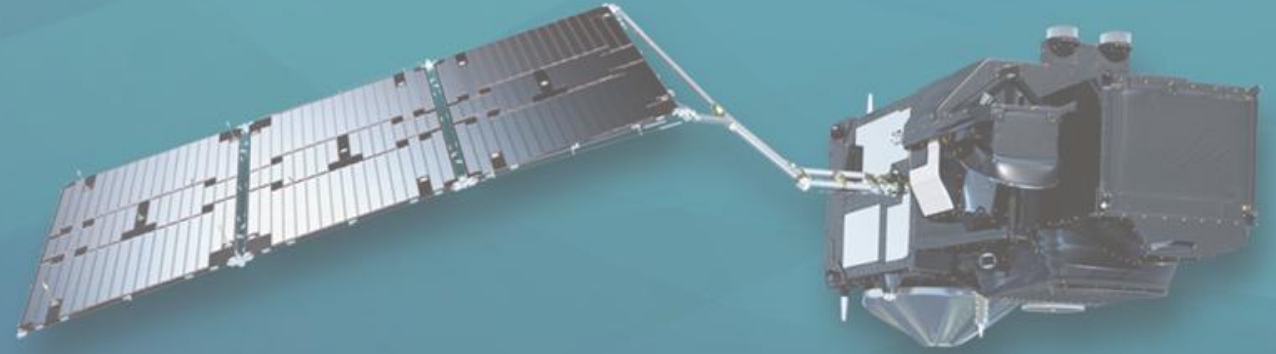




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9th Sentinel-3 Validation Team meeting 2026

30 March–01 April 2026 | ESA–ESRIN | Frascati (Rome), Italy

Global Sentinel-3 versus Tide Gauges comparisons: current results and uncertainty budget

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¹CLS Group (France), ²EUMETSAT (Germany), ³CNES (France)



Context



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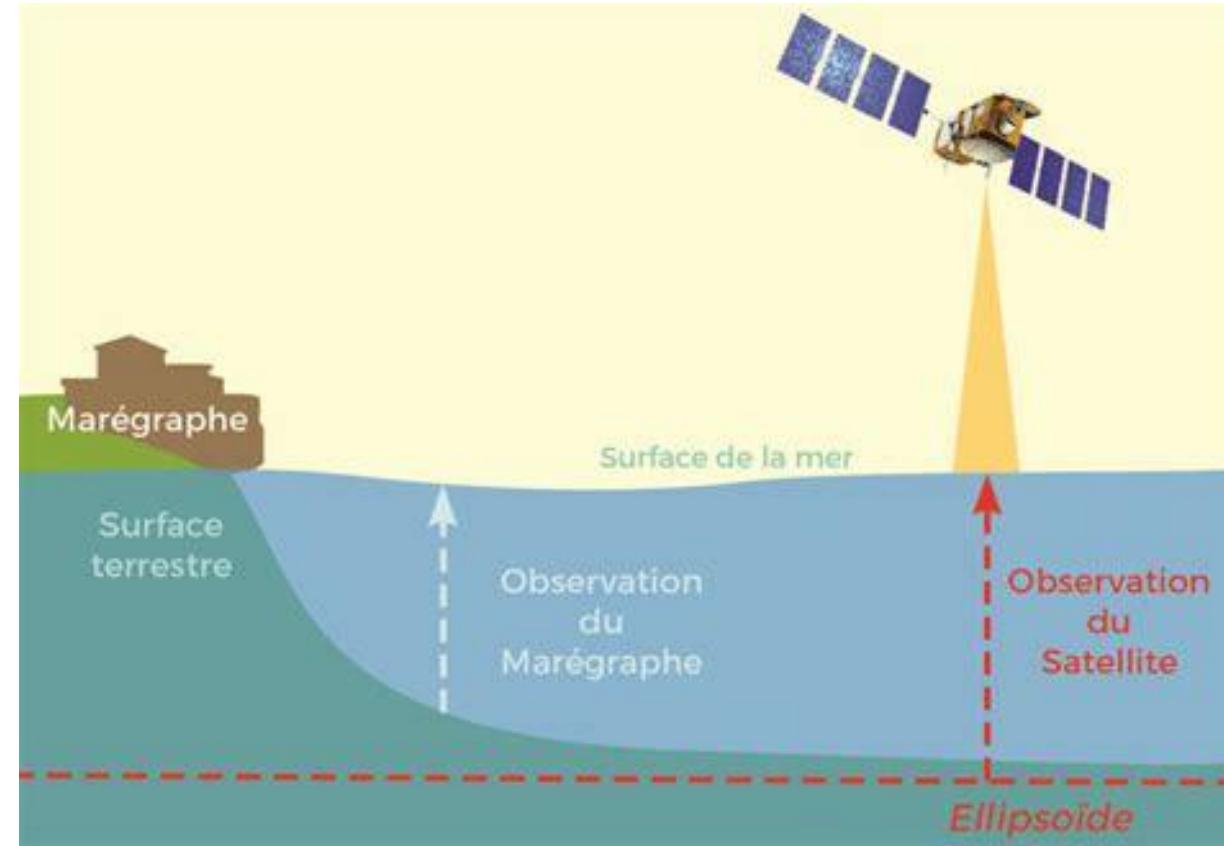


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- Tide gauges (TG) are measuring the coastal sea level,
- Completely independent from satellite altimetry,
- Challenges to retrieve the global mean sea level are different with these two measurement systems,
- It is interesting to compare observations from both systems.

- Work performed in the frame of the **COPAS** project funded by **EUMETSAT** and the **SALP** project funded by **CNES**.



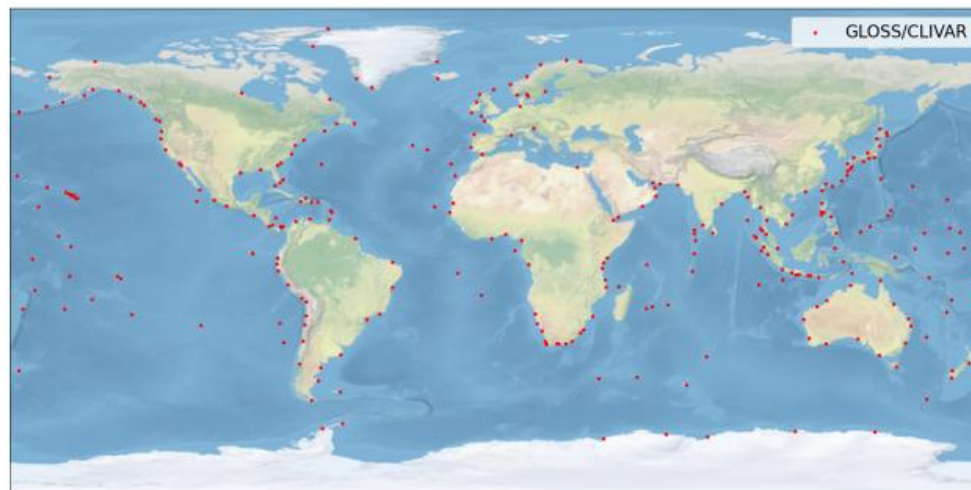
SERVICE
ALTIMETRIE
&
LOCALISATION
PRECISE

- Two tide gauges network :

