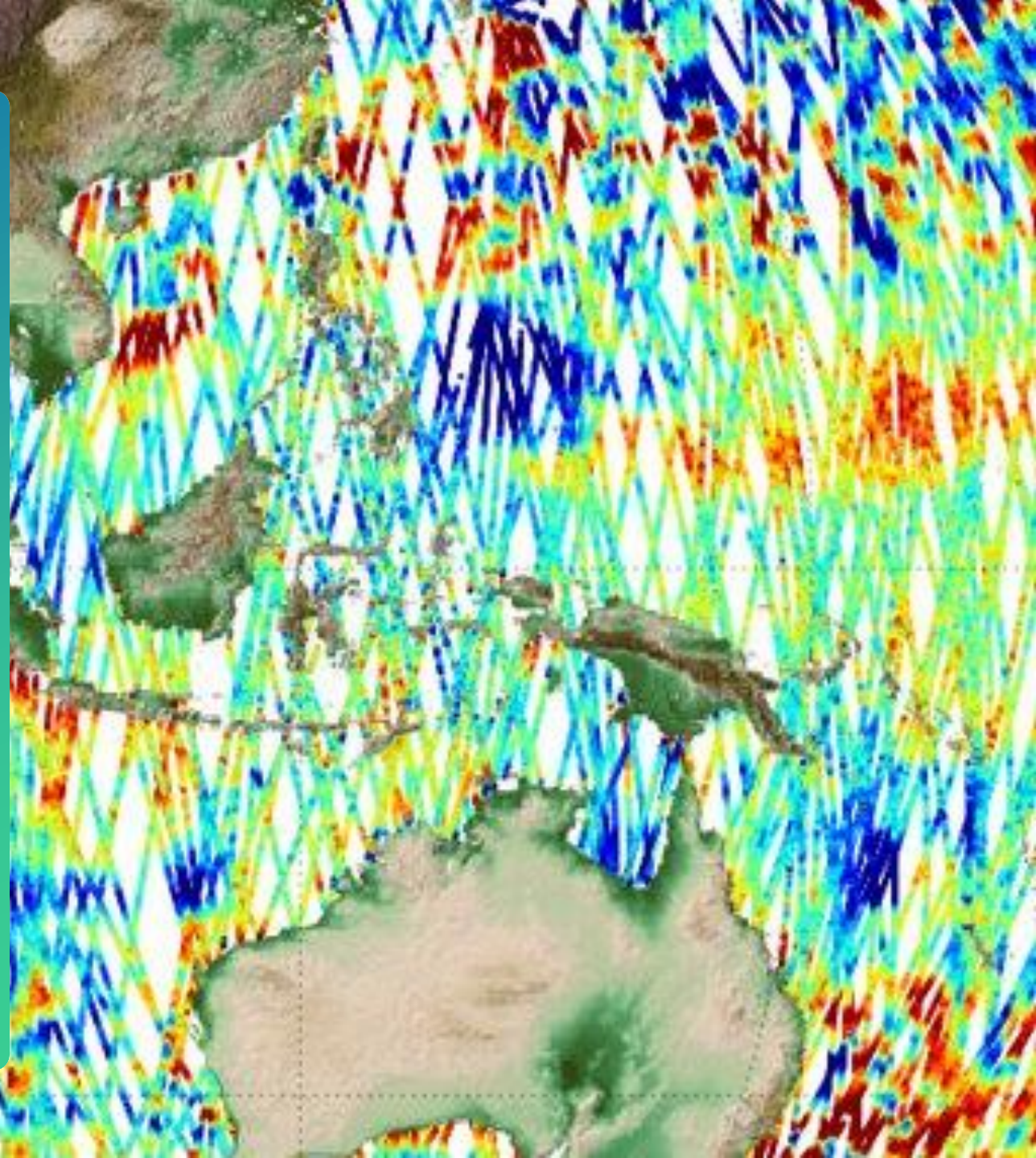

30 years of sea level anomaly reprocessed to improve climate and mesoscale satellite data record

OSTST conference 2023

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1 **CNES**, Centre National d'Etudes Spatiales, Toulouse, France
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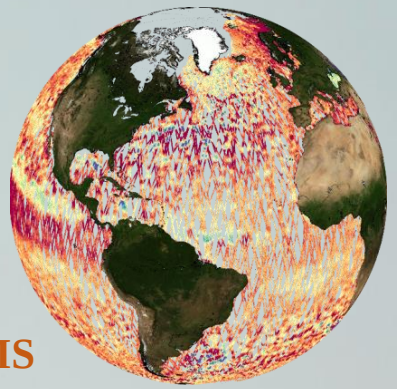
3 **EUMETSAT**, Darmstadt, Germany
4 **CLS/CELAD/ALTEN**, France

CONTEXT : unified and up-to-date dataset for all altimetry missions

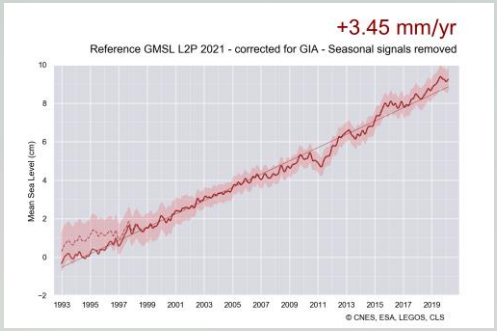
L2 products come from more than 15 missions :
-> operated by different agencies
-> different : file formats, geophysical standards, reprocessing time, …

-> difficulties to build a stable dataset for sea level rise



<u>L2P Products :</u> Sea Level Anomalies, wind and waves :

- **Homogeneous & up-to-date physical content for all missions -> ensure mesoscale accuracy for CMEMS**
- **Intermission calibrations -> ensure climate continuity for C3S**
- **In-situ calibration (waves)**



- **Different timeliness to address various applications**

All data (+ 100 years cumulated) are reprocessed every 3 years.

