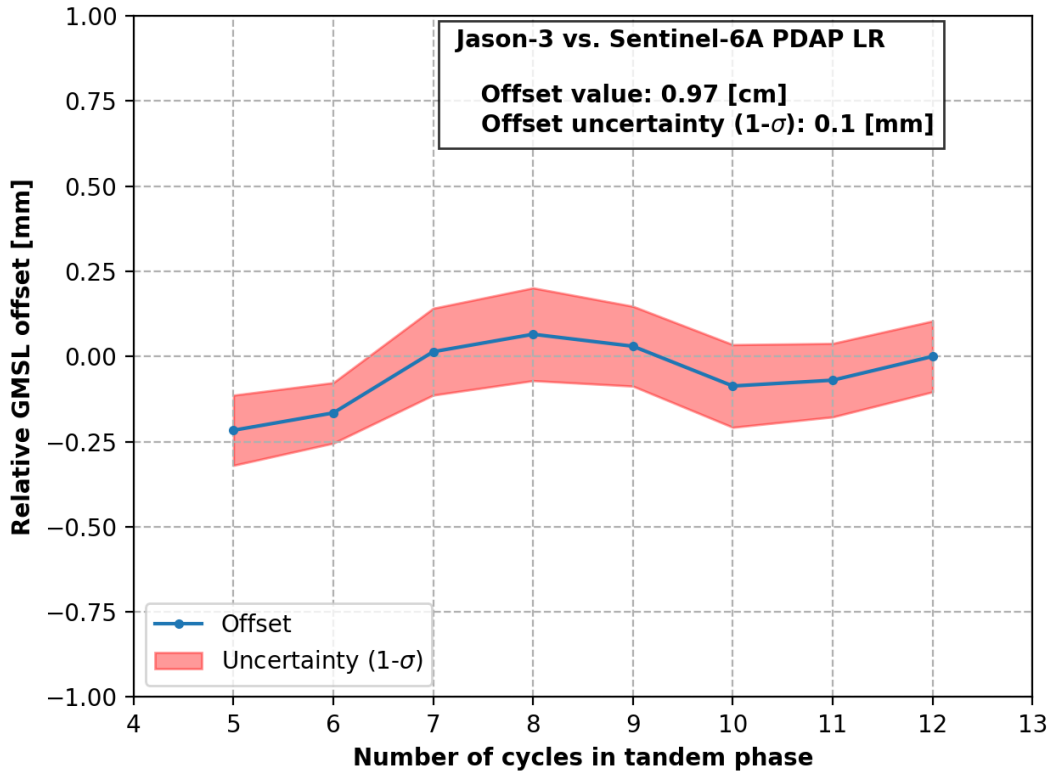
Long-term stability: Cross-calibration with Jason-3

- Experience with Side A and B shows that this can be done within requirement after 5-6 months of tandem

