

Sea level stability improved using an alternative wet troposphere correction derived from water vapour climate data sets (*)

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(*) Study supported by CNES in the frame of the SALP project



→ **Altimetry missions** provide more than 30 years of precise, accurate, and continuous measurements thanks to the reference missions **in the same orbit**:

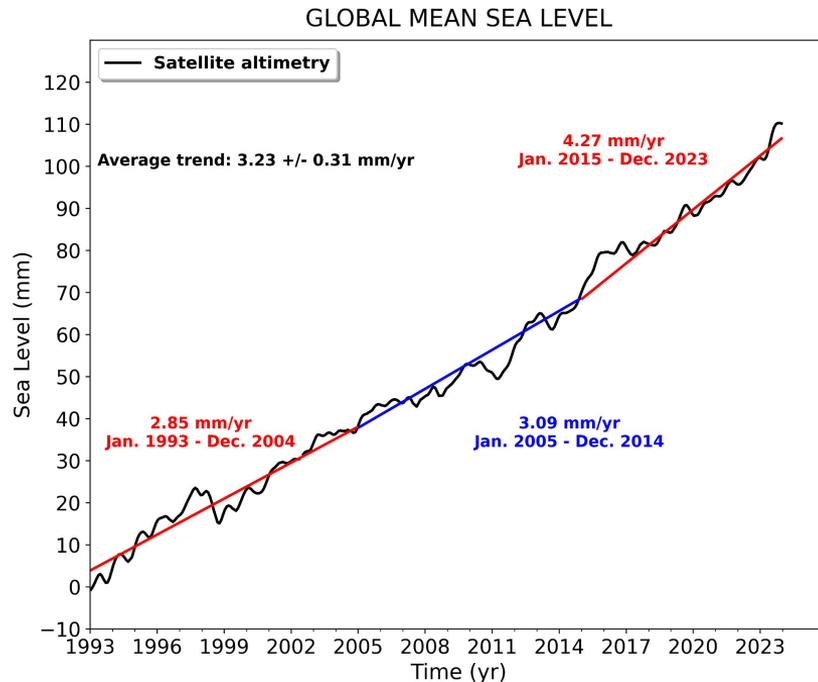
- ◆ TOPEX/Poseidon, Jasons (1,2,3) and Sentinel-6 MF

→ **Complementary altimetry missions** enable to improve the **ocean observability**:

- ◆ ERS (1,2), ENVISAT, SARAL/Altika, Cryosat-2, Sentinel-3 (A,B), ...

→ **Over the 01/1993 - 12/2023 period**:

- ◆ GMSL trend is : $+3.23 \text{ mm/yr} \pm 0.31 \text{ mm/yr}$
- ◆ GMSL acceleration is : $+0.6 \text{ mm/yr/decade} \pm 0.5 \text{ mm/yr/decade}$
- ◆ Within a **[5%,95%] confidence interval**



From C3S sea level gridded products (**vDT2024**)

Update from Cazenave et al., 2023



Radar altimetry is :

