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

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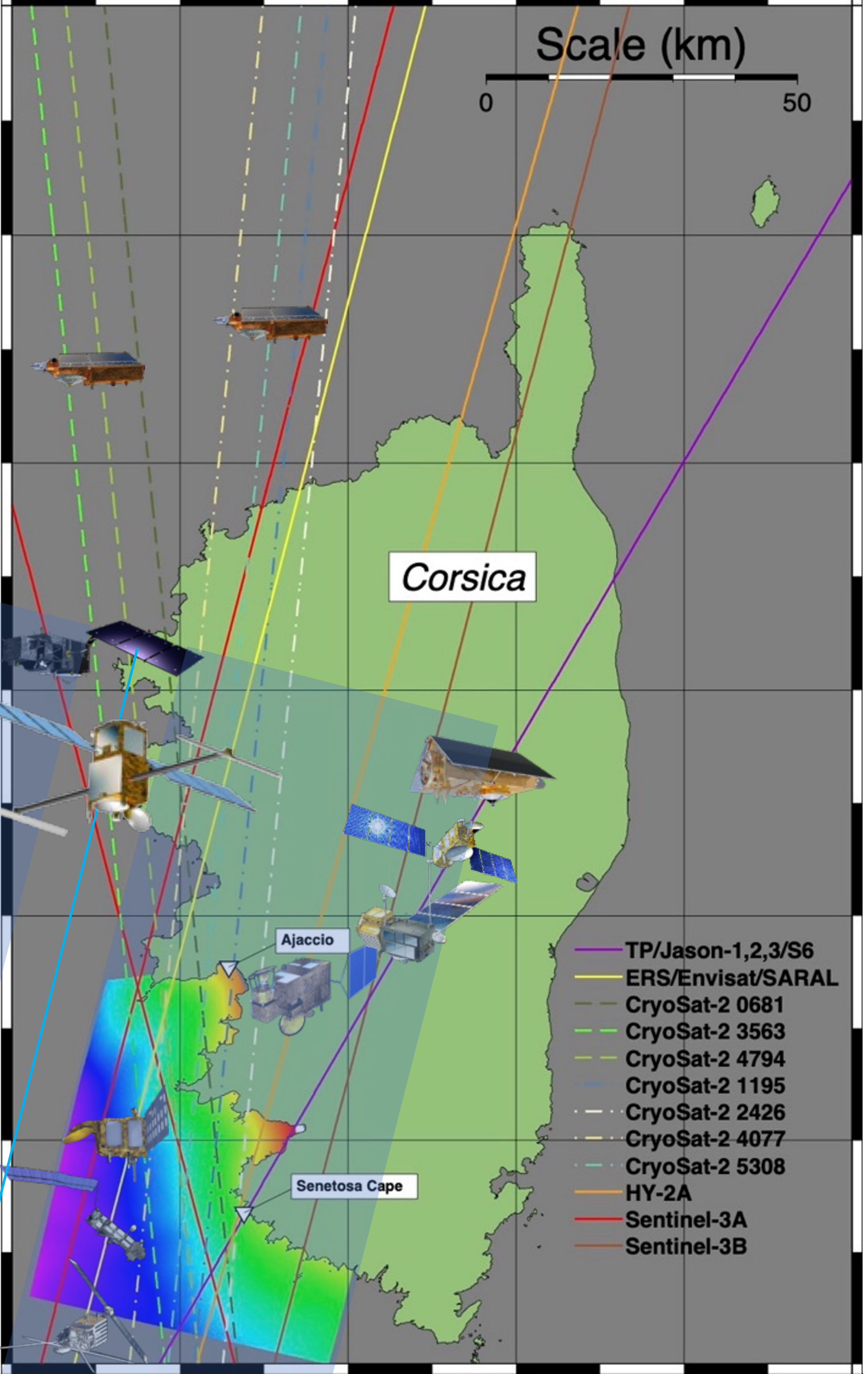


Corsica Multi-mission Calibration Site

History:

- **Senetosa and Ajaccio calibration site** established for continuous monitoring of respectively:
  - Sentinel-6 MF & Jason-3 (and formerly T/P and Jason–1&2)
  - SARAL/AltiKa (and formerly ERS, Envisat)
- **Open-ocean altimeter readings** connected to tide gauges via detailed **local GNSS reference surfaces**