- GLOSS/Clivar maintained by the University of Hawaii (<https://uhslc.soest.hawaii.edu/>) – hourly data from 300 stations
- PSMSL retrieved from the Permanent Service for Mean Sea Level (<https://psmsl.org/>) – monthly data from 1200 stations

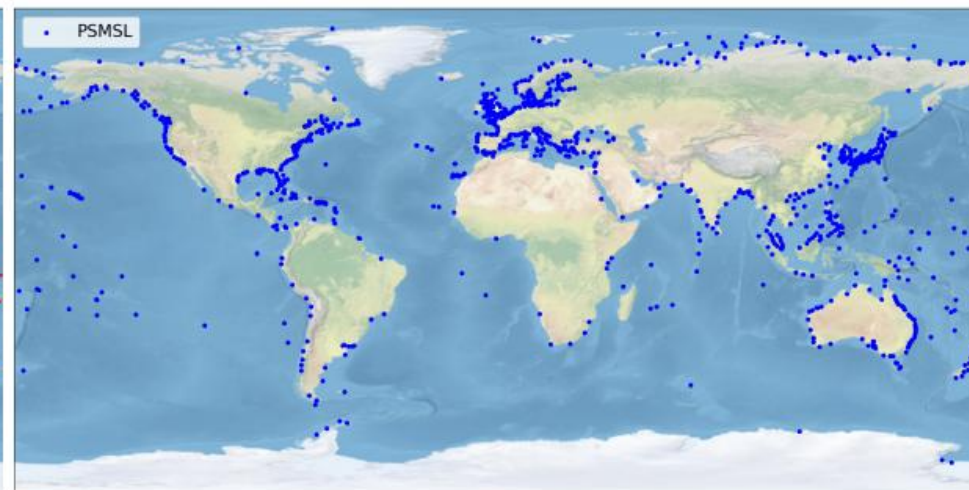
- Maps of locations of in-situ stations are available in the following figure

Locations of tide gauges stations



GLOSS/
Clivar
(GC)

Locations of tide gauges stations



PSMSL

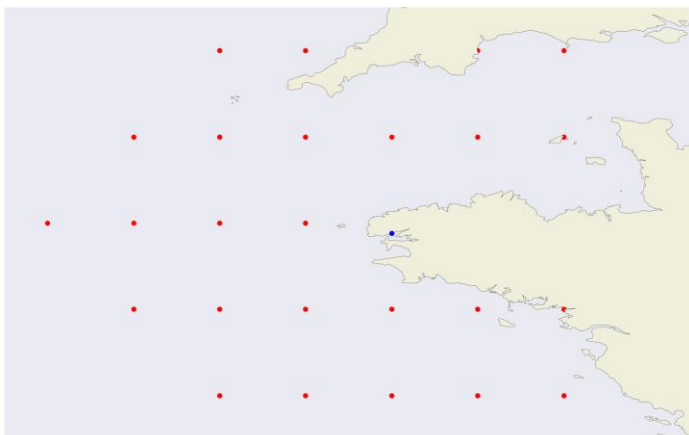
- Tide gauges data are corrected for **ocean tides(1)**, **dynamical atmospheric correction(2)**, **pole tides(3)** and **vertical land motion(4)**.
 - (1): corrected in altimetry measurements so this low frequency signal is also corrected in tide gauges measures, (NB: on hourly GC data, a Demerliac filter is also applied to remove the high frequency signal of ocean tides)
 - (2): response to pressure and wind forcing,
 - (3): same model as the one used in along track SSHA products,
 - (4): corrected with a Glacial Isostatic Adjustment (GIA) model : response of the solid earth to the latest deglaciation.
- Altimetry data are obtained with the following formula with 1 Hz products:

$$SSHA = Orbit - Range - MSS - \sum corrections$$

- The comparison between altimetry and TG data consists in two steps :
 - **Colocation** of Alti/TG measurements,
 - **Interpolation** of TG measurements on altimetry times.

Cells of 1°x1° grid around the Tide Gauges at Brest

Blue: Tide Gauges - Red: cells positions

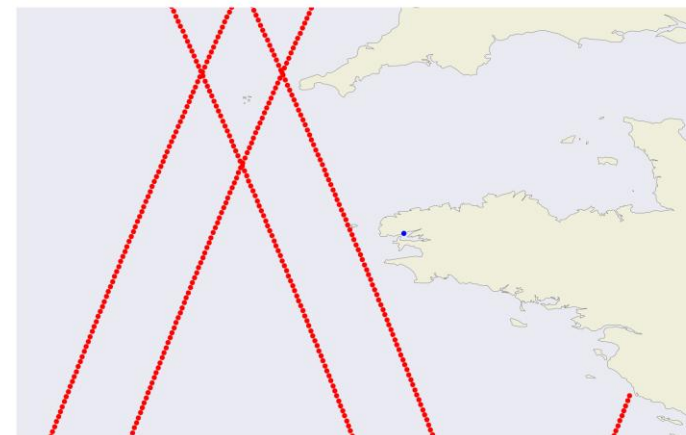


Altimetry data averaged in a grid of 1°x1°, 3 methods:

- Best correlated time series,
- Linear spatial interpolation on TG position,
- Nearest spatial interpolation on TG position

Along track S3A positions around the Tide Gauges at Brest

Blue: Tide Gauges - Red: along track positions



Along track altimetry data, 2 methods:

- Linear spatial interpolation on TG position,
- Nearest spatial interpolation on TG position

- The comparison between altimetry and TG data consists in two steps :
 - **Colocation** of Alti/TG measurements,
 - **Interpolation** of TG measurements on altimetry times.

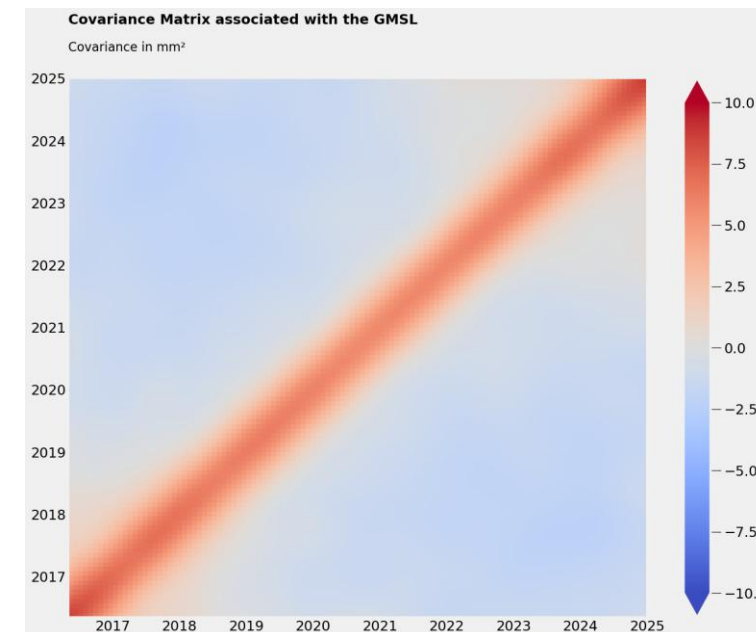
- **Three criteria** are applied in order to select time series kept among all stations for the global comparison:
 - $Corr(SLA_{ALTI}, SLA_{TG}) > 0.7$,
 - $STD(SLA_{ALTI} - SLA_{TG}) < 10 \text{ cm}$,
 - $Max(SLA_{ALTI} - SLA_{TG}) < 12 \text{ cm}$.

