CNES/Aviso
New GMSL L2P21 record

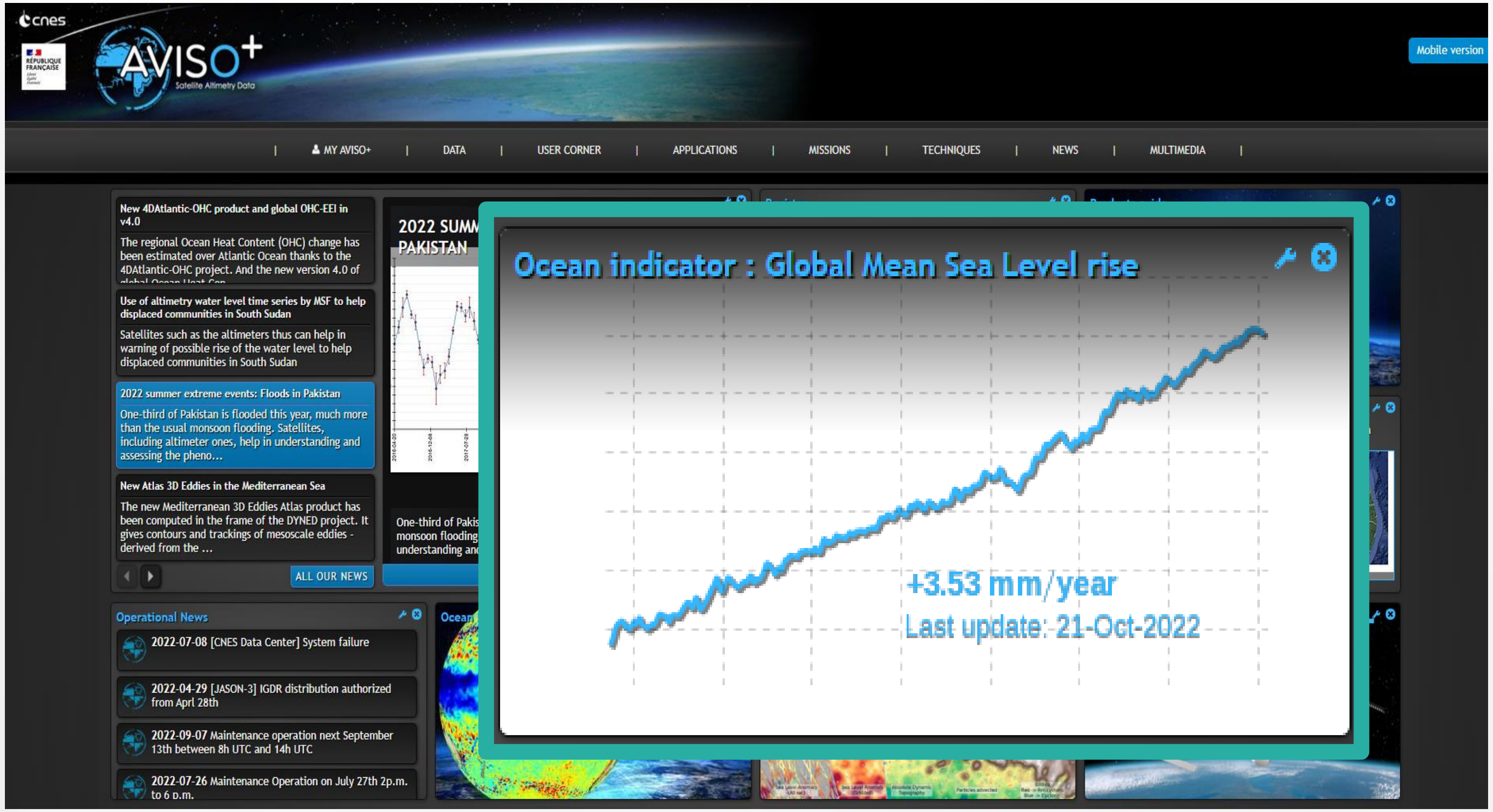
Limiting factors of the altimetry observing system to the GMSL monitoring accuracy

Adrien Guérou[1], Pierre Prandi[1], Benoit Meyssignac[2,4], Michaël Ablain[3], Gérald Dibarboure[4], François Bignalet-Cazalet[4]

(1) CLS ; (2) LEGOS, (3) Magellium, (4) CNES

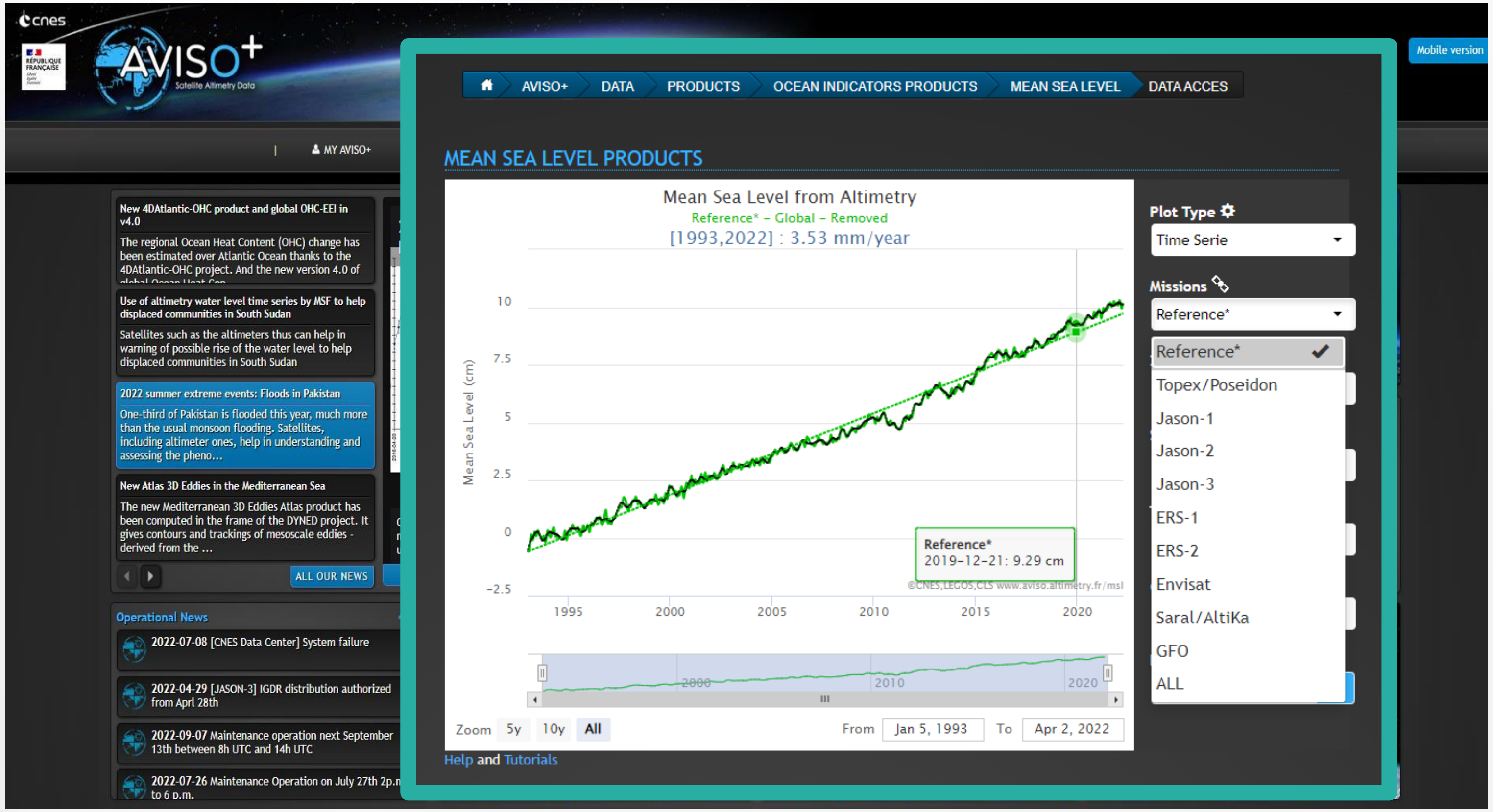
CNES/Aviso GMSL L2P21 record

- ✓ Based on L2P+21 CNES along-track products



CNES/Aviso GMSL L2P21 record

- ✓ **Based on L2P+21 CNES along-track products**
- ✓ Reference missions
  - Topex / Jason-1/-2/-3
- ✓ Auxiliary missions
  - Envisat / ERS-1/-2 / Saral Alti-Ka / GFO