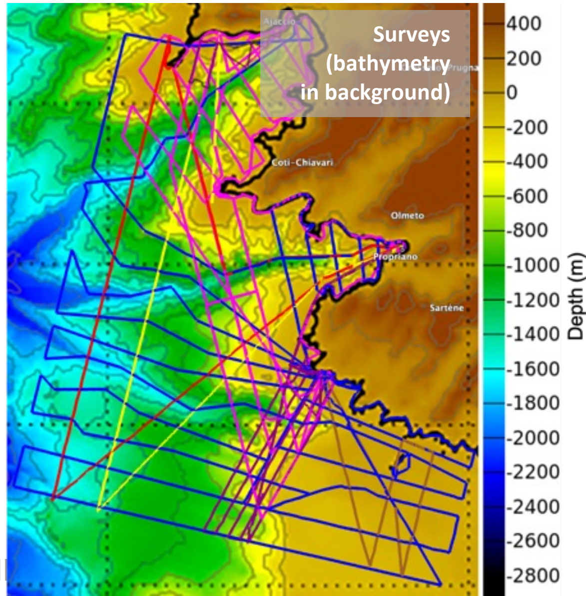
New developments:

- **Building an enlarged reference surface to cover a full half SWOT swath but also to perform monitoring of the nadir missions in a common geodetic reference frame**
  - Connection of the Ajaccio and Senetosa local reference surfaces along the Sentinel-3A track (#741) done in June 2021 with CalNaGeo and Cyclopée.
  - Extension under SWOT swath in the Gulf of Ajaccio and offshore finalized in May 2022 with CalNaGeo and Cyclopée.
  - Additional surveys with Cyclopée only along nadir missions tracks (2023-2025): SARAL/AltiKa (#130), Sentinel-6 MF (#085), Sentinel-3A (#044), Sentinel-3B (#157)

=> **2100 kilometers surveyed using GNSS instruments** (CalNaGeo and/or Cyclopée)

All details of the process are given in the following presentation:

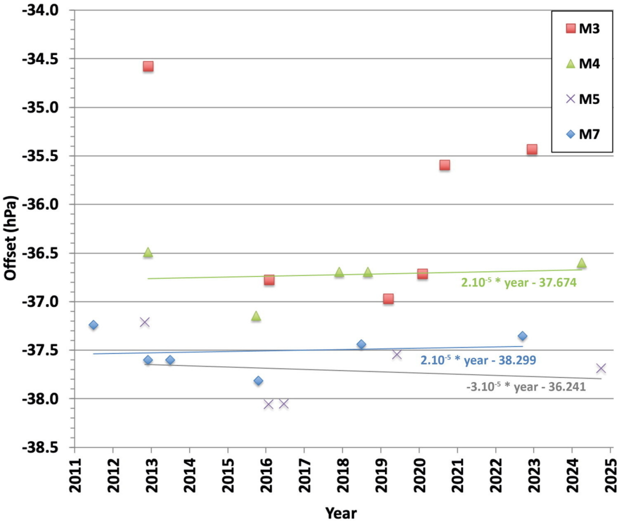
Extending the Corsica facilities up to SWOT swath (this OSTST meeting)



Towards 0.1mm/yr stability over decades for measuring sea level using tide gauges together with GNSS-based instruments?
Part 1: Instrumental stability
All details in: https://doi.org/10.1080/01490419.2025.2546920

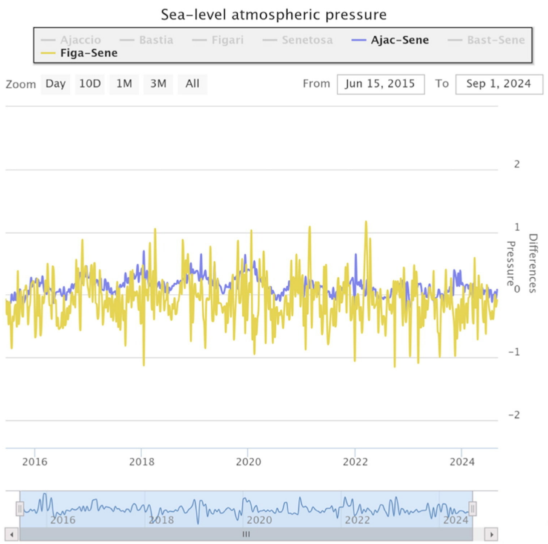
Senetosa tide gauges SSH stability monitored by:
- A: Pressure sensors' calibrations (~every 2 years)
- B: Atmospheric pressures used for compensation of tide gauge pressures
- C: Relative differences between the 4 tide gauges
- D: External control using GNSS-based measurements (GNSS-zodiac)

Derived potential drift: ~-0.1mm/yr



Variations of the calibration of the mean offset (~37hPa by construction) over the last 14 years for the Senetosa tide gauges.

