OSTST – 2023/11/09 - Regional and Global CAL/VAL for Assembling a Climate Data Record

Estimation of the Topex A / Topex B bias – A multi methods approach

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Context and goals of the study

Context :

- In February 1999, Topex satellite switch from the first instrument (Topex A) to the second one (Topex B). This change has an impact on the continuity of the measurement of the mean sea level : a jump is observed in the Sea Level Anomaly time series (see figure1).
- The release of the latest Topex reprocessed data (GDR-F) is an opportunity to work on the estimation of the bias between TPA and TPB data.

Study's objectives :

- The first one is to insure the continuity of the mean sea level measurement from 1993 as it is defined as an essential climate variable (ecv) by the Copernicus Climate Change Service. Moreover, this bias value is important for the next reprocressing of L2P products (L2P DT 24).
- The second one is about the error budget of the mean sea level. Errors of bias estimation between missions are an important component of the GMSL parameters' uncertainties (trend and acceleration), and the error related to the TPA/TPB bias is about ten times higher than others bias errors (see Guerou et al. 2023 – see figure 2). The current estimation of the uncertainty associated with the TPA/TPB bias is 2 mm (see Ablain et al. 2009). This study aims to give a new estimation of this uncertainty.

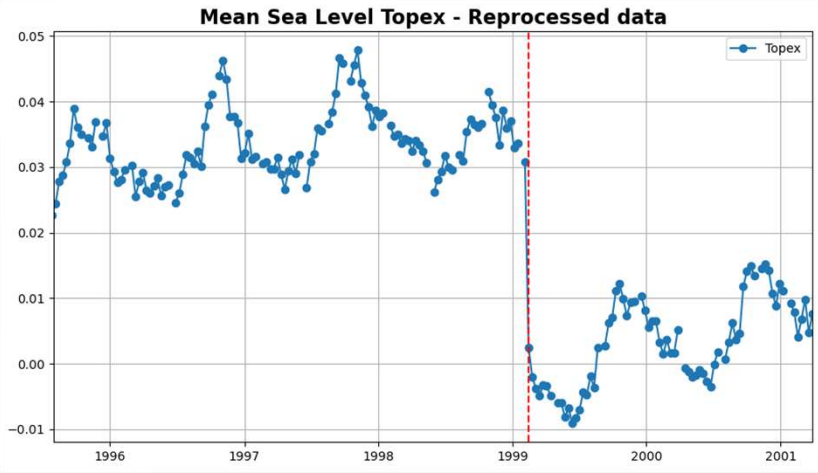


Figure 1

Source of uncertainties	Type of errors	Uncertainty (1σ)	Method / References
Altimeter noise / geophysical corrections	Correlated errors λ =2-months	$u_\sigma = 1.7$ mm over TP period $u_\sigma = 1.2$ mm over J1 period $u_\sigma = 1.1$ mm over J2 period $u_\sigma = 1.0$ mm over J3 period	This paper (Sect. 2.3)
Geophysical corrections / orbit	Correlated errors λ =1-year	$u_\sigma = 1.4$ mm over TP period $u_\sigma = 1.2$ mm over J1 period $u_\sigma = 1.1$ mm over J2 period $u_\sigma = 1.1$ mm over J3 period	This paper (Sect. 2.3)
Radiometer WTC	Correlated errors λ =5-years	$u_\sigma = 1.1$ mm over TP, J1, J2 periods $u_\sigma = 1.8$ mm over J3 period	Legeais et al. (2014) Thao et al. (2014) This paper (Sect. 2.3)
Orbits determination	Correlated errors λ =10-years	$u_\sigma = 1.12$ mm over TP period $u_\sigma = 0.5$ mm over Jasons period	Couhert et al. (2015); Rudenko et al. (2017)
Intermissions calibration offsets	Bias	$u_\Delta = 2mm$ for TP-A/B $u_\Delta = 0.3mm$ for TP/J1 $u_\Delta = 0.1mm$ for J1/J2 $u_\Delta = 0.2mm$ for J2/J3	This paper (sec. 2.2.1)
International Terrestrial Reference Frame (ITRF)	Drift	$u_\delta = 0.1mm/yr$ over 1993-present	Couhert et al. (2015)
Global Isostatic Adjustement (GIA)	Drift	$u_\delta = 0.05mm/yr$ over 1993-present	Spada (2017)
Topex-A/-B altimeter drift	Drift	$u_\delta = 0.7mm/yr$ over TP-A period $u_\delta = 0.1mm/yr$ over TP-B period	Ablain et al. (2017)

Figure 2
From Guerou et al. 2023

Presentation of various methods and hypotheses

Constraints on the estimation of the TPA/TPB bias :

- The switch between both instruments occurred during a strong El Nino event (ENSO) so the natural dynamic of the ocean was really high
- This kind of event could introduce natural non linearities in the mean sea level that are not well understood
- No tandem phase could be carrie out

Various methods tested in this study :

- **Constant** method:
  - The idea is to suppose that the GMSL does not change before and after the Topex A/B switch
  - The mean of values of MSL measured by Topex A before the switch over N cycles is equal to the mean of MSL measured by Topex B after the switch over the same amount of cycles.
  - Really strong hypothesis, but it gives a first approximation of the bias value
- **Most linear** method :
  - The idea is to suppose that the GMSL has a linear evolution over a 10 years period around the Topex switch.
  - The trend of the GMSL and the associated uncertainty can be computed over 10 years with an OLS (Ordinary Least Square) with various values of bias. The bias giving the lower uncertainty on the trend is the one kept.
  - Still a strong hypothesis as we know the GMSL is accelerating
- **Comparison** with an other satellite altimetry mission : **ERS-2**
  - The hypothesis is that over a same period (10 days), both Topex and ERS-2 missions measure approximately the same ocean.
  - The difference of GMSL measured by Topex and ERS-2 with the same temporal sampling should be constant.
  - The second hypothesis made here is the stability of ERS-2 data over the time period studied.

Description of used datasets

Used datasets:

- Topex : The goal of the study is to estimate the bias of the mean sea level of the latest reprocessed data. Thus, Topex data used in this study are GDR-F.
  - Please note that the empirical Topex A drift (see Ablain et al. – OSTST 2017) was not applied to this dataset for this study as it was computed on MGDR Topex data. There is no evidence that this empirical correction should be applied to this new dataset without any update.

- ERS-2 : two datasets were used. The goal was to quantify the impact of the choice of the auxiliary dataset on the results obtained
  - L2P DT 21 data : latest reprocessed L2P data
  - FDR4ALT data : latest reprocessed ERS-1, ERS-2 and ENVISAT from FDR4ALT ESA project (see 'Excellent performances of the newly reprocessed ERS-1, ERS-2 and ENVISAT products for altimetry and radiometry : the FDR4ALT products' by F. Piras et al. In the Regional and Global CAL/VAL for Assembling a Climate Data Record session for more details about this dataset)

Results obtained – Constant Method

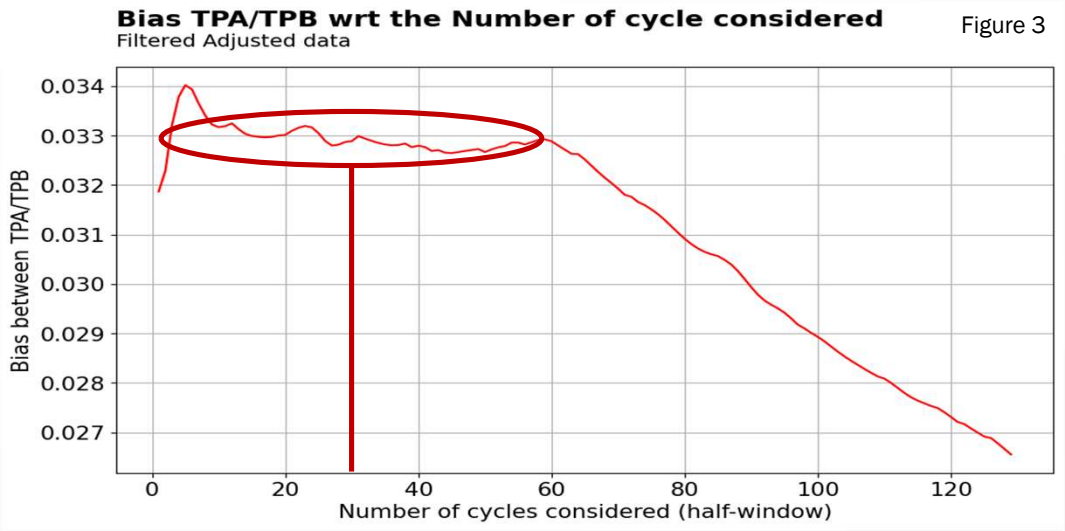


Figure 3

Hypothesis : The mean of the GMSL measured by Topex is equal before and after the switch from TPA to TPB instrument.