- **Estimation of relative trend and uncertainties.**

(1) Uncertainty budget

Time correlation	Network	Uncertainty at 1σ level [mm]	
		Sentinel-3A (SAR/PLRM)	Sentinel-3B (SAR/PLRM)
λ = 6 months	GC	2.4/2.5	2.8/3.2
	PSMSL	2.5/2.5	3.1/3.4
λ = 1 year	GC	1.1/1.0	1.4/1.3
	PSMSL	1.1/1.1	1.4/1.5
λ = 3 years	GC/PSMSL	1.0	
λ = 10 years	GC/PSMSL	1.0	
drift	GC/PSMSL	0.2 mm/yr	

Table 2: Uncertainty budget for the estimation of GMSL drifts between altimetry and TG networks (GLOSS/Clivar and PSMSL). Value derived from estimations made in 2024 [1].



(2) Covariance matrix



(3) Trend and uncertainties estimates with an OLS (ordinary least square) estimator:

$$\tilde{\beta} \sim \mathcal{N}(\operatorname{argmin}((y - X\beta)^T (y - X\beta)), (X^T X)^{-1} X^T \Sigma X (X^T X)^{-1})$$

Results – long term monitoring of SLA differences



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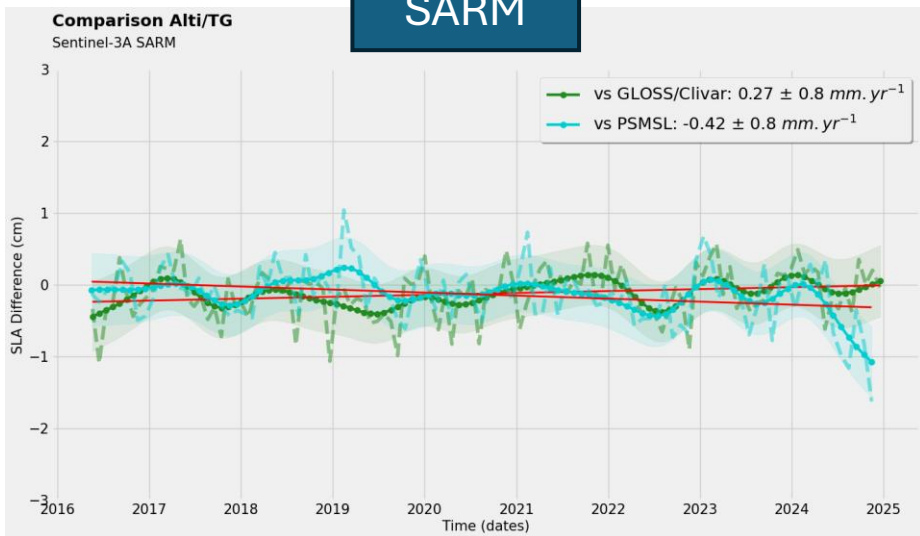
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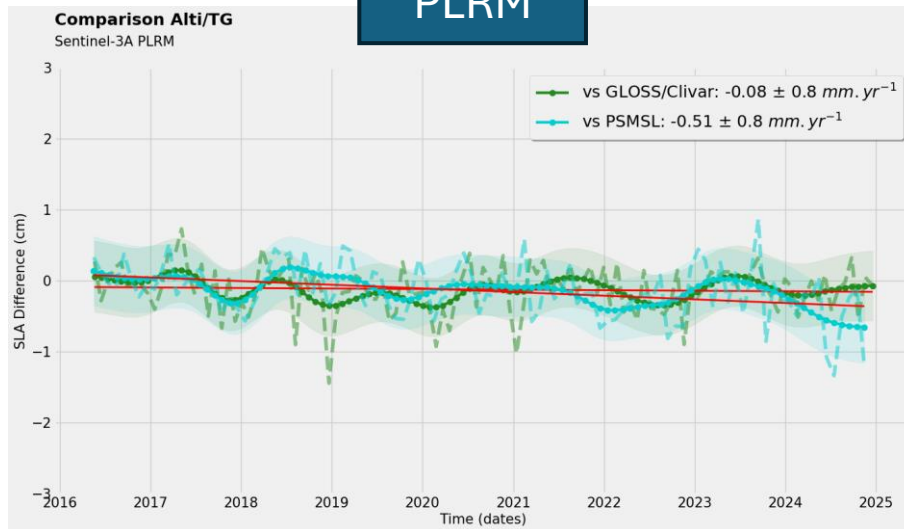


S3A

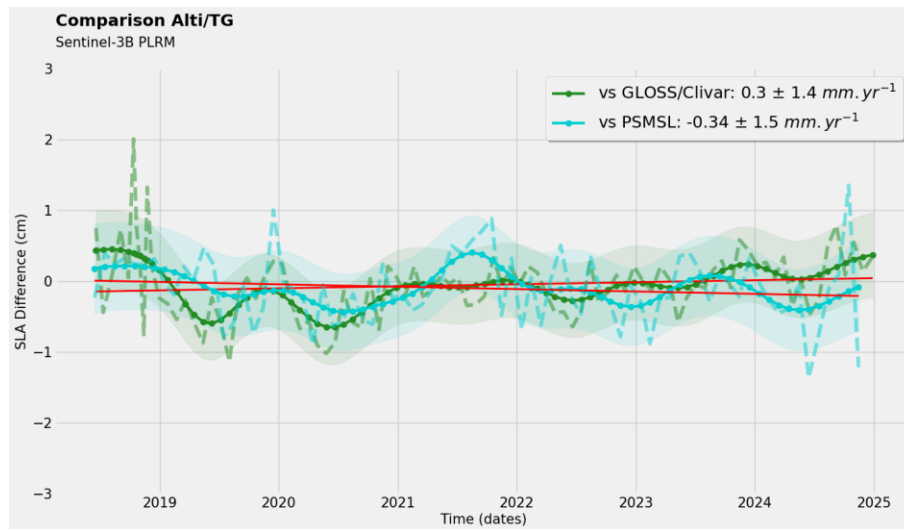
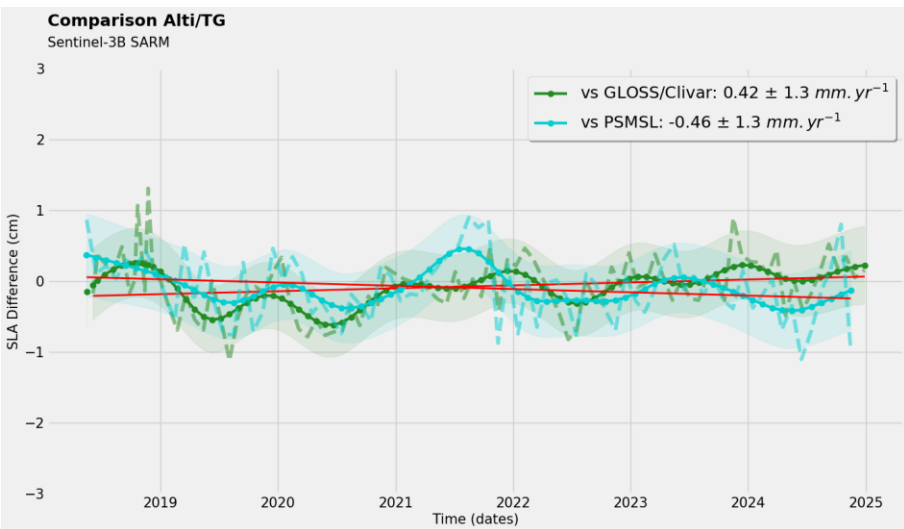
SARM