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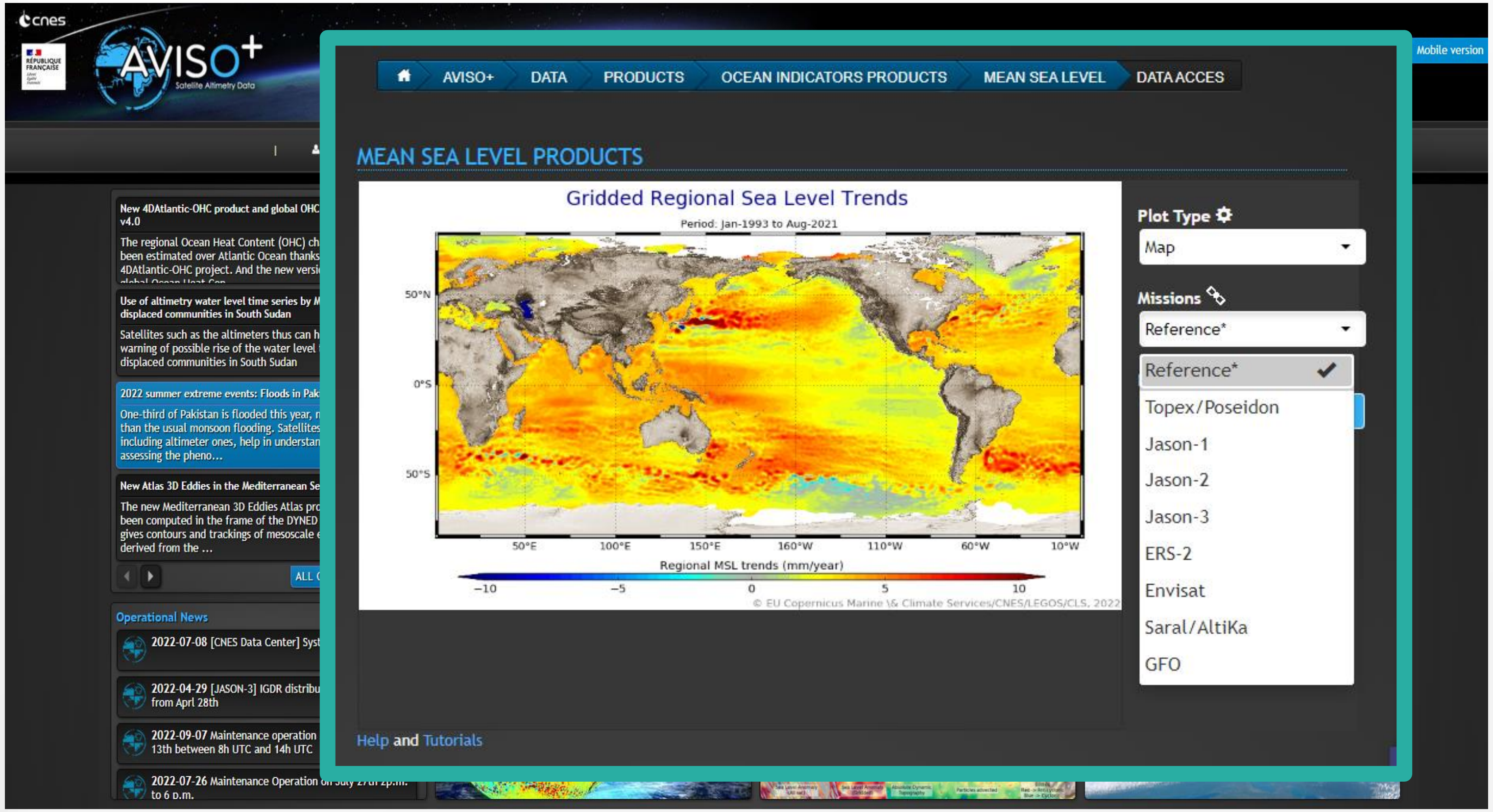
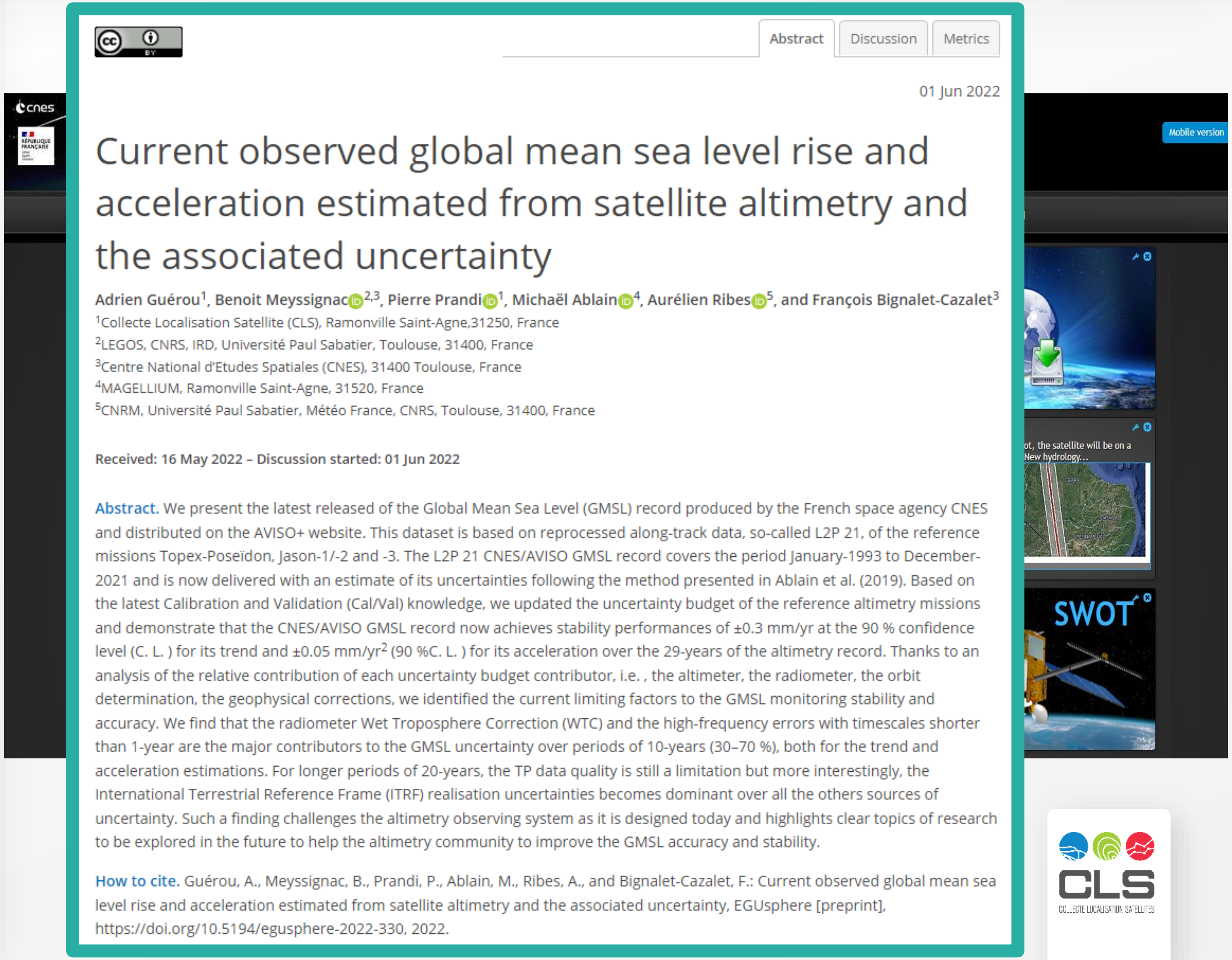
- ✓ Map of regional MSL trends
  - ✓ Reference & auxiliary missions



CNES/Aviso GMSL L2P21 record

- ✓ **Based on L2P+21 CNES along-track products**
- ✓ **Reference missions**
  - Topex / Jason-1/-2/-3
- ✓ **Auxiliary missions**
  - Envisat / ERS-1/-2 / Saral Alti-Ka / GFO
- ✓ **Map of regional MSL trends**
  - Reference & auxiliary missions
- ✓ **Available on-line :**
  - *https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level.html*
- ✓ **Publication:**
  - *Guérou et al. (2022, Ocean Science)*



Abstract | Discussion | Metrics

01 Jun 2022

Current observed global mean sea level rise and acceleration estimated from satellite altimetry and the associated uncertainty

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Abstract. We present the latest released of the Global Mean Sea Level (GMSL) record produced by the French space agency CNES and distributed on the AVISO+ website. This dataset is based on reprocessed along-track data, so-called L2P 21, of the reference missions Topex-Poseïdon, Jason-1/-2 and -3. The L2P 21 CNES/AVISO GMSL record covers the period January-1993 to December-2021 and is now delivered with an estimate of its uncertainties following the method presented in Ablain et al. (2019). Based on the latest Calibration and Validation (Cal/Val) knowledge, we updated the uncertainty budget of the reference altimetry missions and demonstrate that the CNES/AVISO GMSL record now achieves stability performances of ±0.3 mm/yr at the 90 % confidence level (C. L.) for its trend and ±0.05 mm/yr^2 (90 %C. L.) for its acceleration over the 29-years of the altimetry record. Thanks to an analysis of the relative contribution of each uncertainty budget contributor, i.e. , the altimeter, the radiometer, the orbit determination, the geophysical corrections, we identified the current limiting factors to the GMSL monitoring stability and accuracy. We find that the radiometer Wet Troposphere Correction (WTC) and the high-frequency errors with timescales shorter than 1-year are the major contributors to the GMSL uncertainty over periods of 10-years (30–70 %), both for the trend and acceleration estimations. For longer periods of 20-years, the TP data quality is still a limitation but more interestingly, the International Terrestrial Reference Frame (ITRF) realisation uncertainties becomes dominant over all the others sources of uncertainty. Such a finding challenges the altimetry observing system as it is designed today and highlights clear topics of research to be explored in the future to help the altimetry community to improve the GMSL accuracy and stability.