With a 30 cycles half-window :
Estimated bias value : **3,3 cm** (3,30 with a 10^-2 precision)

Associated uncertainty (Ablain et al. 2009) : **2 mm** (**3 mm** given in Cazenave et al. 2018)

Results obtained – Constant Method

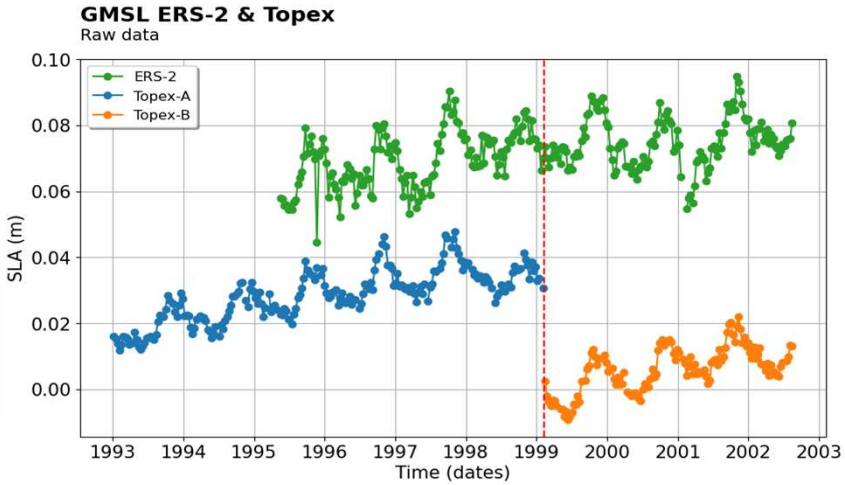


Figure 4

Correction of the Topex bias with the constant method

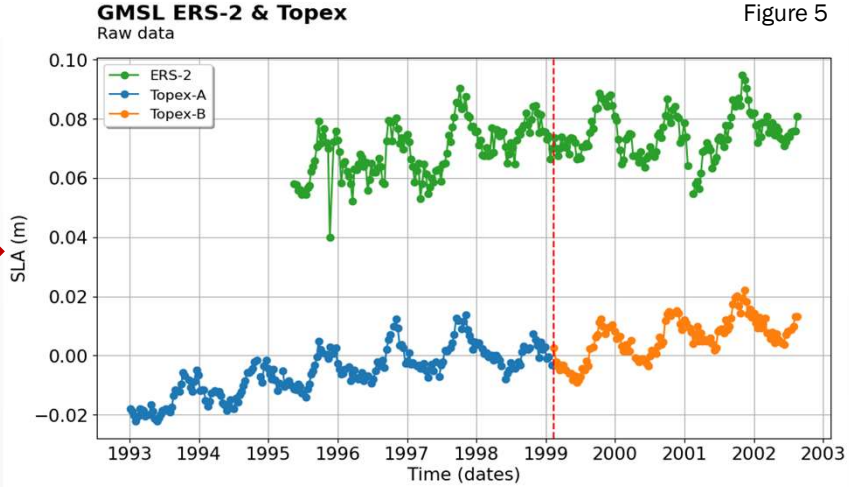
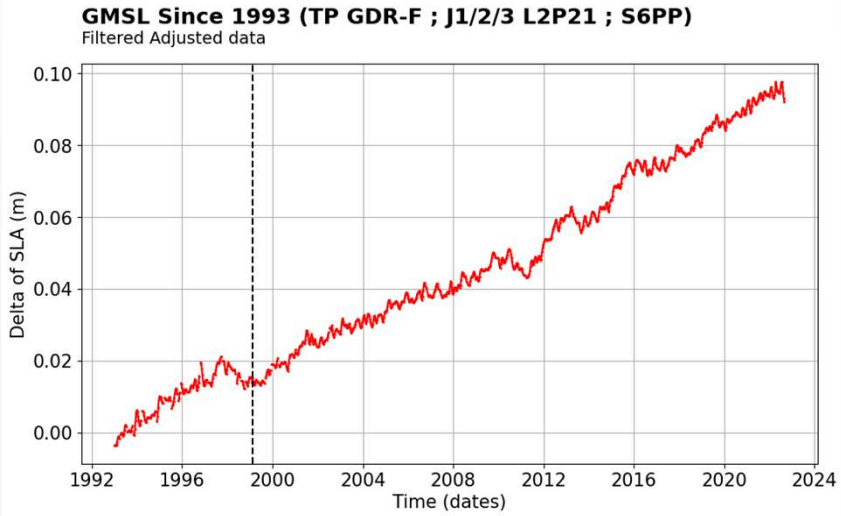


Figure 5



Trend : 3,16 ± 0,32 mm.yr^{-1}
Acceleration : 0,17 ± 0,05 mm.yr^{-1}

Figure 6

Results obtained – Most Linear Method

Hypothesis : The GMSL is as linear as possible over 10 years around the switch from TPA to TPB instrument

Figure 7

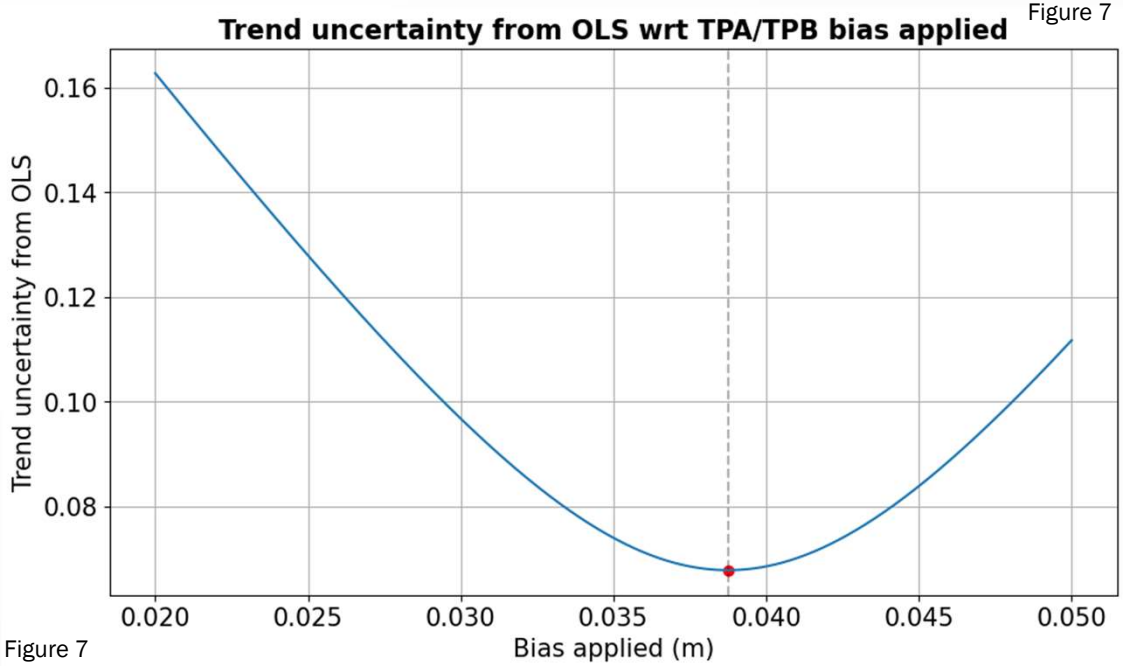


Figure 7

Bias estimated with the most linear method : **3,9 cm** (3,87 with a 10^-2 precision) (consistent with Adrien Guerou's results with this method)

Estimation of the uncertainty : see slide 10

Figure 8

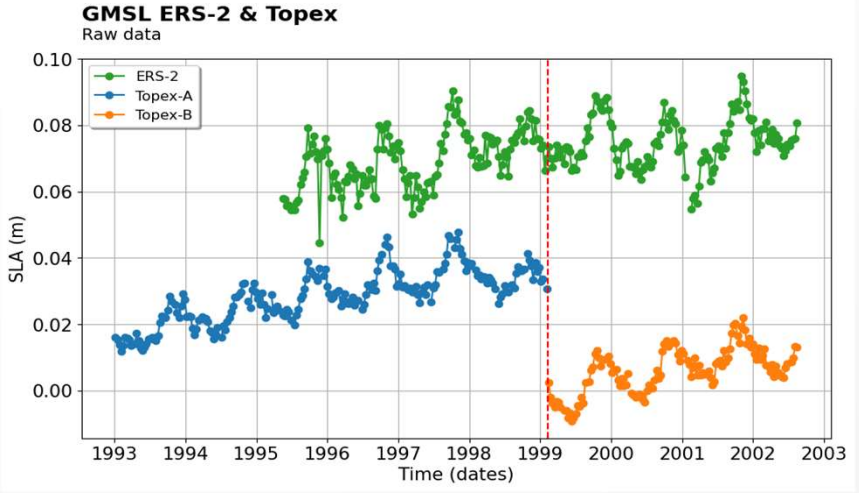
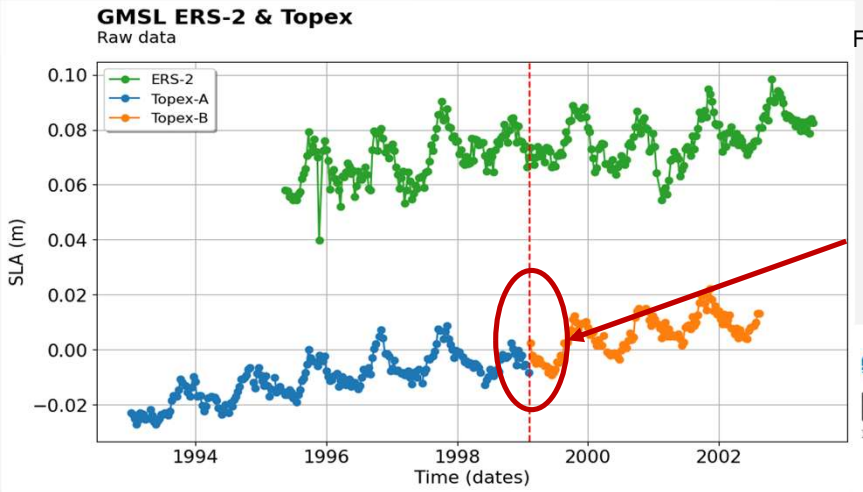