PLRM



S3B



Uncertainty budget of the method



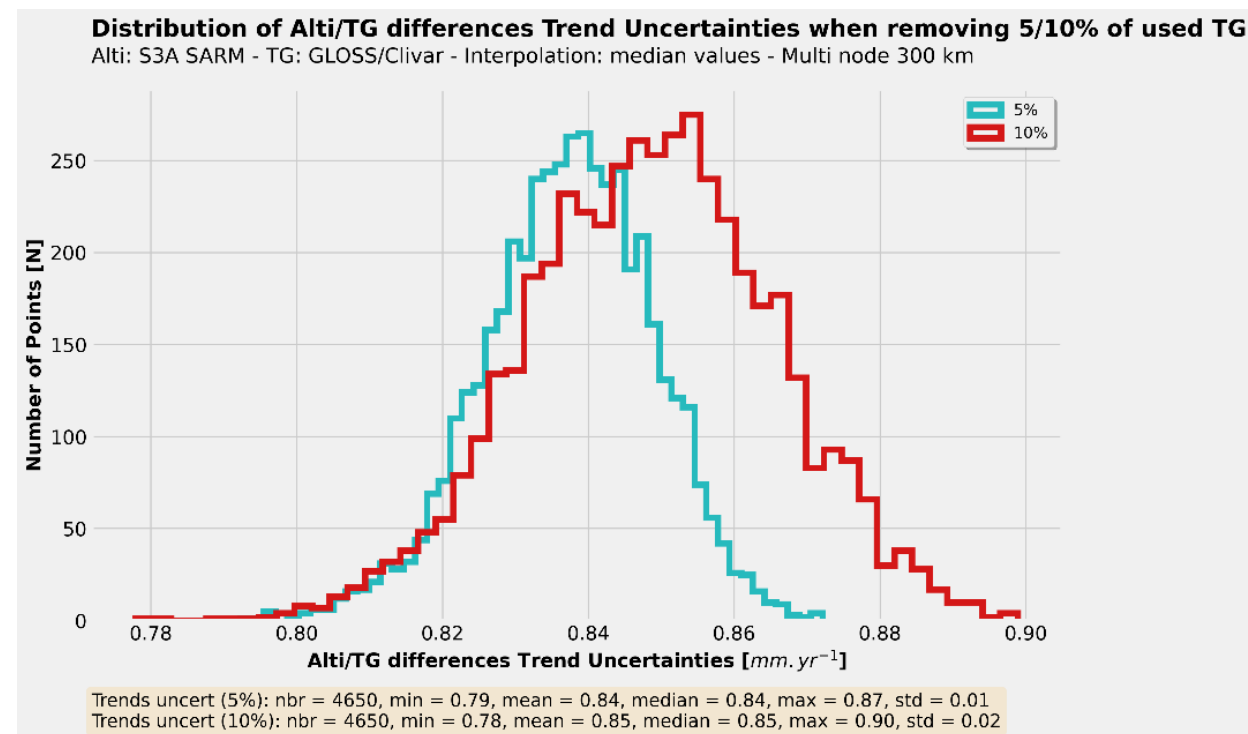
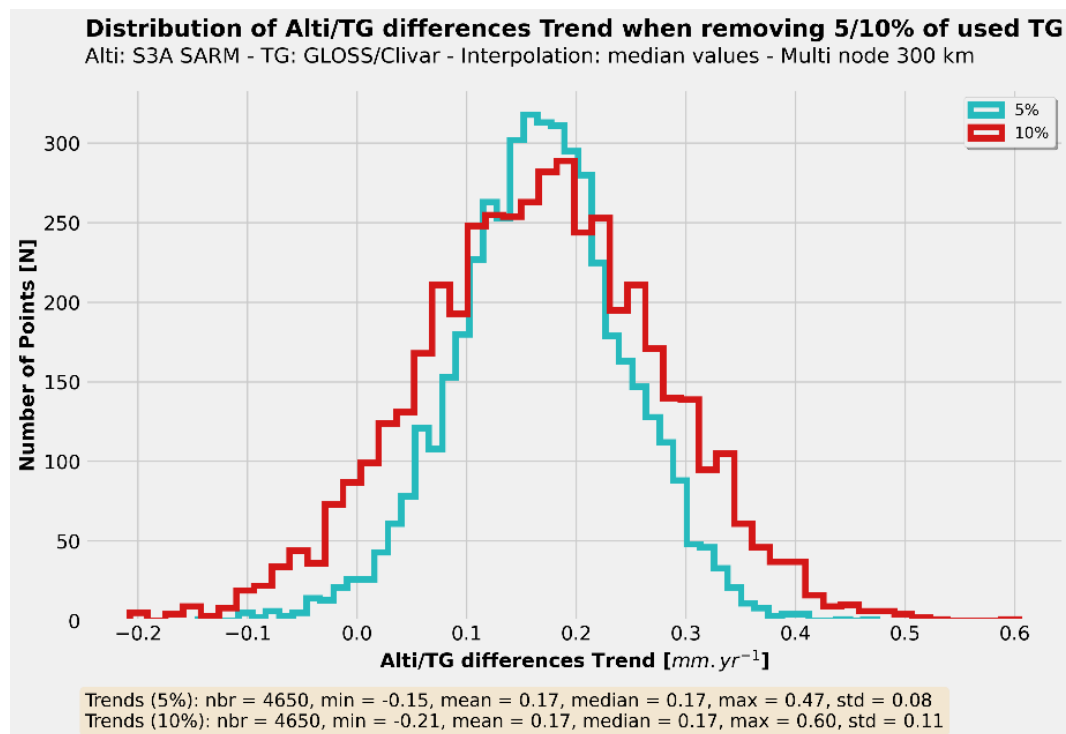
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- Number of available tide gauges
 - Significant variability ($\sim 50\%$ at 1σ) of the trend estimate when removing 5 to 10 percent of available TG,
 - Expected impact on the associated uncertainty (less tide gauges \rightarrow higher uncertainty).