A: Drift equivalent to 0.2–0.3mm/yr
Over the last 14 years but the calibration is applied and removes such potential drift



Atmospheric pressure differences in hPa between Ajaccio (Ajac) or Figari (Figa) and Senetosa (Sene) weather stations

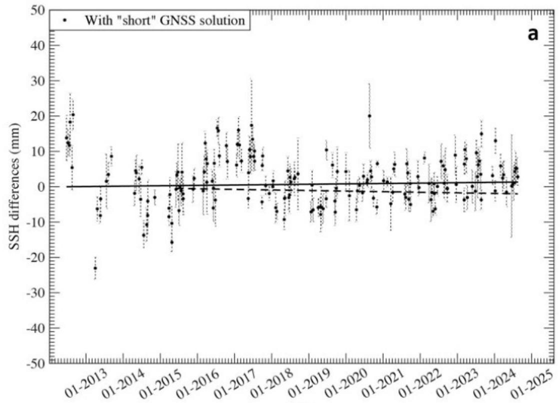
B: Drift due to the atmospheric pressure of ~-0.1mm/yr over the last 10 years

C: relative drift < -0.1mm/yr over last 10 years and mean SSH differences at a few mm level

Table 5. Statistics of the SSH differences between tide gauges themselves (Mi where i is the tide gauge number) at Senetosa, from 1 June 2015 to 30 August 2024.

Type of comparison (distance)	Mean (mm)	σ (mm)	Drift (mm/yr)	Number of values
M4-M3 (~1.7 km)	+5.3	7.9	+0.17 ± 0.02	242282
M5-M3 (~1.7 km)	+6.9	8.3	+0.05 ± 0.01	292166
M3-M7 (~0.3 m)	−1.8	6.2	−0.11 ± 0.01	266058
M4-M5 (~0.3 m)	−2.4	4.3	−0.16 ± 0.01	354880
M4-M7 (~1.7 km)	+2.3	8.7	−0.04 ± 0.02	323352
M5-M7 (~1.7 km)	+4.5	8.6	−0.13 ± 0.02	345364
Average	+3.1	7.3	−0.04 ± 0.01	304017

The distances between the instruments are indicated in brackets.



SSH differences between GNSS-zodiac and tide gauges from 6 July 2012 to 30 August 2024.

D: Drift of ~-0.1mm/yr over last 12 years and mean SSH differences at a few mm level

Towards 0.1mm/yr stability over decades for measuring sea level using tide gauges together with GNSS-based instruments?
Part 2: Vertical Land Motion (VLM)
All details in: https://doi.org/10.1080/01490419.2025.2546920

Methodology:

- Coordinates' time series have been produced by SPOTGINS (https://ac-gnss.pagelab.univ-lr.fr/spotgins/)
- Analysis of GNSS time series for 4 stations in the South of Corsica with more than 10 years of data