Figure 9



The bias seems to be overestimated

Results obtained – Most Linear Method

Hypothesis : The GMSL is as linear as possible over 10 years around the switch from TPA to TPB instrument

Figure 10

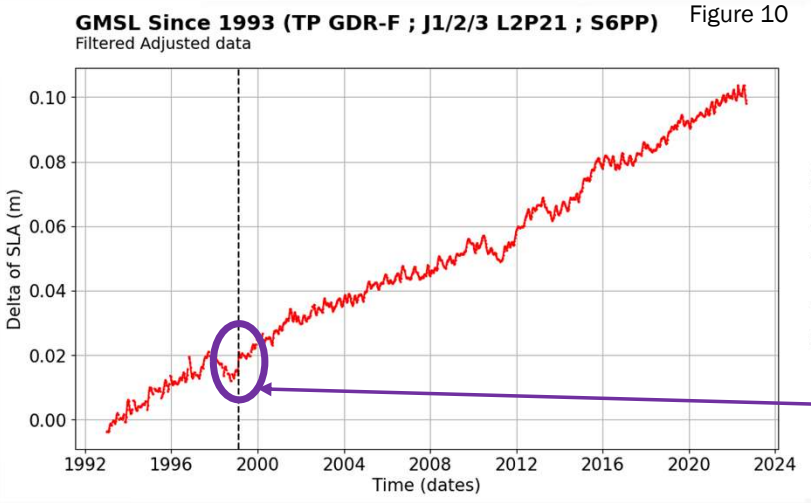
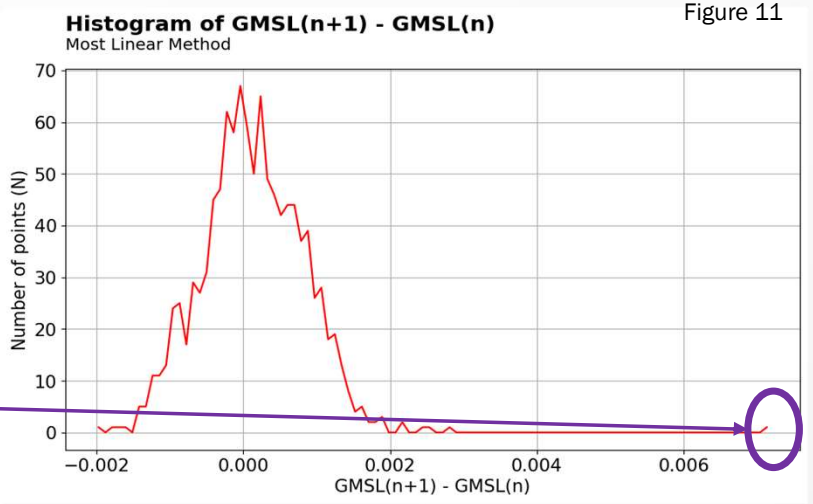


Figure 11



Trend : 3,36 ± 0,32 mm.yr^{-1}
Acceleration : 0,09 ± 0,05 mm.yr^{-1}

A non physical jump is observed on the GMSL since 1993 after the bias estimated with the most linear method was applied.

The histogram of the GMSL(n+1) – GMSL(n) confirms an outlier in differences between two consecutive cycles.

This method should not be considered to estimate this bias.

Results obtained – Constant & Most Linear Method

Another way to obtain an estimation of the uncertainty is to apply both methods at each step of the time series

The standard deviation of all bias values obtained can be considered as a measure of the uncertainty associated with the method itself

The result of this test is presented below :

- The value obtained with the constant method with a 30 cycles half-window is **2,14 mm**
- The most linear method (with a 10 years window) gives an uncertainty of **2,55 mm**

Both values are consistent with the interval given by Ablain et al. 2009 and Cazenave et al. 2018 values (see previous slides)

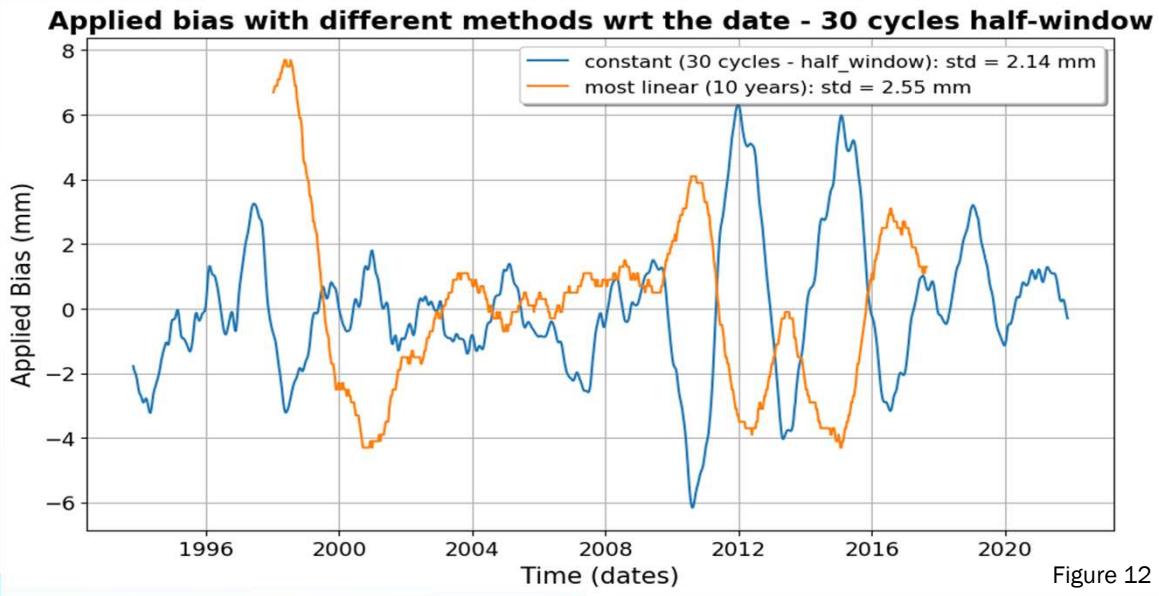


Figure 12

Results obtained – Comparison to ERS-2 data – differences of GMSL

Hypothesis : Stability and consistency of ERS-2 data

The third method presented is a comparison with ERS-2 data

- The differences of GMSL between Topex and ERS-2 is computed with the same time sample base (10 days) and the same restriction on latitudes (± 66°).
- The mean of this difference is computed over different number of cycles before and after the swith from Topex A to Topex B.
- The total bias computed with a 30 cycles half-window is **3,4 cm**
- The geophysical information measured by ERS-2 is conserved with this method : uge advantage compared with the constant and the most linear methods

