



# Uncertainty in satellite estimate of Global Mean Sea Level changes, trend and acceleration

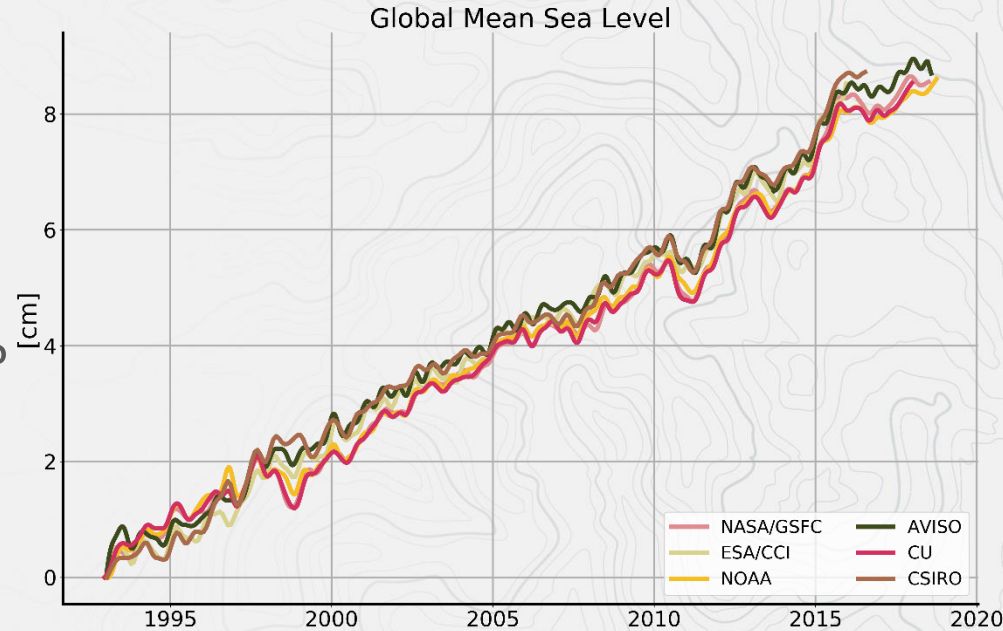
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# Overview

- GMSL from T/P, Jason-1, 2 & 3,
- Solutions from different groups are **not** independent,
- Can we estimate reliable uncertainties for GMSL timeseries ?
- essential for budget closure, detection & attribution, ...



# Mathematical elements

- Express SLA as forced response, plus IV, plus error:

$$Y = AX + IV + E$$

- Then the forced response is given by:

$$\hat{A} = (X^t X)^{-1} X^t Y$$

- And its variance-covariance by:

$$\Omega_{\hat{A}} = (X^t X)^{-1} X^t C_E X (X^t X)^{-1}$$



# Mathematical elements

$$\Omega_{\hat{A}} = (X^t X)^{-1} X^t C_E X (X^t X)^{-1}$$

- $C_E$  is the variance-covariance matrix of errors,
- Goal: estimate  $C_E$
- Method: combine elementary error terms
- Measurement system errors only, no internal variability