REPROCESSING & INSTRUMENTAL IMPROVEMENTS : GLOBAL

DT24 reprocessing goal :
improve MESCOSCALE
& ensure CLIMATIC stability

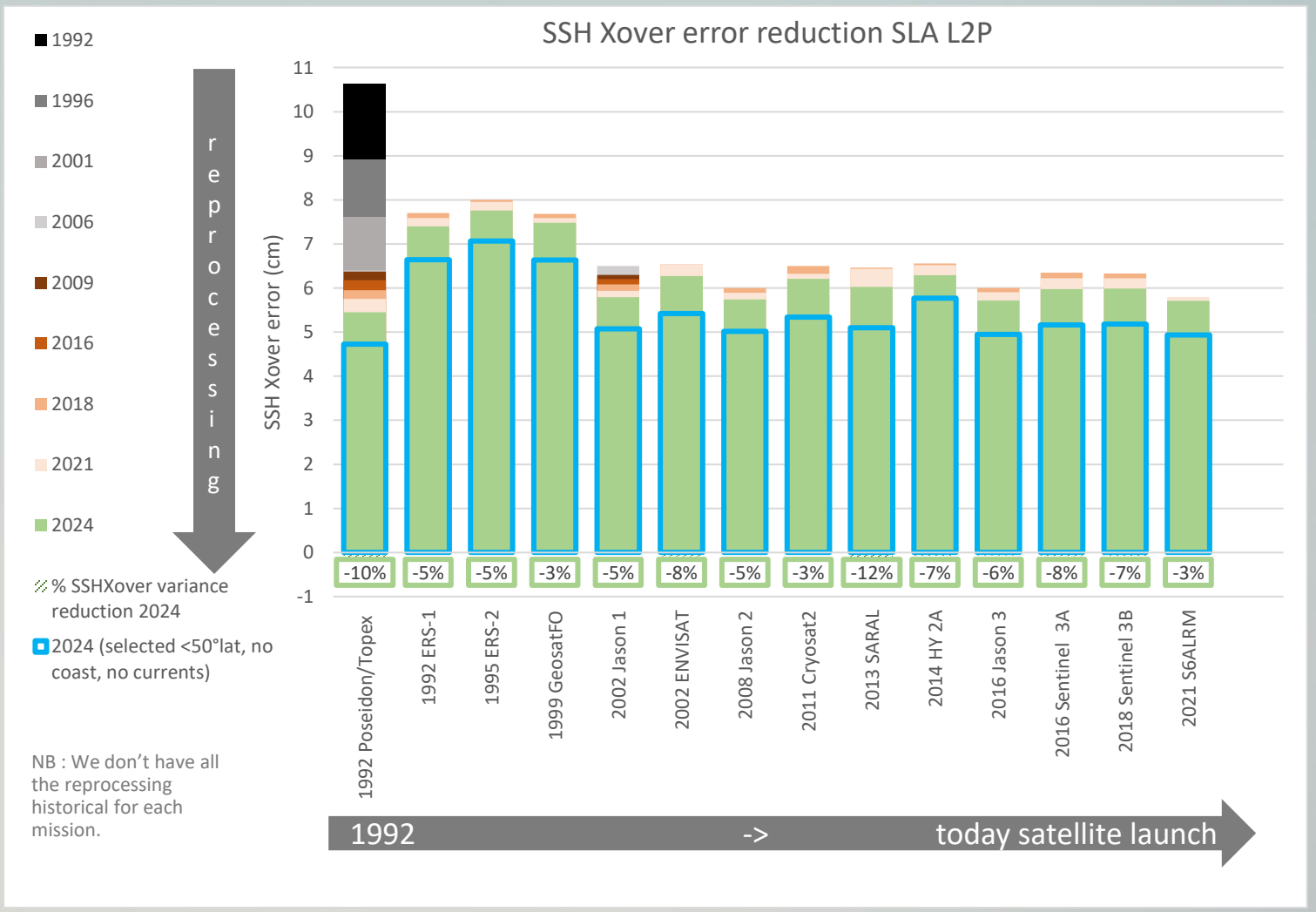
Climate scales relies on **reference altimeters** series (TP, J1/2/3, S6A) and high latitude missions (EN, C2, S3A, S3B, ERS1, ERS2)

Mesoscale signal is retrieved by all missions

Gains in accuracy mainly comes from
-> Recent instruments showing less errors
-> Reprocessing of algorithms used to compute Sea level anomaly

NB :

- gains in accuracy are smaller over time : ~30% 10 first years, ~5% after
- The errors left may be ocean variability



STANDARDS EVOLUTIONS :

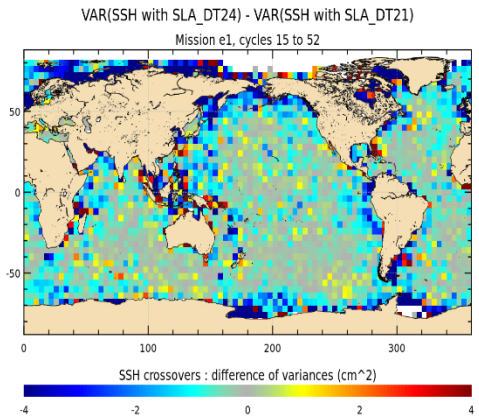
J2 and FDR data for ERS1, ERS2 & EN are being analyzed and should be included in next reprocessing DT27.

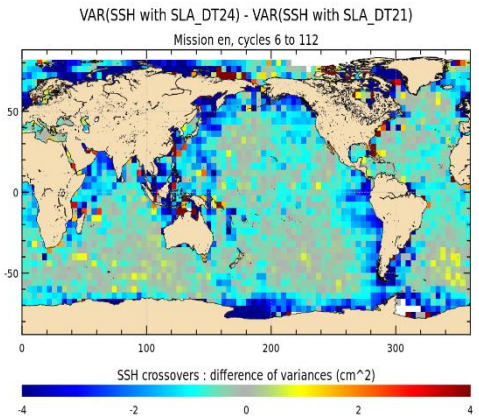
STD27 | STD24 | STD 21 | STD 18

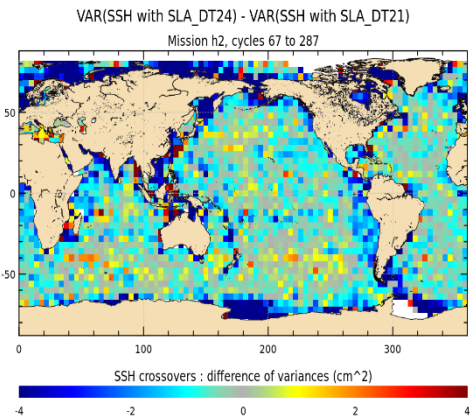
Meso-scale | Stability | Coast | Arctic

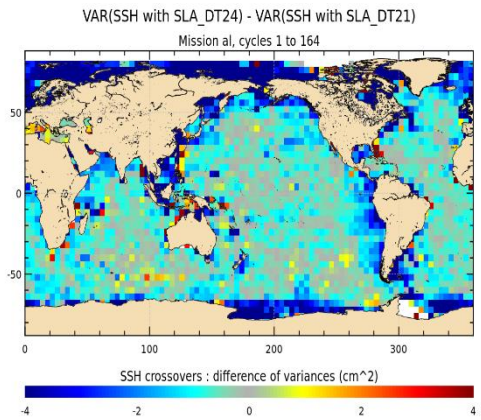
MISSION	Poseidon	Topex	Jason 1	Jason 2	Jason 3	ERS-1	ERS-2	ENVISAT	Geosat FO	SARAL	Cryosat 2	HY 2A	HY 2B	Sentinel 3A	Sentinel 3B	Sentinel6A/JasonCS LRM	Sentinel6A/JasonCS SAR
RETRACKING	MLE3	Numerical	MLE4	MLE4	Adaptive	OPR		MLE3 (OCE-1)	GFO tracker	MLE4	SAMOSA2.3	MLE4		SAMOSA		Numerical	SAMOSA
ORBIT	GSFC std 18		POE-F	POE-F		Reaper		POE-F	GSFC	POE-F	POE-F	POE-D	POE-F	POE-F		POE-F	
IONOSPHERIC CORRECTION	DORIS	Filtered dual-frequency altimeter range	Filtered dual-freq altimeter range [Guibbau 2015]	Filtered dual frequency GDRD [Guibbaud 2015] (SSB C band)	Filtered dual frequency GDRF [Nenciolli 2020]	NIC09 [Scharroo and Smith, 2010]	GIM [Ijima et al., 1999]	Filtered from L2 (SLOOP) ; c>65 GIM (GDR3)	GIM [Ijima et al., 1999]					Filtered dual-frequency altimeter range from L2		Filtered dual-frequency altimeter range from L2 LRM	
SEA STATE BIAS	2D Topex GDRF		2D J1 Non parametric [N. Tran 2015]	2D J2 Non parametric [N. Tran 2020]	2D J3 adaptive Non parametric [N. Tran 2020]	BM3 [Gaspar and Ogor, 1994]	Non parametric [Mertz et al., 2005]	2D EN Non parametric [N. Tran 2017]	Non parametric [Tran& Labroue, 2010]	Non parametric [N. Tran 2018]	Non parametric [Tran 2018] Baseline C	Non Parametric [Tran 2012, Labroue]	L2 product	Non parametric [N. Tran 2021]		Non parametric from [N. Tran 2020] J3 MLE4 GDRF	
WET TROPOSPHERE	TMR GDRF radiometer reproc		JMR/FCDR	AMR radiometer GDRD	AMR radiometer GDRF	GPD+ [Fernandes and Lazaro, 2016]		MWR radiometer	GFO Radiometer & ECMWF model	Neuronal Network (5 entries) V4	GPD+ [Fernandes and Lazaro, 2016]	ECMWF model		GPD+		AMR Radiometer reproc	
DRY TROPOSPHERE	ERA5 (1-hour) model based																
DYNAMICAL ATMOSPHERIC	TUGO High frequencies forced with analysed ERA 5 (and ECMWF from S6A onwards) pressure and wind field + inverse barometer Low frequences																
OCEAN TIDE	FES 2022																
INTERNAL TIDE	ZARON 2019 (HRETv8.1 tidal frequencies: M2, K1, S2, O1)																
POLE TIDE	DESAI et al.2015 ; Mean Pole Location 2017																
SOLID TIDE	Elastic response to tidal potential [Cartwright and Tayler, 1971 ; Cartwright and Edden, 1973]																
MEAN SEA SURFACE	Composite (SCRIPPS22,CNES/CLS22,DTU21)																