Uncertainty budget of the method



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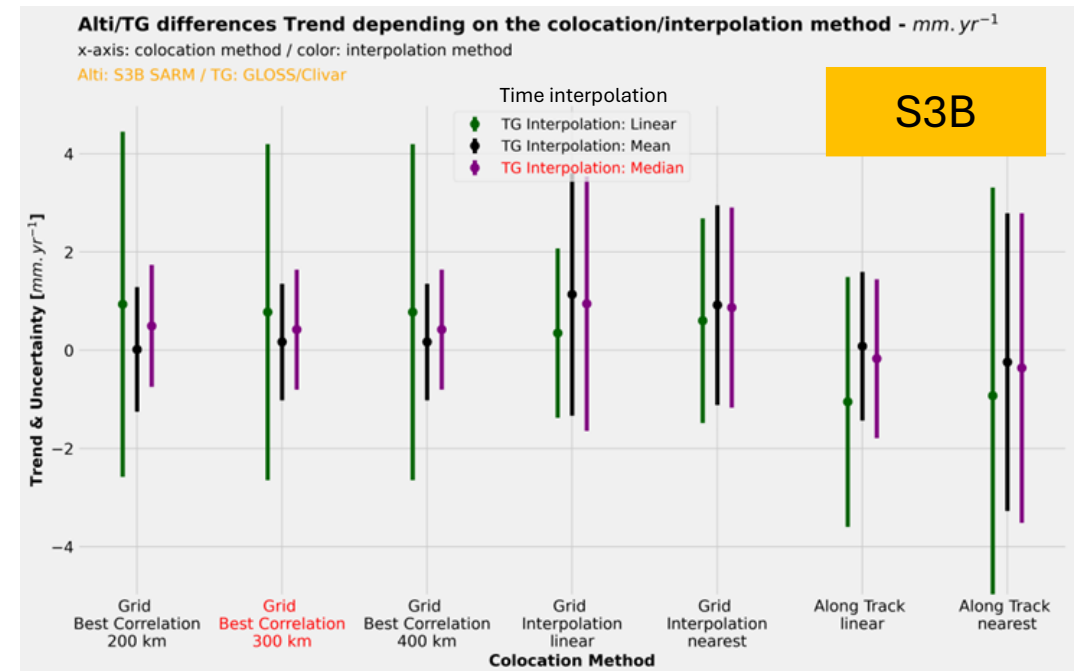
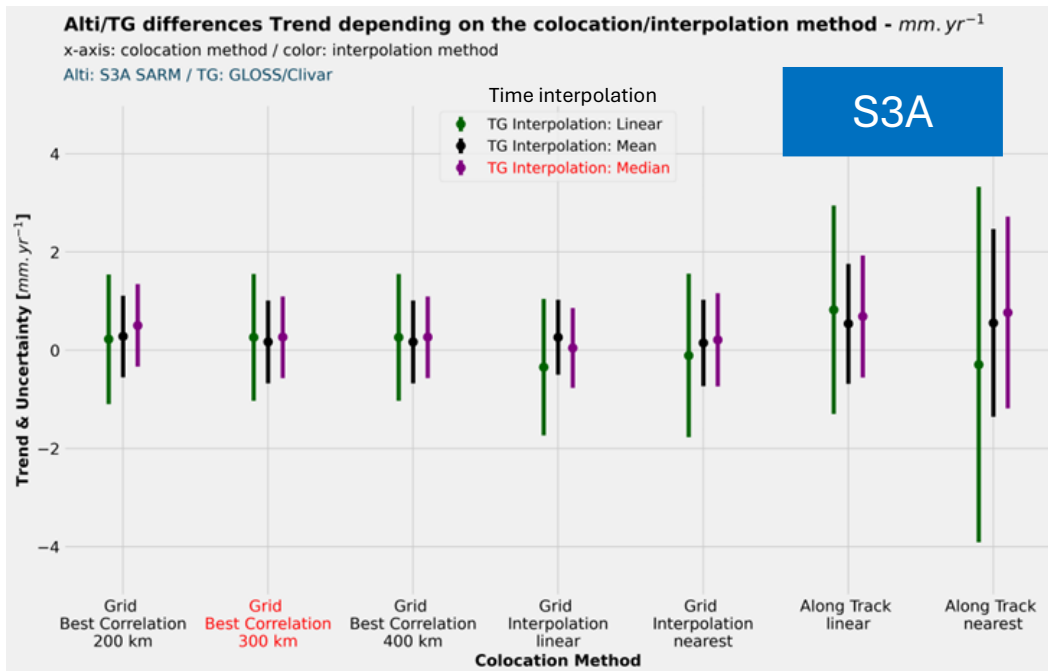


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- Choice of the collocation/interpolation methods:
 - Various examples of method for altimetry/tide gauges collocation,
 - Various possibility for the interpolation of tg data over altimetry times,
 - No significant impacts on both trend estimates and associated uncertainties.
- Default choices in the processing chain for alti/TG comparisons in red



Uncertainty budget of the method



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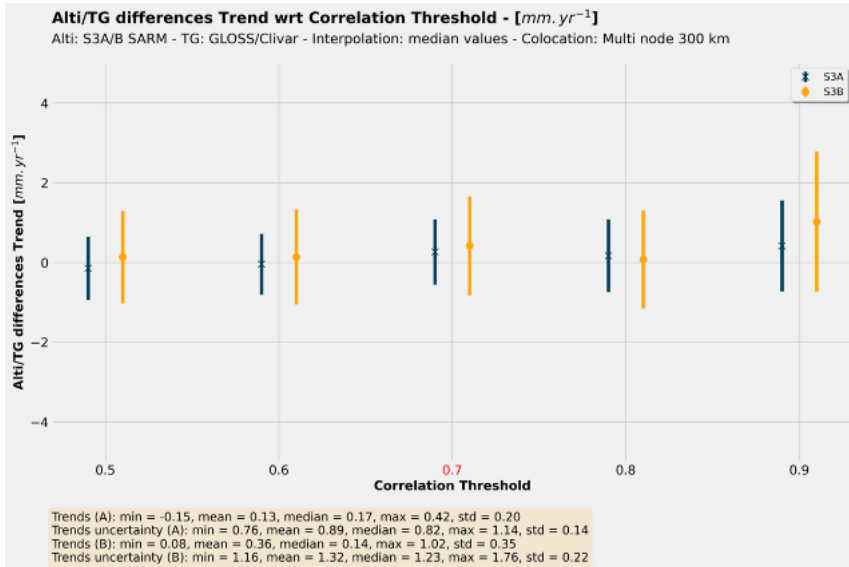


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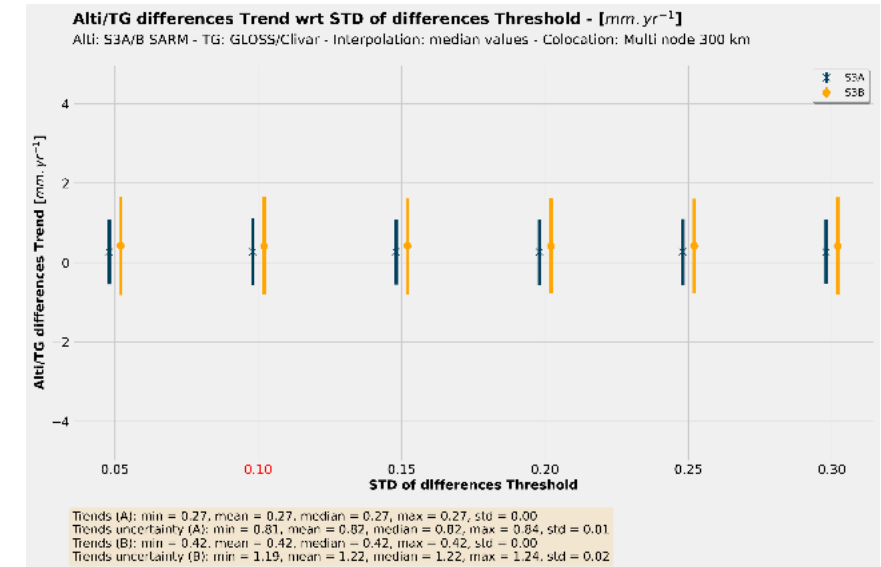
- Choice of the correlation & the STD thresholds :