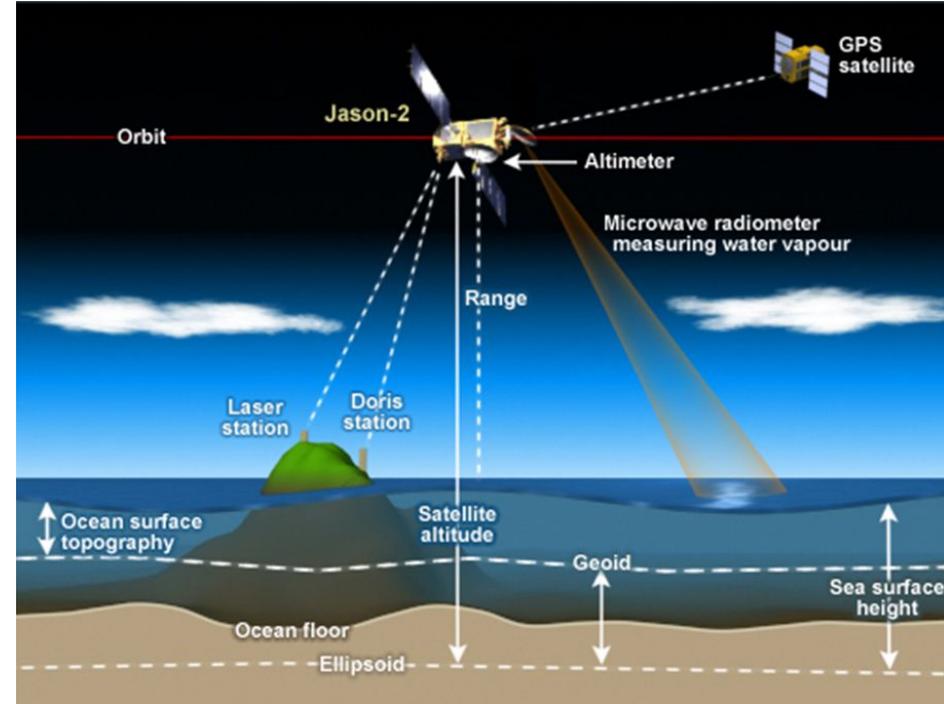
SSH = orbit - range - Σ corrections

including tides, ionosphere and

radar signal propagation ie

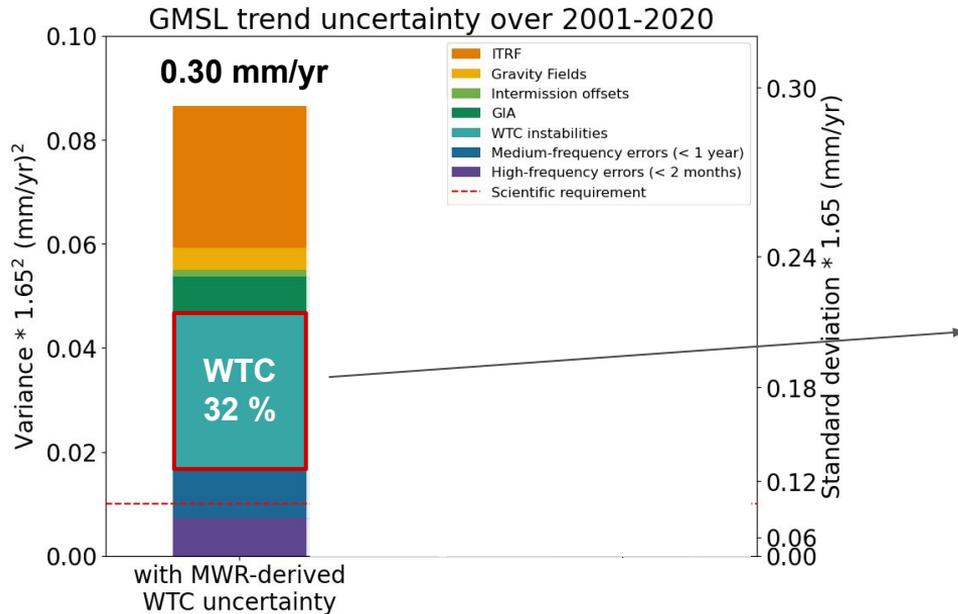
dry tropospheric correction and

wet tropospheric correction





1) Motivation

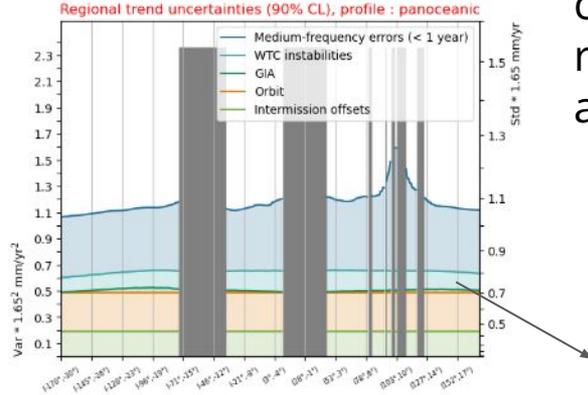
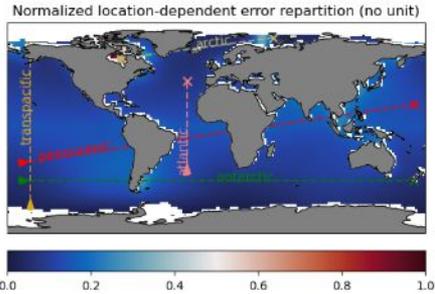