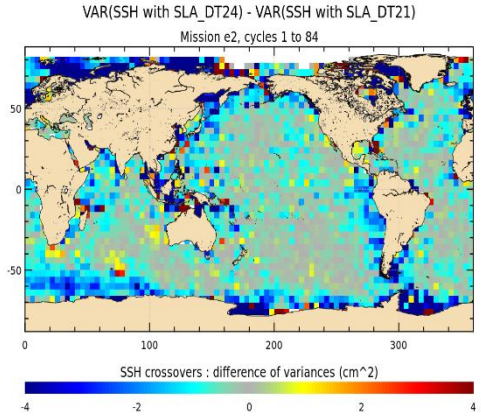
MESOSCALE IMPROVEMENTS :

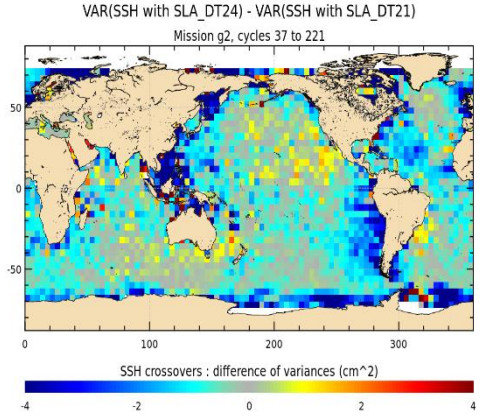


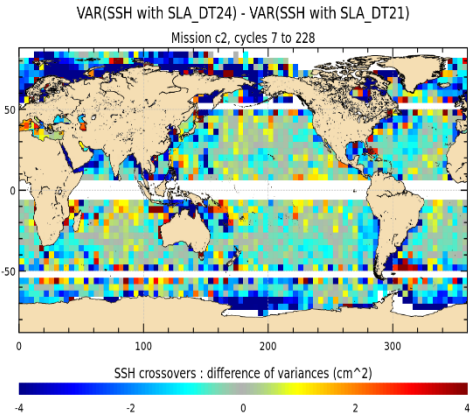


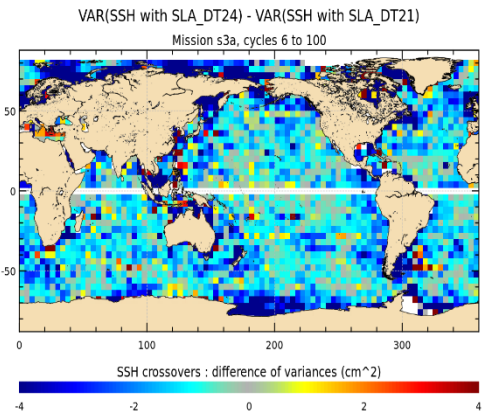


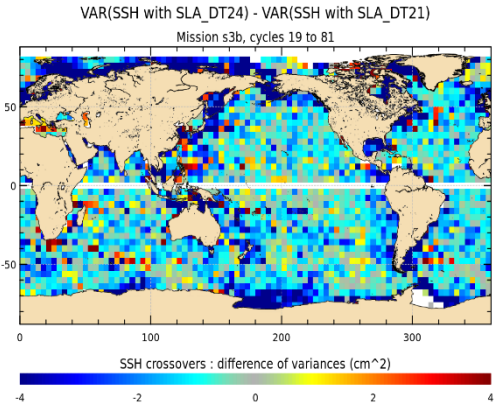


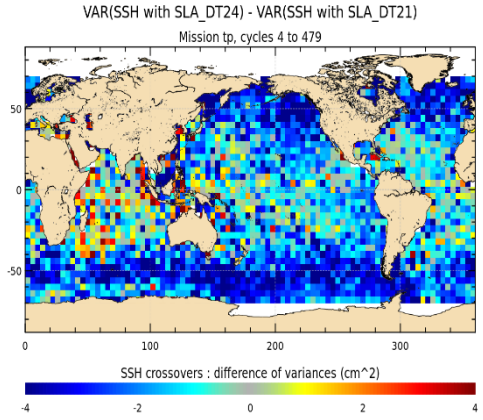


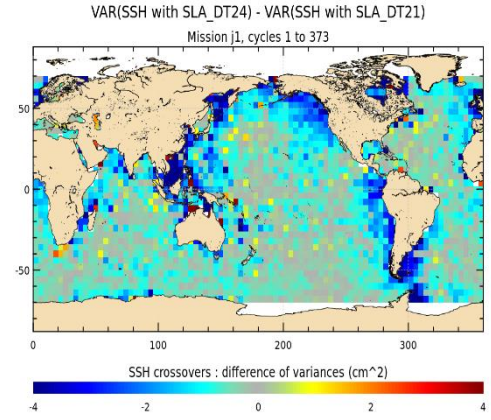


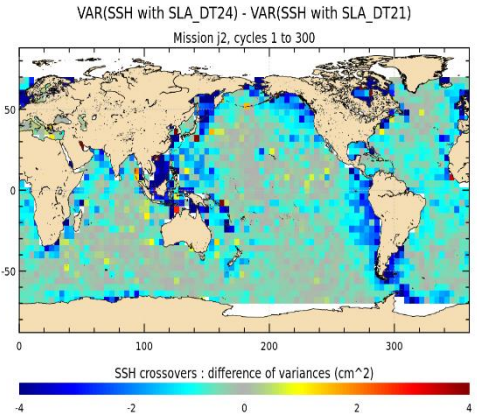


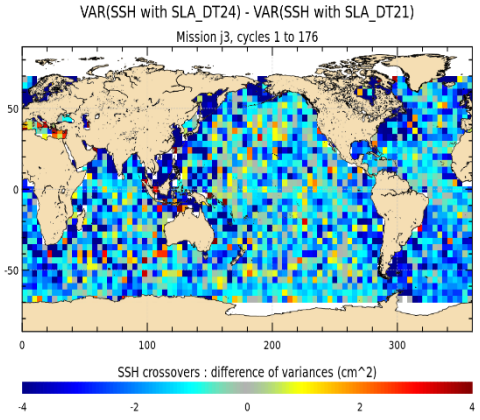


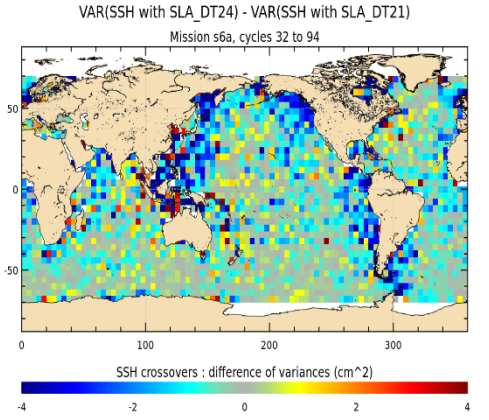












Crossover gain from DT21 to DT24.

