Jason-3 & Sentinel-6 MF calibration at the Corsica facilities

(with additional studies on Sentinel-3 BC005 reprocessing)

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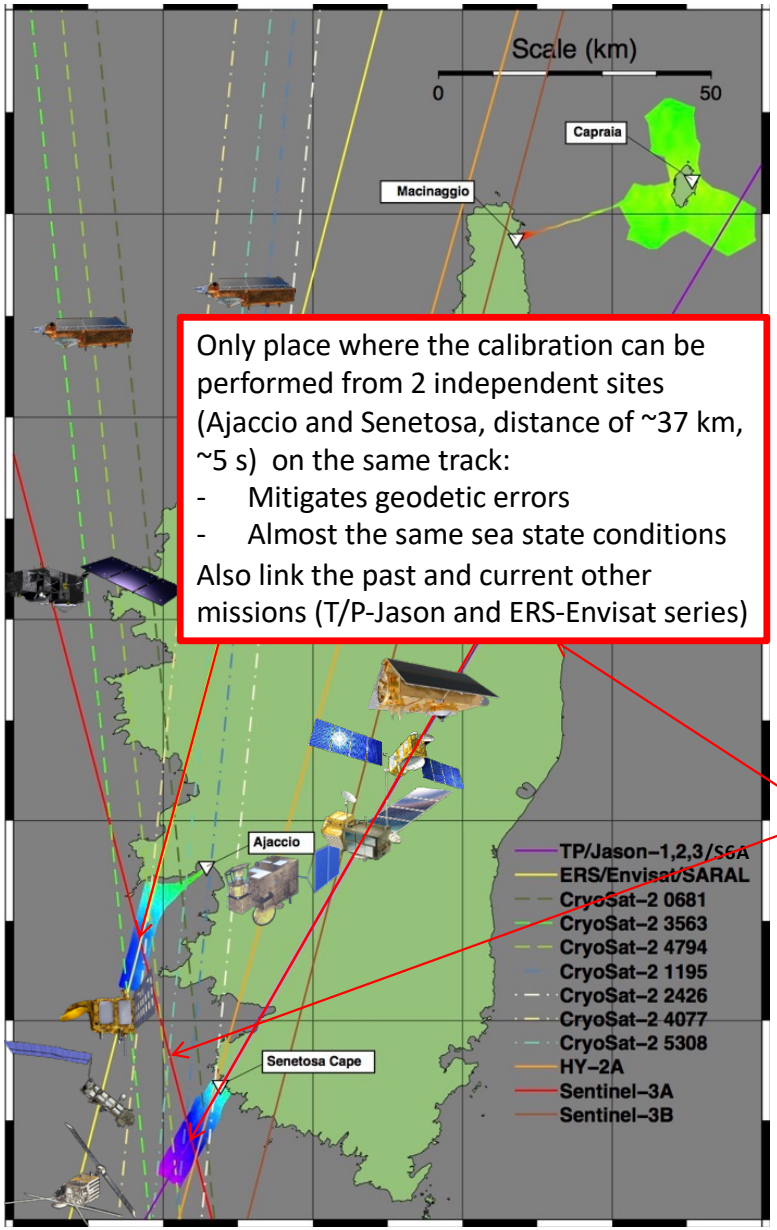
Corsica Multi-mission Calibration Site



Only place where the calibration can be performed from 2 independent sites (Ajaccio and Senetosa, distance of ~37 km, ~5 s) on the same track:
- Mitigates geodetic errors
- Almost the same sea state conditions

Also link the past and current other missions (T/P-Jason and ERS-Envisat series)

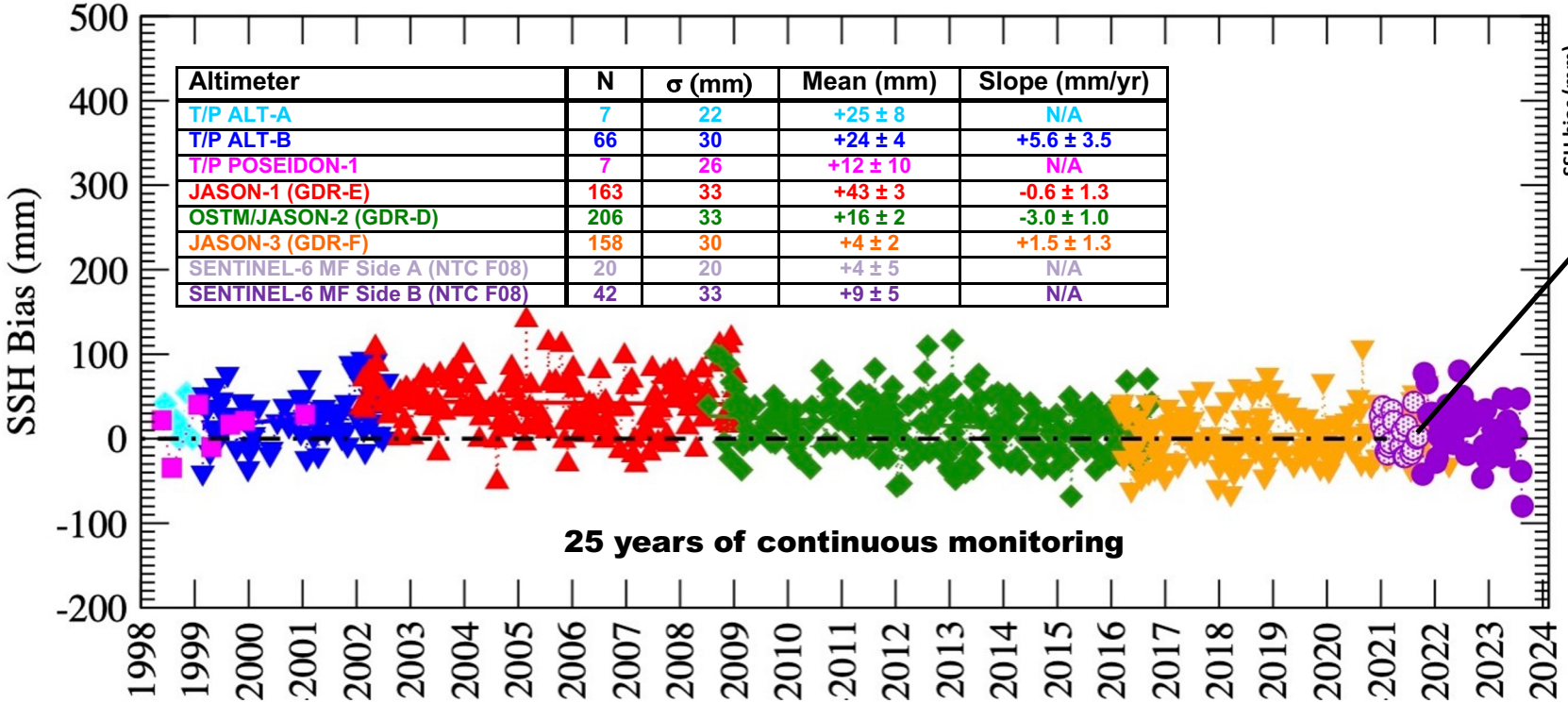
- **Senetosa CNES calibration site** established in 1998
  - Supports continuous monitoring of Sentinel-6 MF & Jason-3 (and formerly T/P and Jason–1&2)
  - Equipped with 4 pressure tide gauges leveled to the permanent GPS receiver
- **Ajaccio configuration** established in 2000
  - Supports continuous monitoring of SARAL/AltiKa (and formerly ERS, Envisat)
  - Fiducial point near Ajaccio equipped with GPS/SLR(FTLRS)/DORIS.
  - Equipped with a radar tide gauge (SHOM) leveled to the permanent GPS receiver
- **Corsica multi-mission calibration site: existing facilities also used for CryoSat-2, HY-2A and Sentinel-3A&B**
- **Open-ocean altimeter readings** connected to tide gauges via detailed **local geoid model**
  - Derived from intensive GPS buoy and catamaran surveys along ground track (in 1999 for Senetosa). Extension to Ajaccio (2005) and Capraia (2004)
  - Open-ocean verification locations for GPS-based SSH measurement systems deployments.
  - **Connection of the Ajaccio and Senetosa local geoids along the Sentinel-3A track done in June 2021 with CalNaGeo and Cyclopée. Extension for SWOT finalized in 2022 (see poster "CVL2023_001 - Extending the Corsica facilities up to SWOT swath" for details)**

Tide gauges: last recovery 2023-09-01

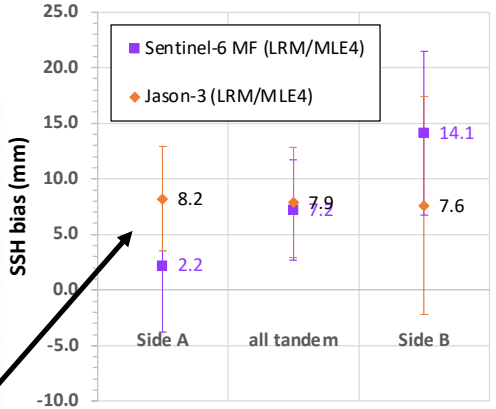
Products analyzed in this study (focus on reprocessing):

- **Jason-3: GDR-F (LRM/MLE4), cycles 1-226**
- **Sentinel-6 MF: NTC F08 (LRM/MLE4&NR and SAR), cycles 4-104**
- **Sentinel-3A: NTC BC005 (SAR and PLRM), cycles 4-102**

Corsica Long-Term SSH Calibration Record



Altimeter	N	σ (mm)	Mean (mm)	Slope (mm/yr)
T/P ALT-A	7	22	+25 ± 8	N/A
T/P ALT-B	66	30	+24 ± 4	+5.6 ± 3.5
T/P POSEIDON-1	7	26	+12 ± 10	N/A
JASON-1 (GDR-E)	163	33	+43 ± 3	-0.6 ± 1.3
OSTM/JASON-2 (GDR-D)	206	33	+16 ± 2	-3.0 ± 1.0
JASON-3 (GDR-F)	158	30	+4 ± 2	+1.5 ± 1.3
SENTINEL-6 MF Side A (NTC F08)	20	20	+4 ± 5	N/A
SENTINEL-6 MF Side B (NTC F08)	42	33	+9 ± 5	N/A