How to cite. Guérou, A., Meyssignac, B., Prandi, P., Ablain, M., Ribes, A., and Bignalet-Cazalet, F.: Current observed global mean sea level rise and acceleration estimated from satellite altimetry and the associated uncertainty, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2022-330, 2022.

New L2P21 CNES/Aviso products

- New orbit solutions in POE-F
  - Reduction of the variance of the SSH crossovers differences
- Use of new DAC ERA-5 solution
  - Better bathymetry definition
  - TUGO model
  - Large reduction of the variance of the SSH crossovers difference (~50% of total reduction)
- New MSS solution
  - Better spatial coverage (coastal areas)

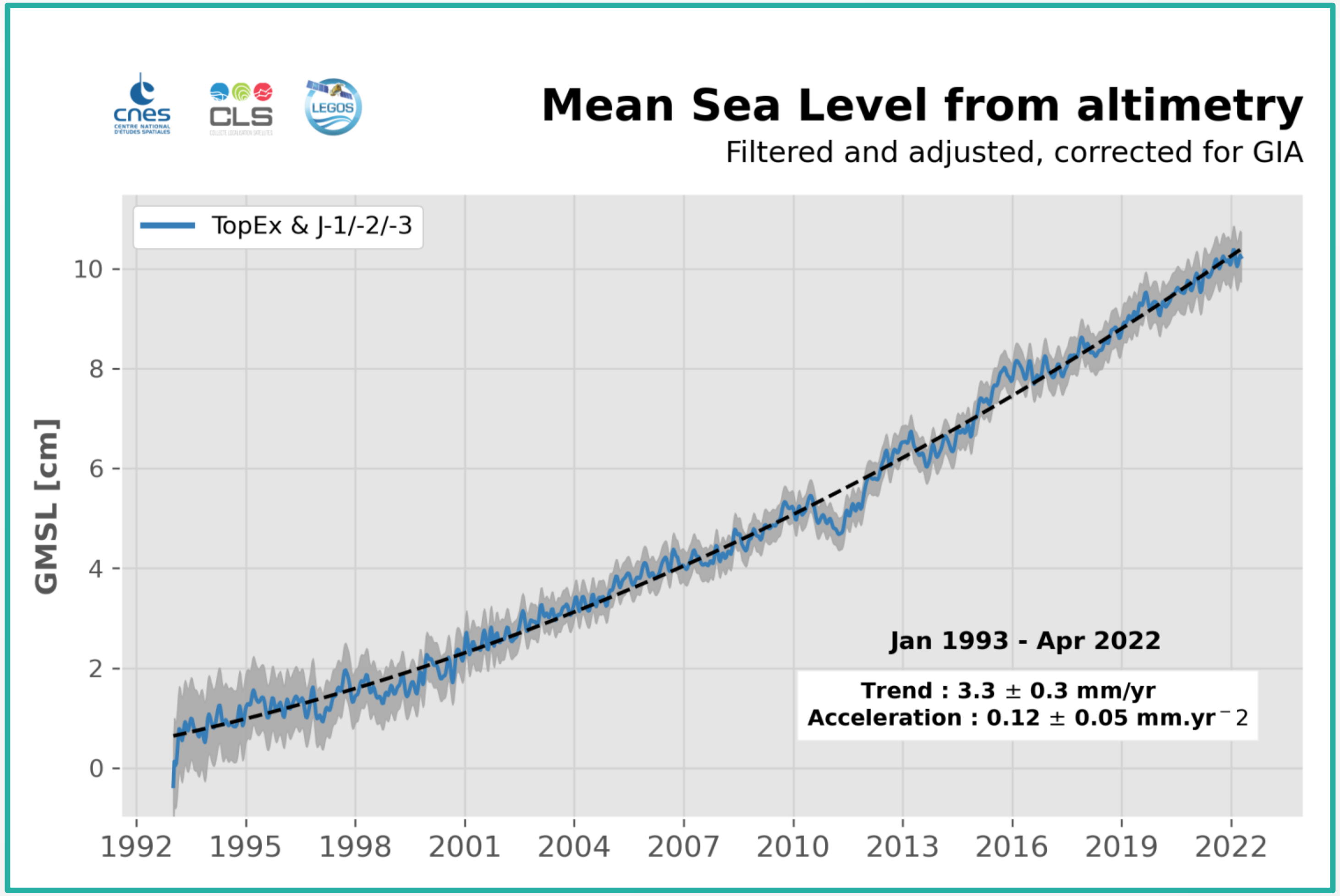
Detailed in Guérou et al. (2022)

Table 1. Origins and references of the corrections contained in the L2P 21 along-track 1 Hz products. These products are the ones used to compute the current GMSL CNES/AVISO record. The terms in blue are the ones updated as compare to the previous version L2P 18.

Geophysical correction	Topex-Poseïdon	Jason-1	Jason-2	Jason-3
Orbit	GDR GSFC STD18	CNES POE-E	CNES POE-F	
Range	M-GDR	GDR-E	GDR-D	GDR-D/-F
Sea State Bias	CLS update (Tran et al., 2010)	GDR-E	CLS update (Tran et al., 2012)	CLS update (based on Tran et al., 2012)
Ionosphere	CLS update (Nencioli, 2021)			
Wet Troposphere	CLS update (Fernandes and Lázaro, 2016)	GDR-E (from radiometer)	GDR-D (from radiometer)	GDR-D/-F (from radiometer)
Dry Troposphere	CLS update (from ERA-5 sea level pressure model)			
DAC	CLS update From ERA-5 model (Carrere et al., 2020)			GDR-D/-F (Carrère and Lyard, 2003)
Ocean tide	CLS update FES2014 (Carrere et al., 2014; Lyard et al., 2021)			GDR-F FES2014
Internal tide	CLS update (Zaron, 2019; Carrere et al., 2021)			
Solid Earth tide	GDR (Cartwright and Tayler, 1971; Cartwright and Edden, 1973)			
Pole tide	CLS update (Desai et al., 2015)			
MSS	CLS update (composite SCRIPPS, CNES/CLS 15, DTU 15, see DOI)			

CNES/Aviso GMSL record

- **Temporal extension ➔ April 2022**
  - Jason-3 GDR-F reprocessed
  - Upcoming reprocessing campaigns
    - TP,
    - Jason-2
- **To be available soon on-line**
  - Topex-A empirical correction *(Ablain+17 / WCRP+18)*
  - Uncertainty envelope