Mesoscale improvements thanks to :

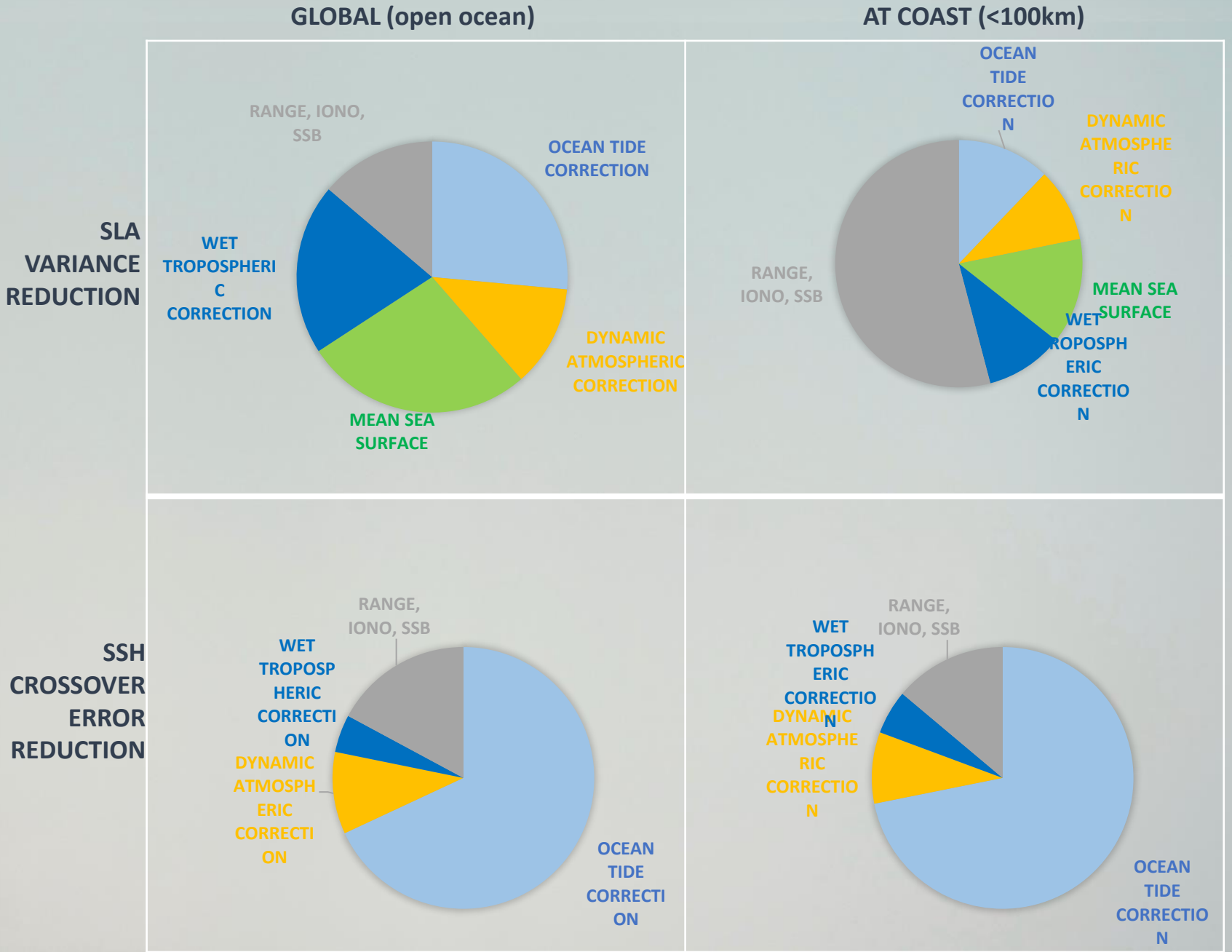
- **Instrumental correction** (this year we have the chance to profit of the reprocessing of some reference missions)
- **geophysical correction** mostly
  - **At high latitudes**
  - **Along the coast**

Improvement contributor budget for DT2024 reprocessing (S3A) :

Here you can see the participation towards mesoscale improvements for each standard change.

Variance reduction shows the contribution of the mean sea surface. We can see that all the standards are balanced.
At coast, we see the importance of improving variance reduction through mission reprocessing (for S3A see F. Nencioli & al, OSTST 2023, for S6A see F08 Reprocessing Calval Assessment, CLS/CNES/EUMETSAT).

Crossover error reduction is the main most consistent diagnostic. It demonstrates that most improvements are brought by the **ocean tide correction FES22** for DT24 reprocessing.



GEOPHYSICAL CORRECTION :

OCEAN TIDE CORRECTION :

New **FES 22** model (L. Carrere et al.)

- insitu data assimilation
- 8 times higher resolution
- regional bathymetry
- finer precision for polar regions

improves mesoscale (Ocean tide explain ~70% of improvements)

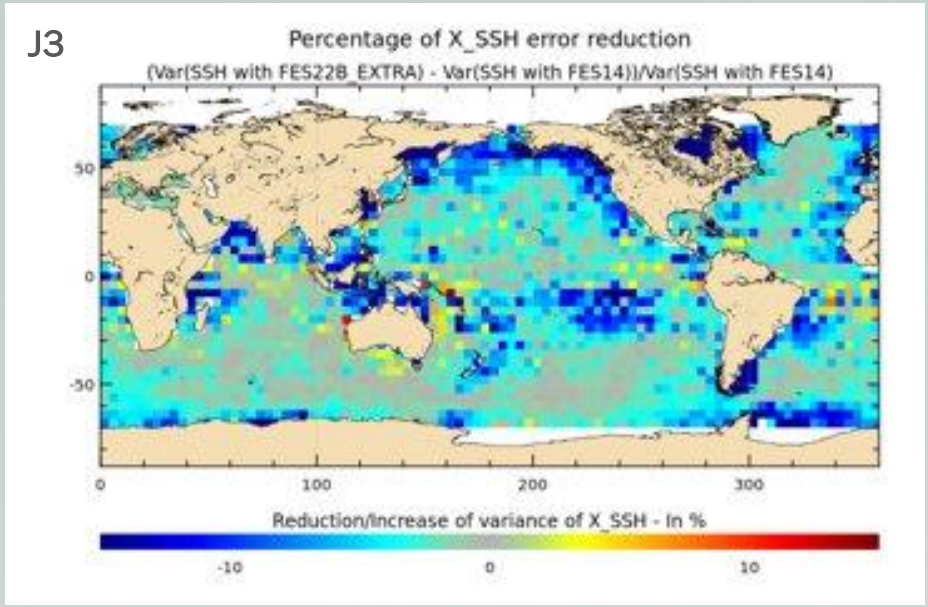
Particularly :