Update from Barnoud et al., 2023

Wet troposphere correction (WTC) computed from the microwave radiometer (MWR) onboard the altimetry missions contribute :

- to **32 % of the** uncertainties in the global mean sea level trend

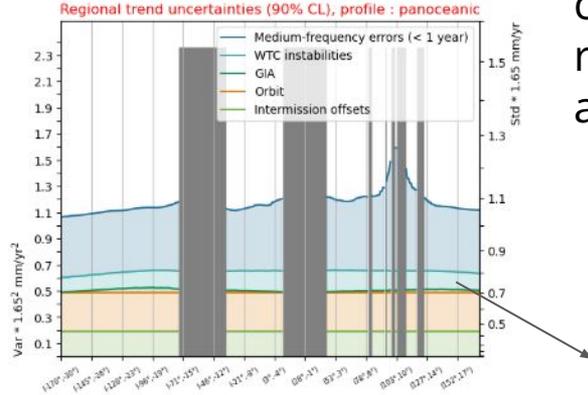
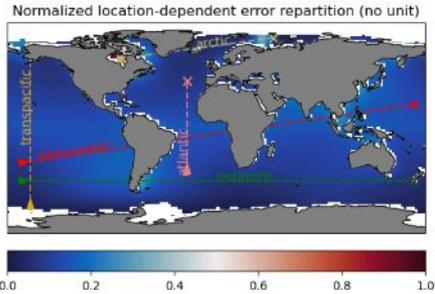
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Wet troposphere correction (WTC) computed from the microwave radiometer (MWR) onboard the altimetry missions contribute :

- to **32 % of the** uncertainties in the global mean sea level trend
- to **about 10-15 % of the** uncertainties in the regional scales sea level trends

1) Motivation



Wet troposphere correction (WTC) computed from the microwave radiometer (MWR) onboard the altimetry missions contribute :

- to **32 % of the** uncertainties in the global mean sea level trend
- to **about 10-15 % of the** uncertainties in the regional scales sea level trends

A more stable WTC can be calculated from the CDRs of total column water vapour (TCWV) :

- derived from brightness temperature measurements of the SSM/I and SSMI/S
- highly stable in time, GEWEX water vapour assessment (Schröder et al., 2018)

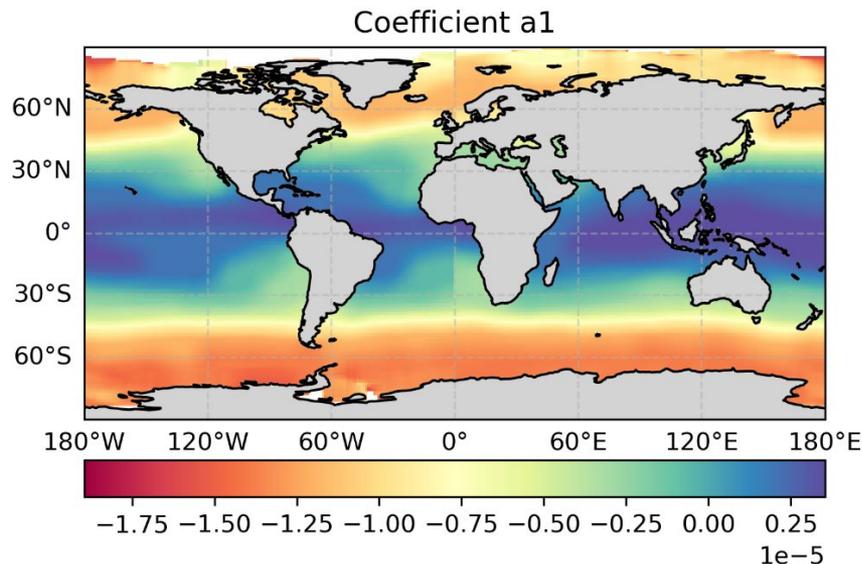


2) From water vapour to wet troposphere correction

- a) **WTC is derived from TCWV at the regional scales (from B. Picard, paper in preparation)**

$$\text{WTC} = a_0 \text{TCWV} + a_1 \text{TCWV}^2 \quad \text{new formulation}$$

a_i are estimated for each classes of WTC : same a_i values for a given class then smoothing to avoid jumps at class transition