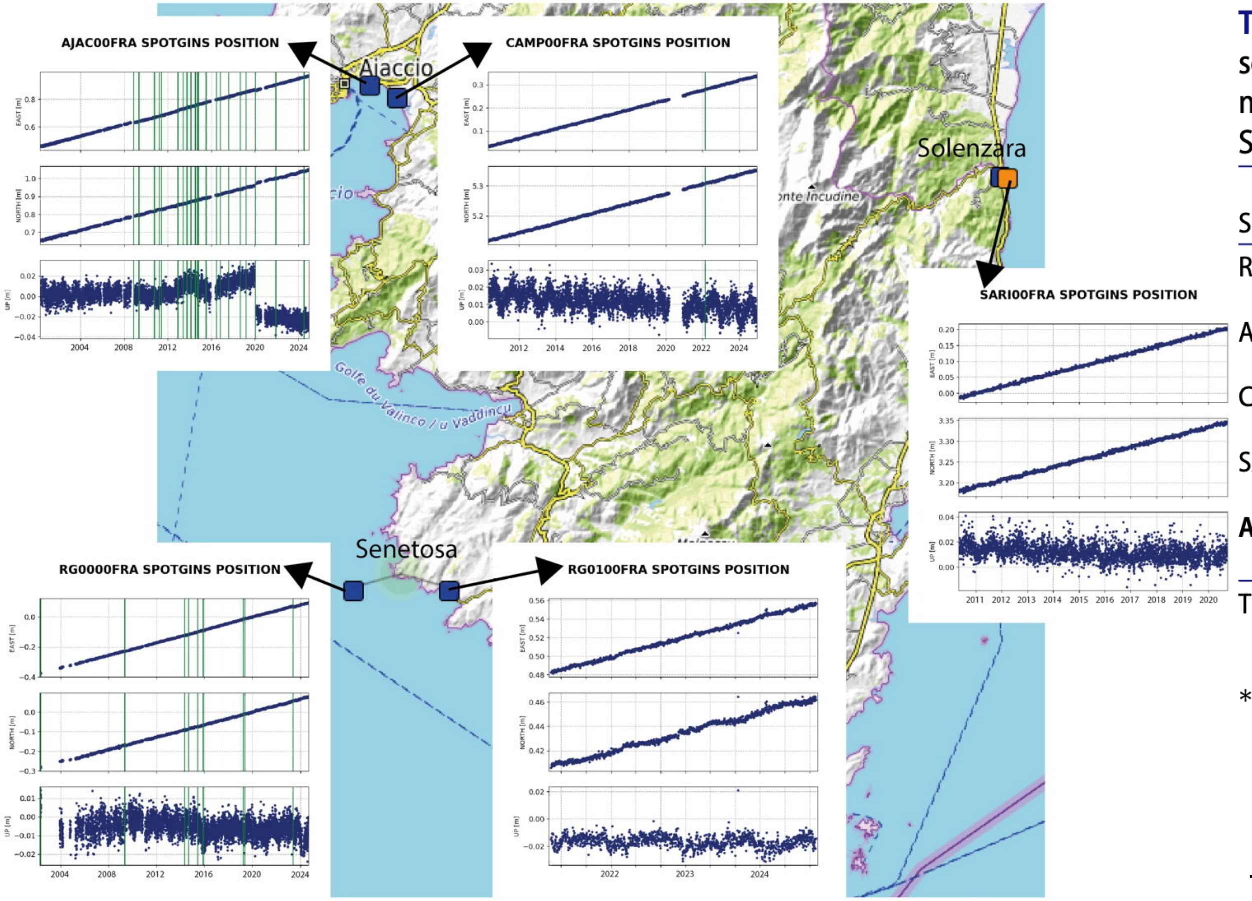


Table 2. Vertical velocities of GNSS sites in the South of Corsica issued from SPOTGINS time series (https://ac-gnss.pagelab.univ-lr.fr/spotgins/) and estimated with a more sophisticated model before linear least squares weighted by the standard deviation of each daily point using SARI tool (Santamaría-Gómez 2019) from (https://en.poleterresolide.fr/geodesy-plotter-en/).

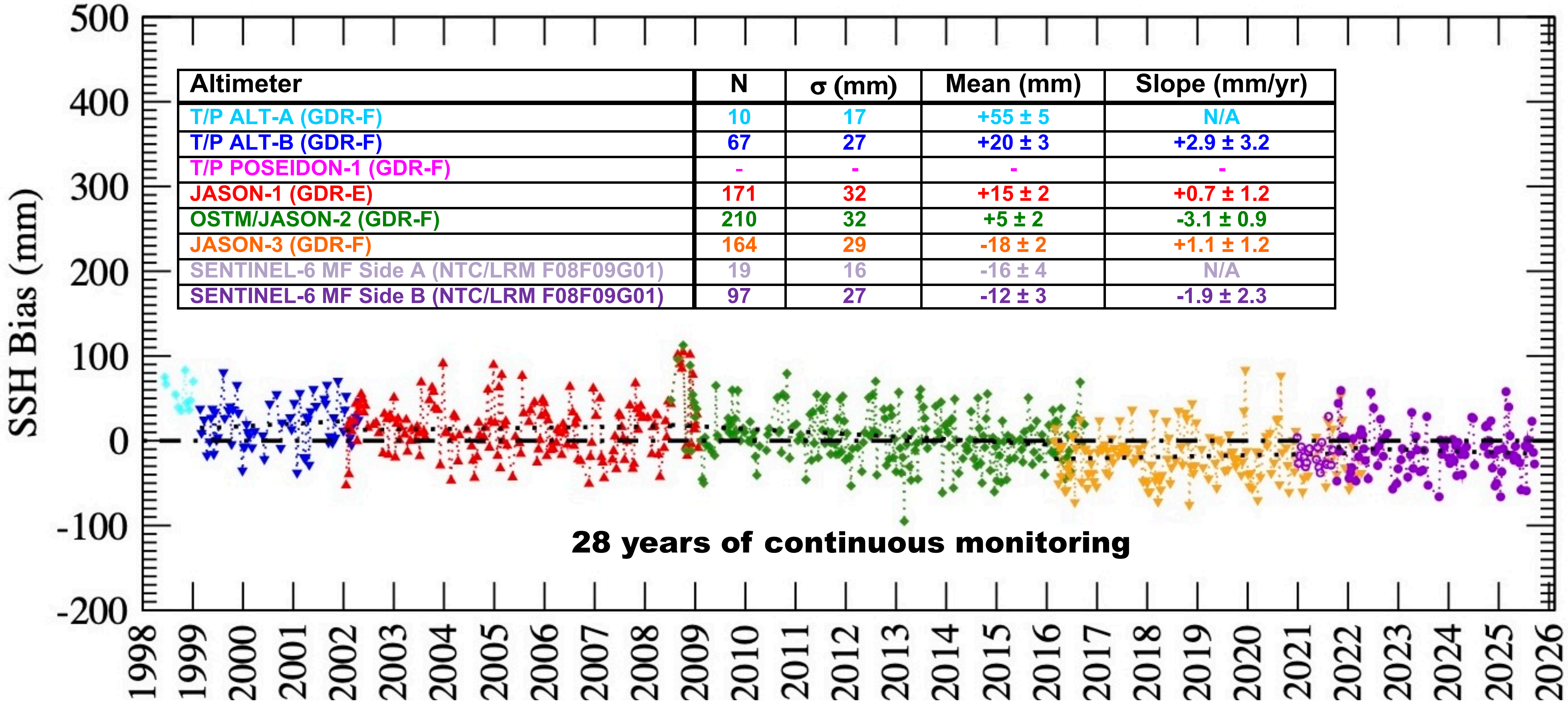
Site name	Vertical velocity and uncertainty (mm/yr)	Series length (yr)	Series range (yr start – yr end)
RG00	+0.24 ± 0.03 [0.23]* (+0.11 ± 0.03 [0.34]*)	20.7488 (12.17)	2003.9356–2024.6844 (2012.5–2024.67)
AJAC	−0.13 ± 0.02 mm/yr [0.19]* (−0.63 ± 0.07 [0.37]*)	24.6065 (12.17)	2000.3402–2024.9467 (2012.5–2024.67)
CAMP	−0.56 ± 0.02 mm/yr [0.28]* (−0.50 ± 0.04 [0.34]*)	14.5810 (12.17)	2010.3657–2024.9467 (2012.5–2024.67)
SARI	−0.78 ± 0.03 mm/yr [0.38]* (−0.67 ± 0.04 [0.48]*)	10.3597 (8.2186)	2010.3657–2020.7254 (2012.5–2020.7254)
Average	**−0.31 ± 0.03 mm/yr [0.27]* (−0.42 ± 0.05 [0.38]*)**		