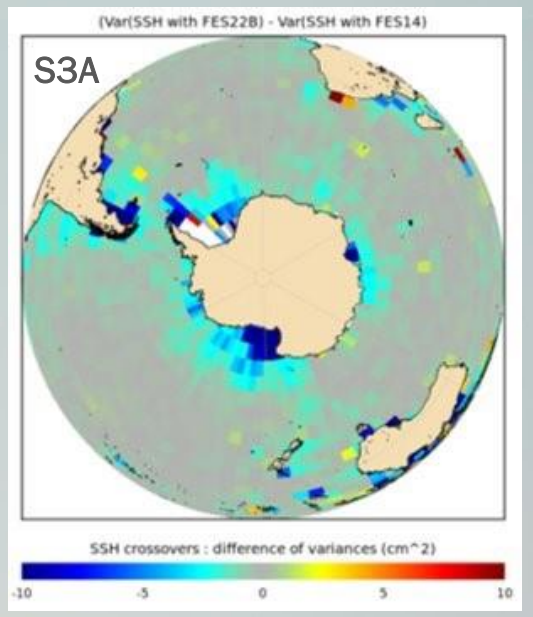
→ on high plateaus

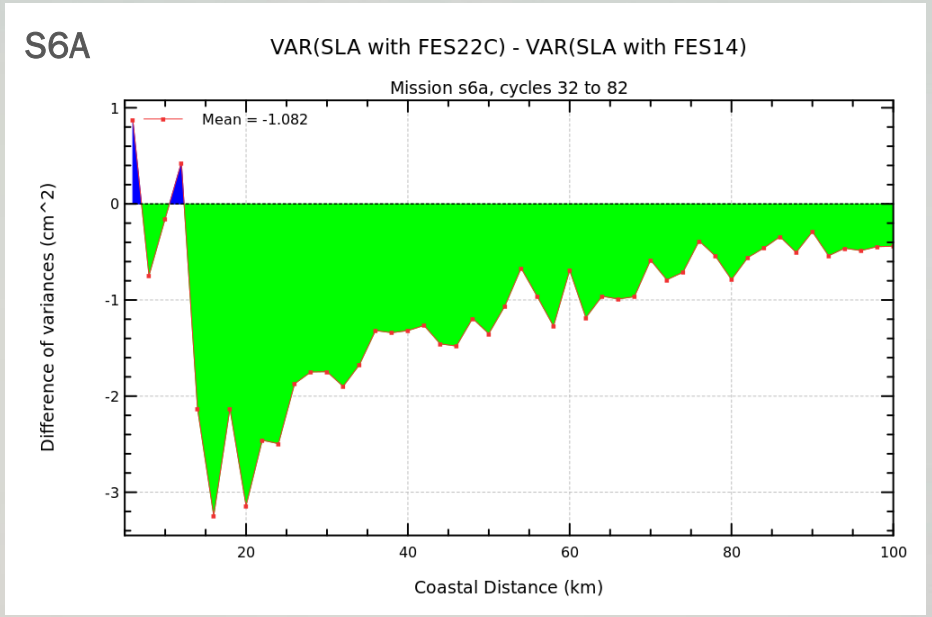
→ on the coast

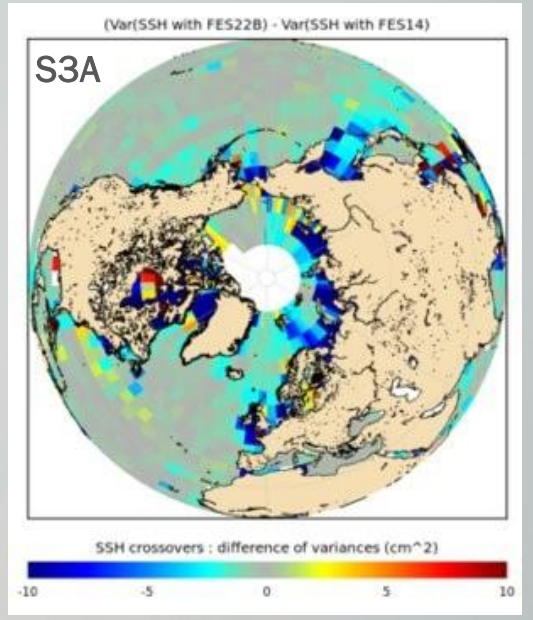
→ in polar regions

→ Without impacting significatively global & regional trends

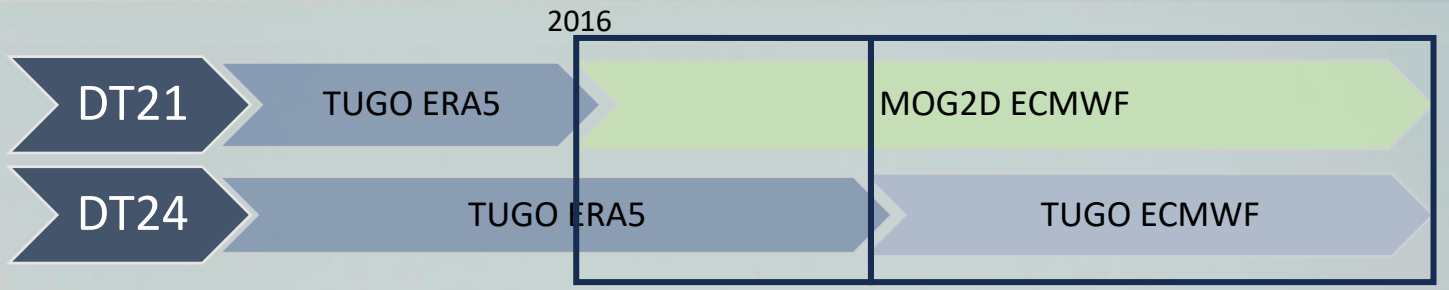








GEOPHYSICAL CORRECTION :



DYNAMIC ATMOSPHERIC CORRECTION :

New **TUGO** DAC model (L.Carrere et al.) is operational with **ECMWF** meteorological model

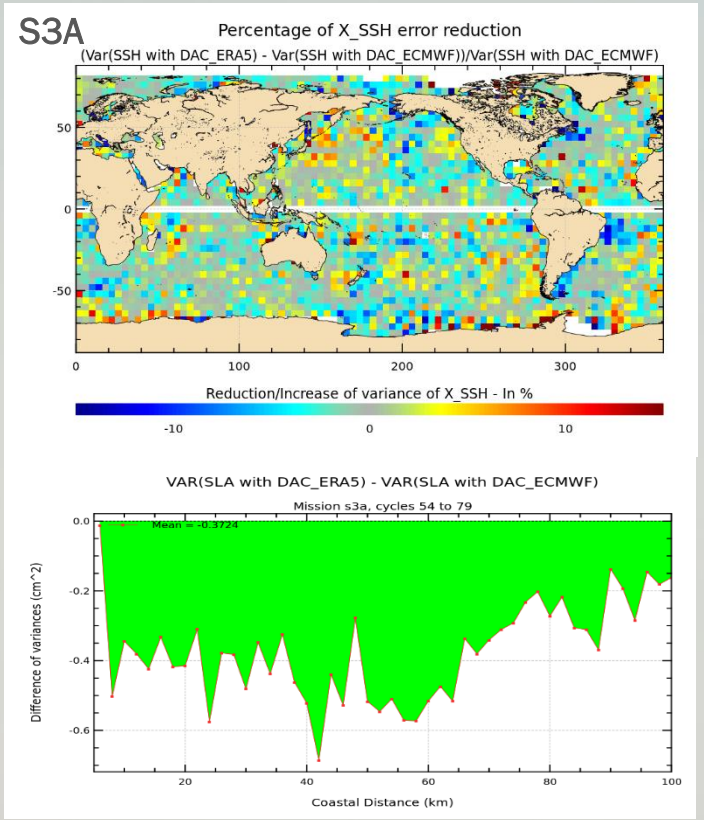
- regional bathymetry
- Improvement of the interpolation of wind & pressure forcing/variables
- Improvement of the internal wave drag dissipation parameterization