Correlation

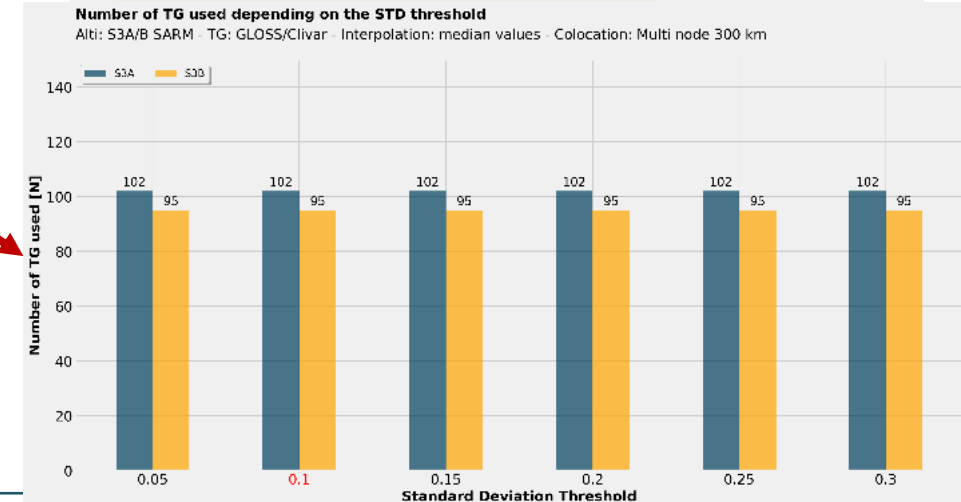
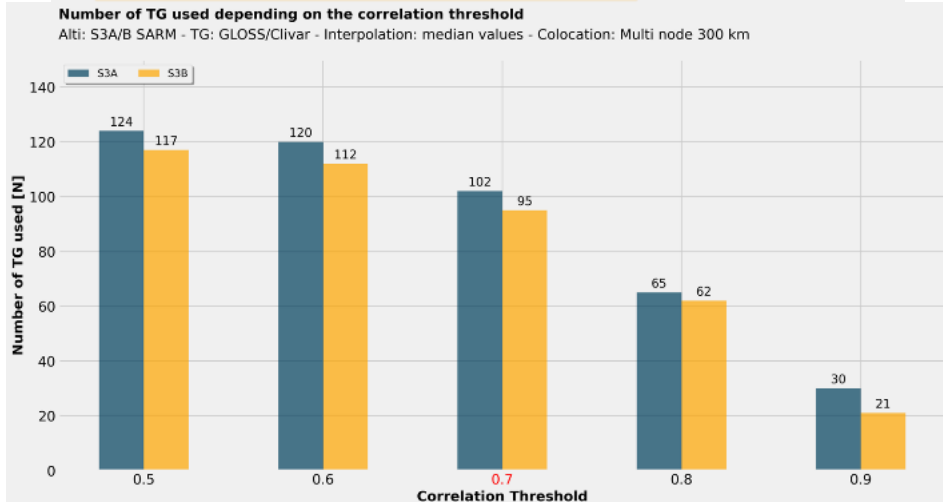
threshold:

➤ Impact through the number of available tide gauges



STD threshold:

➤ No impact on TG selection so no impact on trend estimates



Results – long term monitoring of SLA differences



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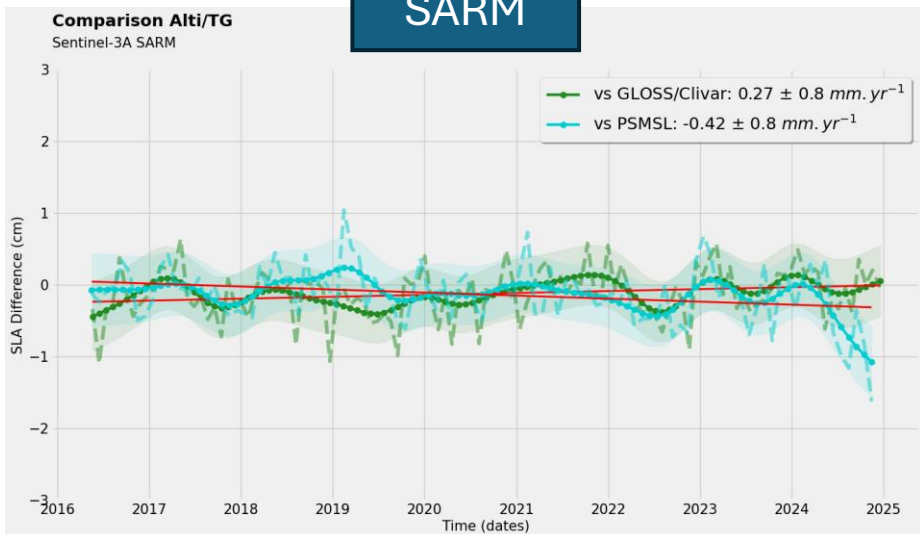
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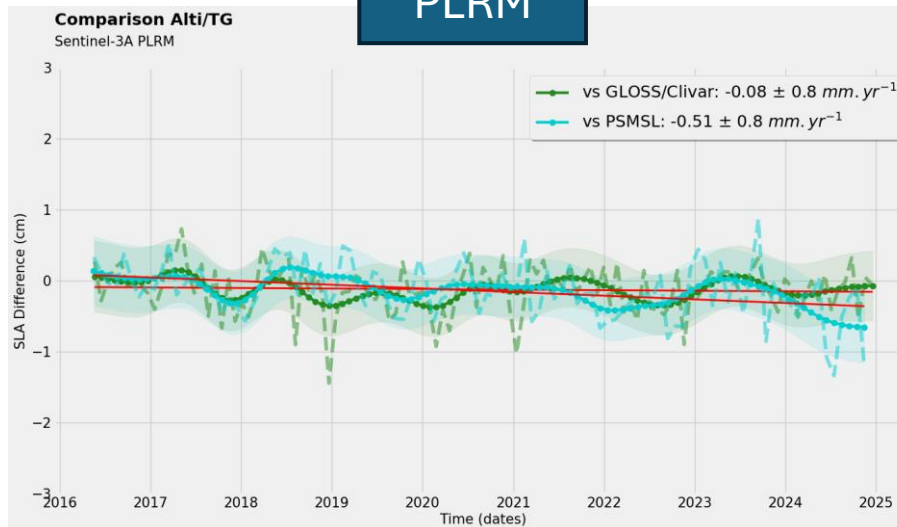
COLLECTE LOCALISATION SATELLITES