# Altimetry Errors

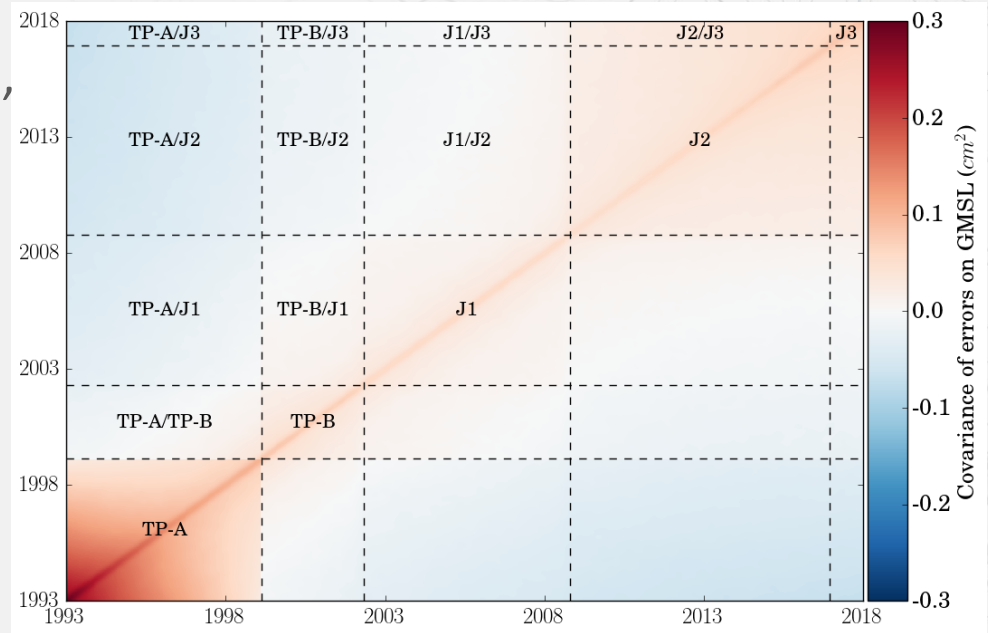
Error source	Category	Magnitude (at 1 $\sigma$ )	References
High frequency errors: altimeter noise, geophysical corrections, orbits ...	correlated error ( $\lambda = 2$ months)	$\sigma = 1.7$ mm for TOPEX period $\sigma = 1.5$ mm for Jason-1 period $\sigma = 1.2$ mm for Jason-2/3 period	Cal/Val activities
Medium frequency errors: geophysical corrections, orbits ...	correlated error ( $\lambda = 1$ year)	$\sigma = 1.3$ mm for TOPEX period $\sigma = 1.2$ mm for Jason-1 period $\sigma = 1$ mm for Jason-2/3 period	Cal/val activities
Large frequency errors: wet troposphere correction	correlated error ( $\lambda = 5$ years)	$\sigma = 1.1$ mm over all the period ( $\Leftrightarrow$ to 0.2 mm/yr for 10 years)	Legeais et al, 2015, Thao et al., 2014
Large frequency errors: orbits (gravity fields)	correlated error ( $\lambda = 10$ years)	$\sigma = 1.12$ mm over TOPEX period (no GRACE data) $\sigma = 0.5$ mm over Jason period ( $\Leftrightarrow$ to 0.05 mm/yr for 10 years)	Couhert al., 2015 Rudenko et al., 2017
Altimeter instabilities on TOPEX-A/B	drift error	$\sigma = 0.7$ mm/yr on TOPEX-A period (*) $\sigma = 0.1$ mm/yr on TOPEX-B period	Watson et al, 2014 ; Beckley et al., 2017; Ablain et al. 2017
Long-term drift errors: orbit (ITRF and GIA)	drift error	$\sigma = 0.12$ mm/yr over all the period	Couhert et al., 2015 Spada, 2017
Error when linking altimetric missions together.	bias errors	$\sigma = 2$ mm for TP-A/TP-B $\sigma = 0.5$ mm for TP-B/J1, J1/J2, J2/J3.	Zawadzki et al., 2018