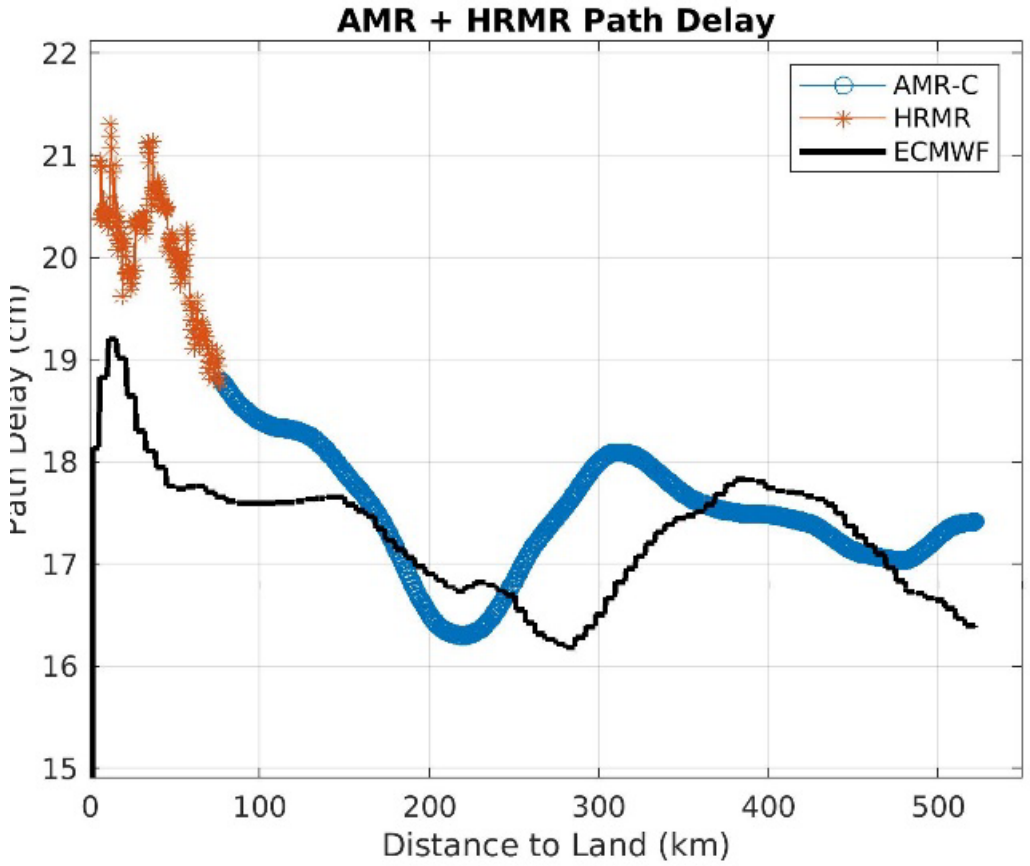
Side A



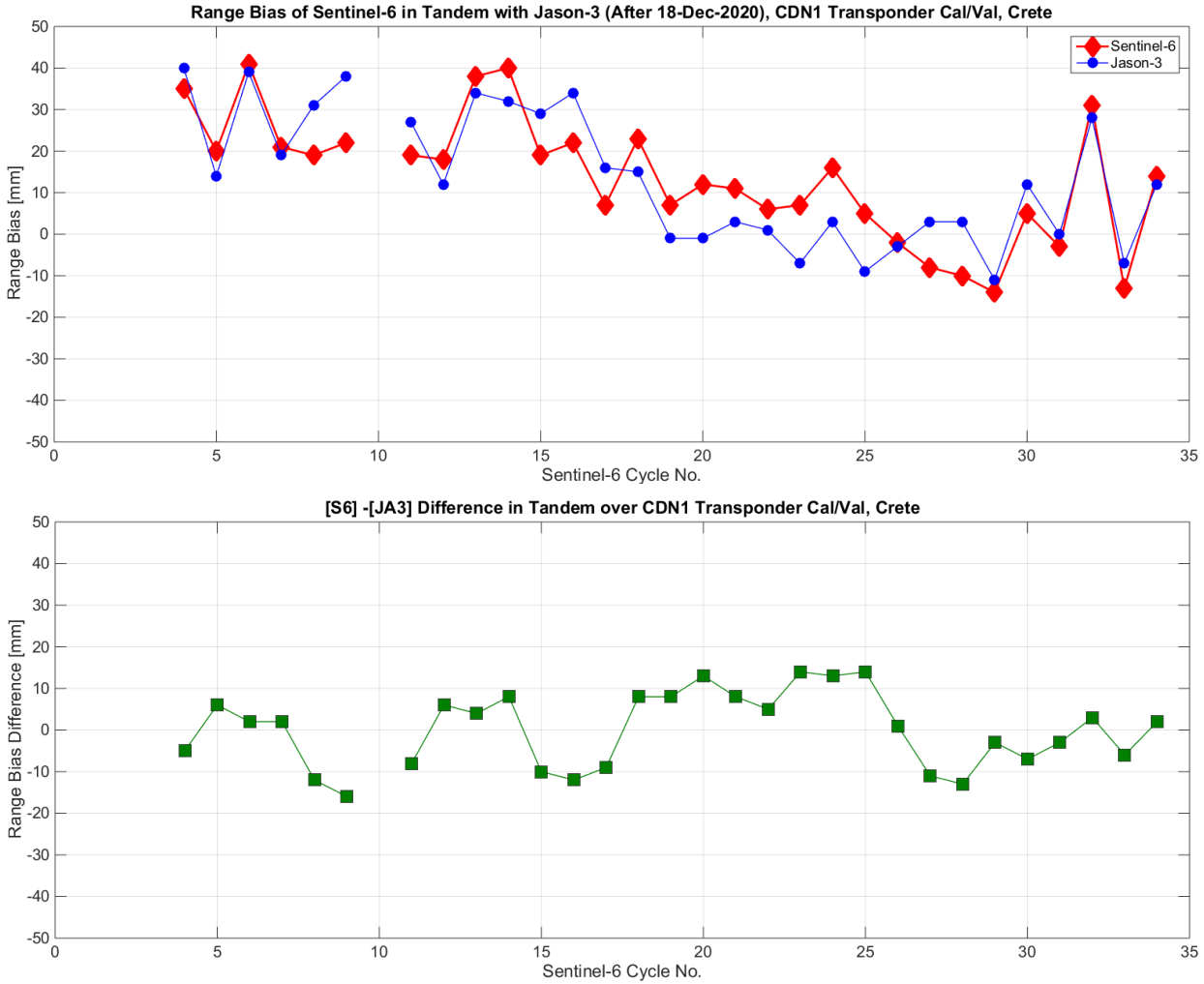
Side B



- HRMR
  - Expected to smoothly extend AMR wet path delay to the coast



- CDN1 Transponder results: robust results



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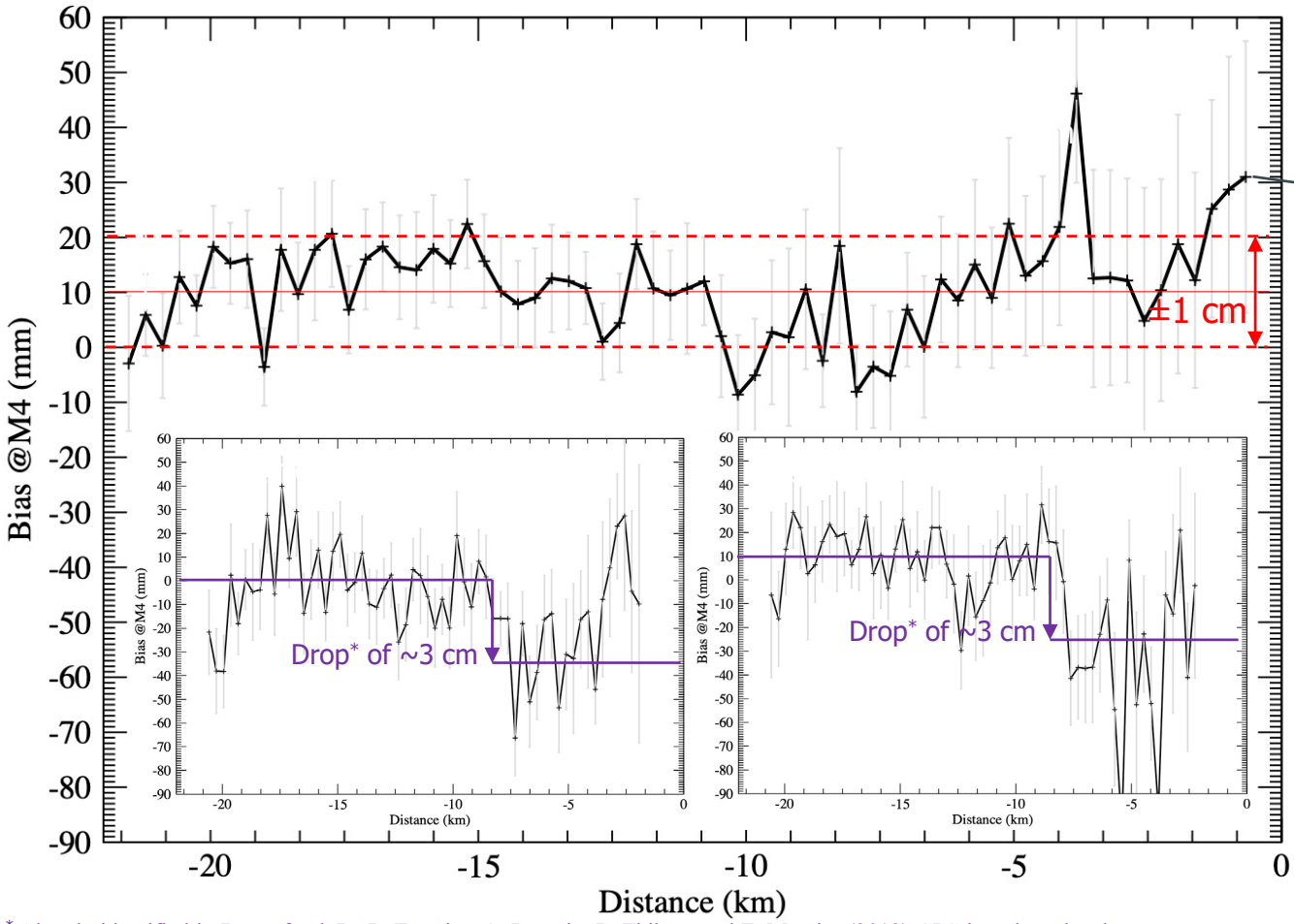
Space Geomatica P.C.

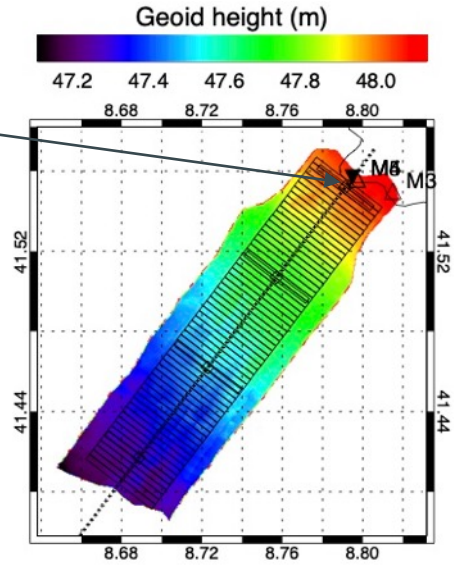
Range bias (N=30) :

- **Sentinel-6 = +14 mm ± 15 mm**
- **Jason-3 = +14 mm ± 16 mm**
- **Difference = + 0.0 mm ± 9 mm.**

- Results from Corsica facilities

Sentinel-6 MF (NTC, SAR) close look up to the coast (~300m from tide gauges)





- **Most of the averaged of 20Hz SSH biases in boxes of 316 m are within ±1 cm (standard deviation of 9.6 mm)**
- **The drop in LRM due to land contamination for distance below ~10-8 km disappears in SAR (standard deviation reduced from 20.9 mm in LRM to 9.6 mm in SAR)**
- **Comparable drop in LRM for Sentinel-6 MF and Jason-3**

Absolute SSH biases (over side A tandem phase):