The aforementioned model is characterized by a more sophisticated design, incorporating a sinusoidal fit in conjunction with offsets (see Table 3). Values in brackets correspond to the time period studied in section 'comparisons of the measurement systems (tide gauges and GNSS-zodiac)' (6 July 2012 to 30 August 2024).
*Square bracket corresponds to uncertainty including noise analysis (white and flicker)

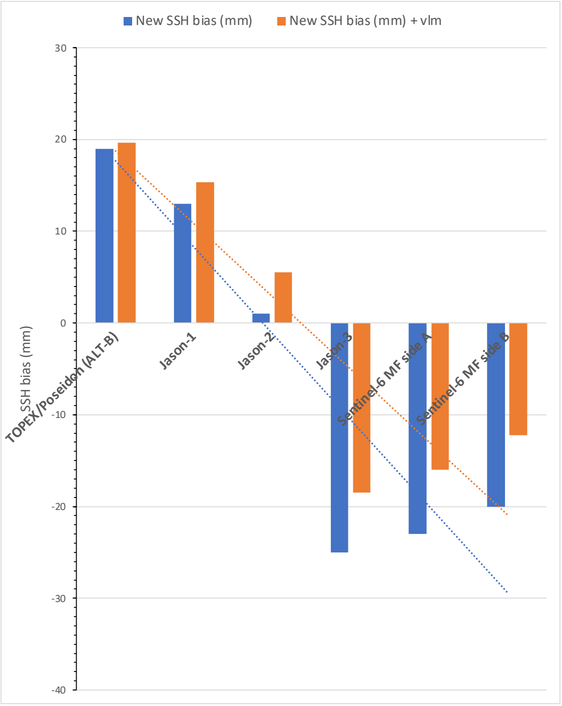
Even close to the uncertainty (0.27mm/yr), the averaged Vertical Land Motion suggests a subsidence of the South of Corsica at the level of -0.31mm/yr

In consequence, the SSH biases from altimeter calibration increase by +0.31mm/yr (applied for results presented in the following slides).