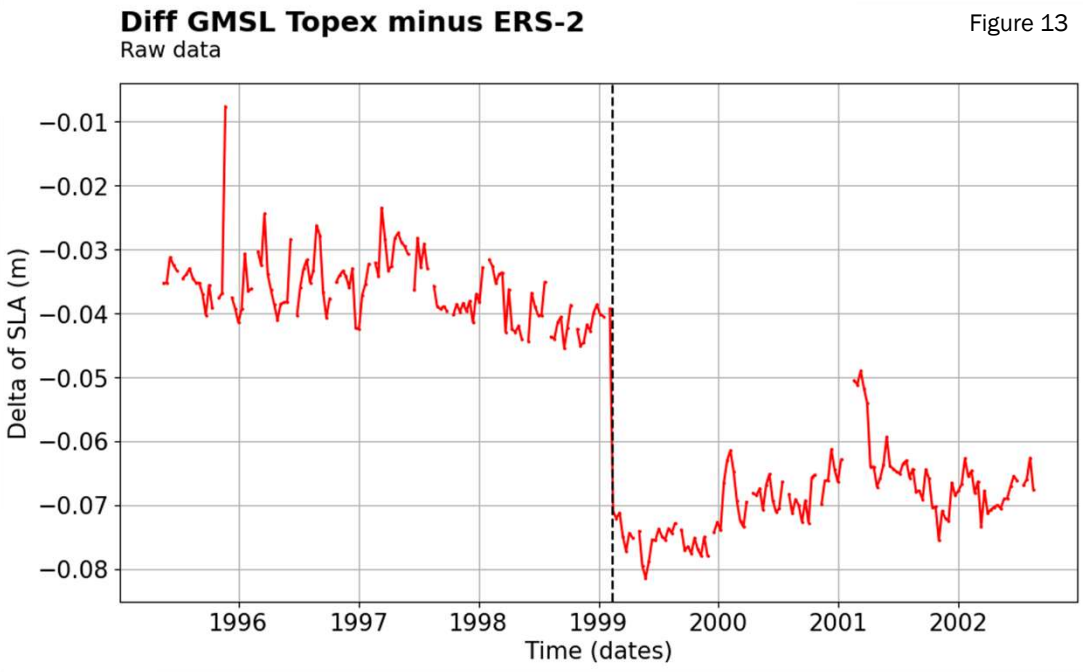


Figure 13

Results obtained – Comparison to ERS-2 data – differences of GMSL

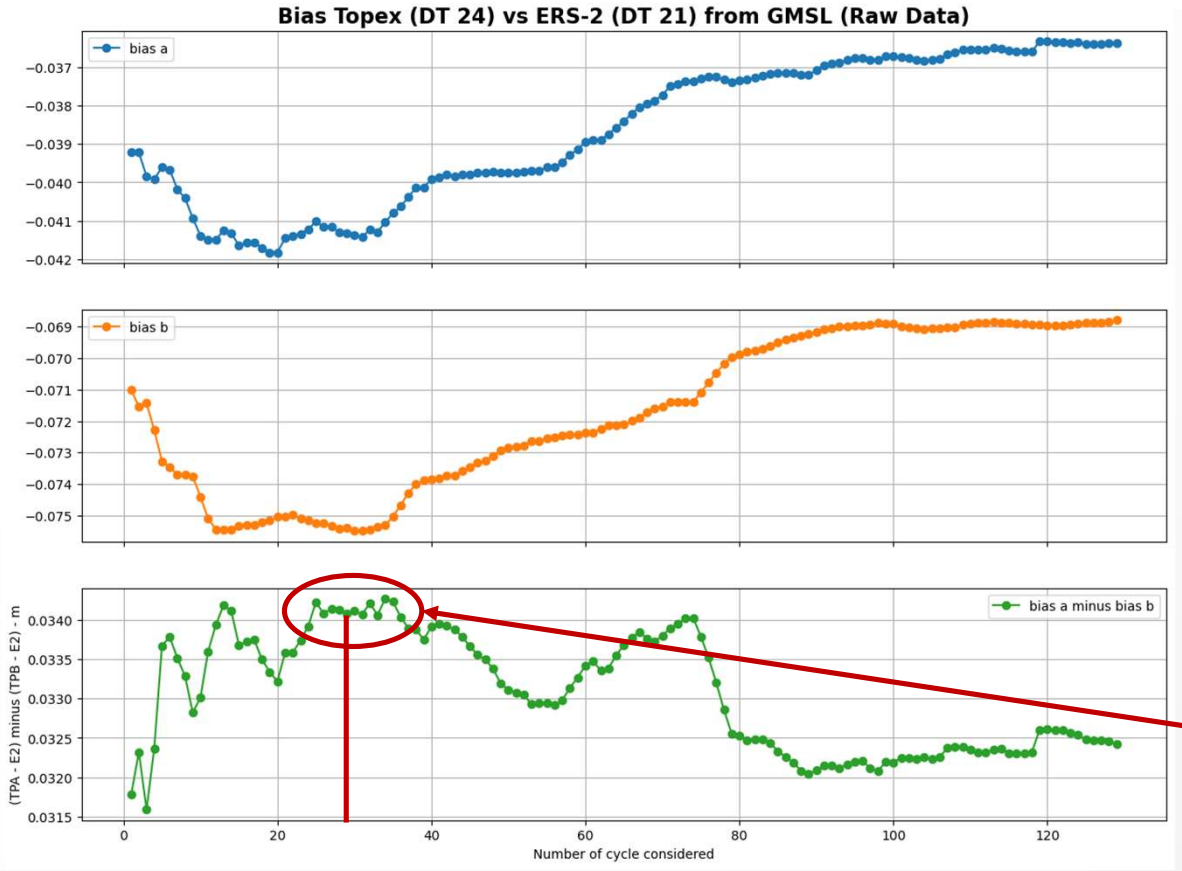


Figure 14

Hypothesis : Stability and consistency of ERS-2 data

Computation of the bias (m) Topex A / ERS-2 over N cycles : blue curve
Computation of the bias (m) Topex B / ERS-2 over N cycles : orange curve
Differences (m) between both to estimate the Topex A / Topex B bias : green curve

Stability around 30 cycles (consistent with the constant method)