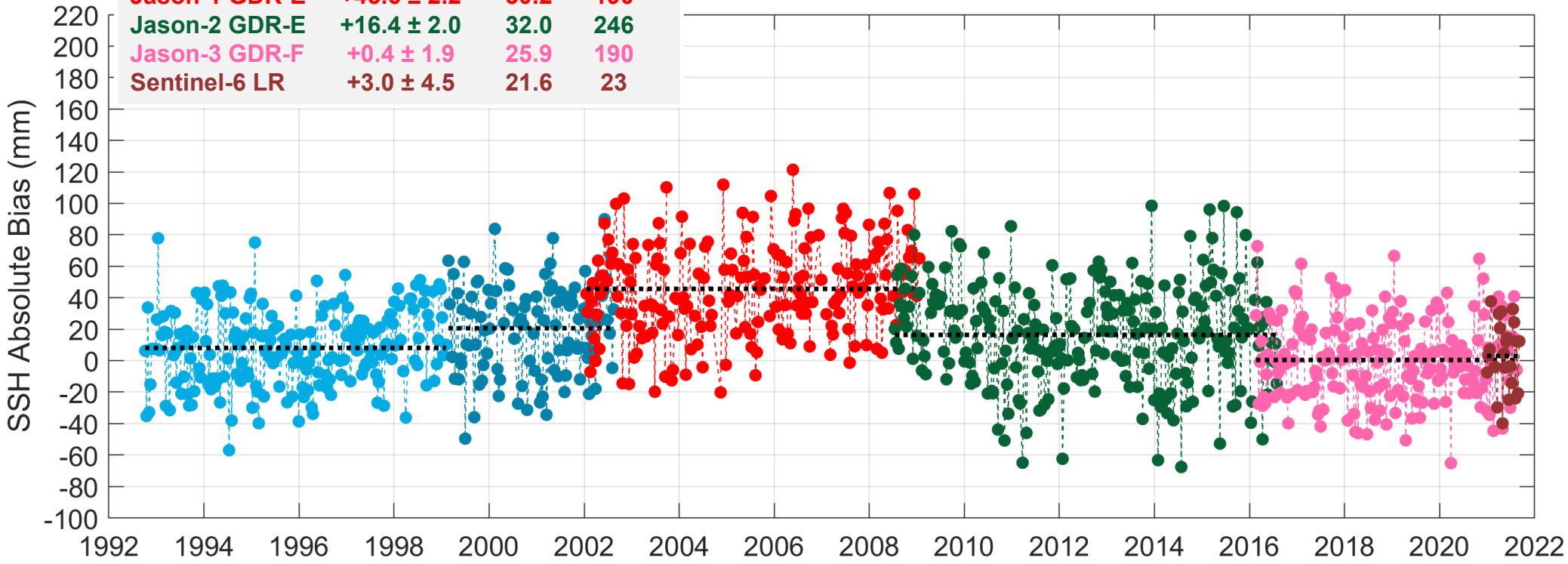
- **Jason-3 (LRM, GDR-F):** +11.2 ±7.2 mm
- **Sentinel-6 MF (LRM, NTC):** +0.5 ±4.5 mm
- **Sentinel-6 MF (SAR, NTC):** +13.5 ±6.3 mm

* Already identified in Bonnefond, P., P. Exertier, O. Laurain, P. Thibaut and F. Mercier (2013) GPS-based sea level measurements to help the characterization of land contamination in coastal areas, Advances in Space Research, 10.1016/j.asr.2012.07.007

Absolute Bias at Bass Strait: Reference Missions v TG
(S6/MF 1 Hz LR NTC, all side A)