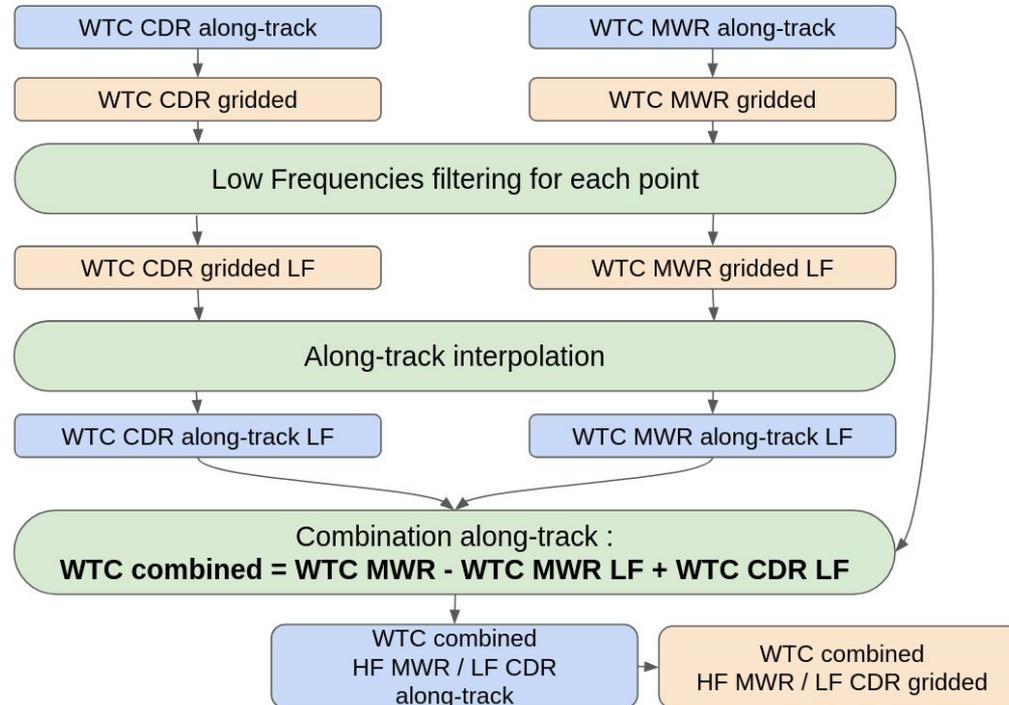
See presentation from Picard et al., CM SAF user workshop records, Bonn, Germany, January 2025

[2025_01_29_picard_CMSAF_user_meeting_2025.pptx](#)



2) From water vapour to wet troposphere correction

- b) **MWR WTC high frequencies (< 2 months) and CDR WTC low frequencies (> 2 months) are combined to get the best content signal from each dataset**





c) At the regional scales, uncertainties are propagated from TCWV to WTC based on a formal mathematical formalism

If $y = f(a_0, a_1, x)$, the variations of y (Δy) due to small variations of a_i (Δa_i) and x (Δx) can be determined by applying a Taylor development of order 1 (assuming the covariance terms null or negligible):

$$(\Delta y)^2 = \left(\frac{\partial f}{\partial a_0}\right)^2 (\Delta a_0)^2 + \left(\frac{\partial f}{\partial a_1}\right)^2 (\Delta a_1)^2 + \left(\frac{\partial f}{\partial x}\right)^2 (\Delta x)^2$$

Applying this principle to :

$$WTC = a_0 TCWV + a_1 TCWV^2$$

where a_0 and a_1 are constant over time and the covariance with TCWV is null, we obtain the following formulation:

$$(\Delta_{WTC})^2 = (TCWV \Delta_{a_0})^2 + (TCWV^2 \Delta_{a_1})^2 + ((a_0 + 2a_1 V) \Delta_{TCWV})^2$$



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Δ_{TCWV} is the uncertainty of TCWV represented by a temporal covariance matrix derived from an uncertainty budget provided by the TCWV provider.