CNES/Aviso GMSL record

- **Temporal extension ➔ April 2022**
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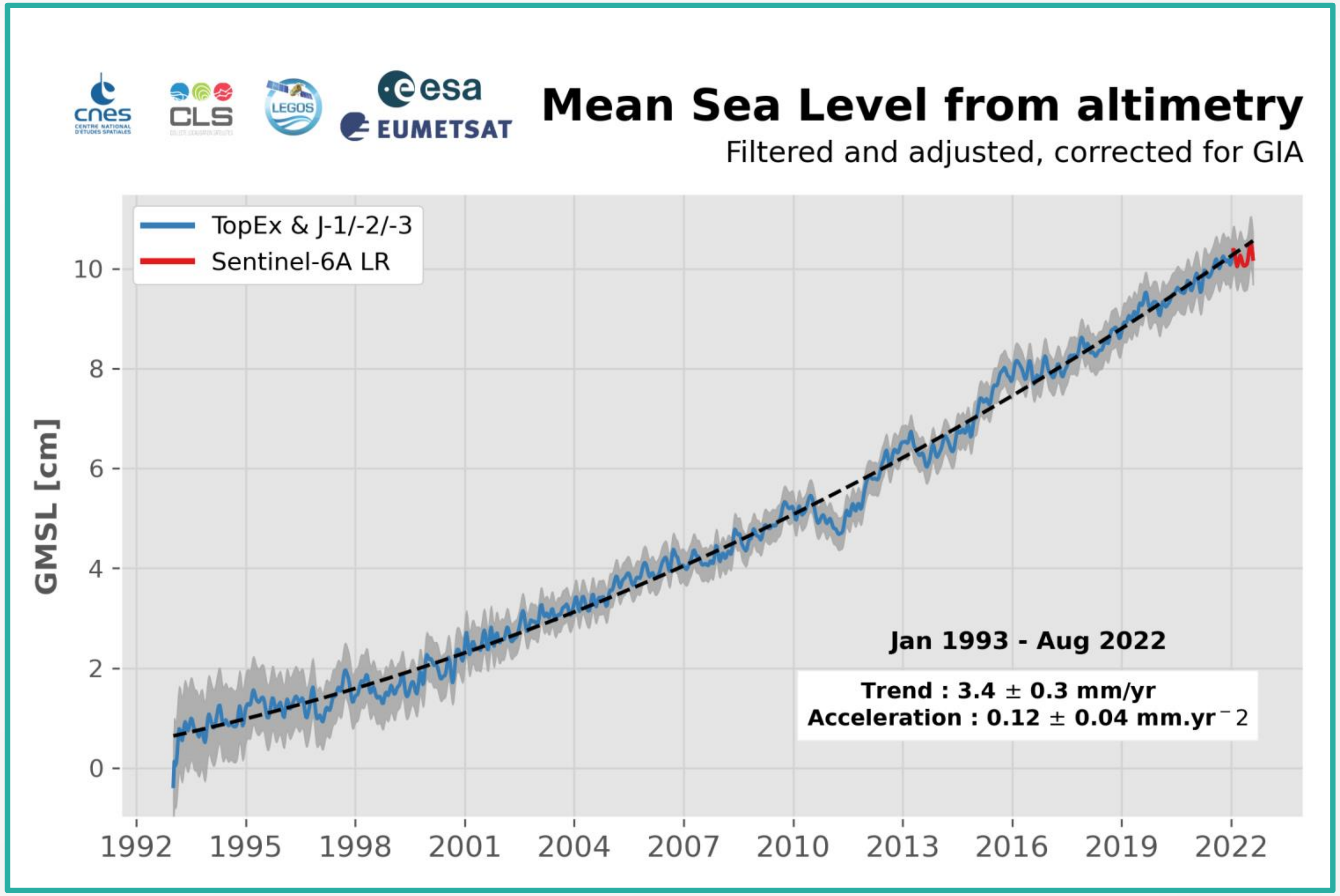
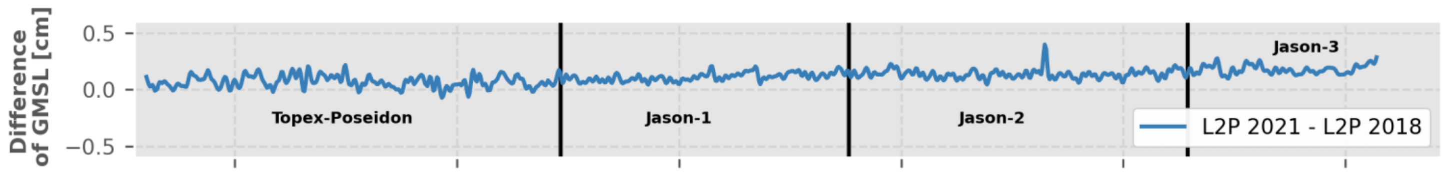
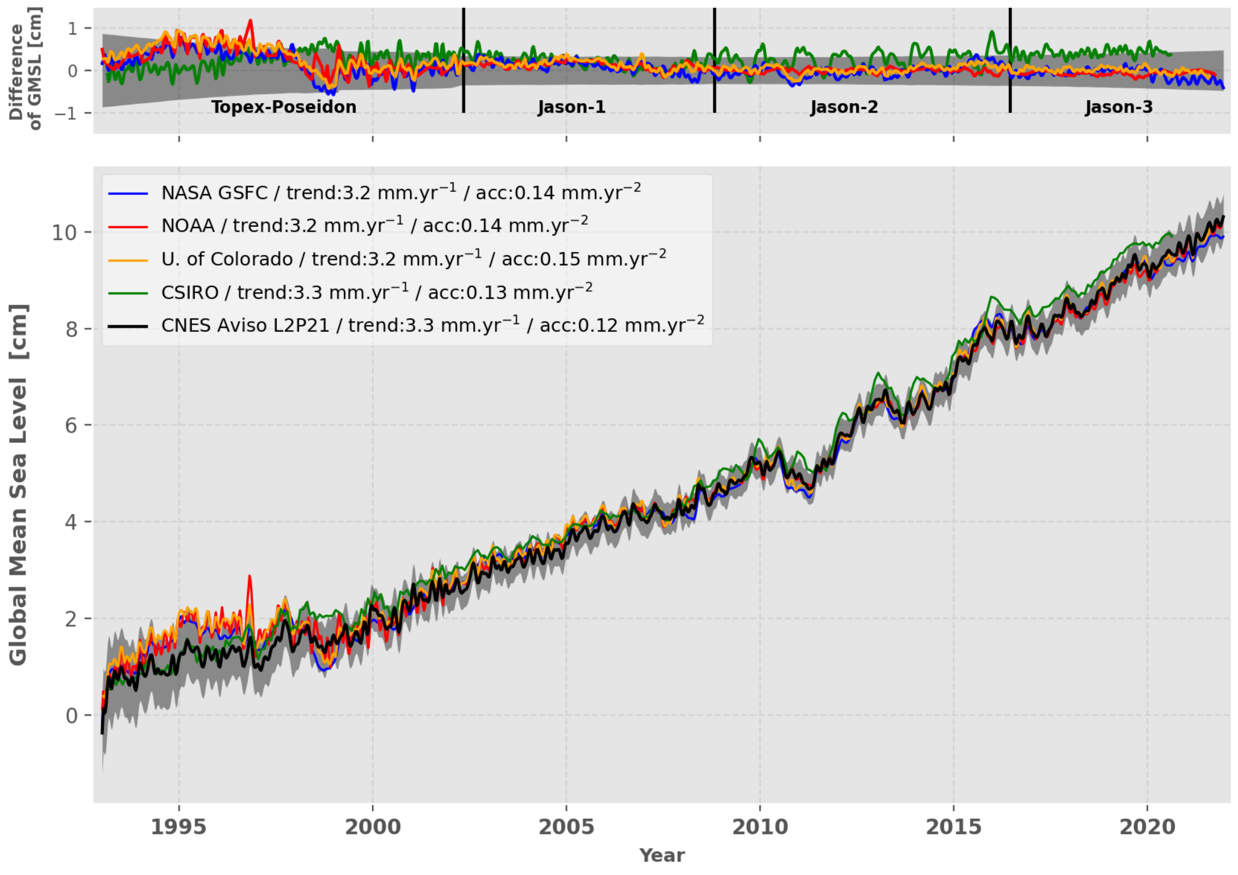
- **Sentinel-6A LR as the new reference**
  - Integration on-going



CNES/Aviso GMSL record

- **Consistent with previous record**
  - Within the uncertainties
- **Consistent with other GMSL products**
  - Within uncertainties
  - Systematic differences during TOPEX period





Instrumental uncertainties

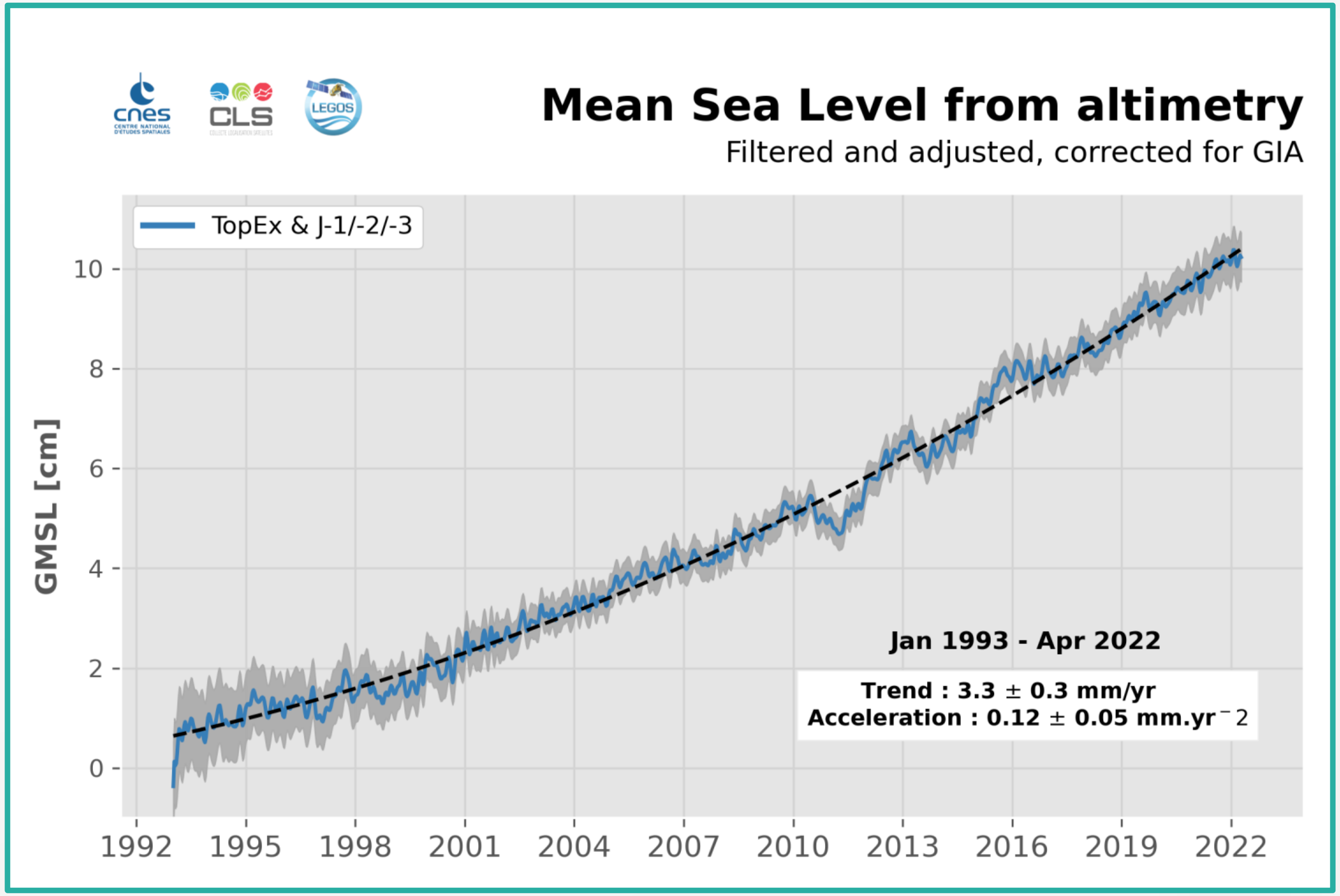
“**The GMSL signal** measured from space that we present here **INCLUDES ALL SOURCES OF VARIABILITY** including the forced response to anthropogenic emissions, the forced response to natural forcing (such as the solar activity) and the internal variability of the climate system.”