Results obtained – Comparison to ERS-2 data – differences of GMSL

Hypothesis : Stability and consistency of ERS-2 data

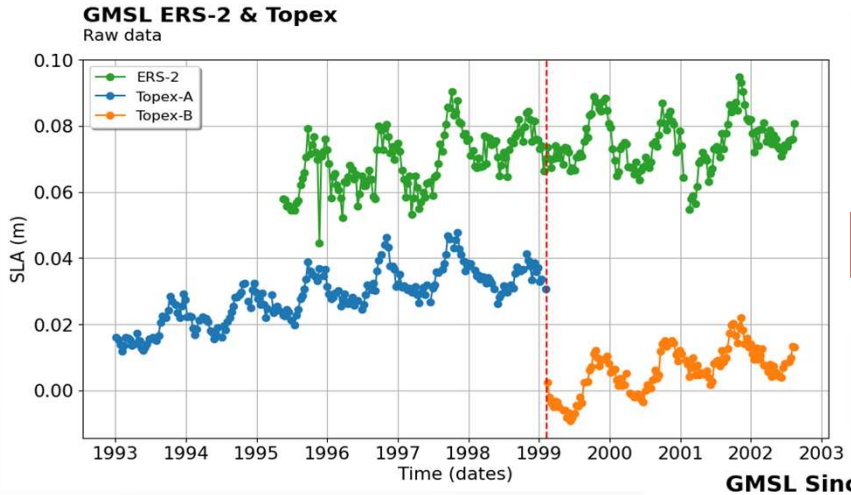


Figure 15

Correction with the comparison to ERS-2 data

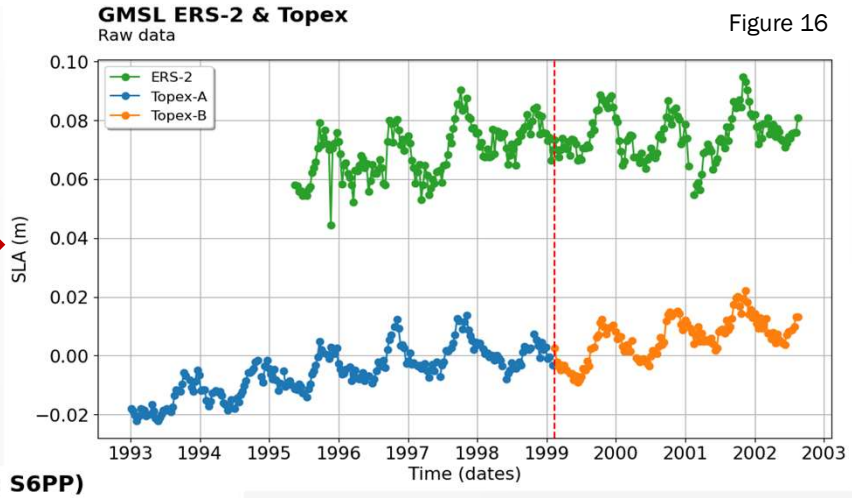


Figure 16

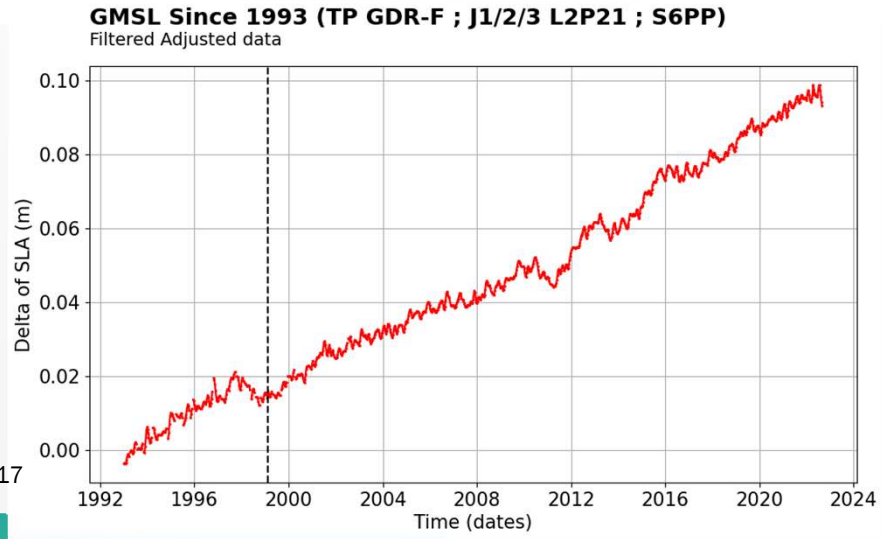


Figure 17

Trend : 3,19 ± 0,32 mm.yr^{-1}
Acceleration : 0,16 ± 0,05 mm.yr^{-1}

Results obtained – Comparison to ERS-2 data – differences of GMSL

Hypothesis : Stability and consistency of ERS-2 data

The uncertainty can be computed as the quadratic sum of uncertainties associated with each intermediate bias computed (TPA/E2 and TPB/E2).

The values depend on the number of cycle used as half-window.

As there is a lot of disparities in those uncertainty values, the mean of all is kept as the uncertainty of the measure : **2,4 mm** at 68% C.L

Once again, the value obtained is consistent with Ablain et al 2009 and Cazenave et al 2018.

It is also consistent with values obtained with the constant and the most linear methods.

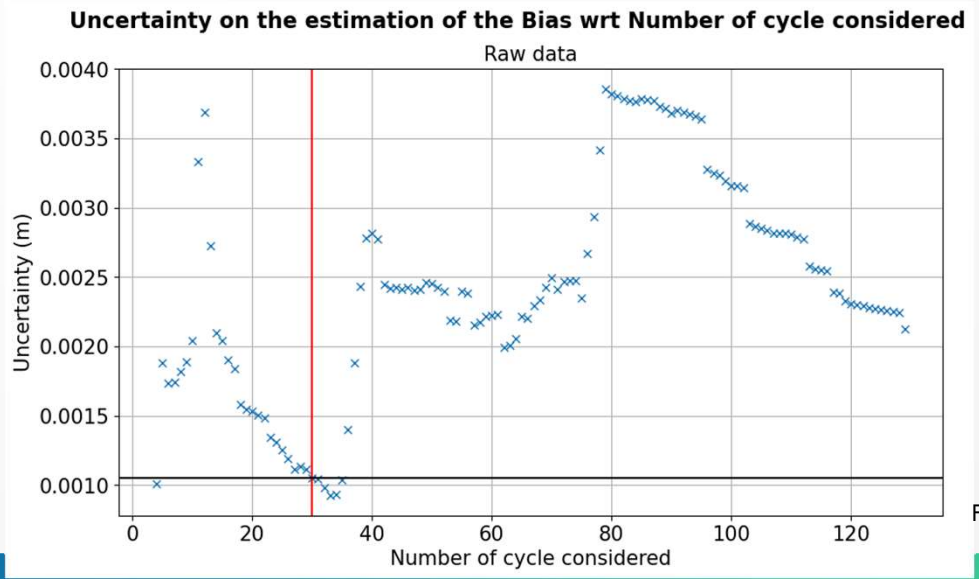


Figure 18

Results obtained – Comparison to ERS-2 data – difference at crossover points

Hypothesis : Stability and consistency of ERS-2 data

- Another way to estimate global differences between both Topex and ERS-2 data is to compute crossover points with a 10 days maximum time difference.
- The spatial distribution of those crossover points over the Topex A and the Topex B time period are represented in Figure 19 and Figure 20

Figure 19

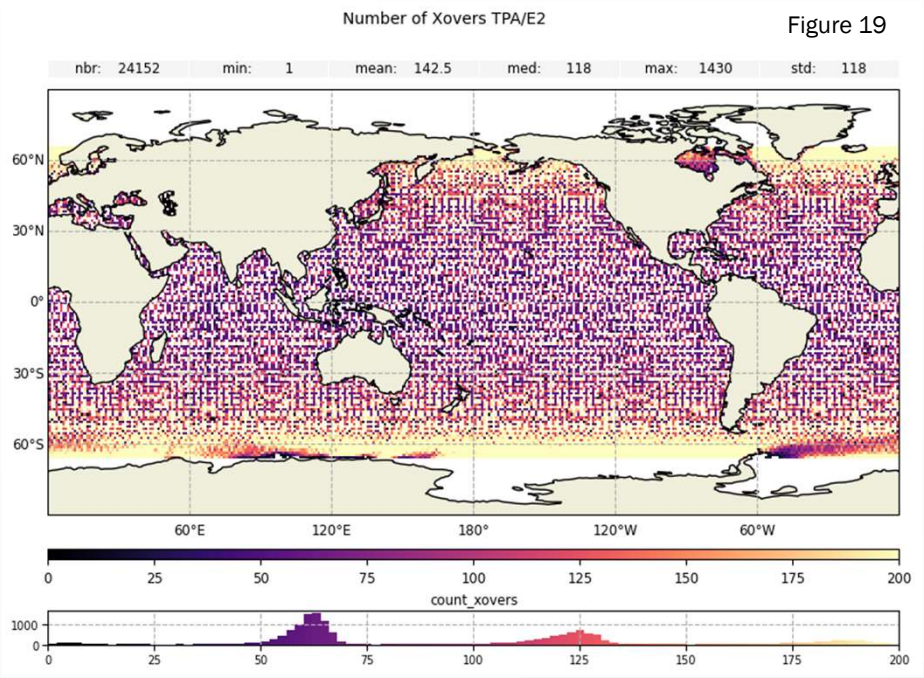
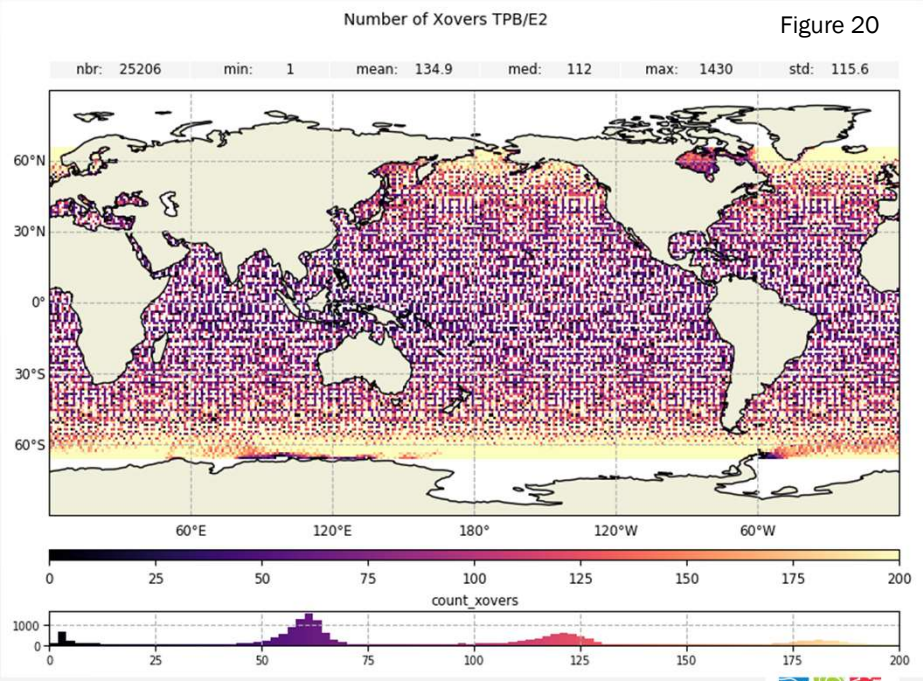