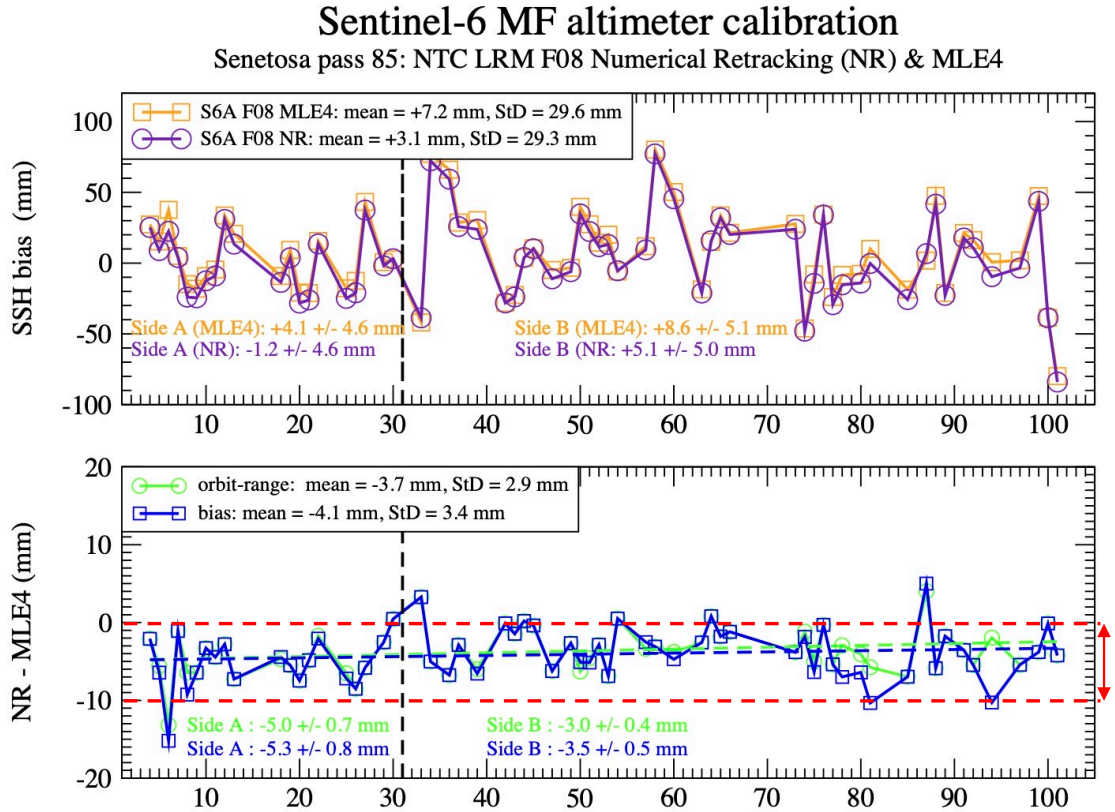
TANDEM PHASE:

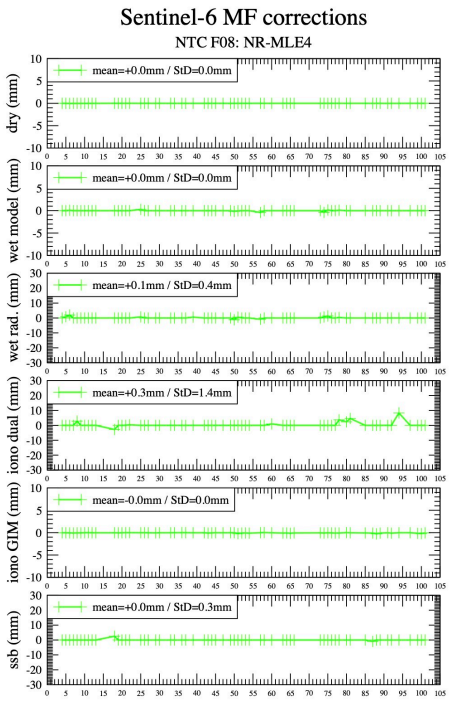
- While Jason-3 SSH bias is stable over Side A and Side B periods (+8.2/+7.6mm), on Sentinel-6 MF the switch between **Side A and Side B exhibits a 12mm difference** (+2.2/+14.1mm). **Side B range is shorter than Side A**.
- Side B being now operational, the **SSH bias with Jason-3 is 6.5mm**.
- No significant correction differences between Jason-3 (GDR-F) and Sentinel-6 MF (NTC, F08). Except for radiometer (4mm, Jason-3 AMR is dryer)

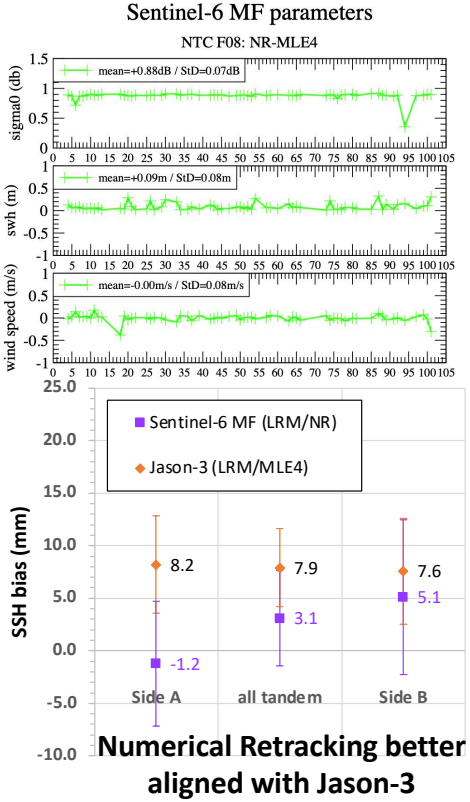
Analysis of the Sentinel-6 MF F08 reprocessing:

- **No significant differences from F06** either for LRM (MLE4) or SAR (see backup slides)
- This was expected because the one of major improvement is the availability of retrievals from the Low Resolution Numerical Retracker (NR) that better accounts from instrument drifts (see next slide)

Sentinel-6 MF (NTC-LR): LRM/MLE4 vs LRM/Numerical Retracking (NR)





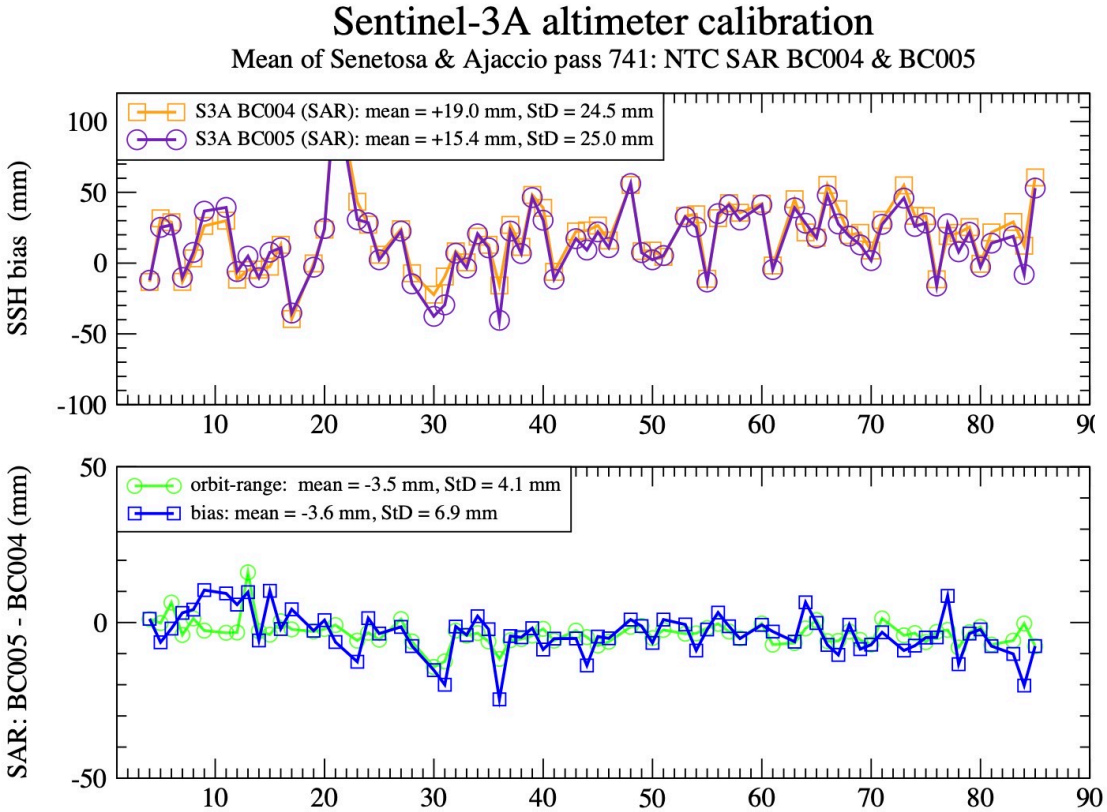


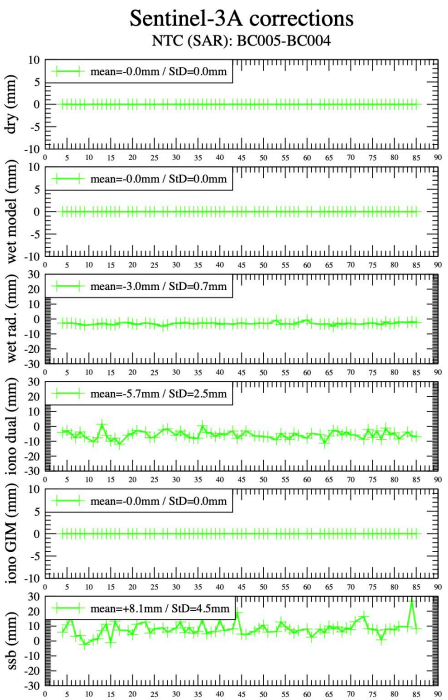
Numerical Retracking better aligned with Jason-3