Corsica Long-Term SSH Calibration Record



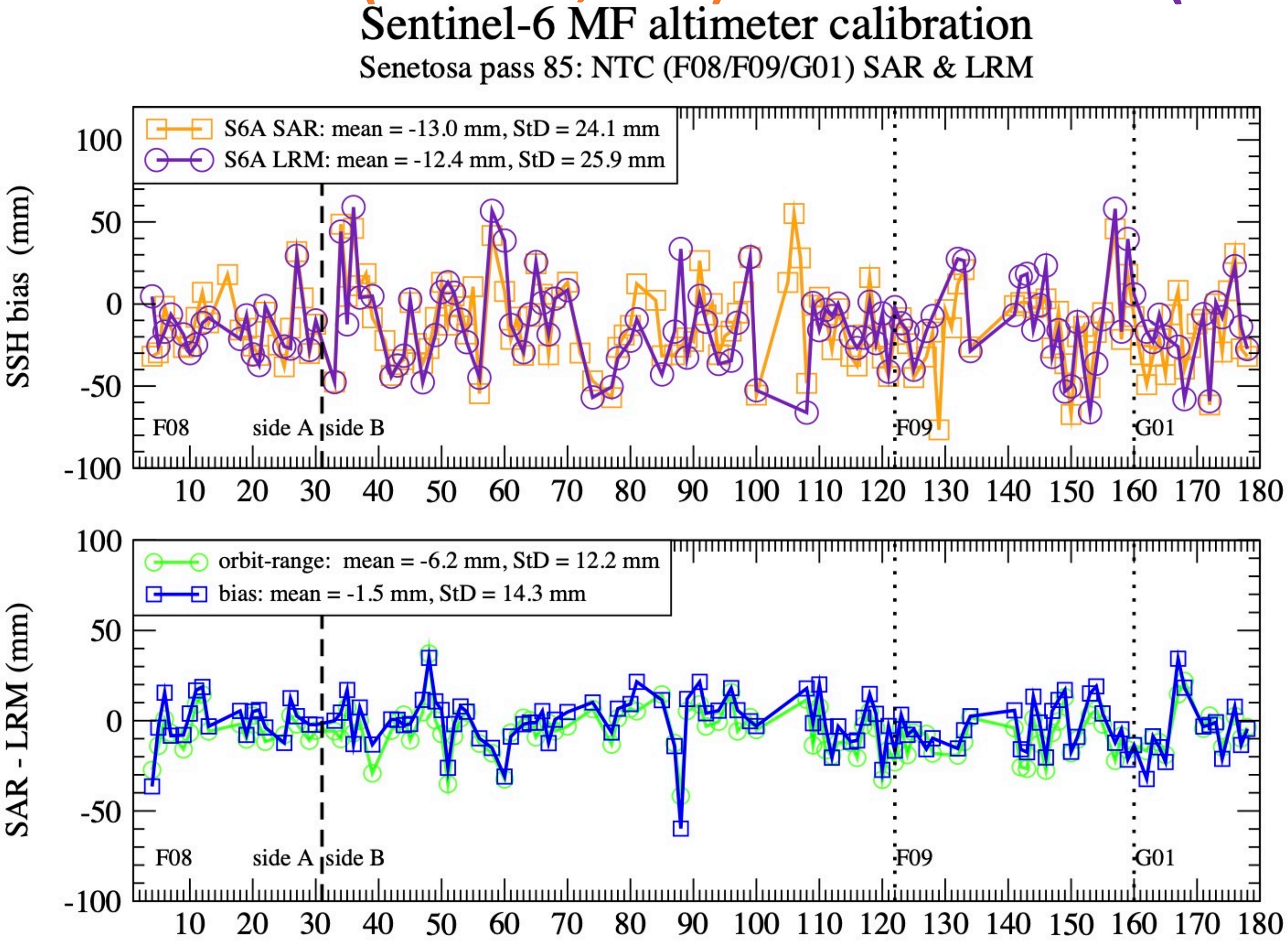
Altimeter	N	σ (mm)	Mean (mm)	Slope (mm/yr)
T/P ALT-A (GDR-F)	10	17	+55 ± 5	N/A
T/P ALT-B (GDR-F)	67	27	+20 ± 3	+2.9 ± 3.2
T/P POSEIDON-1 (GDR-F)	-	-	-	-
JASON-1 (GDR-E)	171	32	+15 ± 2	+0.7 ± 1.2
OSTM/JASON-2 (GDR-F)	210	32	+5 ± 2	-3.1 ± 0.9
JASON-3 (GDR-F)	164	29	-18 ± 2	+1.1 ± 1.2
SENTINEL-6 MF Side A (NTC/LRM F08F09G01)	19	16	-16 ± 4	N/A
SENTINEL-6 MF Side B (NTC/LRM F08F09G01)	97	27	-12 ± 3	-1.9 ± 2.3