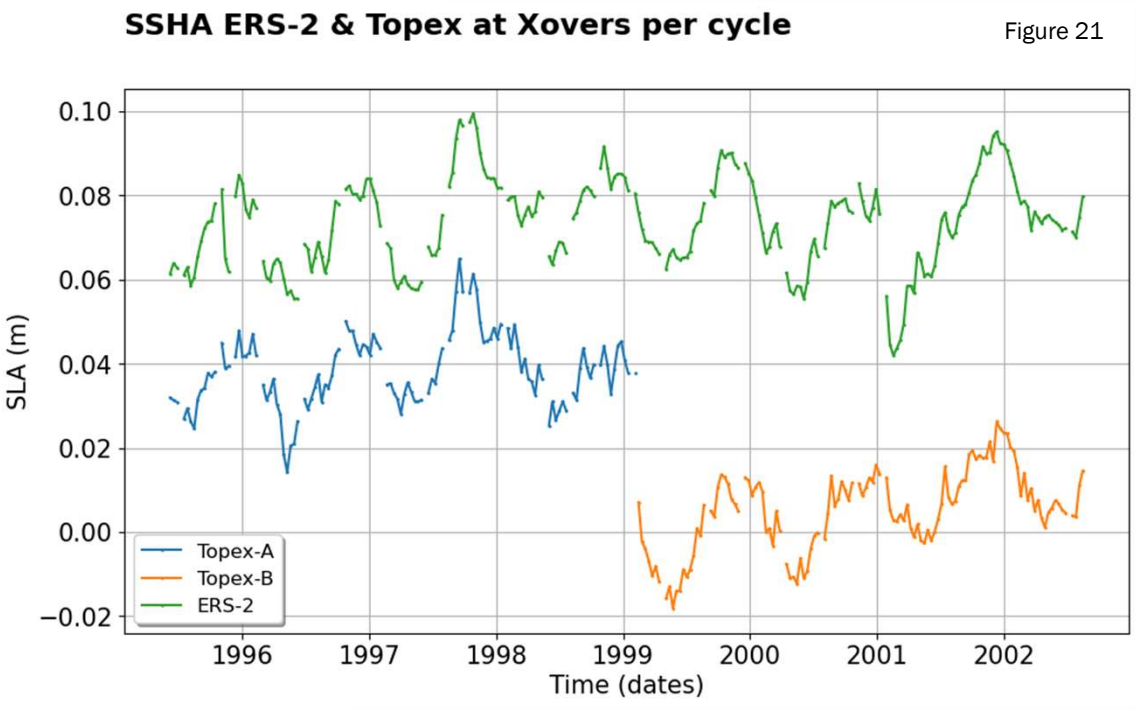
Figure 20



Results obtained – Comparison to ERS-2 data – difference at crossover points

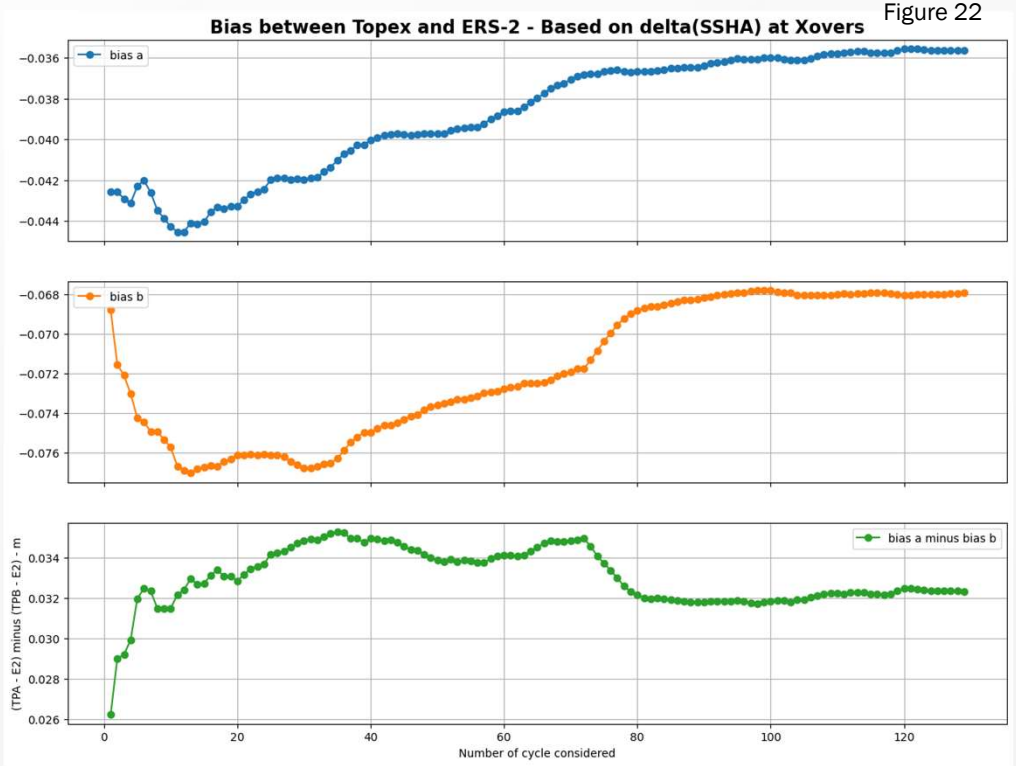
Hypothesis : Stability and consistency of ERS-2 data

Figure 21



Mean of Sea Level Anomaly per cycle from Topex and ERS-2 data

Figure 22



Same diagnosis as the one computed on GMSL from Topex and ERS-2 missions
This one is computed with data from Figure 21

Results obtained – Comparison to ERS-2 data – difference at crossover points

- A similar diagnosis as the one computed with both GMSL is computed with differences of mean at crossover points (Figure 22)

- The associated uncertainty of this estimation is computed from SLA differences at all crossover points. A Student's law is applied from the number of independants measures and the standard deviation of the distribution :
- $uncertainty = t_N^{\alpha} * \frac{STD}{\sqrt{N-1}}$
- The number of independant points is estimated at one out of two thousand of the total number of points
- t_N^{α} is the Student coefficient : the confidence level is given at 68% to be consistent with other results presented

- The bias obtained is **3,5 cm**
- The associated uncertainty obtained is **2,3 mm** at 68% CL

- The value obtained for the bias is consistent with the results obtained with the constant method and the comparison of GMSLs.
- The value of the uncertainty is consistent with all other values

Results obtained – Comparison to ERS-2 data

Same analysis was performed with the FDR4ALT dataset as auxiliary data

Results on the estimation of the bias are really consistent (all values are in the 68% confidence interval):

- Comparison of GMSLs : the estimated bias is **3,5 cm**
- Comparison at crossover points : the estimated bias is **3,2 cm**

With uncertainties, results are a bit different :

- Comparison of GMSLs : the associated uncertainty obtained is **4,5 mm** at 68% CL (much higher than other estimations)
- Comparison at crossover points : the associated uncertainty is **2,5 mm** at 68% CL (consistent with other values)

As all diagnoses are the same than the one presented with L2P DT 21 data, figures obtained with FDR4ALT data are not represented in this presentation.

Results obtained – Impact on the GMSL parameters

The chosen value of the bias between Topex A and Topex B data has an impact on the final parameters of the GMSL (trend and acceleration).

This impact was quantified computing a reference GMSL with new GDR-F Topex data, and L2P DT 21 data for Jason-1, Jason-2 and Jason-3 missions.

Results are presented in Table 1 :

Method	Constant	Most Linear	Versus ERS-2			
			GMSL - DT21	Xovers - DT21	GMSL - FDR	Xovers - FDR
Hypotheses	GMSL constant over a few cycles	GMSL linear over 10 years	Stability of ERS-2 data			
Bias cm	3,3 ± 0,2	3,9 ± 0,25	3,4 ± 0,24	3,5 ± 0,23	3,5 ± 0,45	3,2 ± 0,25
Trend mm/yr	3,16	3,36	3,19	3,23	3,23	3,13
Acceleration mm/yr/yr	0,17	0,09	0,16	0,14	0,14	0,18

Table 1

The final value sustained from this study for the TPA/TPB bias is **3,4 ± 0,24 cm**

Variations of the trend : 3,13 to 3,36 mm/yr

Variation of the acceleration : 0,09 to 0,18 mm/yr/yr

Variations of both parameters are in the confidence interval (90% CL) published in Guerou et al. 2023 :

- Trend : 3,3 ± 0,3 mm/yr
- Acceleration : 0,12 ± 0,05 mm/yr/yr

Validation on a simulated case – Description of the simulation

- In order to prove the efficiency of the new method suggested, the constant method and the comparison to an auxiliary dataset was tested on a simulated case. The most linear method did not gave a result consistent with other methods so it will not be tested in this simulated case

- In this section of, datasets used were :
  - Jason-1 and Jason-2 L2P DT 21 data
  - ENVISAT L2P DT 21 and FDR4ALT data

- The bias to be computed is the global bias corrected in L2P products between Jason-1 and Jason-2 data : real value **2,05 cm**

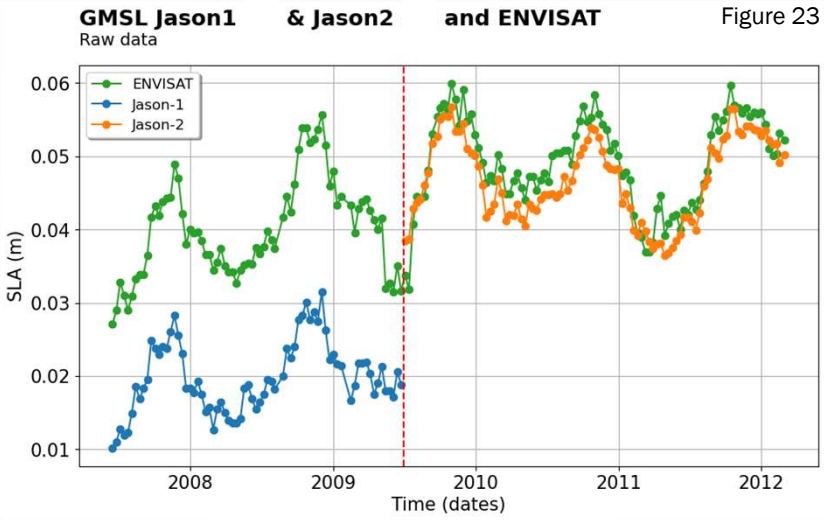


Figure 23

Validation on a simulated case – Results obtained – constant method

When the constant method is applied to this new dataset, results are not really convincing.