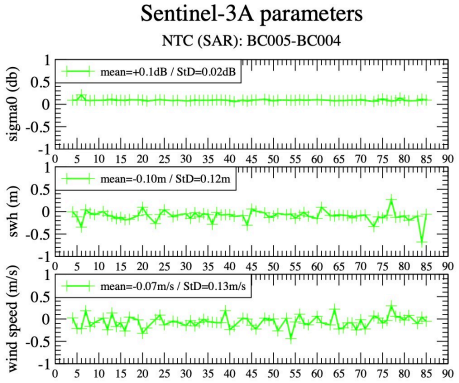
<u>Main findings:</u> Very close results in terms of **bias (-3.7 mm)**, **orbit-range (-4.1 mm)** and **corrections (+0.4 mm)**

- Standard deviation is a little reduced for **NR** compared to **MLE4** (29.3 mm / 29.6 mm)
- A small but maybe significant slope between **MLE4** and **NR** (small jump between side A and side B: the main hypothesis for this jump is the instrumental LUT applied on MLE4 range as noted in S6A_F08_Reprocessing_Calval_Assessment_v2_1.pdf)
  - orbit-range: +0.84 ±0.44 mm/yr (almost insignificant when restricted to side B)
  - bias: +0.55 ± 0.55 mm/yr

Sentinel-3A (NTC, SAR): BC005 vs BC004





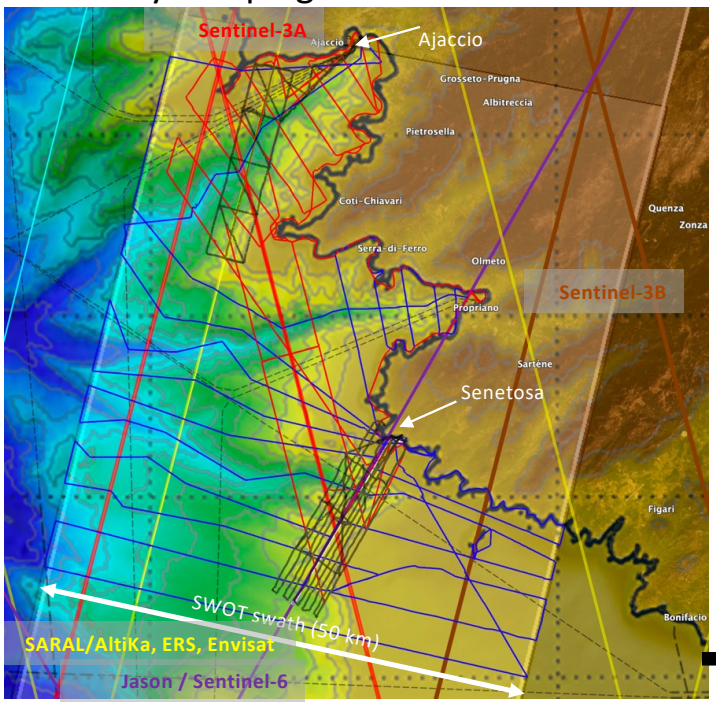


Analysis of the Sentinel-3A BC005 reprocessing (SAR):

- **Main difference comes from orbit-range (-3.5mm)**
- Small contribution from corrections that compensate themselves in average: Wet tropo from radiometer (-3.0mm), Dual iono (-5.7mm) and SSB correction (+8.1mm)
- Similar results for PLRM but with a higher orbit-range difference of -22.6mm (see backup slides)

Evolution of the Corsica facilities

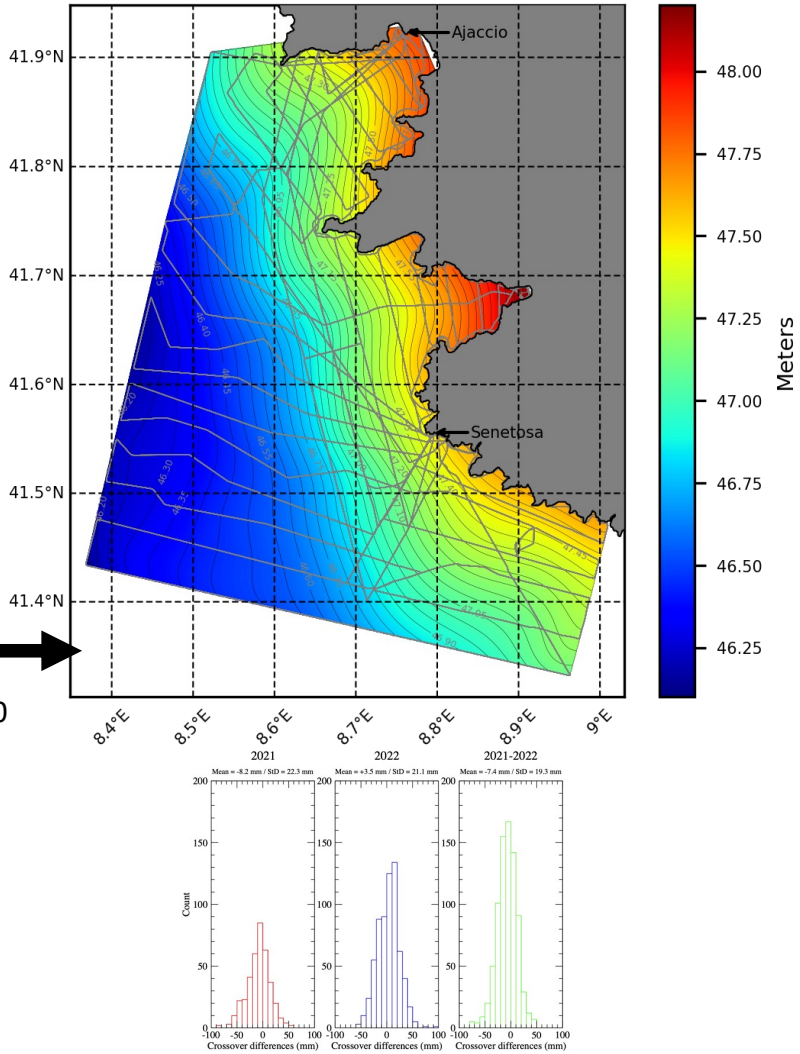
Survey campaigns in **2021** and **2022**



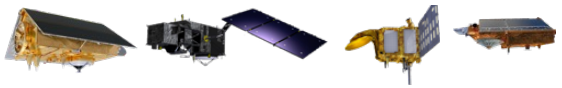
- **Extension/unification of the reference surfaces:**
  - Junction of the historical Senetosa and Ajaccio references surfaces following the Sentinel-3A ground track (**measurements in June 2021, 378 nautical miles**)
  - Extend and densify the reference surface in preparation of SWOT (**measurements in May 2022, 508 nautical miles**)
- **Instruments and processing consistency:**
  - Measurements using **CalNaGeo and Cyclopée**: **very good consistency** (few mm in average / 20 mm standard deviation)
- **"Geoid" realization:**
  - Crossovers shows a good precision (~20 mm rms) and a good consistency between the 2 surveys (-7.4 mm)

see poster CVL2023_001
"Extending the Corsica facilities up to SWOT swath" for details