“**WE DO NOT** intend to detect, separate neither attribute the sea level signal to these different sources of variability. “

“**WE ONLY** intend to provide the most accurate GMSL time series from satellite instruments along with the **INSTRUMENTAL UNCERTAINTIES** that are indicators of the typical level of instrumental uncertainty present in the CNES GMSL record”

“The estimate of the 1993-2020 trend and acceleration **ARE ONLY METRICS** of the lowest frequency in the space-based GMSL time series. “

Extract from *Guérou et al. (2022)*



Uncertainty estimation method

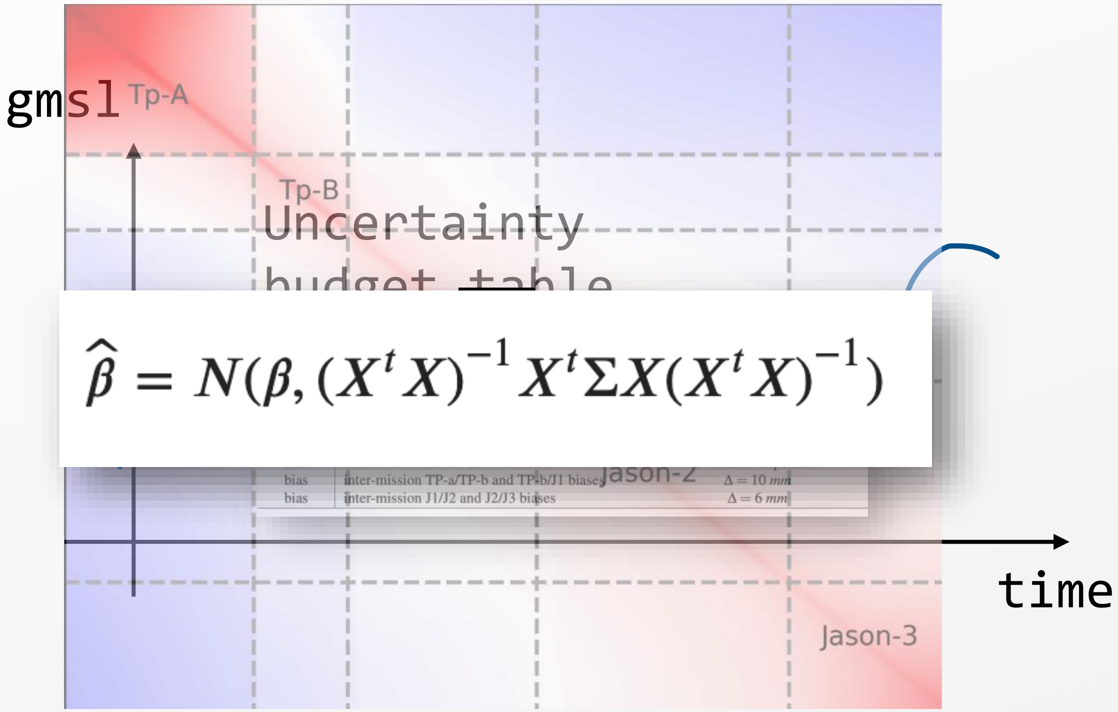
GMSL time serie,

Error budget table,

- Reflects our current knowledge

Derive covariance matrix,

Use covariance matrix to estimate model parameters uncertainties,



$$\hat{\beta} = N(\beta, (X^t X)^{-1} X^t \Sigma X (X^t X)^{-1})$$

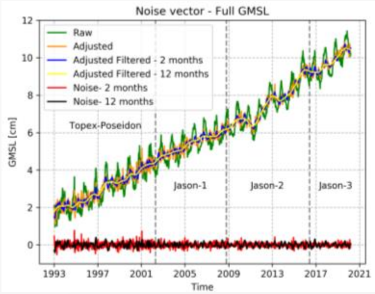
CLS COLLECTE LOCALISATION SATELLITES

Construction of the instrumental uncertainty budget

= Altimeter + Radiometer + Doris & GPS + Geo. Corr

	Source of uncertainties	Type of errors	Uncertainty (1σ)	Method / References
High frequency uncert.	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)
TOPEX	Topex-A/-B altimeter drift	Drift	$u_\delta = 0.7\,mm/yr$ over TP-A period $u_\delta = 0.1\,mm/yr$ over TP-B period	Ablain et al. (2017)
WTC	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	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)
ITRF	International Terrestrial Reference Frame (ITRF)	Drift	$u_\delta = 0.1\,mm/yr$ over 1993-present	Couhert et al. (2015)
GIA	Global Isostatic Adjustement (GIA)	Drift	$u_\delta = 0.05\,mm/yr$ over 1993-present	Spada (2017)
Offsets	Intermissions calibration offsets	Bias	$u_\Delta = 2\,mm$ for TP-A/B $u_\Delta = 0.3\,mm$ for TP/J1 $u_\Delta = 0.1\,mm$ for J1/J2 $u_\Delta = 0.2\,mm$ for J2/J3	This paper (sec. 2.2.1)

Empirical estimation of HF uncertainties
–contains geophysical signals (limitations here)

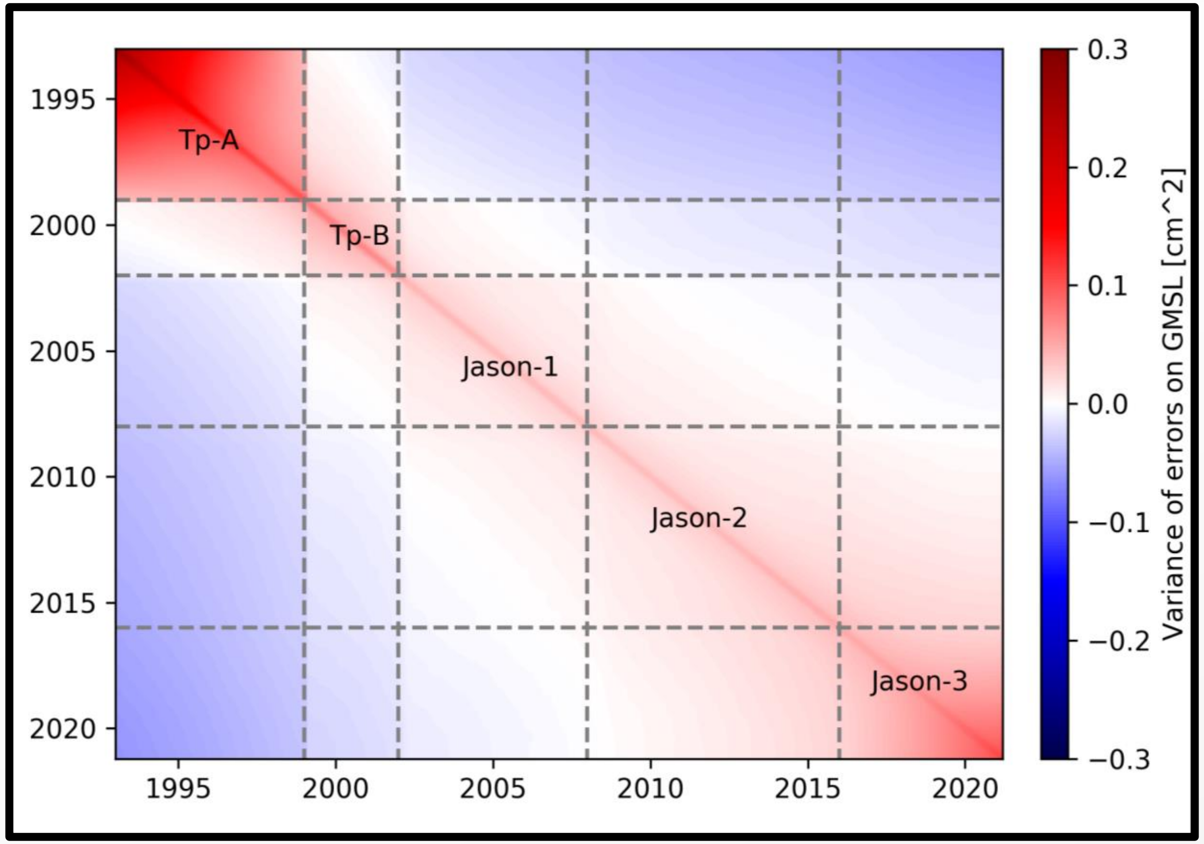


Higher uncertainties on WTC from Jason-3
–Barnoud et al. 2021 (GRL publication)