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Δa_i polynomial coefficient uncertainties estimated by calculating the standard deviation of monthly \tilde{a}_i coefficients





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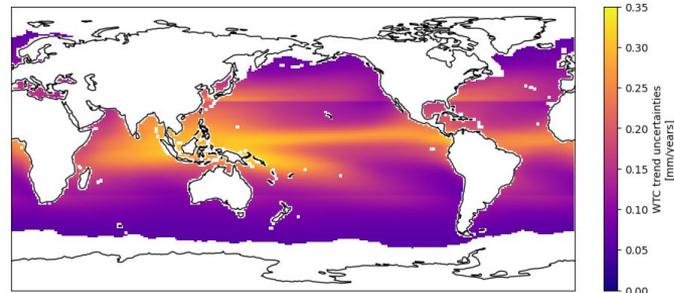
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WTC CDR trend uncertainty





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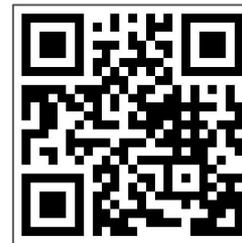
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Jupyter Notebook provided in ASEL SU:

<https://colab.research.google.com/drive/1knUPlawqndU8FqT630U8oGgQok-0eS0Z?usp=sharing>

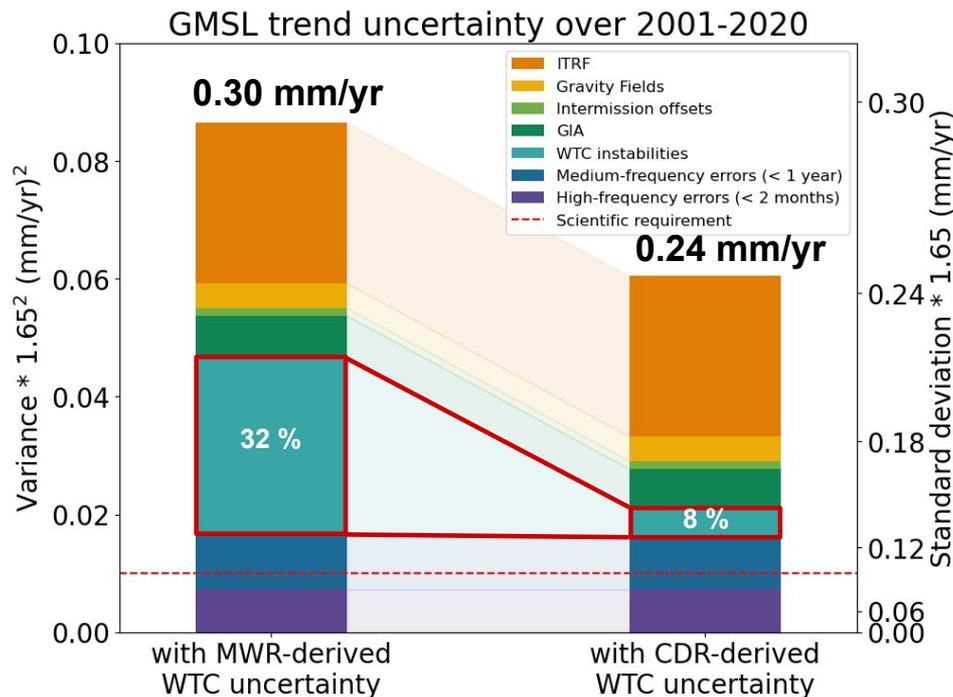




3) Results : uncertainty reduction is sea level estimates

At the global mean from Barnoud et al. 2023 and updated in ASELSU project:

- CDR-derived WTC trend uncertainty is **0.07 mm/yr** over 20 year (90 % CL)
- GMSL trend uncertainty over 2001-2020 reduced **by 20 %** with respect to using the MWR-based WTC uncertainty
- Better characterisation of regional trend uncertainties