Decorrelation time



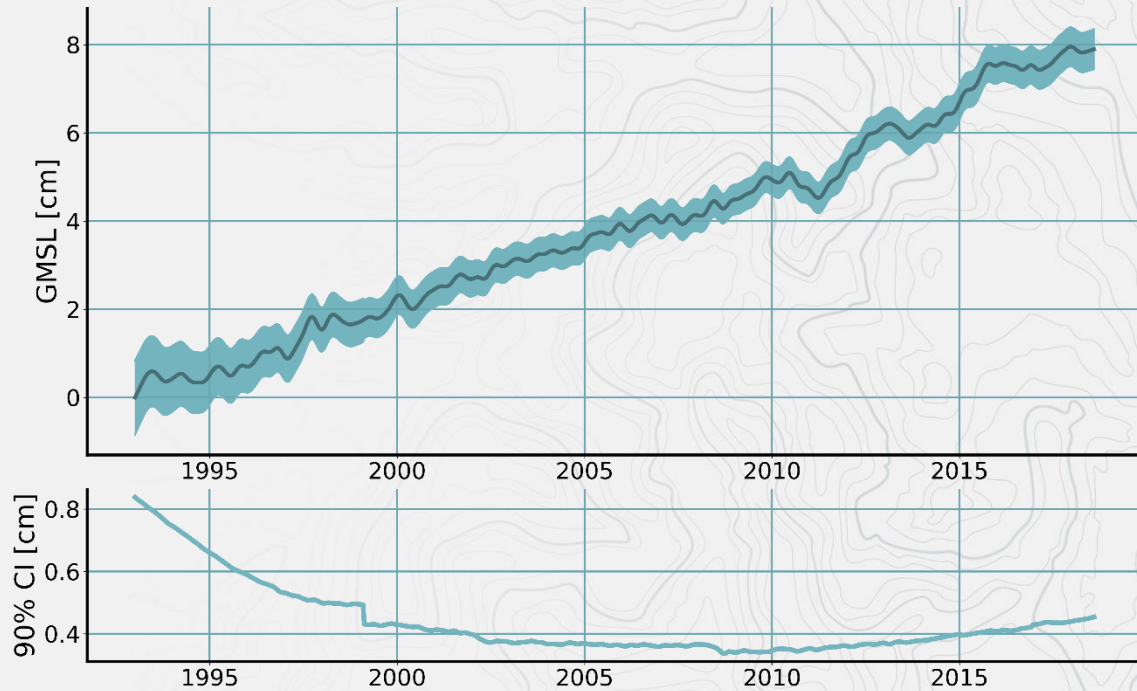
# Error Covariance

- Total error covariance,
- Sum of all individual contributions,
- Is used to estimate 90% CI on trends and acceleration,
- Errors **covary** from one end of the record to the other,
- **Available** to users  
<https://doi.org/10.17882/58344>



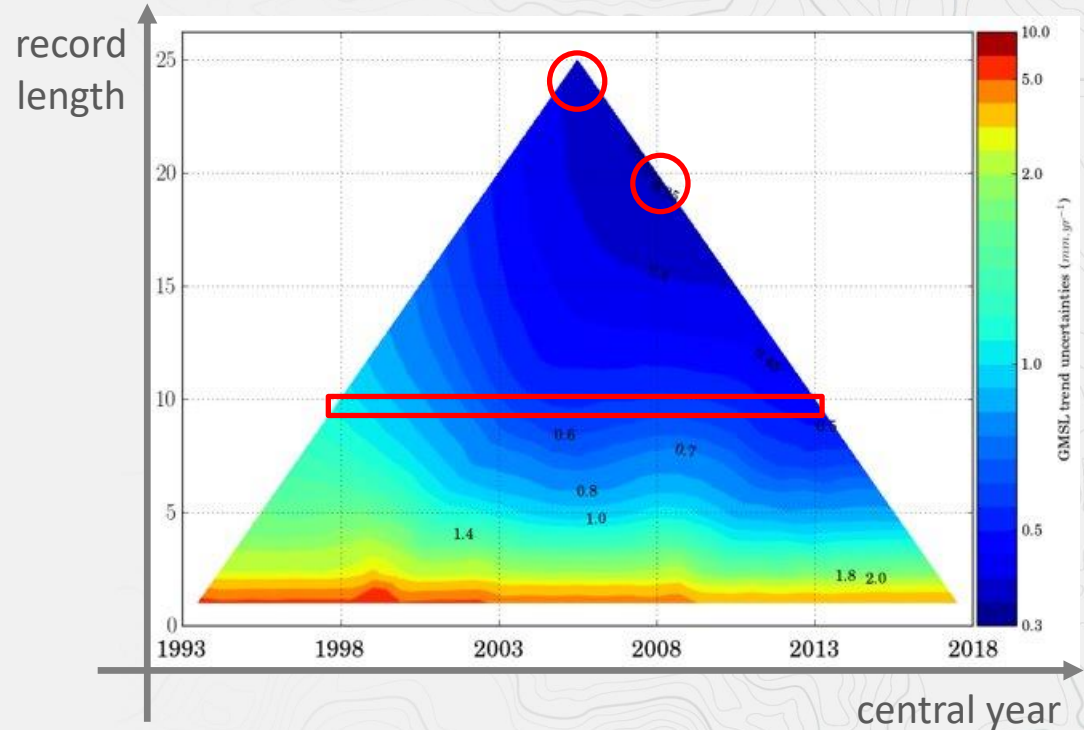
# Error enveloppe

- Error enveloppe as the square root of matrix diagonal,
- Corrections for the TOPEX-A drift fall outside the enveloppe