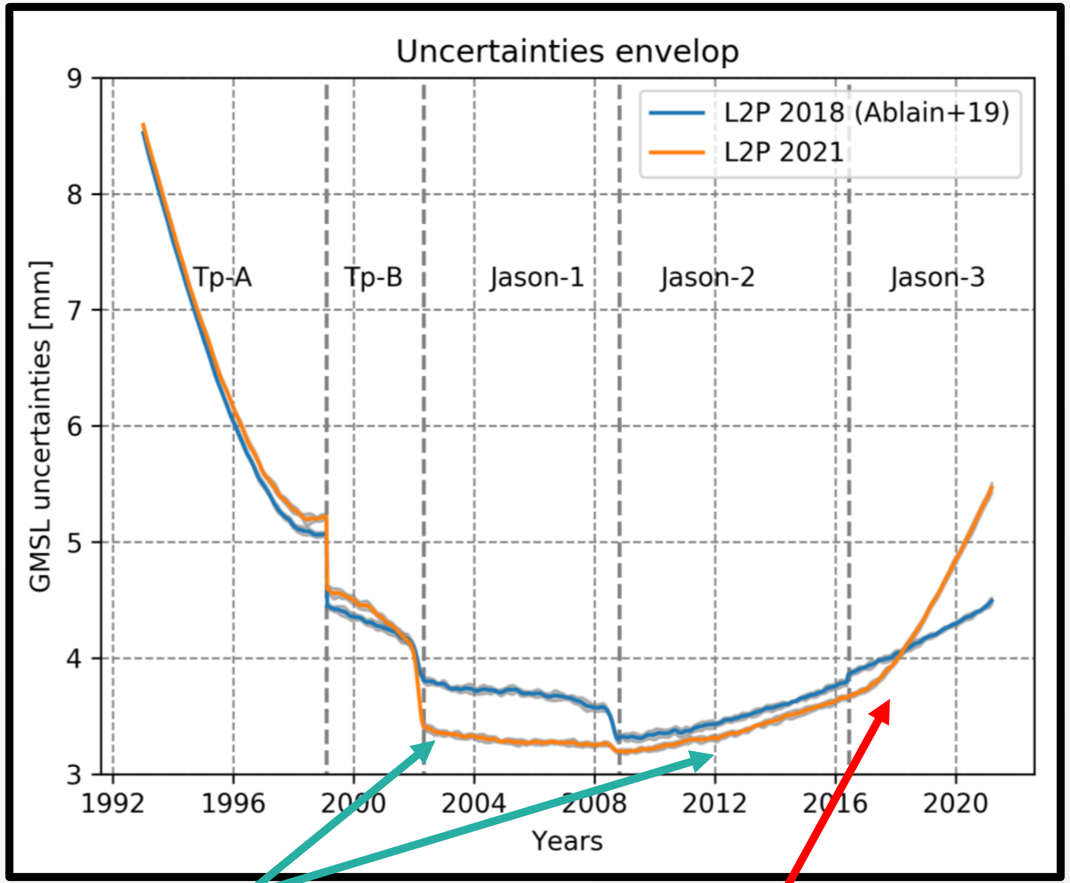
Improvement of the uncertainties level
– method revised in Guérou et al. (2022)