Extension of TUGO DAC model with ERA5 meteo model

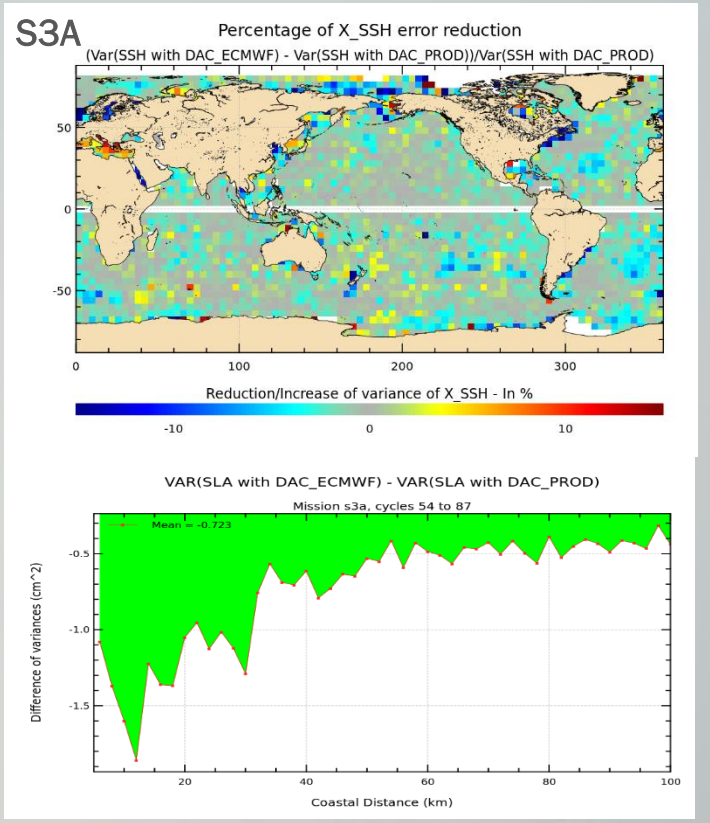
Both improves mesoscale
Particularly :
→ on high plateaus
→ on the coast
→ in polar regions

→ Without impacting global & regional trends

TUGO ERA 5 extension Vs MOG2D ECMWF



TUGO ECMWF Vs MOG2D ECMWF



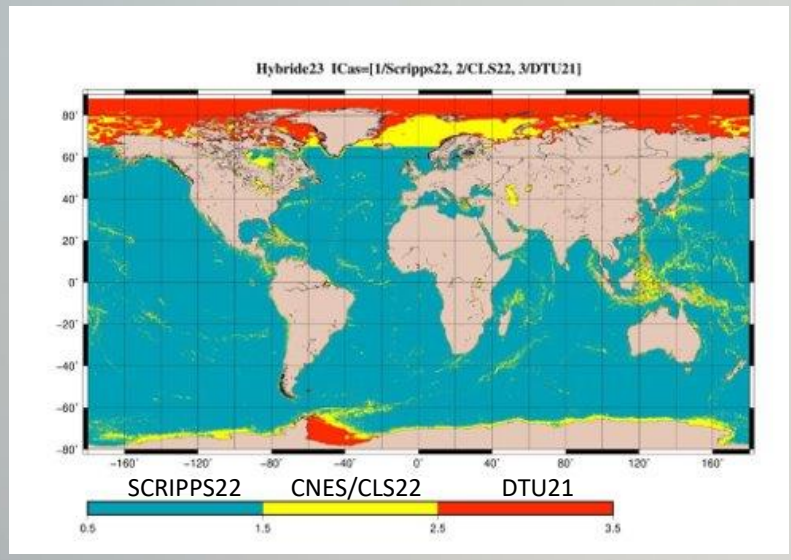
MEAN SEA SURFACE :

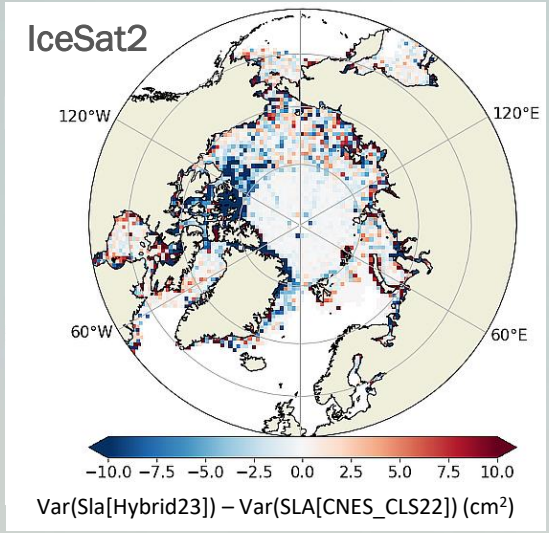
MEAN SEA SURFACE :

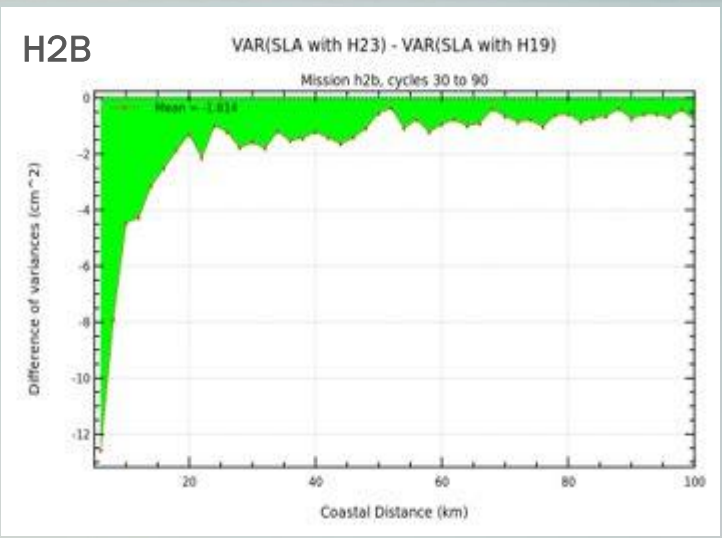
We combine 3 corrections to take advantage of each one (P.Schaeffer et al.):

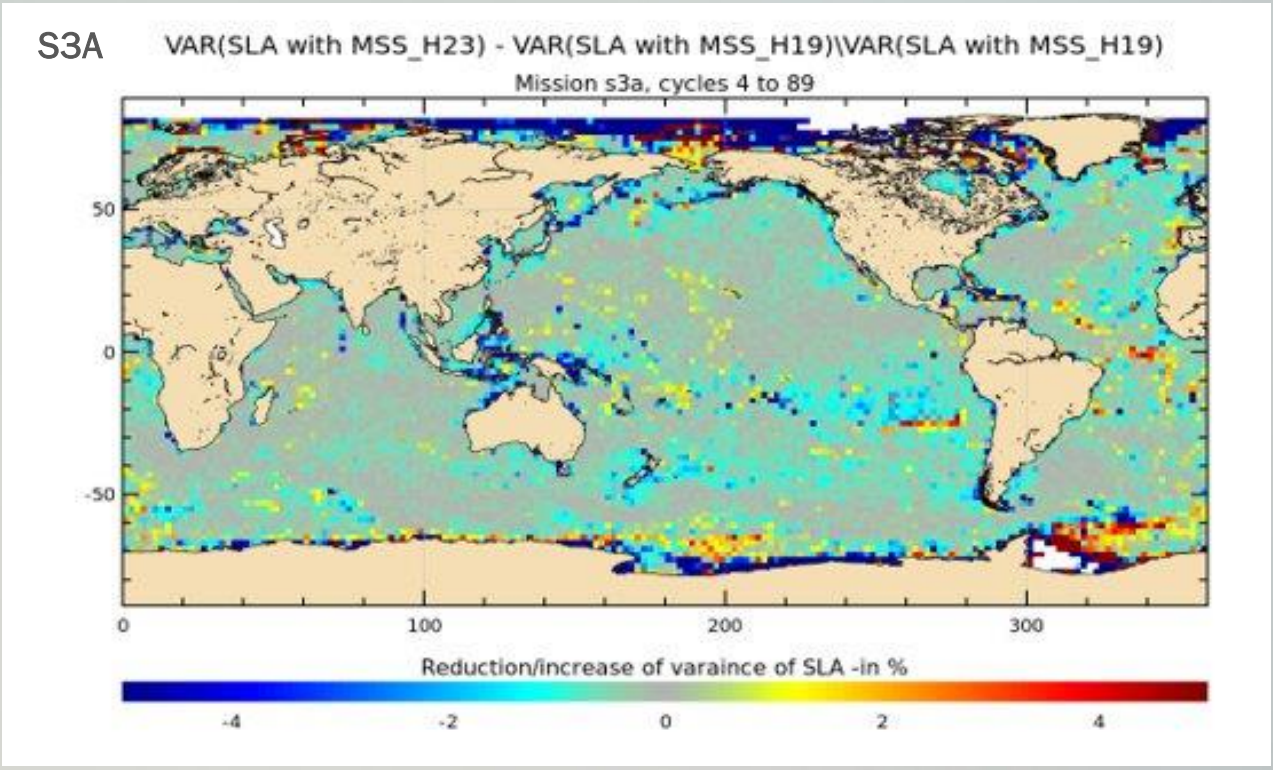
- SCRIPPS 22 -> gain in variance in open ocean
- CNES/CLS 22 -> Coastal improvements & leads
- DTU21 -> Polar improvements