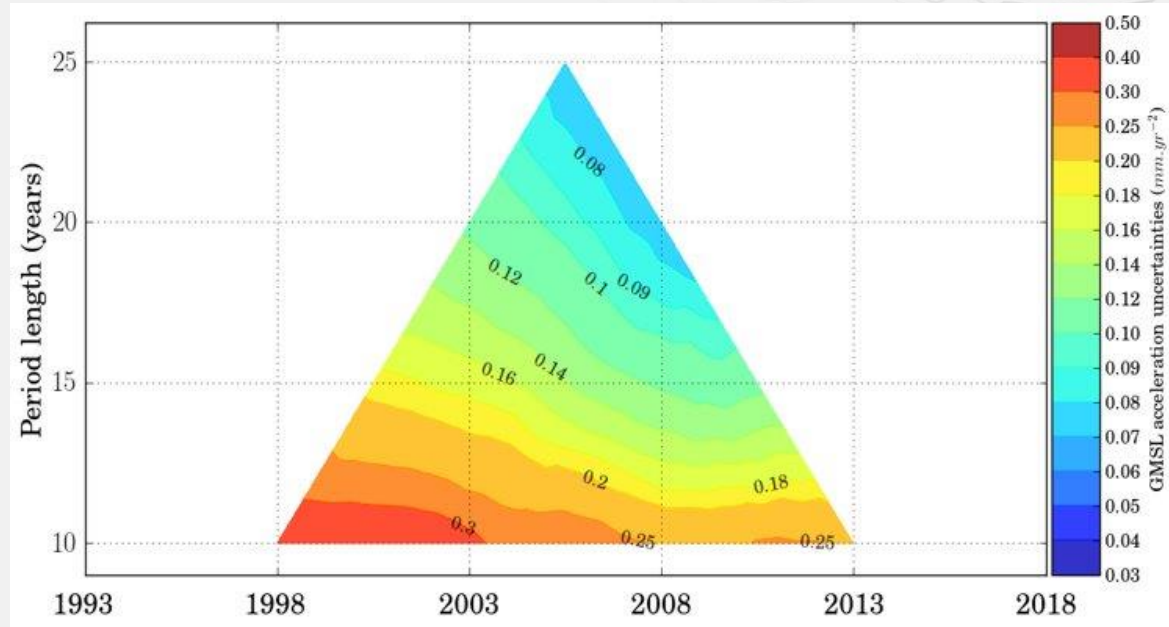
# GMSL trend uncertainty

- 25-yr record:  
 $3.35 \pm 0.4 \text{ mm/yr}$
- Uncertainties decrease over time
- [1998-2018] is the most accurate  
 $\pm 0.35 \text{ mm/yr}$