S3A

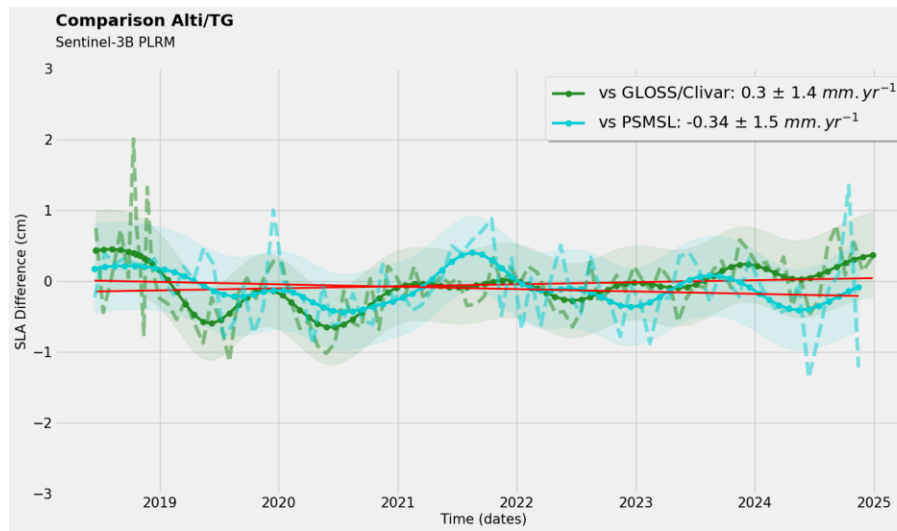
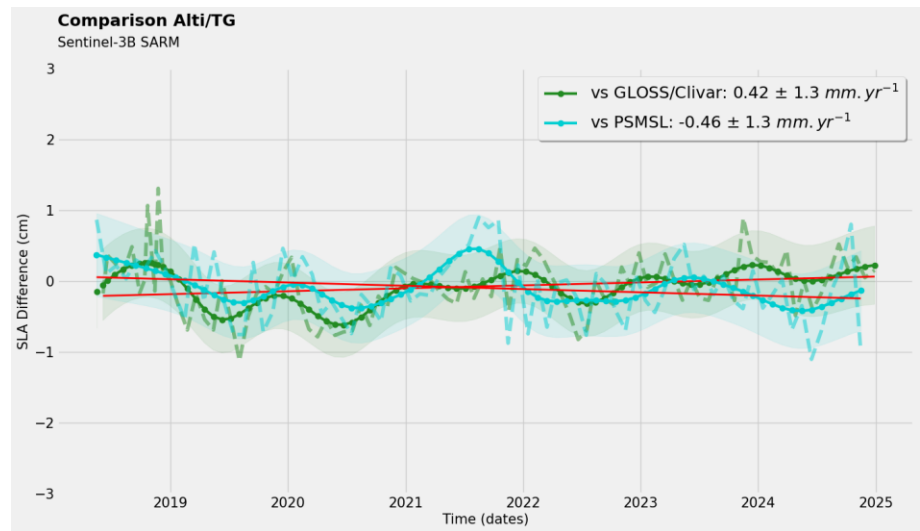
SARM



PLRM



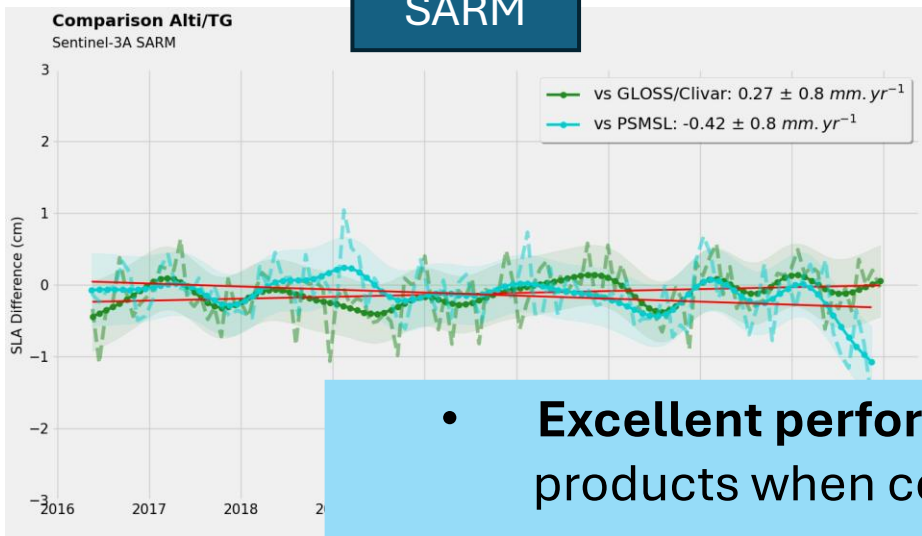
S3B



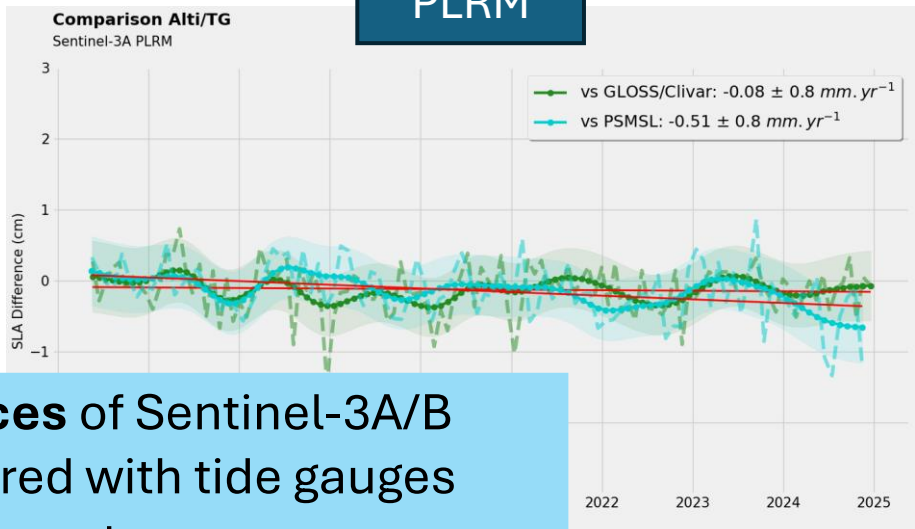
Results – long term monitoring of SLA differences