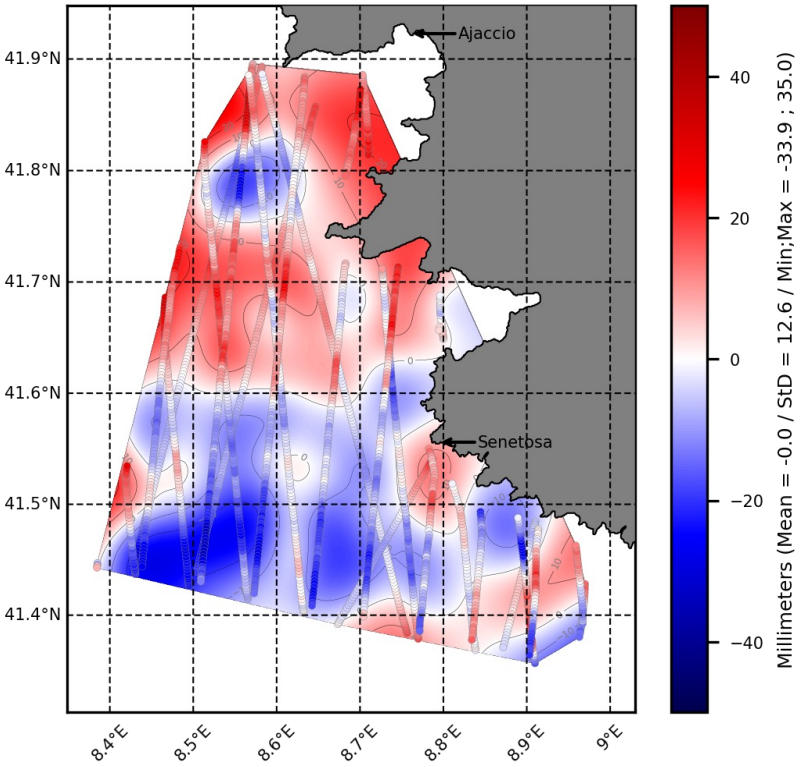
"Geoid" heights from the 2 campaigns



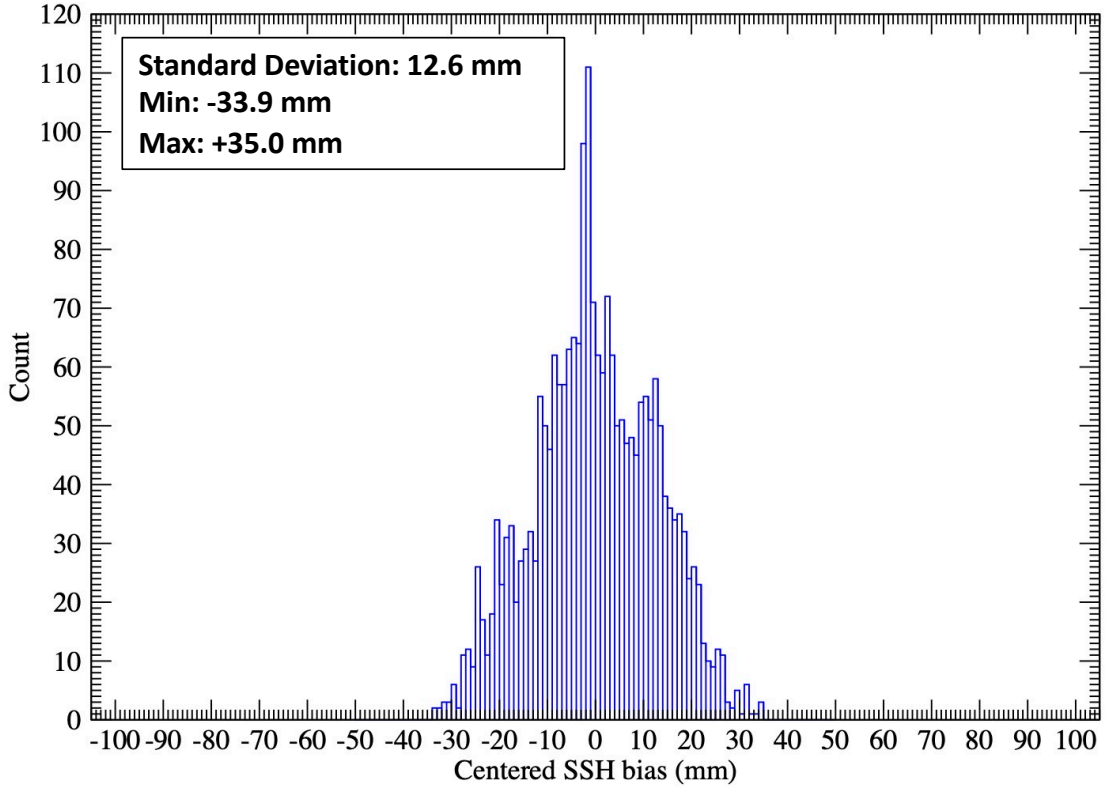
Multi-missions SSH bias in a common reference system



Map of all satellites centered SSH bias



Histogram of all satellites centered SSH bias



Data: CryoSat-2, SARAL/AltiKa, Sentinel-3A&B and Sentinel-6 MF (from 2010 to 2022)

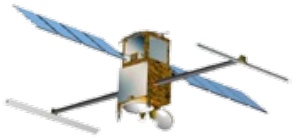
Method: All missions SSH bias using a combined Ajaccio and Senetosa tide gauge time series (individual mission mean SSH bias removed => "centered")

Results:

- A **very good consistency** of the centered SSH biases: **Standard Deviation of 12.6 mm**
- Remaining patterns need to be further investigated but remaining large scale slopes are small (<<1mm/km): need to increase the spatial resolution with additional surveys in some areas?

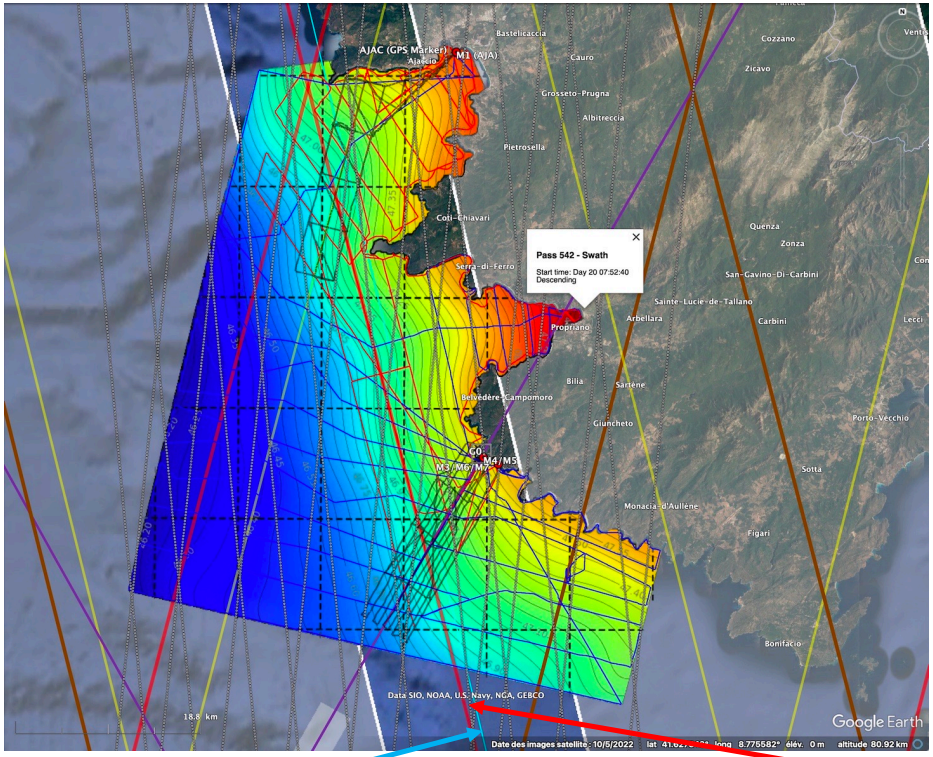
see poster CVL2023_001
"Extending the Corsica facilities up to SWOT swath" for details

Using the new “geoid” map for SWOT nadir SSH bias

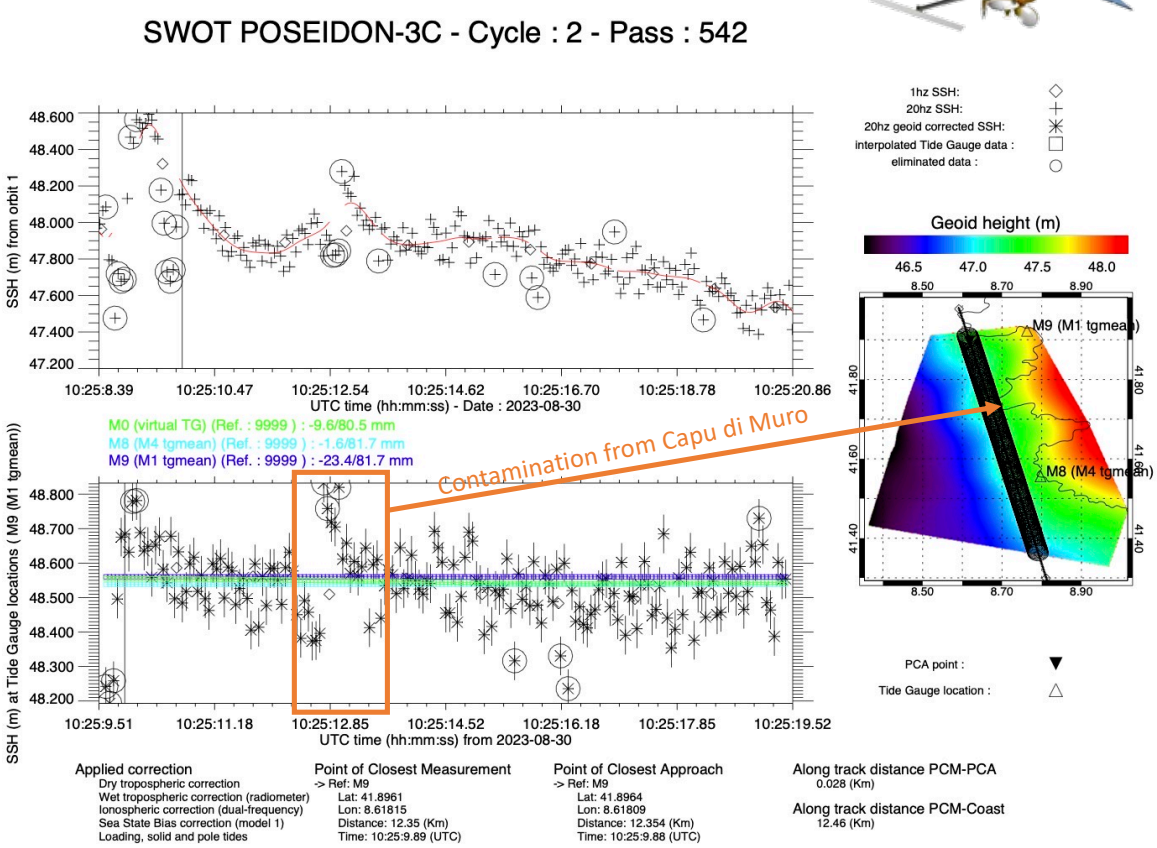


Pass 542:

Eastern part of right swath and western part of left swath



(nadir **SWOT track #542** close (~1.5km) to **Sentinel-3A track #741**)



Very promising results !