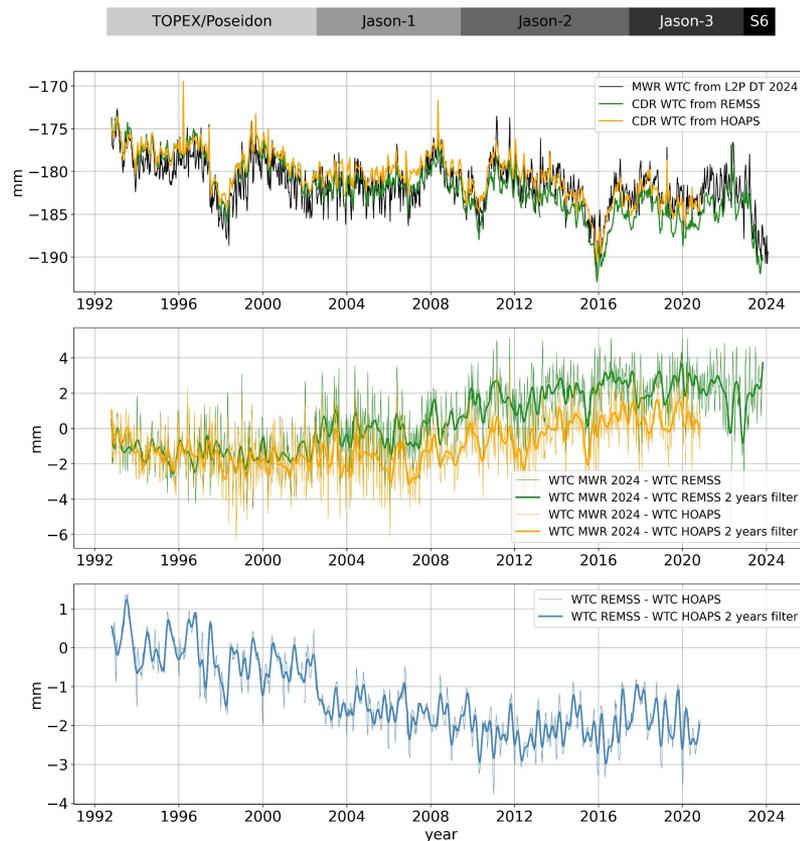


Update from Barnoud et al., 2023



Comparison between different WTC available help to quantify the uncertainty on WTC

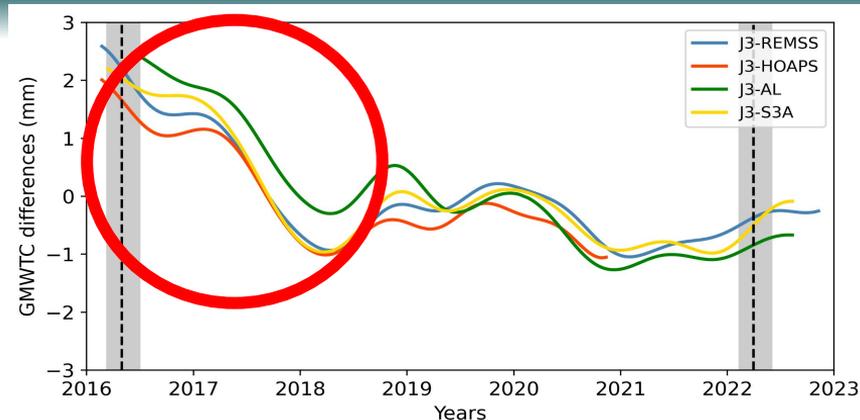
- WTC from TCWV computed from 2 CDR datasets:
 - **HOAPS**: Vinterim, precursor HOAPS v5 from EUMETSAT CM SAF (Schröder et al., 2013) from 1987 to the end of 2020.
 - **REMSS**: Version 7 release 2 (Wentz, 2015) from 1988 to end of 2023.
- WTC from MWR calculated from reference missions (TP, J1, J2, J3) and linked during tandem phases
- Ongoing discussions with HOAPS to better understand the possible source of differences in 2002-2003