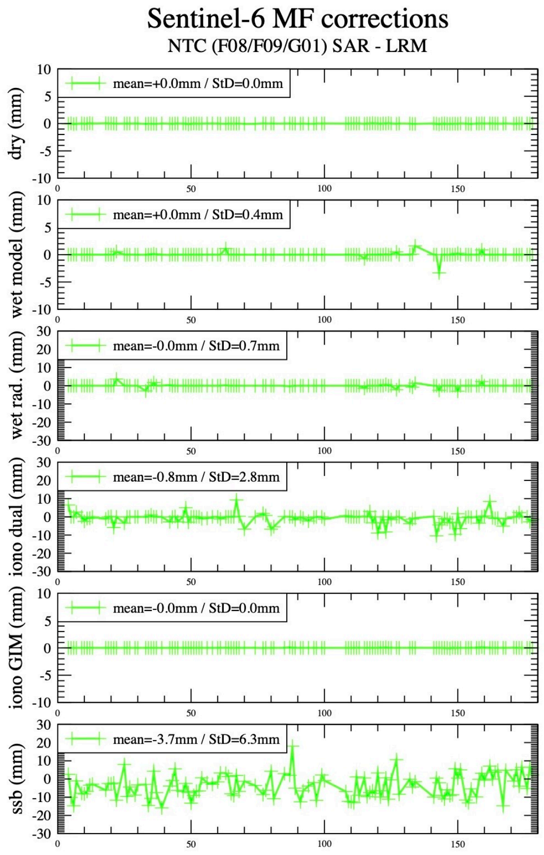


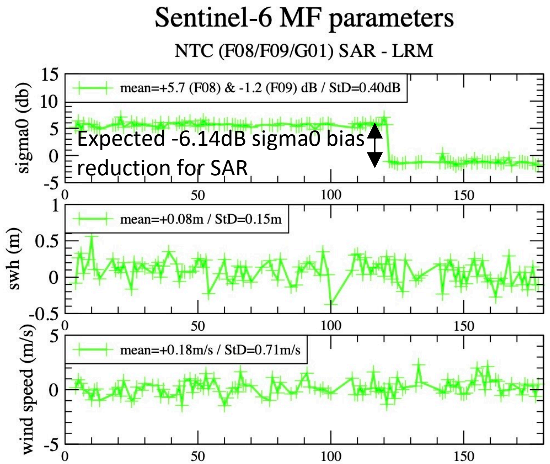
<u>Analysis of the full time series with latest reprocessing available and new reference surface:</u>

- Latest reprocessing (GDR-F) improves the inter-mission consistency and reduce the individual mission’s standard deviations
- Applying the Vertical Land Motion (VLM, -0.31mm/yr) also improves the inter-mission consistency (reduces the standard deviation of the SSH biases time series by ~3mm)
- Waiting for all missions reprocessing in GDR-G (G01) standard to consolidate results