First cycles studied show a small SSH bias (~-1cm)

Conclusions

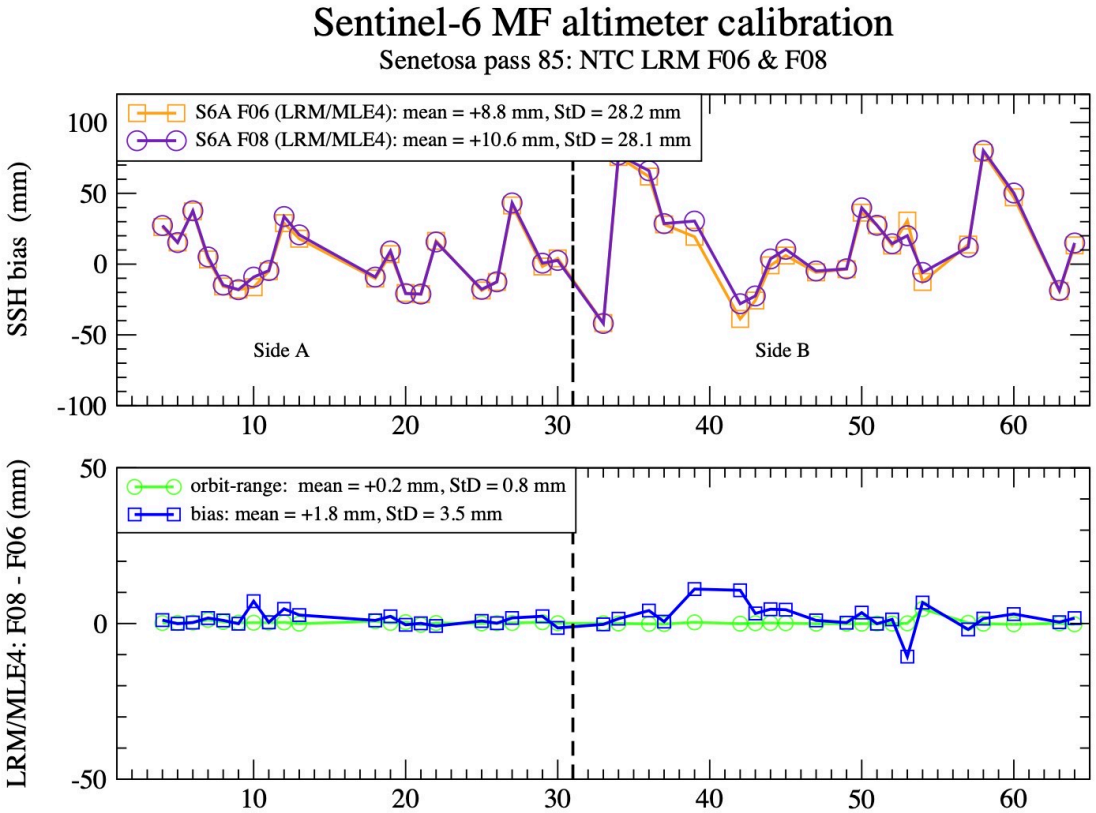
Absolute SSH biases:

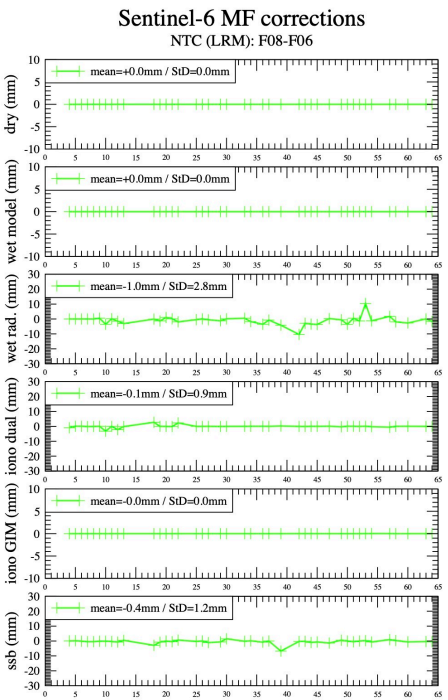
- **Jason-3 (LRM, GDR-F):** **+4.4 ±2.4 mm (over all mission time)**
- **Sentinel-6 MF (LRM, NTC, F08):** **+8.2 ±5.3 mm (side B cycle 31 to 104)**
- **Sentinel-6 MF (SAR, NTC, F08):** **+11.1 ±5.0 mm (side B cycle 31 to 104)**

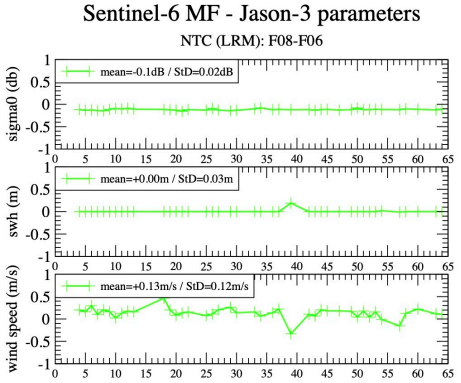
- **Sentinel-6 MF:**
  - **No major changes from F06 to F08 (except the addition of Numerical Retracking)**
  - **Numerical retracking (NR) shows a small improvement** in terms of SSH bias standard deviation
  - SSH bias lower by 3.7mm for NR compared to MLE4 => **NR provide a better agreement with Jason-3**
- **Sentinel-6 MF - Jason-3 during tandem phase (LRM/MLE4)**
  - The switch between Side A and Side B exhibits a 12mm difference: **Side B range is shorter than Side A**.
  - Side B being now operational, the **SSH bias difference with Jason-3 is 6.5mm** (7.2mm from global studies). SSH from Sentinel-6 MF is higher than Jason-3 one.
- **Sentinel-6 MF: Improvement thanks to SAR** (see backup slide)
  - Valid (and accurate) measurements up to the coast (few hundred meters)
  - On the whole set of cycles, the standard deviation of 20Hz data is improved by ~2: 28 mm compared to 58 mm with LRM (65 mm for Jason-3)
- **Sentinel-3A: Reprocessing (BC005** vs previous BC004**)**
  - Differences of SSH bias are small for SAR -3.6mm but more pronounced for PLRM -21mm: those **differences are mostly coming from orbit-range**
  - Small contribution from corrections that mostly compensate themselves in average (Wet tropo from radiometer, Iono dual, SSB)
- **Evolution of the Corsica facilities (up to SWOT swath)**
  - Validation using all overflying satellites over a 13yr period show a good consistency (12.6 mm rms)
  - Very promising results when used for SWOT nadir SSH bias

Backup slides

Sentinel-6 MF (NTC-LR, LRM/MLE4): F08 vs F06



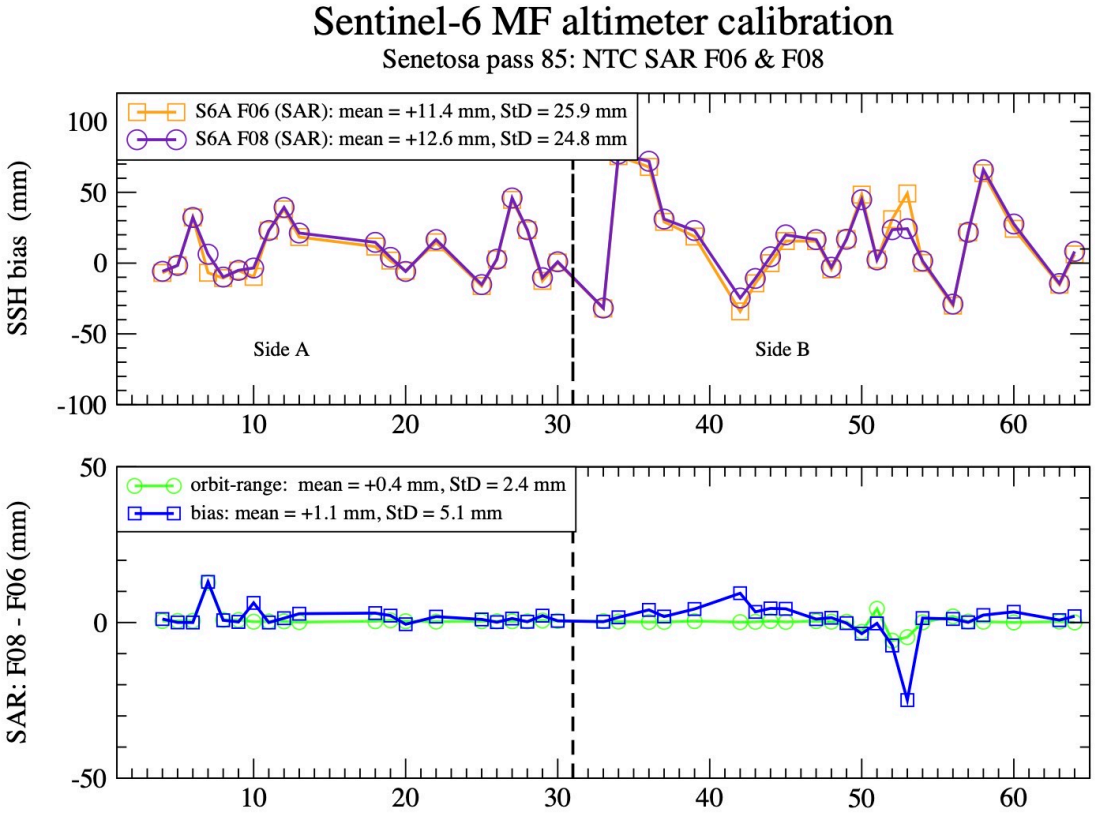


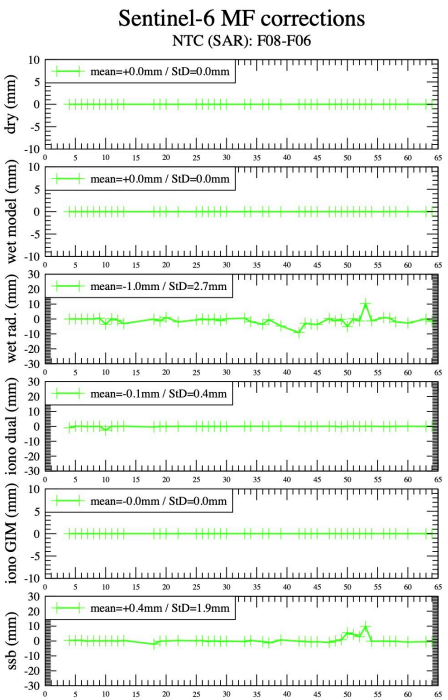


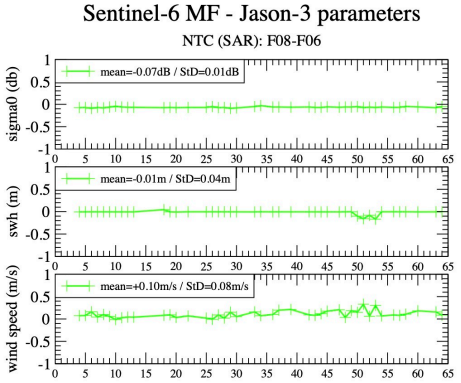
Analysis of the Sentinel-6A F08 reprocessing (NTC-LR, LRM/MLE4):