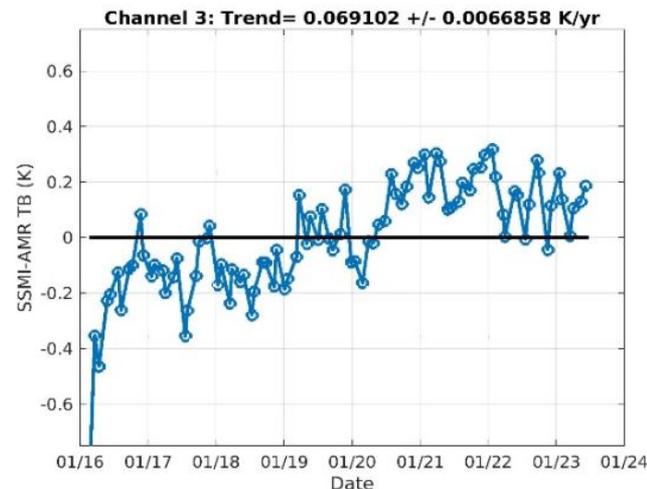


3) Results : WTC CDRs vs WTC MWR

- A drift was detected in Jason-3 MWR WTC by comparison with REMSS, HOAPS, Altika, S3A WTC
- Confirmed by S. Brown, JPL, and now corrected in Jason-3 L2 GDR-F and L2P 2024