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

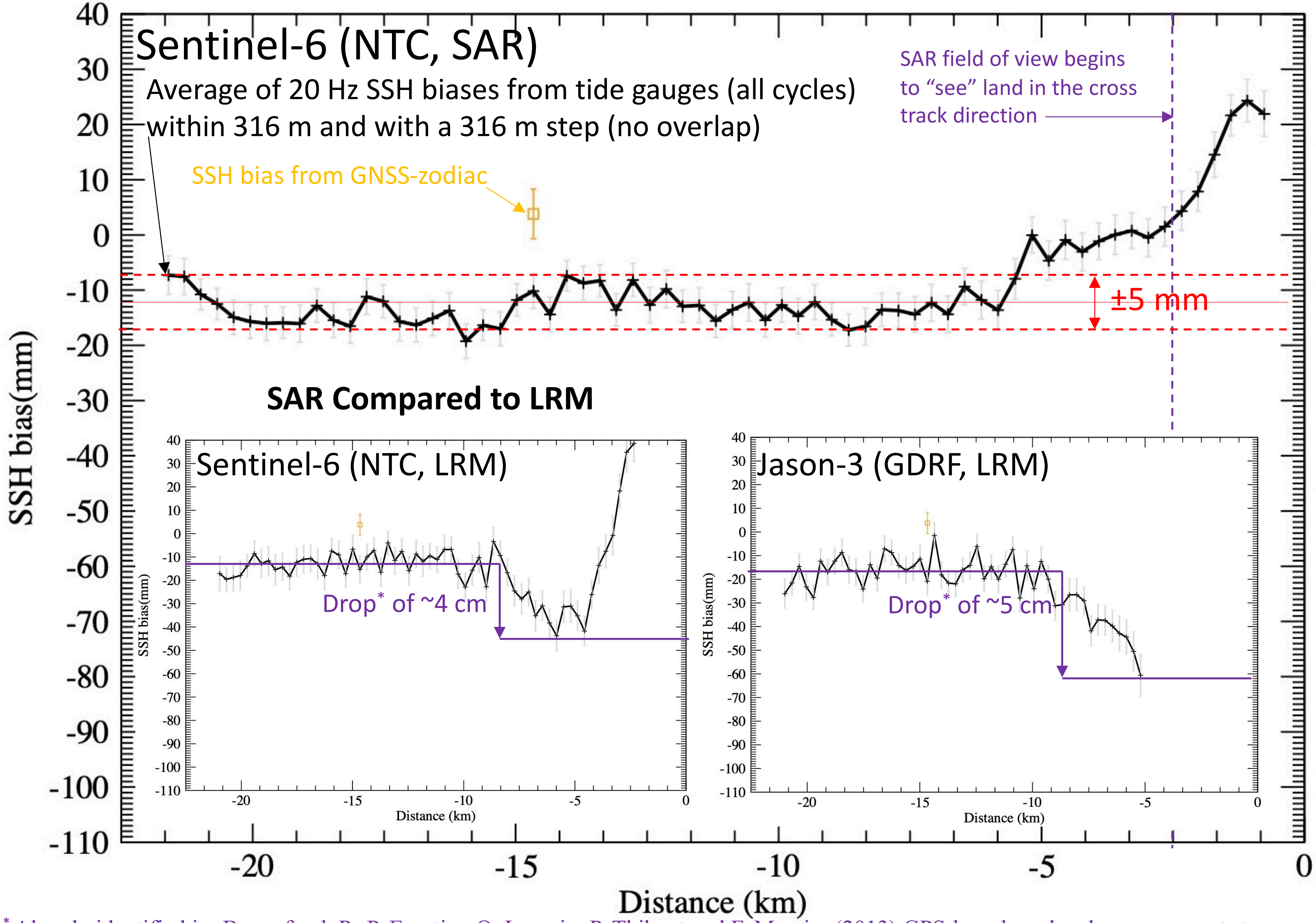






- **Less than 1mm difference in average on the SSH bias between SAR (NTC-HR) and LRM (NTC-LR)** with a mix of side A&B and different processing (F08/F09/G01)
- **-4mm on the SSH bias between side A and Side B (A-B)**
- **Orbit-Range shows a difference of -6.2 mm reduced to -1.5 mm in terms of SSH bias (mainly due to SSB)**
- **8 cm differences in SWH and 0.18 m/s in wind speed (SAR-LRM) is probably the main cause of SSB discrepancy**
- Waiting for Sentinel-6 MF reprocessing in GDR-G (G01) standard to consolidate results

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 ±5 mm (standard deviation of 3 mm)
- Standard error (see error bars) of SAR individual 20Hz data is improved by ~2: 3mm compared to 6mm with LRM (also 6mm for Jason-3)
- The drop in LRM due to land contamination for distance below ~8 km disappears in SAR (comparable drop in LRM for Sentinel-6 MF and Jason-3). More LRM data close to the coast (compared to Jason-3) show an increase of 8cm from ~5km up to the coast while this increase is reduced to ~2cm thanks to SAR and only in the last 3km
- GNSS based sea level measurements (GNSS-zodiac) show a SSH bias higher by ~14mm compared to the one derived from tide gauges: this needs further investigation. Differential approach compared to iPPP one agrees within 3mm.

* 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

Conclusions

<u>Absolute SSH biases:</u>

- **<u>Jason-3 (LRM, GDR-F):</u>** **-18 ±2 mm (over all mission time)**
- **<u>Sentinel-6 MF (LRM, NTC, F08/F09/G01):</u>** **-12 ±3 mm (side B cycle 31 to 178)**
- **<u>Sentinel-6 MF (SAR, NTC, F08/F09/G01):</u>** **-13 ±2 mm (side B cycle 31 to 178)**

- **In situ SSH stability (tide gauges):**
  - **No significant instrumental drift confirmed by internal and external control (<0.1mm/yr)**
  - Vertical Land Motion suggests a **subsidence of the South of Corsica at the level of -0.31mm/yr**
- **Full SSH bias reprocessing for TOPEX/Poseidon, Jason-1,2,3 and Sentinel-6 MF with the new reference surface and latest products' reprocessing:**
  - Latest reprocessing (GDR-F) **improves the inter-mission consistency** and reduce the individual mission's standard deviations
  - Applying the **Vertical Land Motion (-0.31mm/yr) also improves the inter-mission consistency** (reduces the standard deviation of the SSH biases time series by ~3mm)
- **Intermission SSH bias between Jason-3 and Sentinel-6 MF (LRM, side B):**
  - During the first tandem the **relative bias Sentinel-6 MF (F08) – Jason-3 (GDR-F) is +12.5mm** while the difference of absolute biases over the full missions is +5mm
  - Note that it needs to be consolidated because Jason-3 and Sentinel-6 MF products are not the same (respectively GDR-F and a mix of F08/F09/G01)
- **Sentinel-6 MF (NTC-HR, SAR) compared Sentinel-6 MF (NTC-LR, LRM/MLE4):**
  - **Less than 1mm difference in average on the SSH bias** between SAR (NTC-HR) and LRM (NTC-LR) with a mix of side A&B and different processing (F08/F09/G01)
  - Orbit-Range shows a difference of -6.2 mm reduced to ~-1 mm in terms of SSH bias (mainly due to SSB)
  - **Side B SSH bias higher by 4mm compared to Side A**
- **Sentinel-6 MF: Improvement thanks to SAR**
  - **Valid measurements up to the coast (few hundred meters)**
  - Land contamination increases the SSH bias by ~2cm in the last 3km (~8cm for LRM)

Waiting for all missions reprocessing in GDR-G (G01) standard to consolidate results