- **Negligible contribution from orbit-range (+0.2mm)**
- Very small contribution from corrections (1.6mm on average)

Sentinel-6 MF (NTC-HR, SAR): F08 vs F06



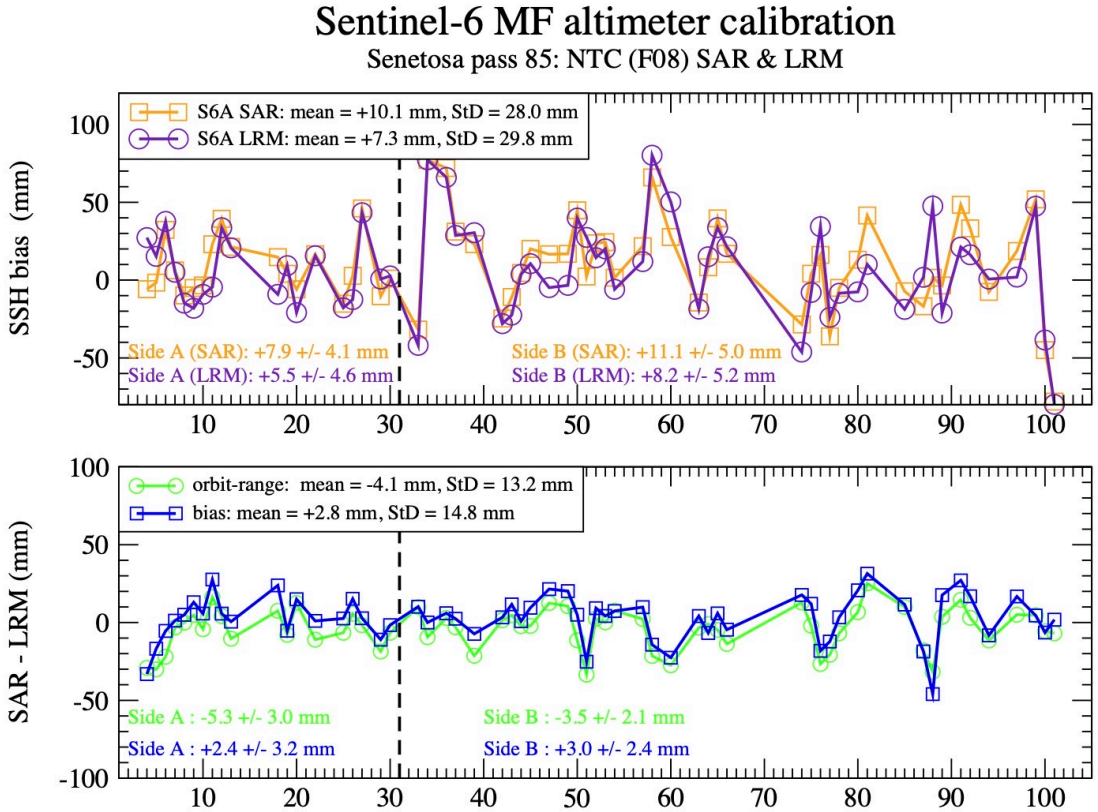


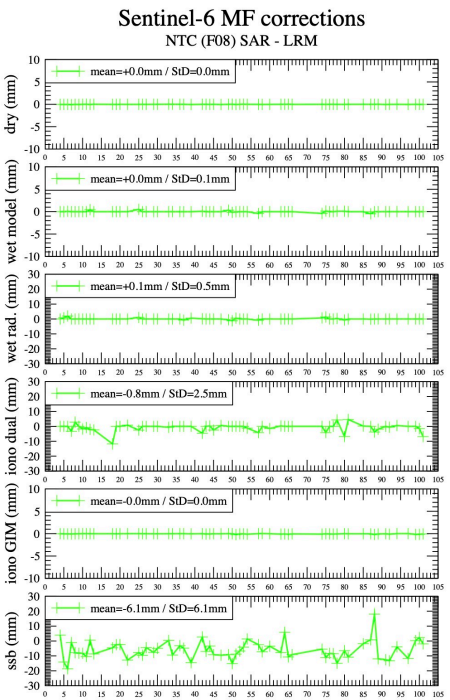


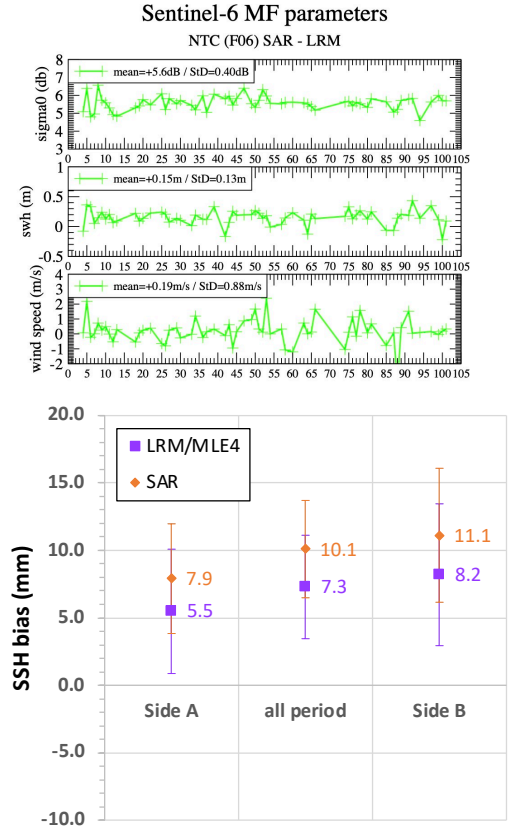
Analysis of the Sentinel-6A F08 reprocessing (NTC-HR, SAR):

- **Negligible contribution from orbit-range (+0.4mm)**
- Very small contribution from corrections (0.7mm on average)

Sentinel-6 MF (NTC-HR, SAR) – Sentinel-6 MF (NTC-LR, LRM/MLE4) (both F08)