CLS
COLLECTE LOCALISATION SATELLITES

Measurement uncertainties in the L2P 21



Variance/co-variance matrix
- of the instrumental uncertainties

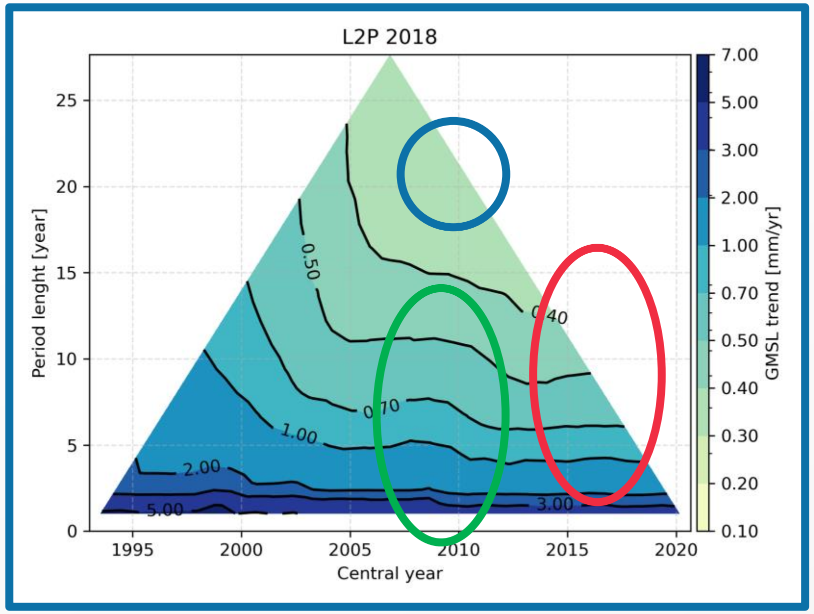


HF uncertainties improvements
– better L2P21 standards

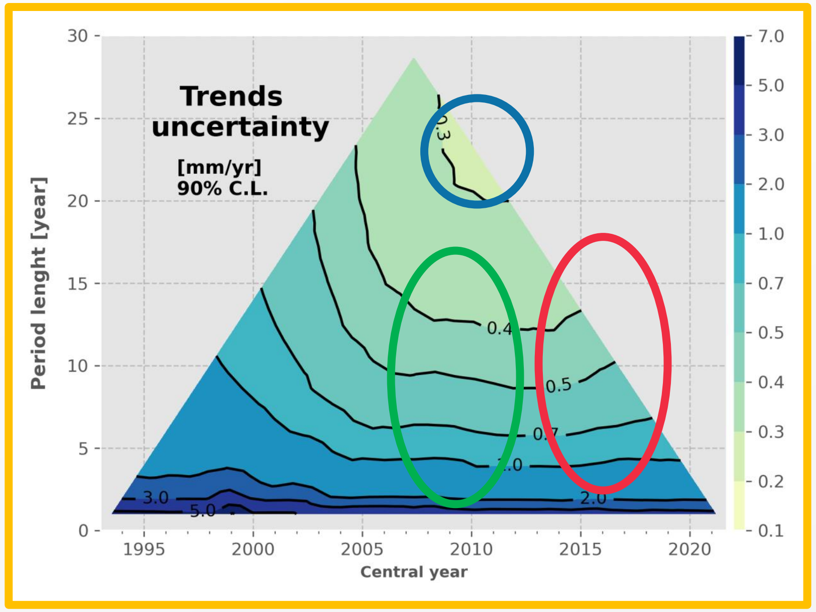
Update WTC Jason-3

GMSL trends uncertainties: L2P21 vs L2P18

2018



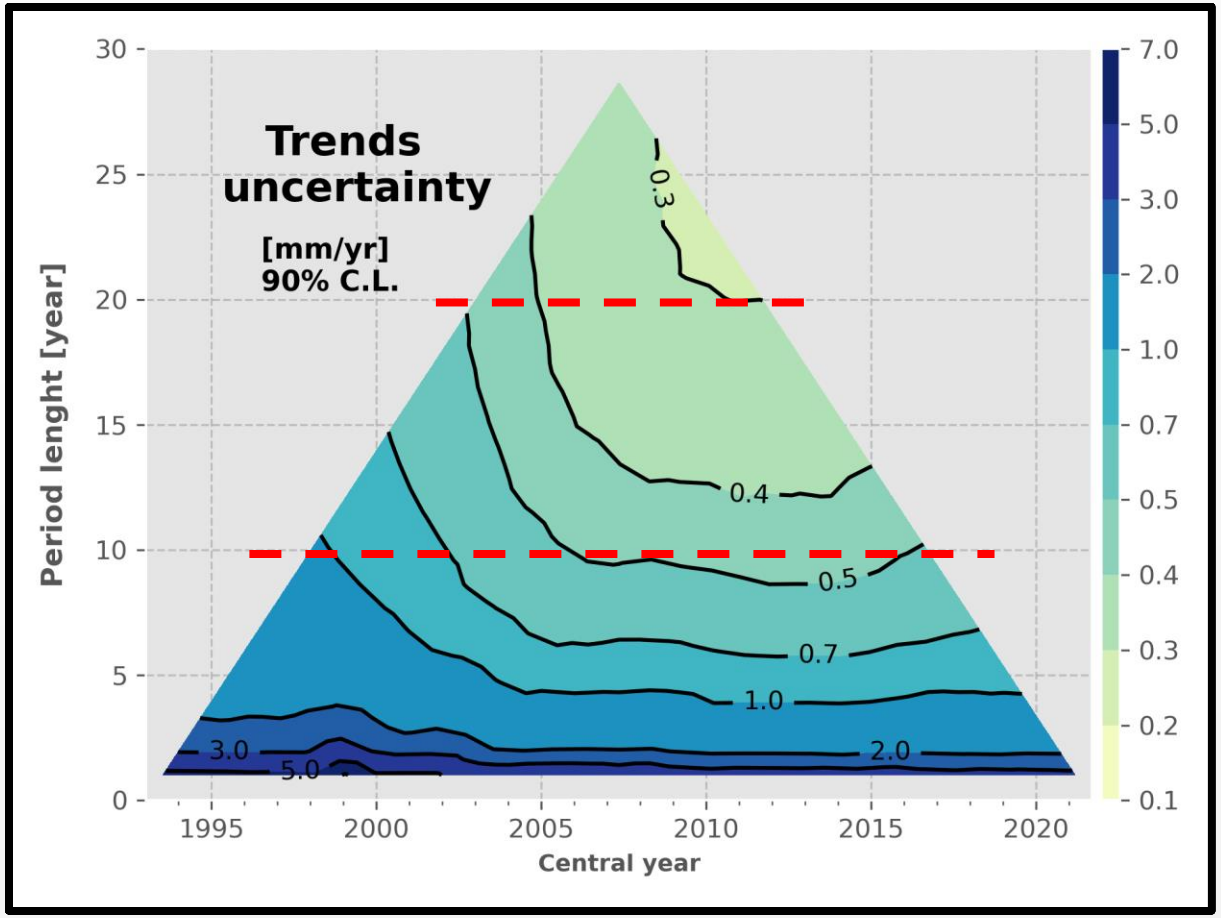
2021



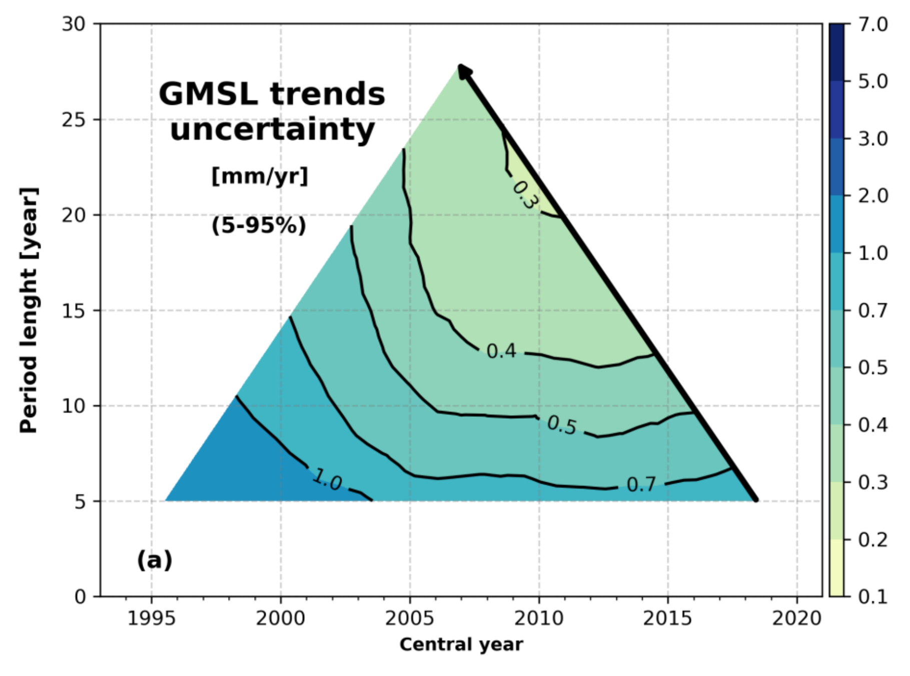
- ✓ Minimum of 0.3 mm/yr [90% C.L.] for 22 years of record centered in 2010
- ✓ Plateau is reduced due to the decrease of the HF uncertainties
- ✓ Increase of the instrumental uncertainties over the last years du to
  - – WTC Jason-3

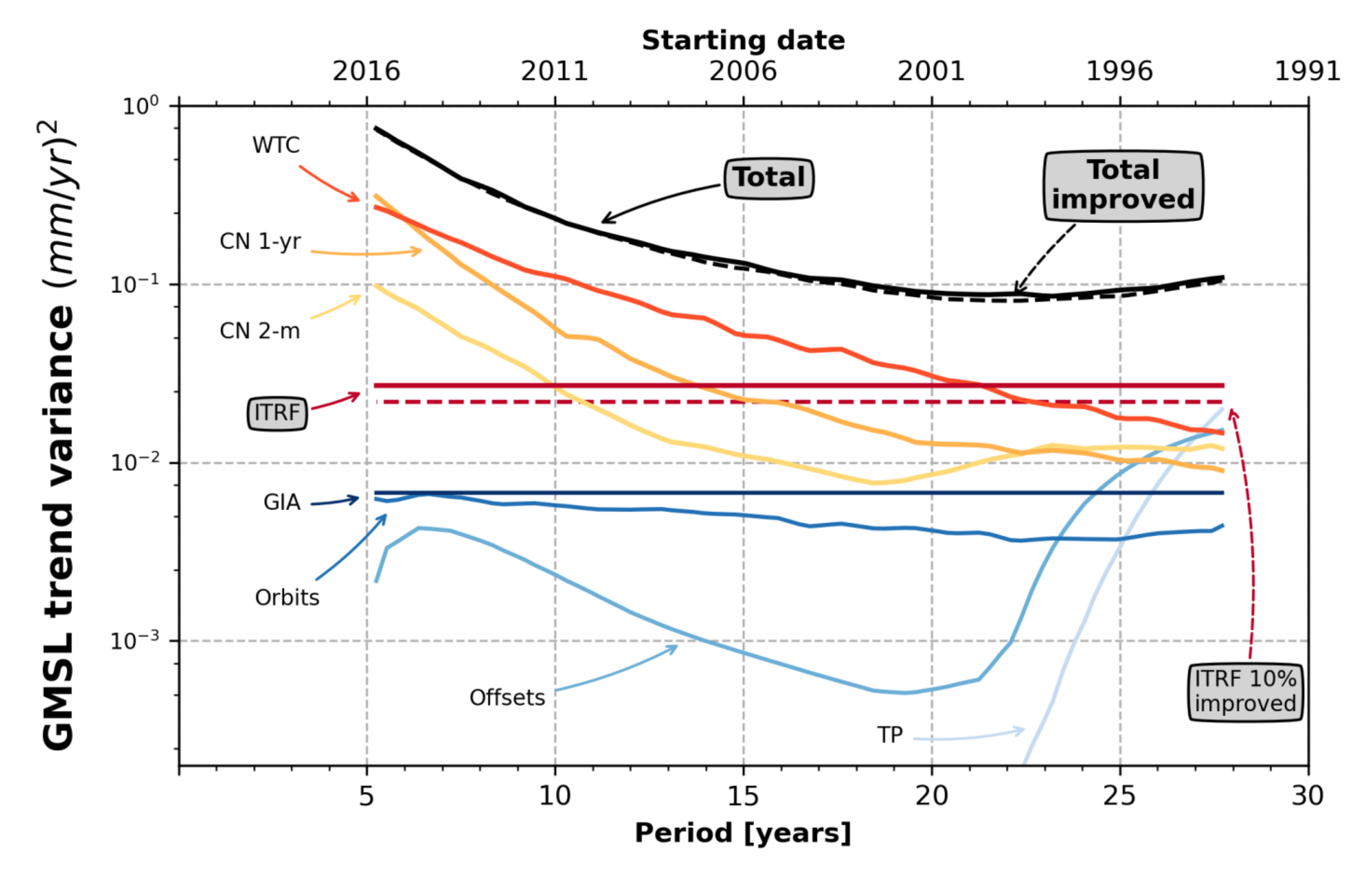
What is needed to meet scientific requirements ?