The value obtained with 1 cycle is 2,0 cm, not that far from the real value.

But there is no stability as there were in the Topex case and the value with a half-window of 30 cycles (number used in the previous case), the bias obtained is 2,4 cm

The error seems to increase with the half window chosen to compute the bias. The efficiency and the consistency of this method is not proved by this second test.

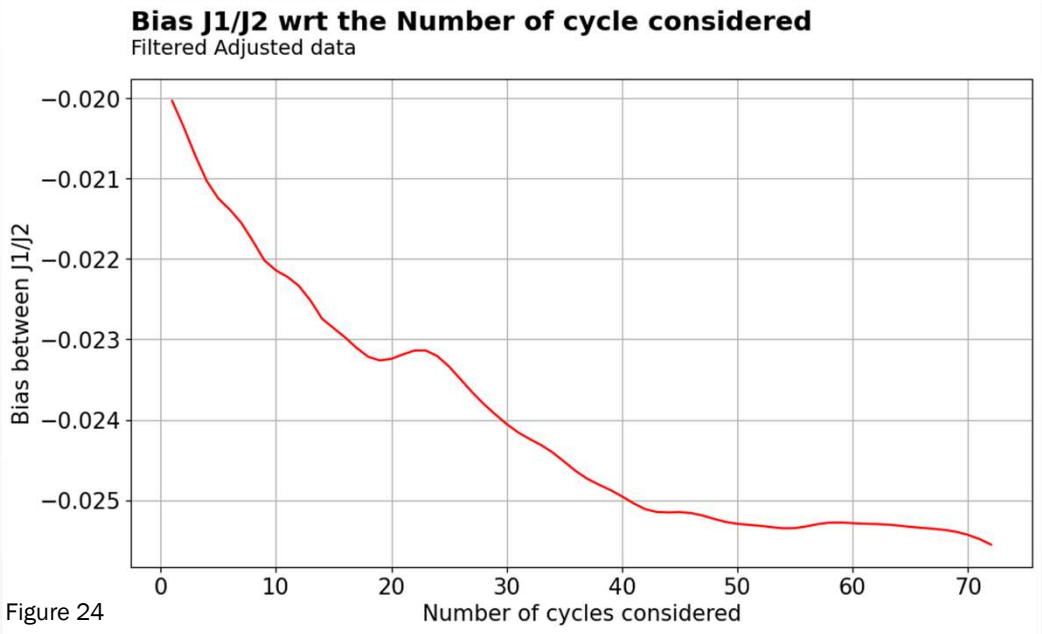


Figure 24

Validation on a simulated case – Results obtained – comparison to ENVISAT data

Same diagnoses as in the previous section were computed on Jason-1/Jason-2/ENVISAT data to estimate the bias and the associated uncertainty. Results are presented in Figures 25, 26 and 27. ENVISAT data used to compute those results are data from L2P DT 21 dataset.

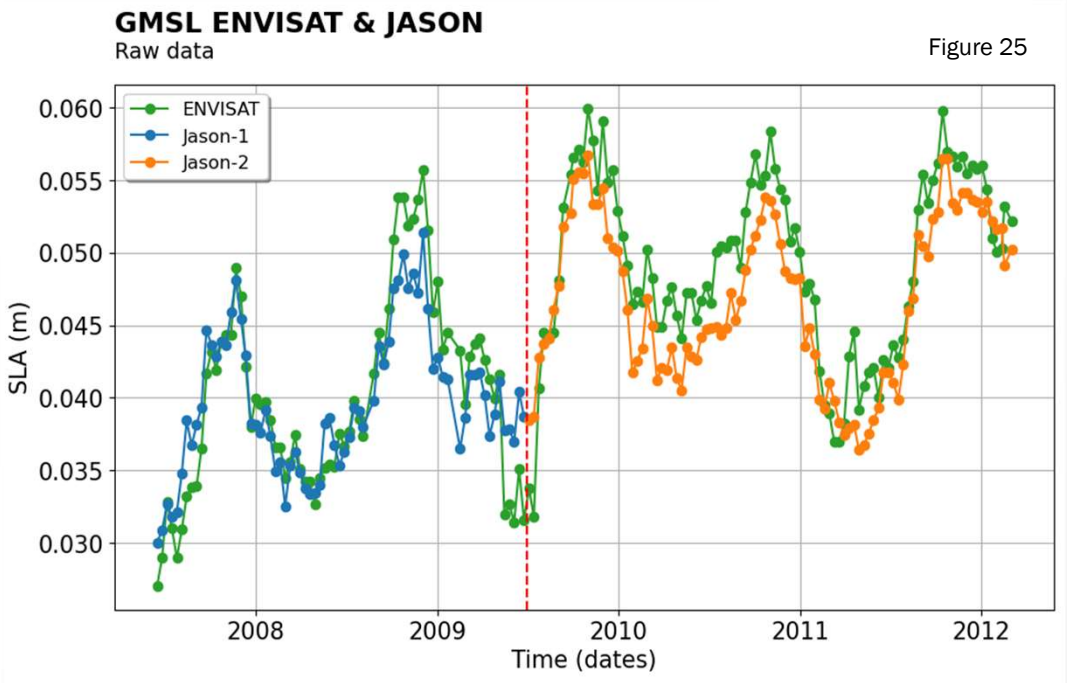


Figure 25

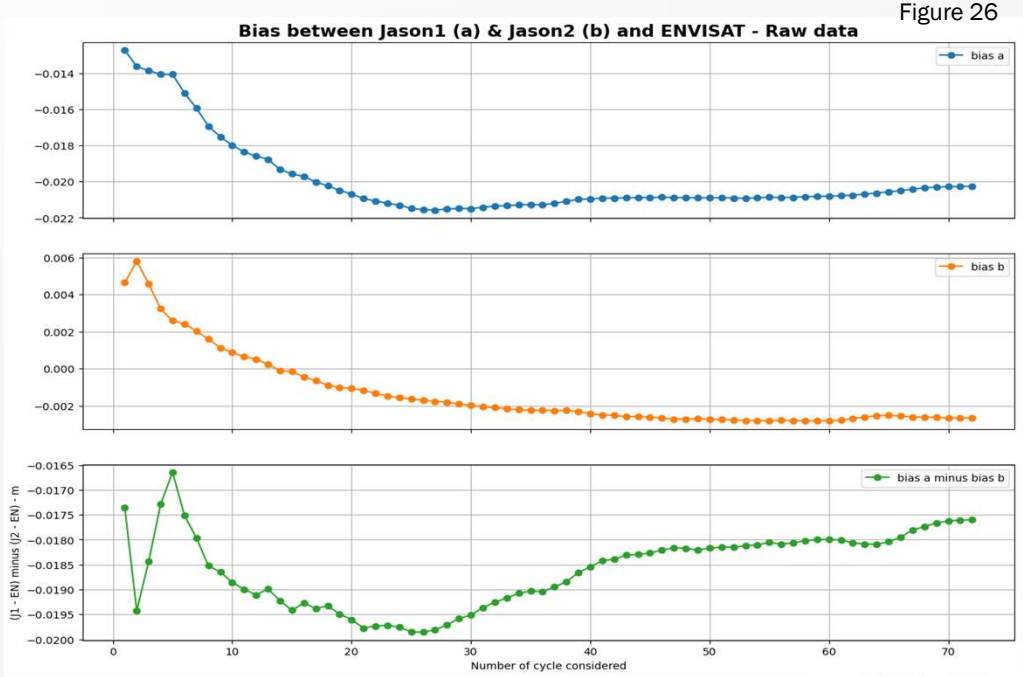


Figure 26

Validation on a simulated case – Results obtained – comparison to ENVISAT data

The computation of the uncertainty is illustrated in Figure 27 with the same method as the computation of the Topex A/B bias associated uncertainty