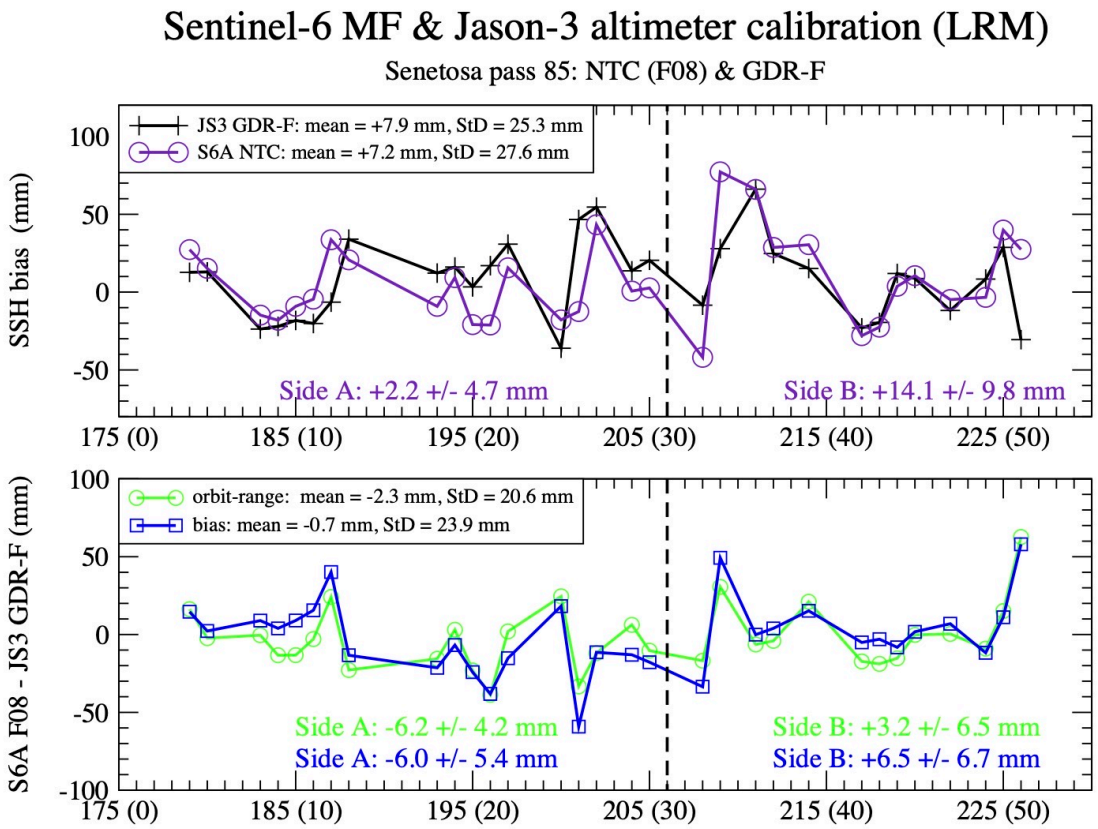


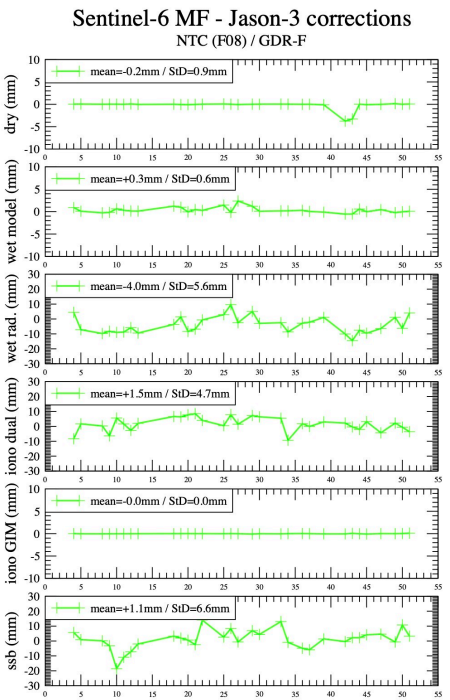


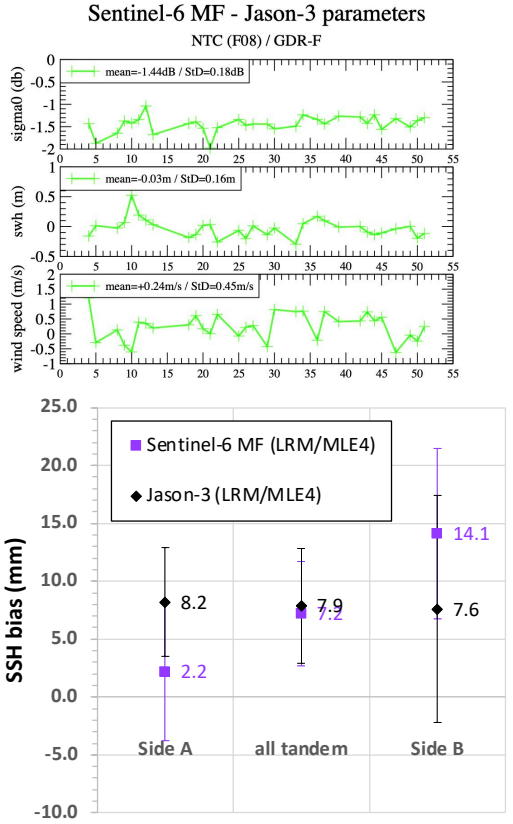


- **Range differences** (orbit-range) between **LR and HR are small and stable** between Side A and Side B (-5.3/-3.5mm), LR range being shorter than HR on average by 4.1mm.
- **SSH biases are even smaller and more stable** (+2.4/+3.0mm) but **mainly due to a compensation by SSB correction.**
- HR (SAR) SWH is biased by 15cm compared to LR (LRM/MLE4); wind speed also biased by 0.19m/s.

Sentinel-6 MF (NTC-LR, LRM/MLE4) – Jason-3 (GDR-F, LRM/MLE4)



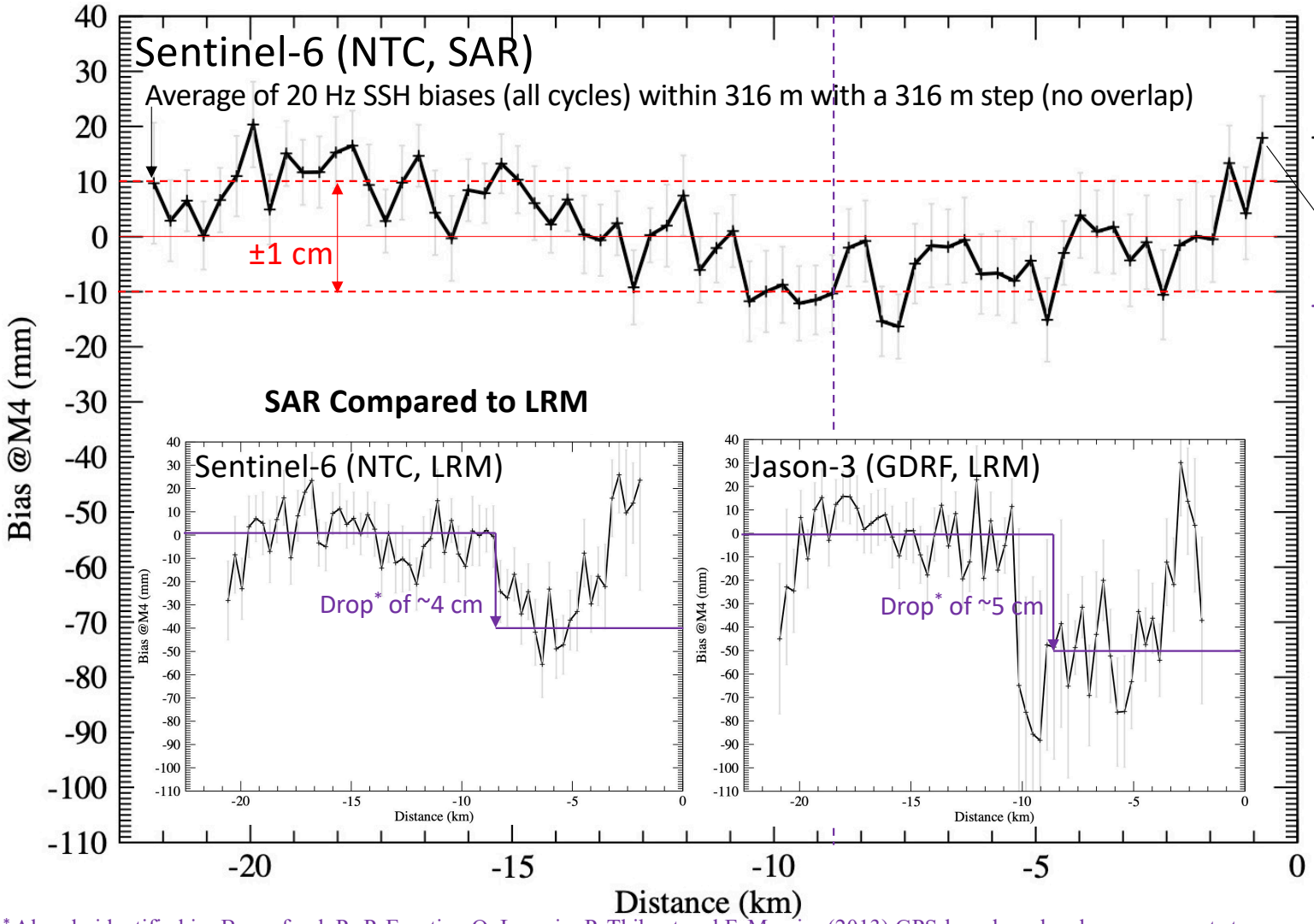




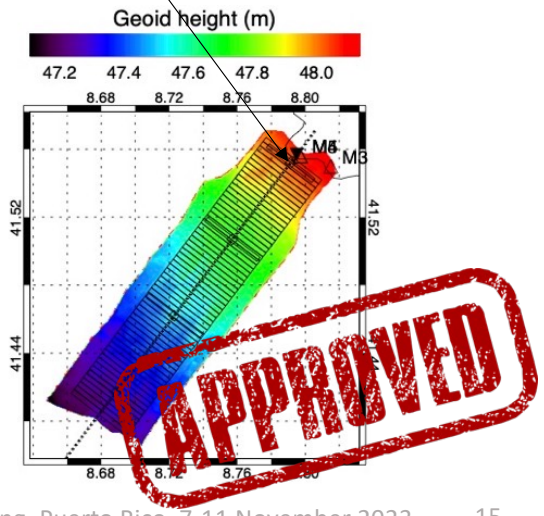
TANDEM PHASE:

- While Jason-3 SSH bias is stable over Side A and Side B periods (+8.2/+7.6mm), on Sentinel-6 MF the switch between **Side A and Side B exhibits a 12mm difference** (+2.2/+14.1mm) during FFP. **Side B range is shorter than Side A**.
- Side B being now operational, the **SSH bias with Jason-3 is 6.5mm** (7.2mm from global studies).
- No significant correction differences between Jason-3 (GDR-F) and Sentinel-6 MF (NTC, F08). Except for radiometer (4mm, Jason-3 AMR is dryer)

Sentinel-6 MF (NTC, SAR) close look up to the coast (all cycles)

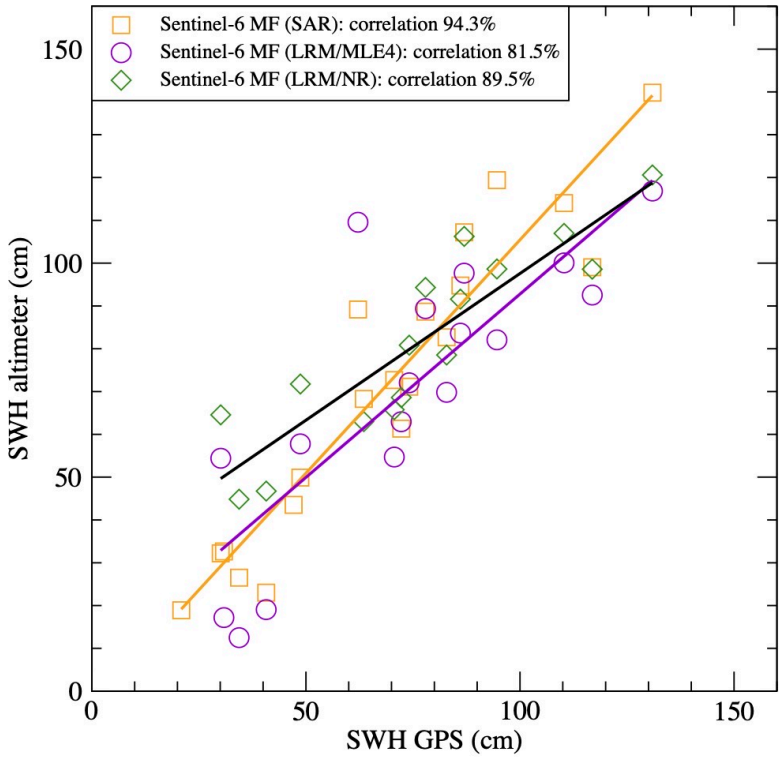


- **Most of the averaged of 20Hz SSH biases in boxes of 316 m are within ±1 cm (standard deviation of 8.6 mm)**
- **Standard deviation of SAR 20Hz data is improved by ~2: 28 mm compared to 58 mm with LRM (65 mm for Jason-3)**
- **The drop in LRM due to land contamination for distance below ~8-10 km disappears in SAR (comparable drop in LRM for Sentinel-6 MF and Jason-3)**