S3A

SARM

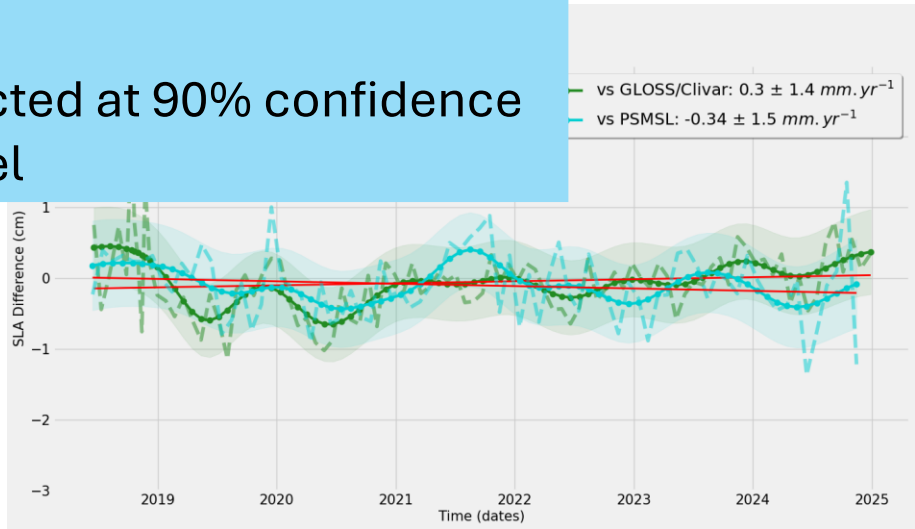
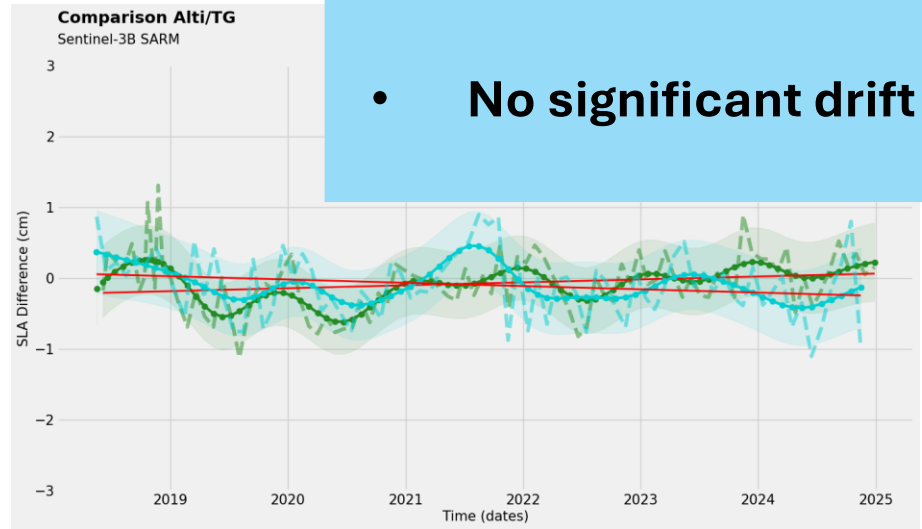


PLRM



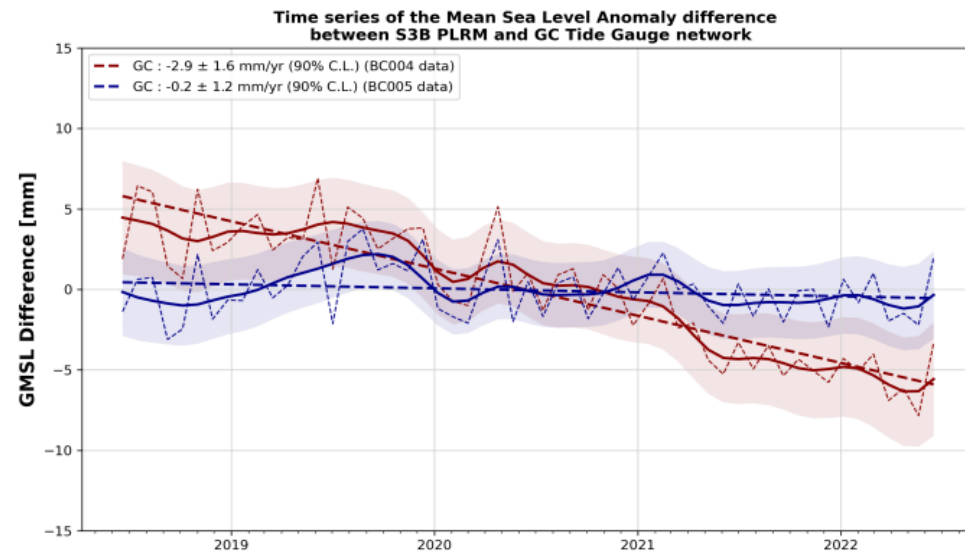
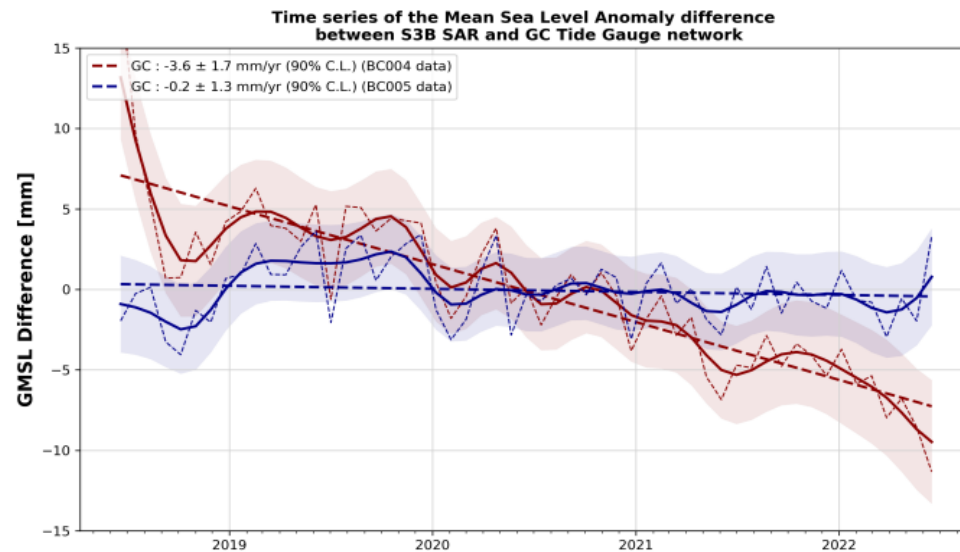
- **Excellent performances** of Sentinel-3A/B products when compared with tide gauges measurements
- **No significant drift** detected at 90% confidence level

S3B



Results – long term monitoring of SLA differences

- Sentinel-3B data was affected by an USO sign reading. It impacted both SARM and PLRM data.
- An important drift was derived from S3B data with respect to other altimeters and Tide Gauges.



S3B compared with GLOSS/Clivar data SARM (left) and PLRM (right)

!! Old plots: not to be compared with previous slide !!

About the use of Vertical Land Motions (VLM)



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- A wrong description of vertical land motions leads to an important component of the current definition of the uncertainty budget.
- Various datasets obtained with different methods and measurement systems are available:
 - SAR-Interferometry (Copernicus European Ground Motion Service)
 - GNSS (four processing center of some GNSS stations)
- The use of such measured VLM can lead to two main impacts:
 - A decrease in altimetry vs tide gauges uncertainties,
 - A better definition of a relative sea level variable for the CCI project.

- **Weak sensitivity** to the **colocation/interpolation method**.
- **Sensitivity** to the **number of available tide gauges** for the global comparison:
 - No change in the mean estimated relative drift between altimetry and tide gauges over a few thousand tests,
 - Significant variability ($\sim 50\%$ at 1σ) between various tests.
- **Sensitivity** to the **correlation threshold** through the change in the **number of available tide gauges** and the quality of the comparison between added/removed tide gauges and altimetry.
- The estimated uncertainty budget is attempting on taking into account these variations due to the choice of the method or the parameterization.

- A possible perspective could be the study of the choice of tide gauges for the global comparison: a possible method would be to estimate the area of influence of each TG and average altimetry values inside this area to compute the collocated altimetry time series.

Thank you for your attention

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