# GMSL acceleration uncertainty



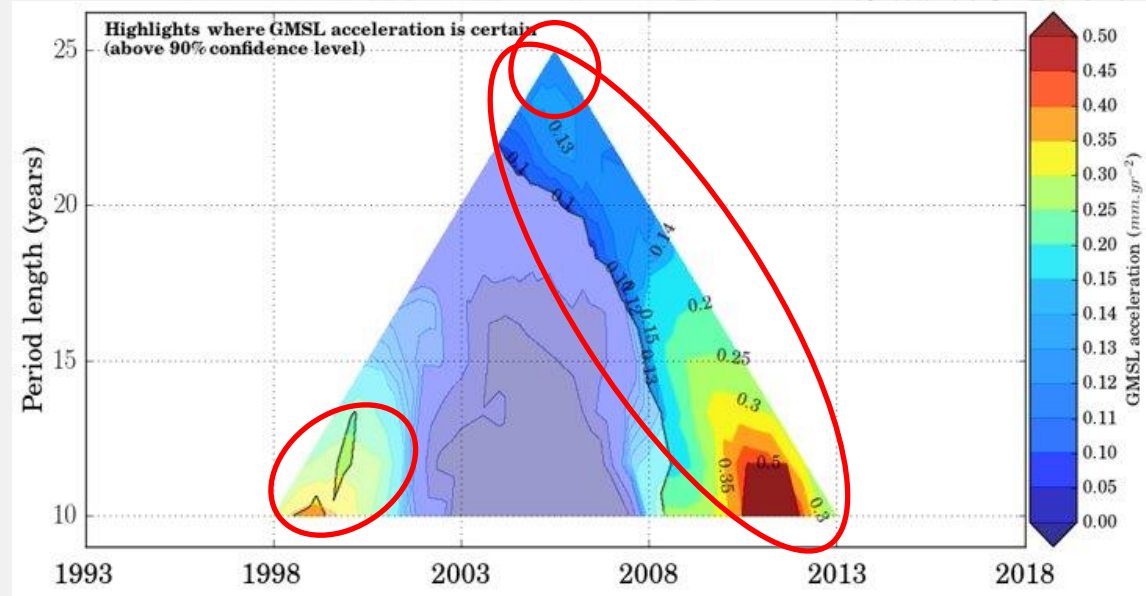
Acceleration uncertainty on periods of 10 years and longer



# When are accelerations detected?

- Any 10+ year record including 2018 shows significant acceleration
- Recovery from Pinatubo is detected
- Significant acceleration on the 25-yr record

$0.12 \pm 0.07 \text{ mm/yr}^2$



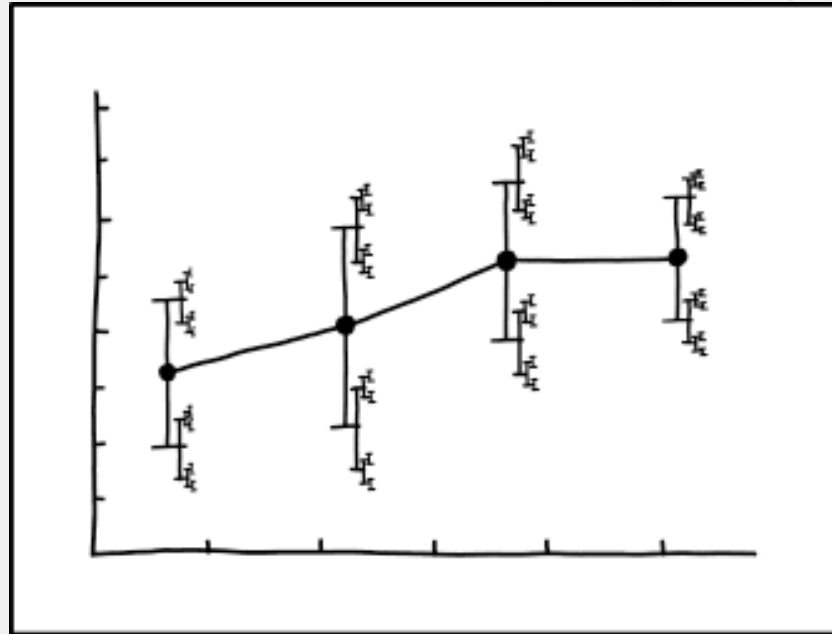
# Conclusions

- Error covariance description, **available** to users
  - To derive confidence levels on any metric
  - <https://doi.org/10.17882/58344>
- Used to derive confidence on GMSL trend and acceleration
  - $3.35 \pm 0.4$  mm/yr,  $0.12 \pm 0.07$  mm/yr<sup>2</sup>
  - On 25 years, at the 90% CL
- Uncertainty built from current knowledge of system errors,
  - should be revised and updated to reflect new findings,
  - does **not** include internal variability,
  - there are uncertainties on the error budget



# BACKUP





I DON'T KNOW HOW TO PROPAGATE  
ERROR CORRECTLY, SO I JUST PUT  
ERROR BARS ON ALL MY ERROR BARS.

<https://xkcd.com/2110/>