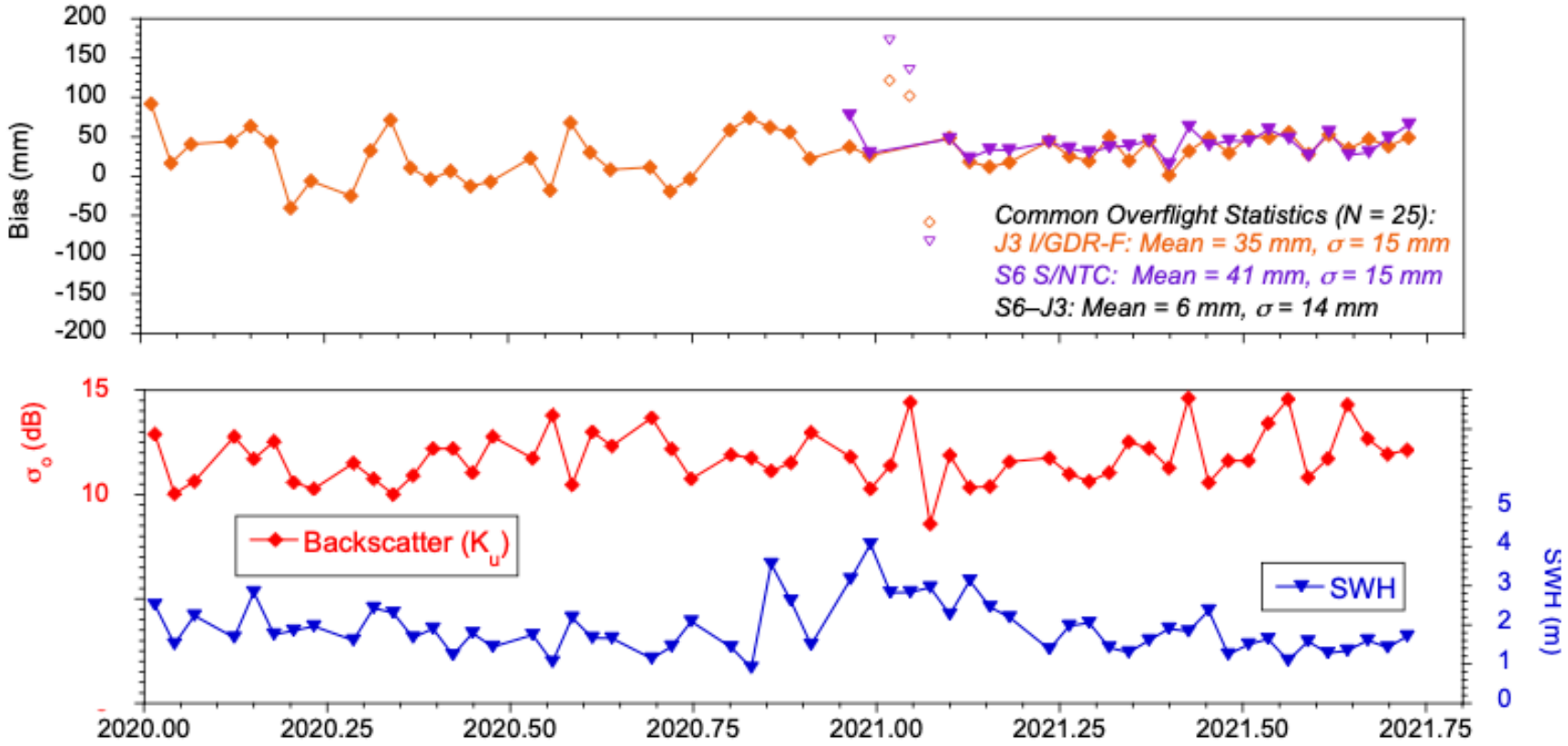
ALTIMETER	MEAN (mm)	σ	N
TOPEX-A	+8.1 ± 1.7	24.1	192
TOPEX-B	+20.6 ± 2.7	28.6	109
Jason-1 GDR-E	+45.6 ± 2.2	30.2	190
Jason-2 GDR-E	+16.4 ± 2.0	32.0	246
Jason-3 GDR-F	+0.4 ± 1.9	25.9	190
Sentinel-6 LR	+3.0 ± 4.5	21.6	23

Computed against tide gauge: expect higher variability than against mooring.



Harvest SSH Calibration Record:
Zoom on Recent Results (J3 and S6 Tandem Overflights with SWH/σ_o)

Relative SSH Bias: 6 mm (Sentinel-6 higher than Jason-3)
Relative "Orbit Minus Range" Bias: 6 mm (Sentinel-6 higher than Jason-3)