→ it explains ~30% of sea level variance reduction









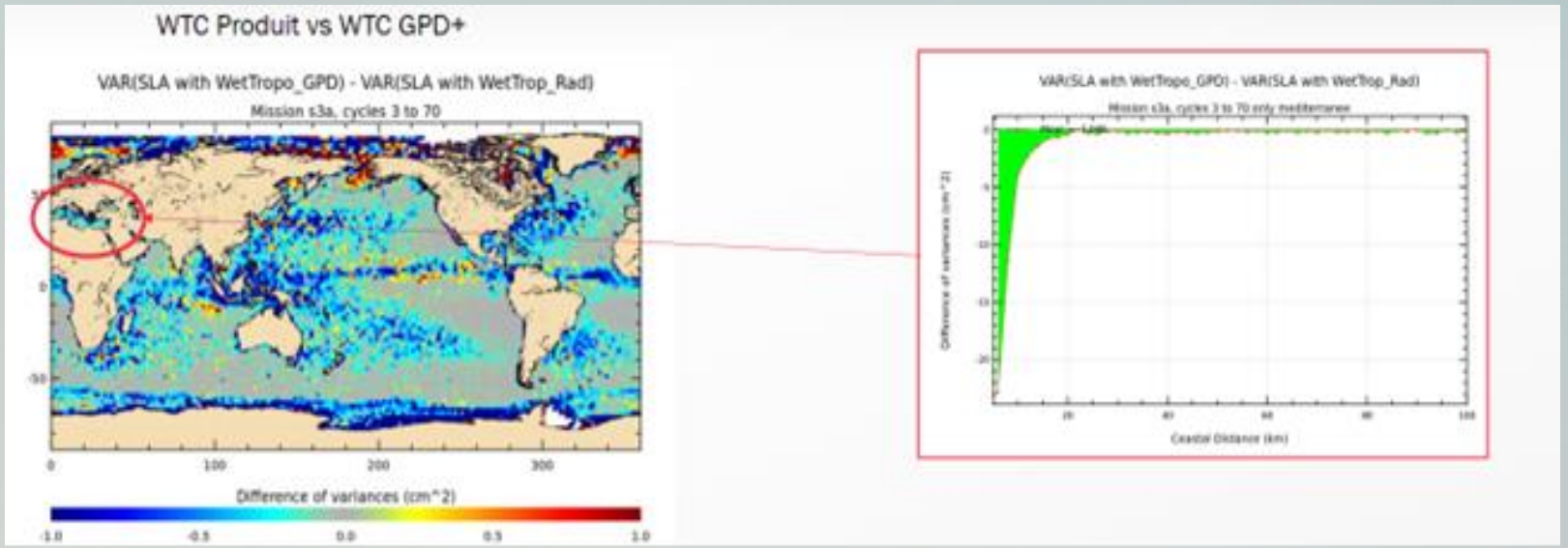
ENVIRONMENTAL CORRECTION :

WET TROPOSPHERIC CORRECTION :

GPD+ (for S3) combine the advantages of
- radiometer data
- SSMI data
- Model data when observations are not reliable enough (coast, poles)

Mesoscale improvements
→ on coasts
→ over rainy areas

→ Without impacting global & regional trends

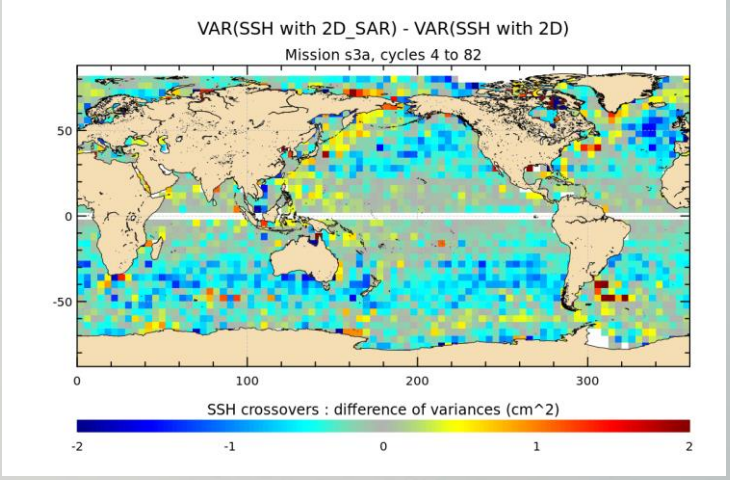


SEA SURFACE STATE CORRECTION :

SEA STATE BIAS:

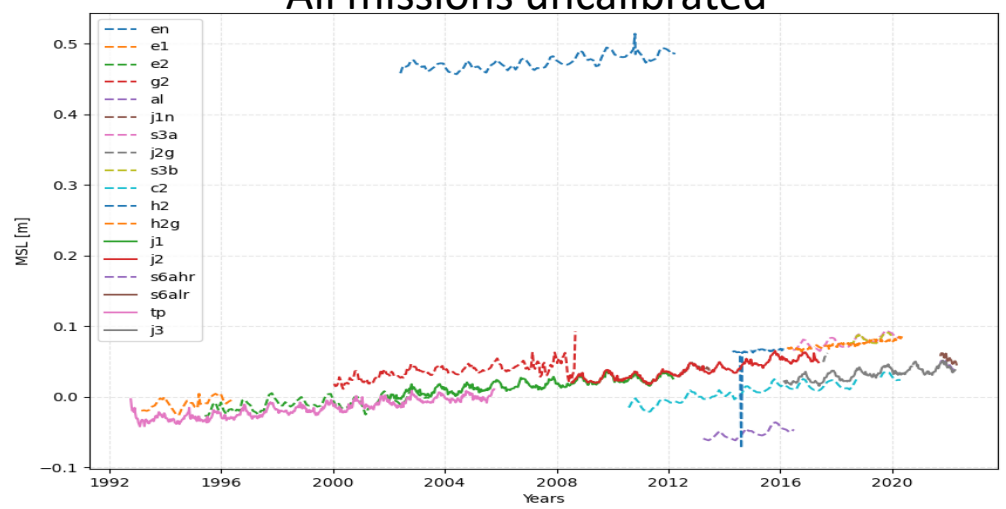
2 parameters (wind/wave) sea surface bias correction
→ has been updated to be in line with satellite algorithm updates (range, ionospheric correction, …)

→ A new 3-parameter correction (wave period from models) is very promising:
studies are ongoing to better assess the impact of such a correction on climate related signals.