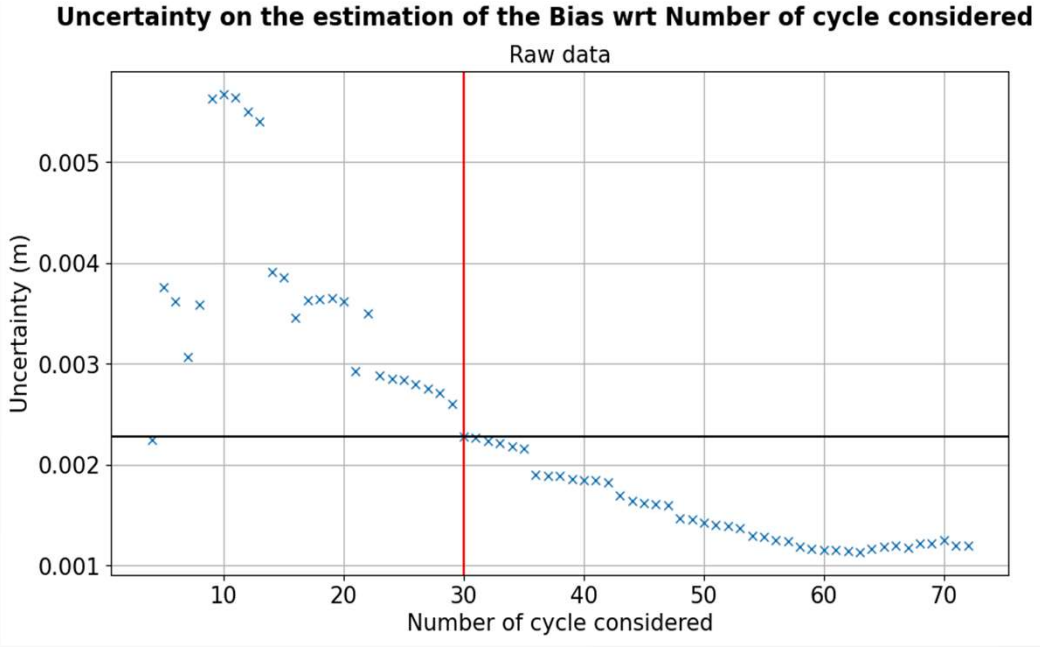
Results are more convincing :

The bias obtained is **1,95 ± 0,23 cm**

The uncertainty is similar to the one obtained in the Topex case and the real bias value (2,05 cm) is in the 68% CL interval given by this comparison to ENVISAT.

This method seems to be efficient and consistent.

Figure 27



Validation on a simulated case – Results obtained

Those diagnoses were also performed with the FDR4ALT dataset of ENVISAT data and results are really close.

The same study with crossover points of Jason-1/ENVISAT and Jason-2/ENVISAT was carried out with both ENVISAT datasets : results are also consistent with the one obtained in the section about Topex.

All results obtained in this simulated case are represented in Table 2 :

Method	Constant	Versus ENVISAT			
		GMSL - DT21	Xovers - DT21	GMSL - FDR	Xovers - FDR
Hypotheses	GMSL constant over a few cycles	Stability of ENVISAT data			
Bias cm	2,4 ± 0,2	1,95 ± 0,23	2,03 ± 0,24	1,98 ± 0,18	1,97 ± 0,24

Table 2

Conclusion and perspectives

The conclusion of this study is that the comparison with an auxiliary altimetry mission is far more consistent and efficient than the constant method or the most linear method.

Our working group recommends to use this new method to estimate the Topex A / Topex B bias.

The value of this bias given to the reprocessing of L2P DT 24 products is **3,4 ± 0,24 cm**

Conclusion and perspectives

The error budget of the global mean sea level will be updated with this new value : the impact on the parameters uncertainties is given in those last figures.

All data used are the same in both GMSL and all parameters of the error budget are unchanged except for the one associated with the Topex bias.

- Slight increase of the uncertainty associated with the acceleration : from 0,05 mm/yr/yr to **0,06 mm/yr/yr**
- Slight increase of the uncertainty associated with the trend : from 0,32 mm/yr to **0,33 mm/yr**

Future work :

With the release of the new version of those Topex data (GDR-F), the estimation of the Topex A drift should be revisited too.

It could lead to a new and more precise value of the Topex A / Topex B bias.

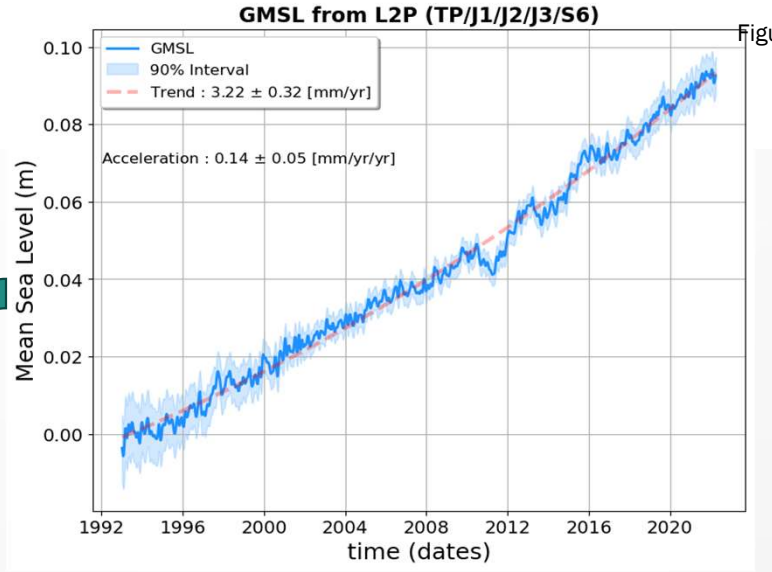


Figure 28

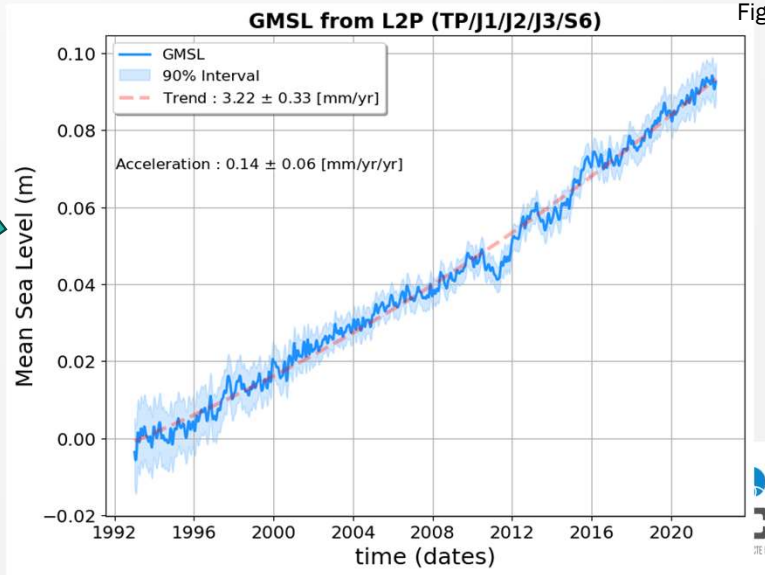


Figure 29

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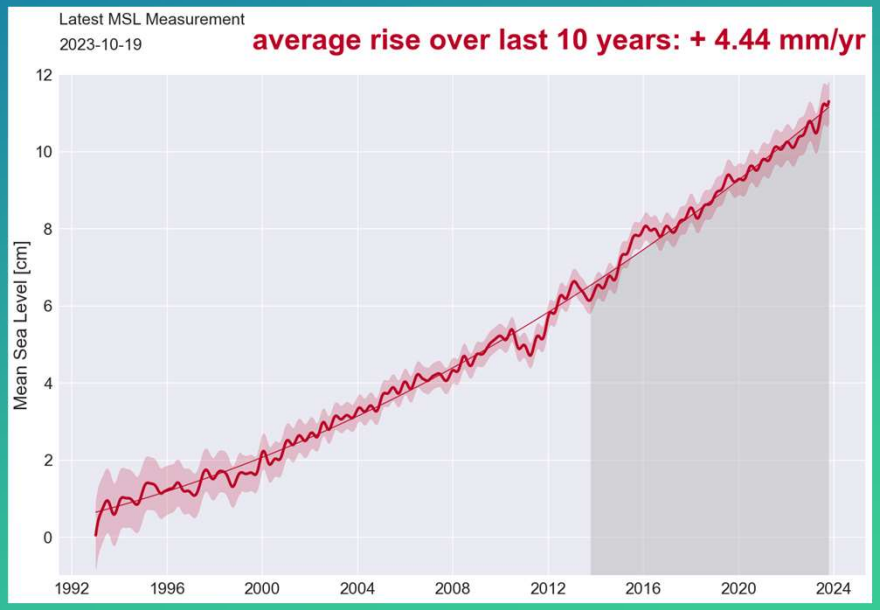
Thank you !


Latest MSL Measurement
2023-10-19
average rise over last 10 years: + 4.44 mm/yr
Mean Sea Level [cm]
12
10
8
6
4
2
0
1992
1996
2000
2004
2008
2012
2016
2020
2024