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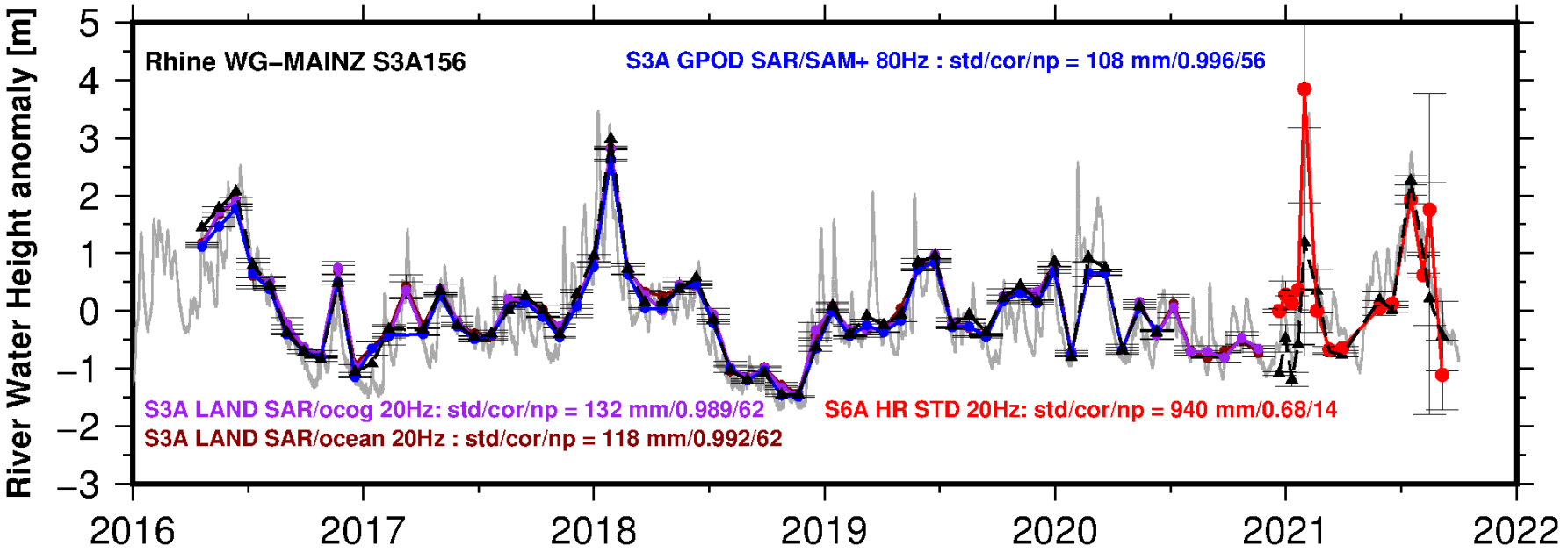
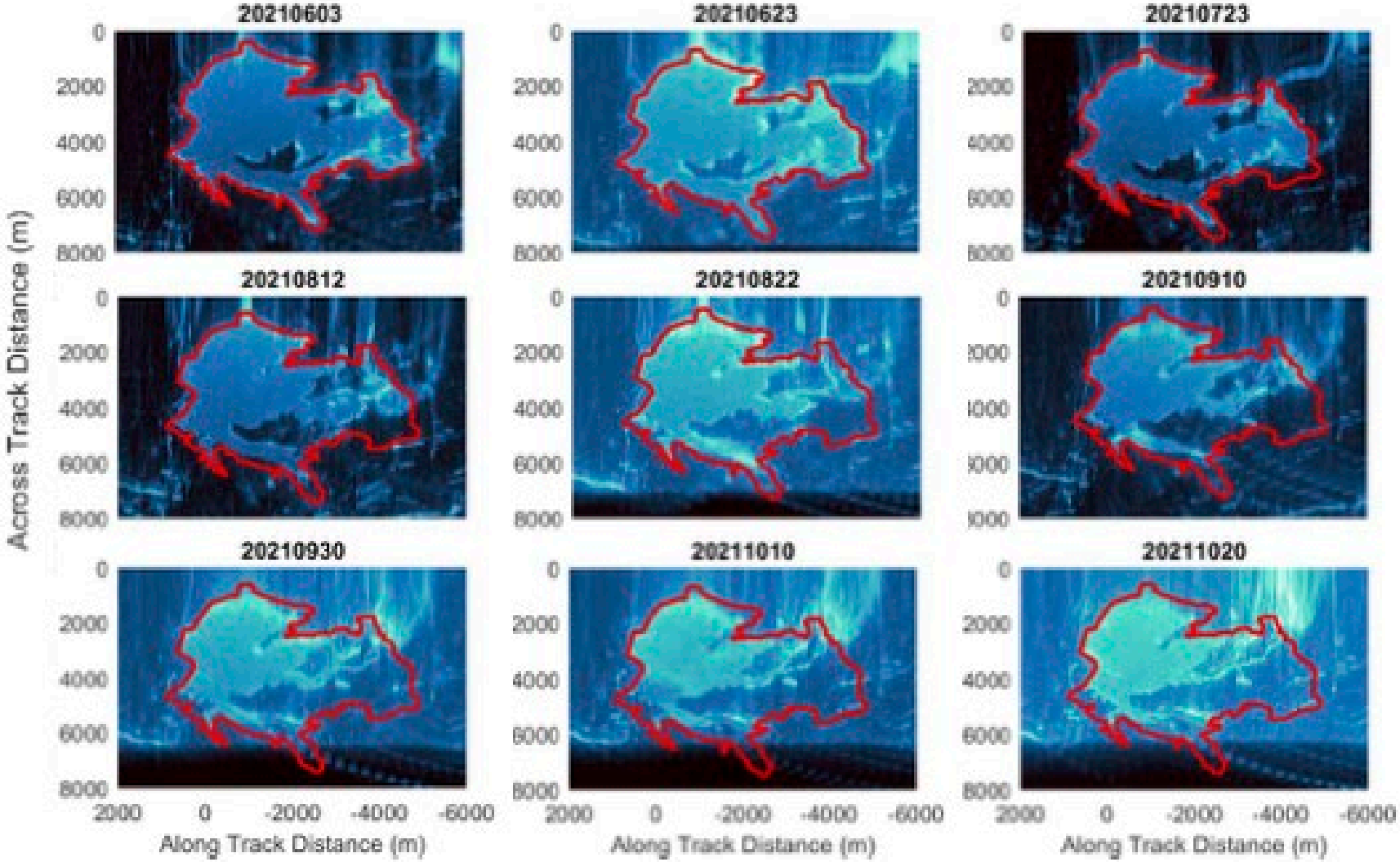
S6VT Meeting, October 27, 2021