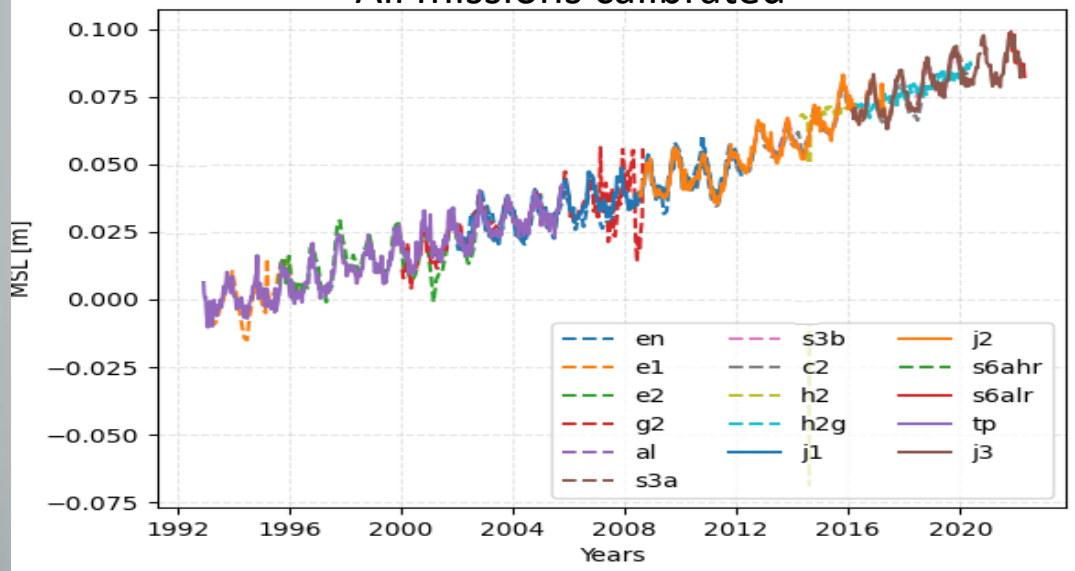


CLIMATE CONTINUITY : global & regional calibration

All missions uncalibrated



All missions calibrated



To build a time series suitable for climate studies.

Need :

Ensure a seamless transition between missions

-> learn how each instrument behaves

Solution:

accurate global & regional calibrations

-> use the tandem phase

-> available only for reference missions

-> the longer the tandem phase,

-> the more accurate the calibration

(< 1 year doesn't cover the seasonal variations)

Latests update of sea level rise : 30 years of multi-mission datasets

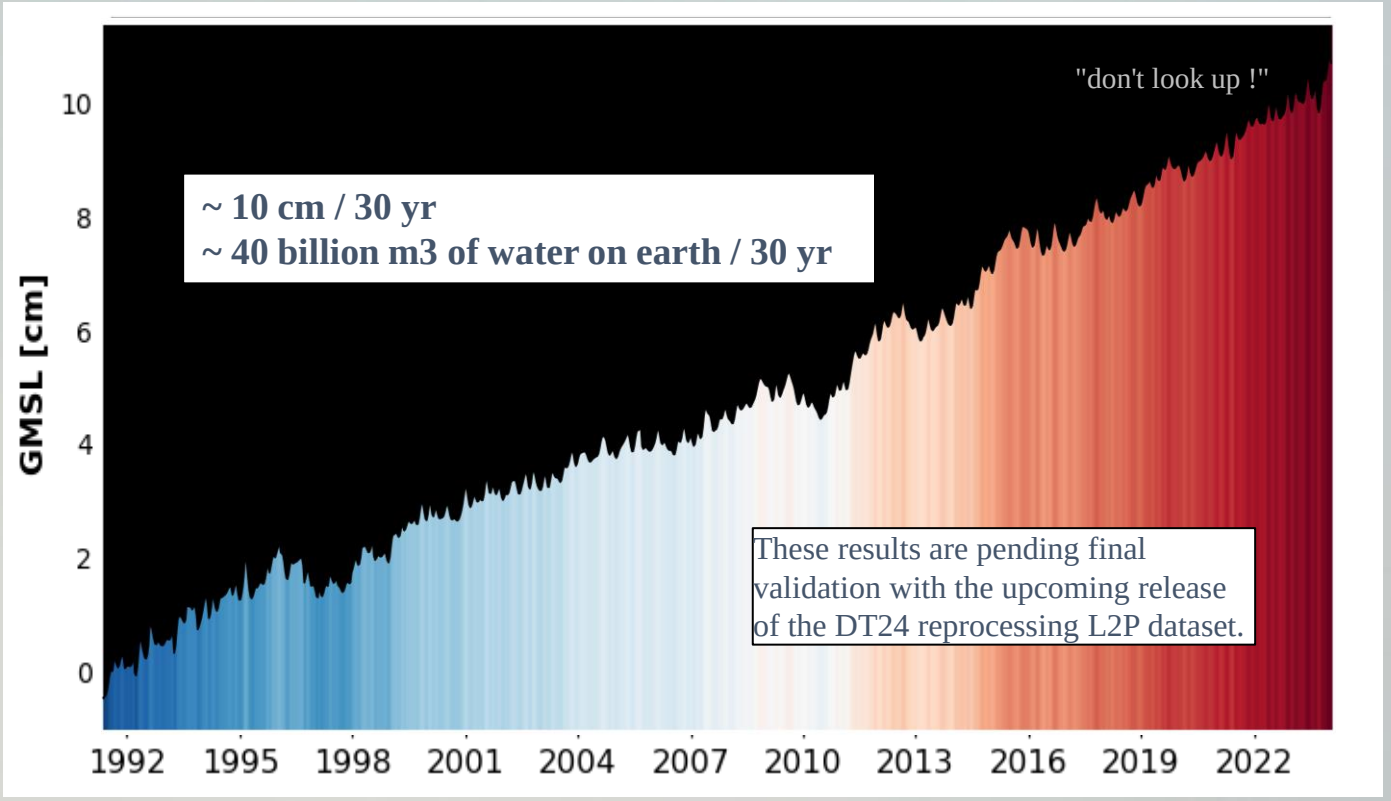
DT24 reprocessing :

Mesoscale improvements particularly on :
- **Coast**
- **Polar regions**

-> Ensuring continuity of mean sea level

Thanks to the update of :
- **Geophysical corrections (Ocean tide FES22, DAC TUGO)**
- **Mean sea surface (MSS H23)**
- **Instrumental corrections (reprocessed missions)**

The Global Mean Sea Level (GMSL) of reference has been recomputed with the new standard L2+ 2024 => will be soon available on AVISO (2024)
(see V. Quet et al. "Estimation of the Topex A/B bias and associated uncertainty- A multi methods approach" OSTST 2023)



AVAILABILITY

Thanks to the joint effort from :

- **CNES L2P-SALP** (Service d'Altimétrie et de Localisation Précise) project supported by CNES (Centre National d'Etudes Spatiales)
- **EUMETSAT Sentinel-3 Marine Altimetry L2P-L3** Service (operated under an EUMETSAT contract in the frame of the COPERNICUS Programme funded by the European Union)
- **COPERNICUS L3-CMEMS and C3S** service Implemented by MERCATOR Ocean International

DOWNLOAD DATA :

- AVISO+ website https://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/along-track-sea-level-anomalies-l2p.html
- EUMETSAT website EUMETCAST
- Copernicus website
  - https://resources.marine.copernicus.eu/product-detail/SEALEVEL_GLO_PHY_L3_NRT_OBSERVATIONS_008_044/INFORMATION
  - https://resources.marine.copernicus.eu/product-detail/SEALEVEL_GLO_PHY_L3_MY_008_062/INFORMATION

Also, we have a higher resolution dataset (1HZ -> 20HZ)==(7km->350m) (see poster Kocha et al., L2P 20Hz,OSTST 23)
-> to investigate smaller mesoscale oceanic geophysical structures
-> to get closer to the coast

COMING SOON :

- **Reprocessed data L2P NTC & NRT/STC DT24**
- **Level 3 high resolution (5Hz) using L2P 20Hz**
- **SWOT**

Email : ckocha@groupcls.com