- **Sea Level Budget Closure**
  - 0.3 mm/yr [90% CL] over 10 years (GCOS)
- **Ocean Heat Content / Earth Energy Imbalance**
  - 0.1 W/m^2
  - 0.1 mm/yr over 20 years for GMSL



Partition of each instrumental contributors - trends



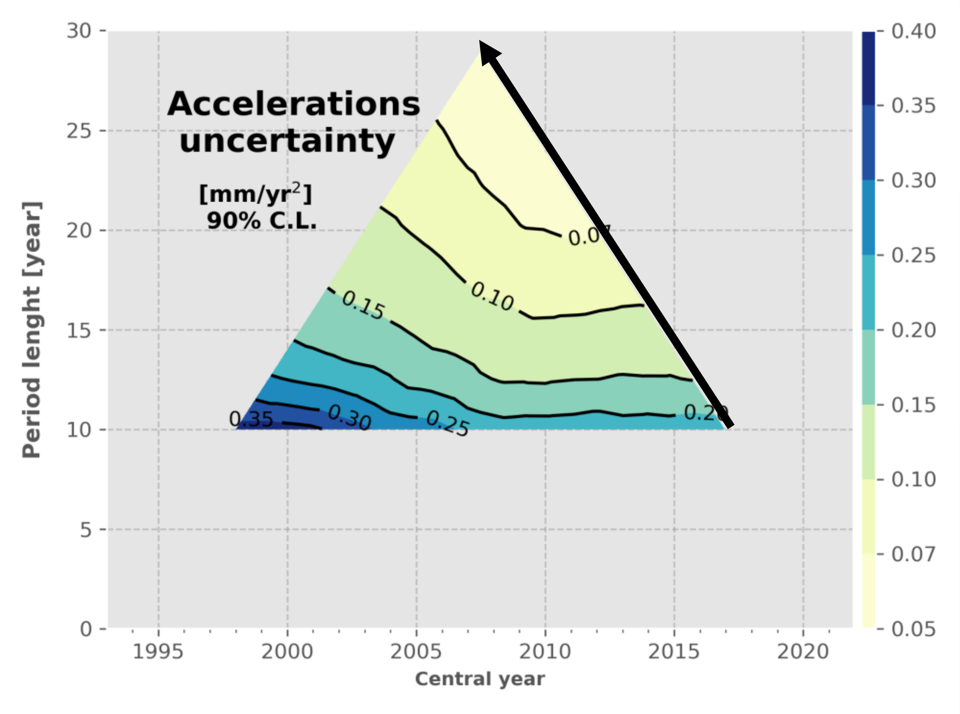


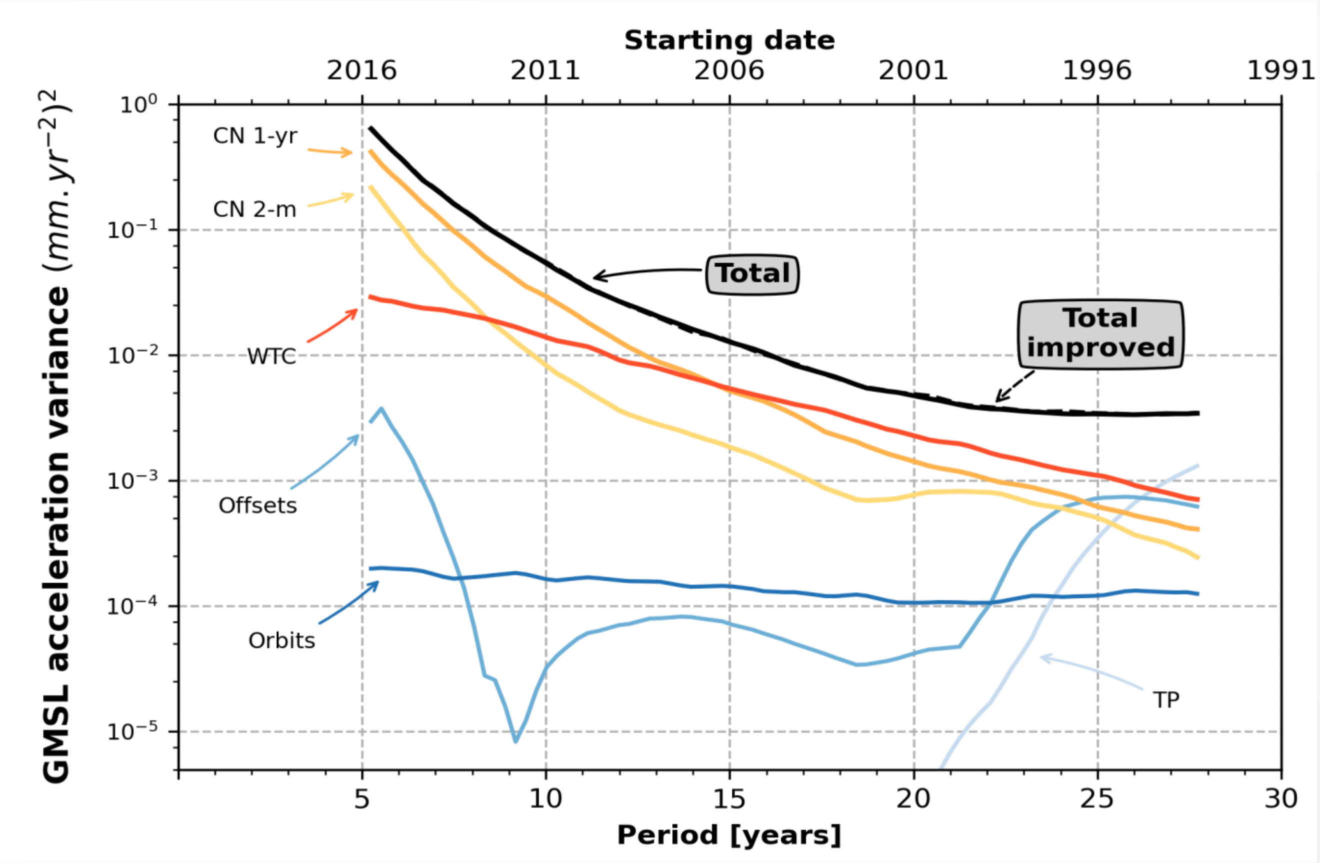
Current limitations to stability requirements

- High frequency and WTC – 10-15 years
- ITRF – >15 years

Meyssignac et al. (submitted)

Partition of each instrumental contributors - accelerations





Current limitations to stability requirements

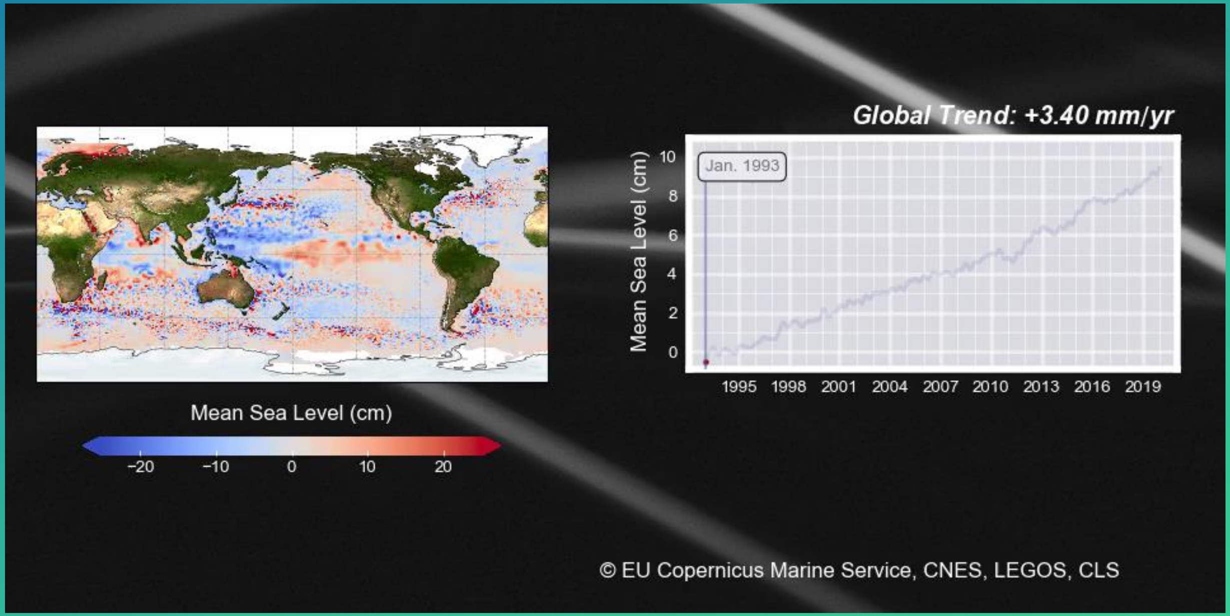
- High frequency and WTC: 10-15 years
- Topex : >25 years
- ITRF and GIA do not contribute (modeled as linear drift – to be improved)

Adapted from Meyssignac et al. (submitted)

Conclusions

- GMSL record updated to latest standards, still rising…
- Re-estimated uncertainty budget to account for latest findings, and provided consistent trend/acceleration uncertainty levels
- Error knowledge is mainly empirical, to be complemented to a top-down approach propagating uncertainties from the instrument to the GMSL
- Science requirements on GMSL stability are getting more and more stringent, we provide insights on which components are currently limiting

QUESTIONS


Global Trend: +3.40 mm/yr
Jan. 1993
Mean Sea Level (cm)
10
8
6
4
2
0
1995 1998 2001 2004 2007 2010 2013 2016 2019
Mean Sea Level (cm)
−20 −10 0 10 20
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