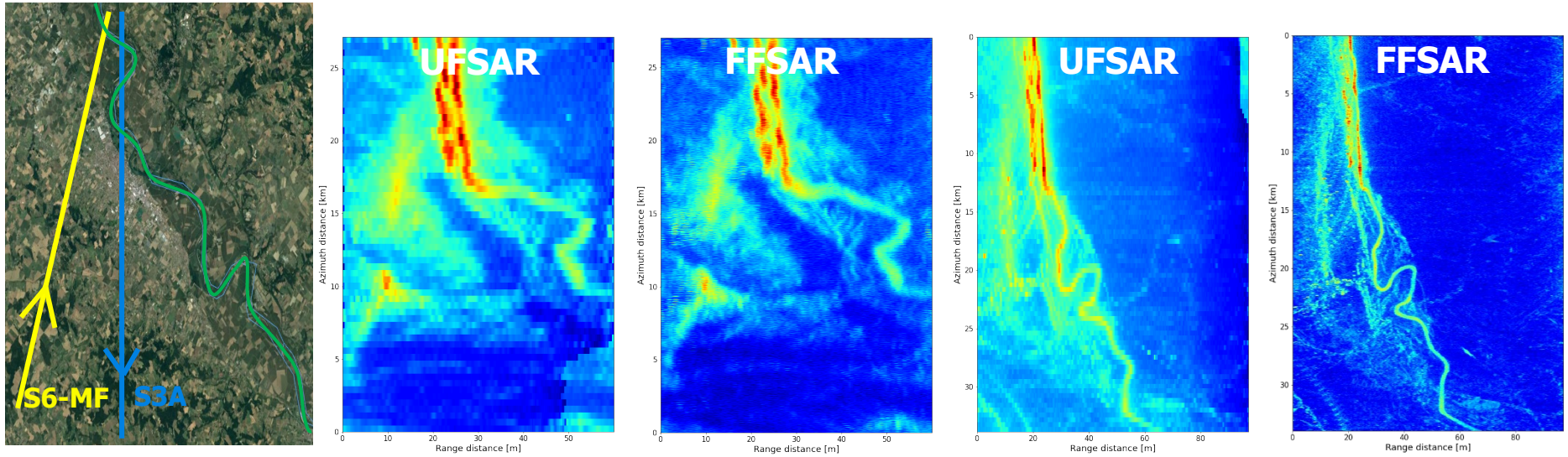
Rhine River @ Mainz: Sentinel-3A and Sentinel-6A