* 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

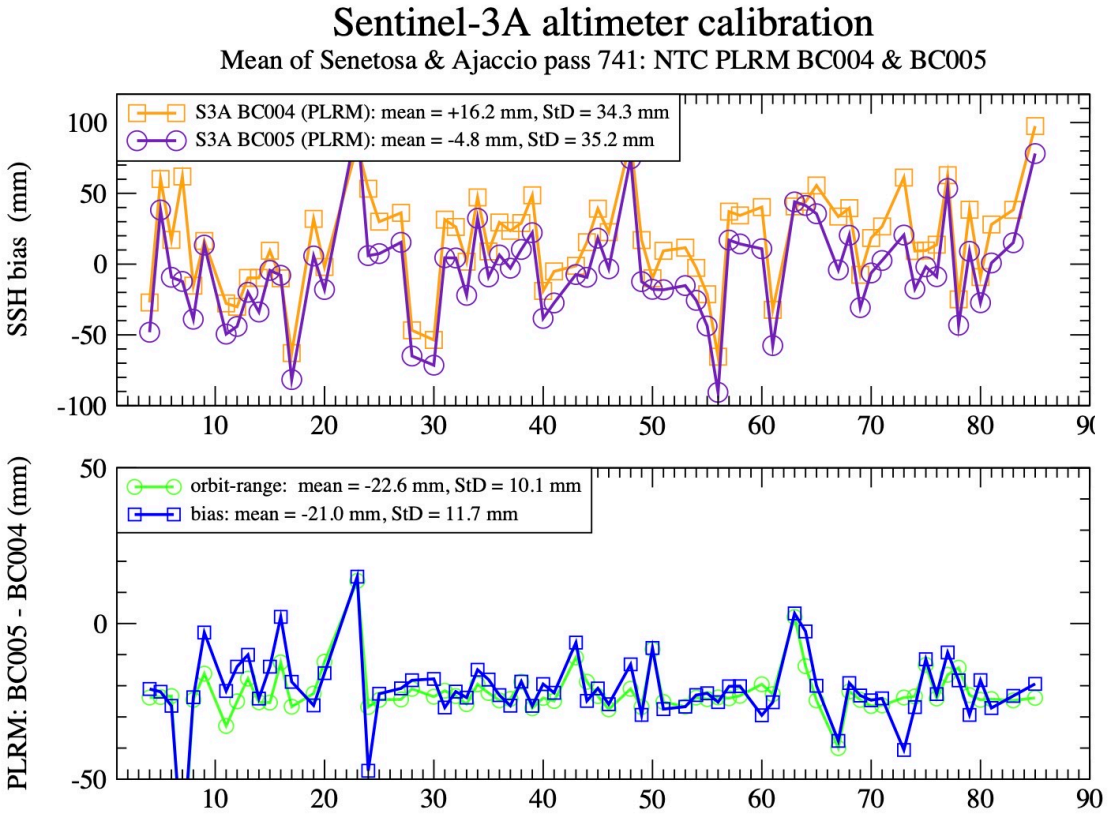
SWH from Sentinel-6 MF (LR&HR) versus SWH from GNSS “buoy”

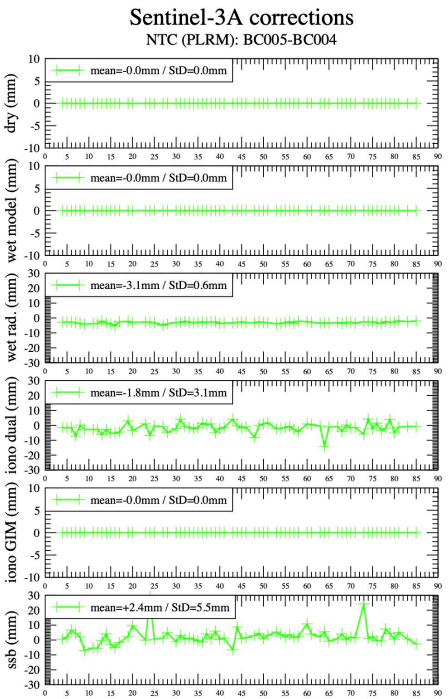


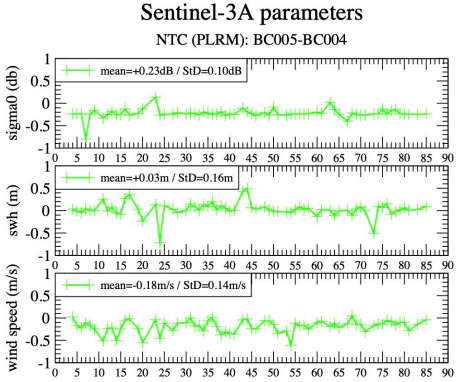
- **Data used:**
  - SWH from altimeter using data from LR (**MLE4** and Numerical Retracking (**NR**)) and from HR (**SAR**)
  - SWH from GNSS deployment at overflight time (~15km offshore)
- **Results:**
  - **SAR** shows the **better correlation and closer slope to 1**
  - **MLE4** shows the **lower correlation and higher σ**
  - **NR** shows the **lower σ but slope is far from 1**. Moreover, no SWH lower than 44.8cm. Probably due to an anomaly (AR 2620): 1 Hz NR SWH can be impacted up to 1 meter .

	Correlation (%)	Bias at 0 (cm)	Slope (cm/cm)	σ (cm)
SAR	94.4	-3.6	1.09	11.8
MLE4	81.5	+7.1	0.86	18.3
NR	89.5	29.0	0.69	9.9

Sentinel-3A (NTC, PLRM): BC005 vs BC004



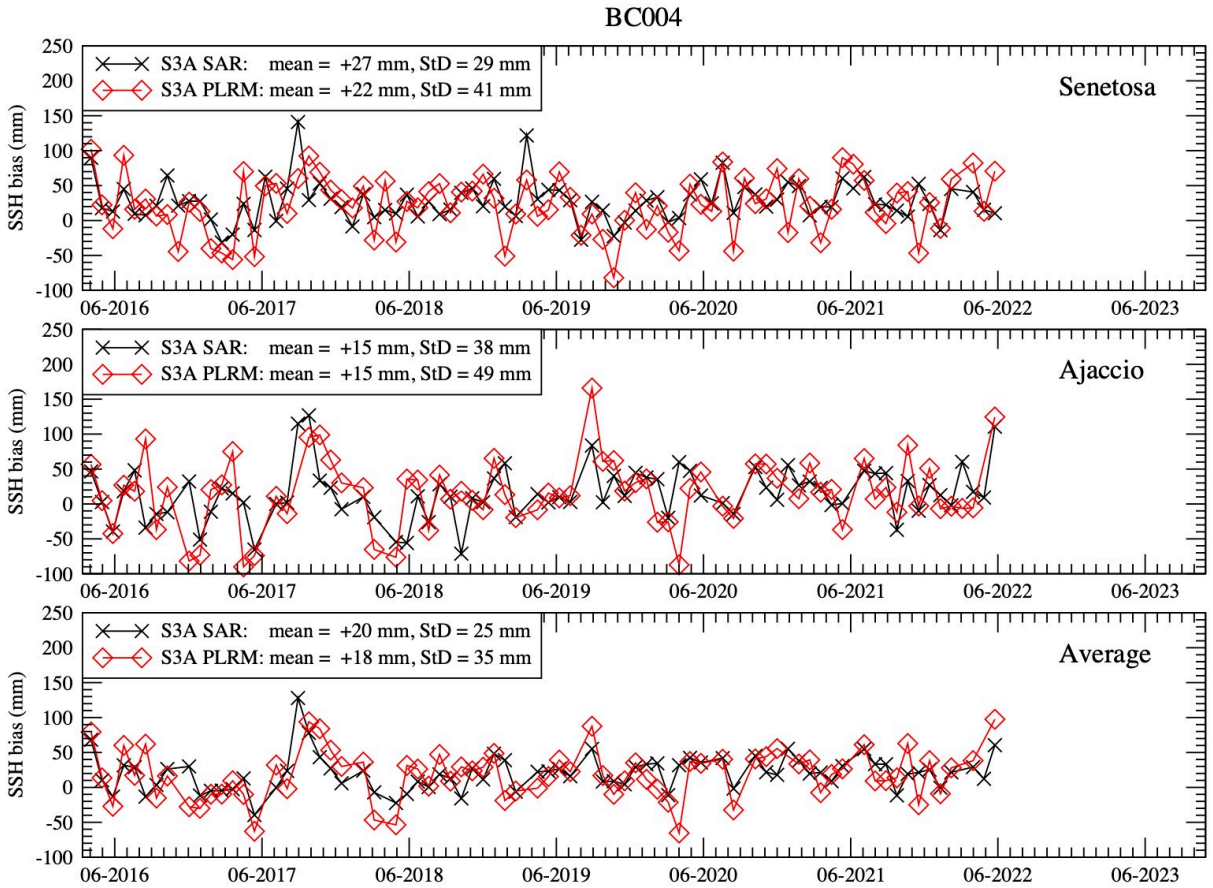




<u>Analysis of the Sentinel-3A BC005 reprocessing (PLRM):</u>

- **Main difference comes from orbit-range (-22.6mm)**
- Small contribution from corrections that mostly compensate themselves in average: Wet tropo from radiometer (-3.1mm), Dual iono (-1.8mm) and SSB correction (+2.4mm)

Sentinel-3A (NTC, SAR&PLRM) from Ajaccio and Senetosa: BC004



Sentinel-3A (NTC, SAR&PLRM) from Ajaccio and Senetosa: BC005