Mapping lake extent with S6A FFSAR

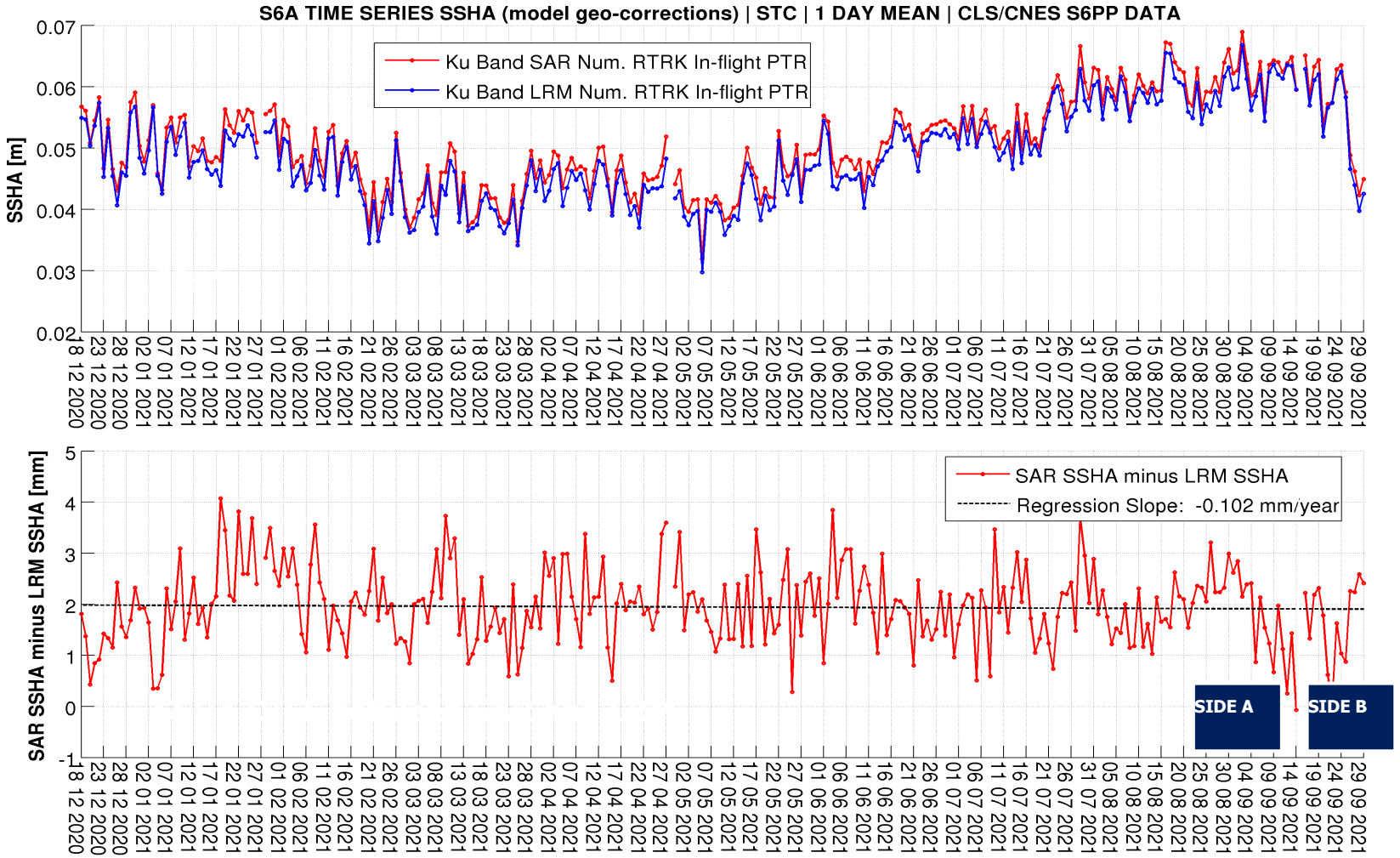


Benefits of FFSAR over rivers



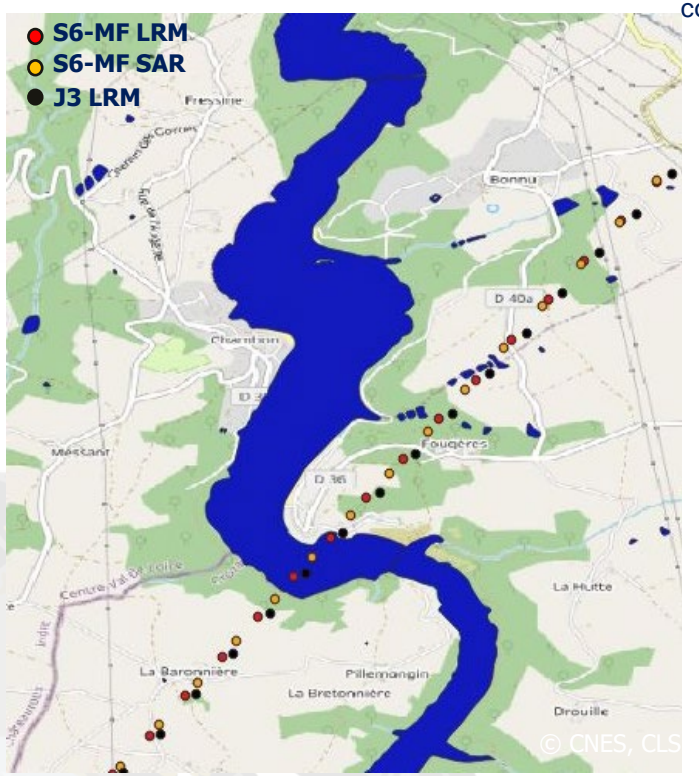
Radargrams over Garonne river (France) at crossing point of S3A (cycle 10 pass 70) and S6-MF (cycle 68, pass 299).

S6PP UF-SAR Chain: Stability between S6PP SAR and LRM chain



Inland Water Analysis

- To determine biases between S6-MF and J3 over a large number of targets (~1000 S6-MF/S3A-B virtual stations) making use of CNES commissioning activity results
- To evaluate S6-MF (LRM, SAR RAW and SAR RMC) performances over inland waters in terms of: missing data, high frequency noise and WSH standard deviation per transect



Vayre et al., 2020

- To characterize the performances of the FF-SAR processing by comparison with UF-SAR, and against in-situ and IceSat-2 data

RAW vs RMC

- Performance over open ocean and coastal areas
  - No difference (François Boy)
- Performance over in-land waters
  - Over Amazonia: 95% within 2 cm, 5% difficult to re-track waveforms; RMC suffices (FB)
  - More analysis over other in-land areas and sea-ice for definite evaluation (FB)
  - No differences seen (Samira)
- Current situation
  - Mode Mask Scenario F: “LRMC everywhere”; i.e. gives LR and HR-RMC data throughout (except transponder and calibration sites that are in RAW)
  - Very tight on data stored on-board and download
- Suggested operational Mode Mask
  - Continue Mode Mask Scenario F
  - EUM to provide more RAW2RMC data to directly compare to RAW, for cycles with RAW over Europe and Arctic
  - In-land / Sea-Ice community invited to suggest any alternative proposal, noting that **for every one second of HR-RAW, one second of HR-RMC needs to be removed from another piece of land on the same orbit**

Mode Mask History

Mode Mask Scenarios (status October 2021)

Box																						
Scenario	N/A	F	A	B	C	E	H	F	A	B	C	E	H	F	A	B	D	E	F	A	B	D	F
Cycle	Drift (1-3)	4-8	9	10	11	12	13	14	15-17	18	19	20	21	22	23-24	25	26	27	28	29	30	31	≥ 32
1	N/A		LX																				
2	N/A																						
3N	N/A																						
3S																							
4																							
coast		LRMC	LX																				
open ocean		LRMC	LRMC																				
land		LRMC	LRM																				
6		LX (7:TXP)	LX																				

"LRMC Everywhere"

Project Scientist's Assessment

Given the analyses performed by the Sentinel-6 Mission Performance Working Group, the analyses presented at the Sentinel-6 Validation Team Meetings, results from the dedicated Calibration sites, and further analyses performed by the Agencies, the Project Scientists of the Sentinel-6 Michael Freilich mission agreed that apart from the long-term drift requirement:

- *The requirements for the performance of the low-resolution measurements as set in the End User and System Requirements Documents have been met;*
- *The requirements for the performance of the high-resolutions measurements as set in the End User and System Requirements Documents have largely been met, with deviations and processing evolutions agreed for their implementation by the end of 2022.*

Regarding the drift requirement, the Project Scientists further agree that:

- *Sufficient altimeter measurements have been captured to cross-calibrate both the Side A and Side B altimeter range measurements with Jason-3 to within 1 millimeter and that the drift requirement is on target to be confirmed based on analysis of a longer time series of measurements.*

Given these findings, the Project Scientists conclude that Jason-3 can safely hand over its role as the Reference Altimetry Mission to Sentinel-6 Michael Freilich and move to an interleaved orbit.

Thank you S6VT members

Thank you for your interest

Questions welcome