34.0 GHz SSMI-AMR

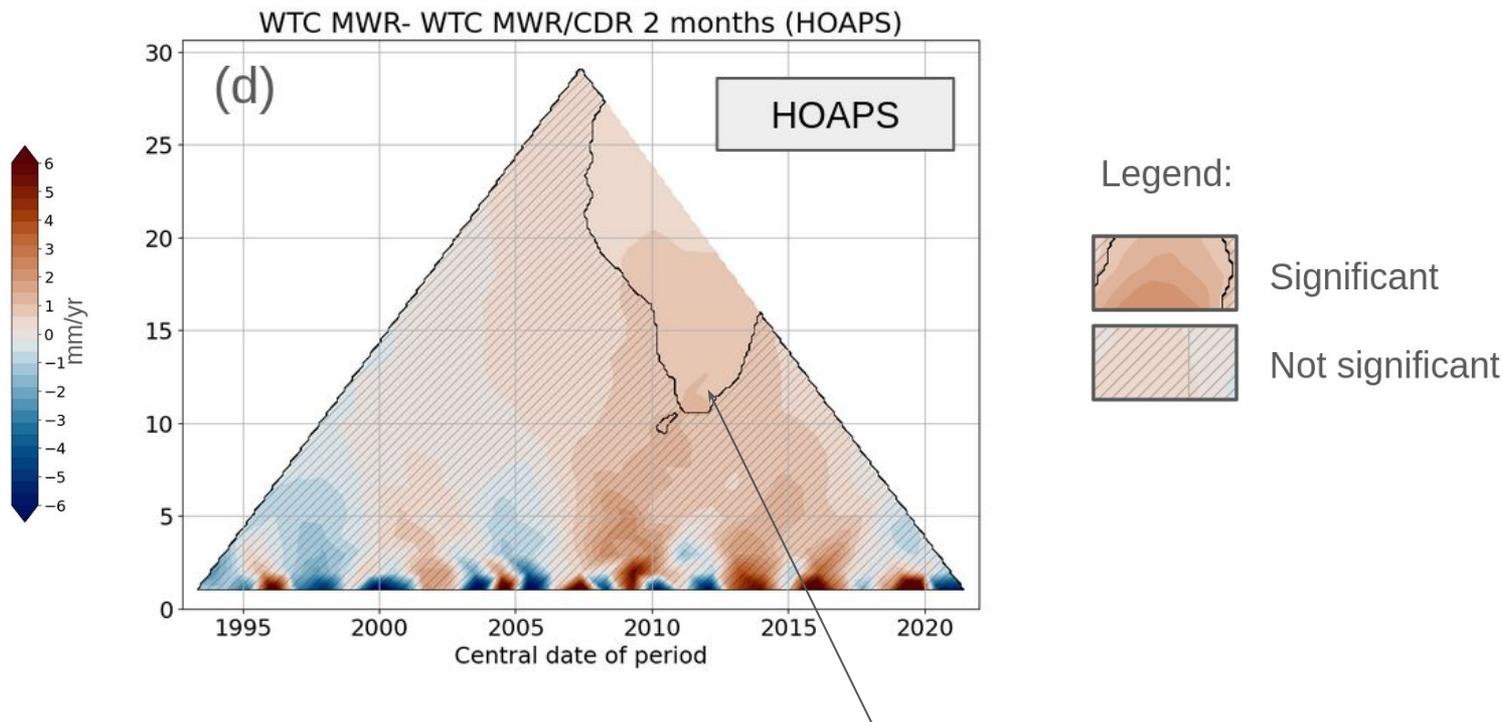


Unexpected result achieved

see Barnoud et al. 2023



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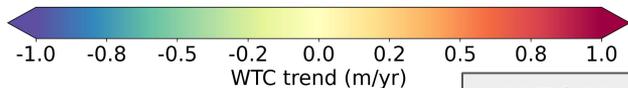
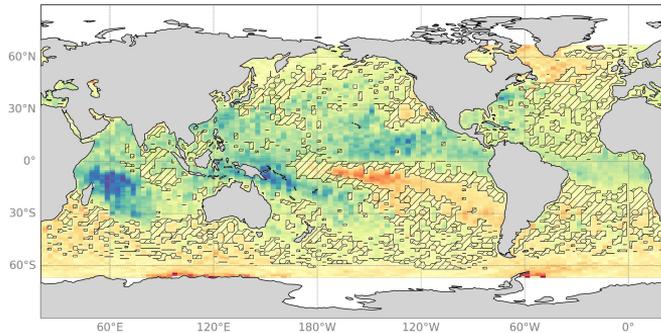


A drift is likely detected on the Jason-2 MWR WTC: about 2 mm over 10 years => **not yet corrected in L2/L2P products**

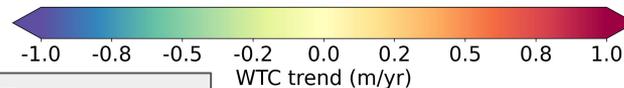
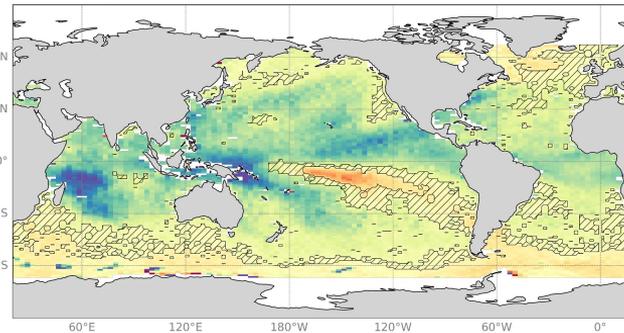


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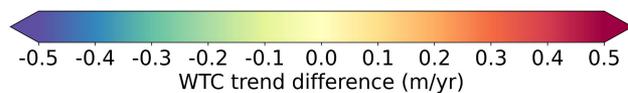
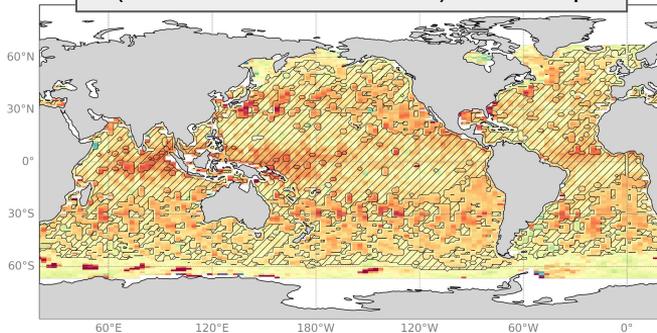
WTC MWR trend map



WTC CDR HOAPS trend map



(WTC MWR - WTC CDR) trend map



Legend

-  : significant
-  : not significant

Trend maps over the 1993-2022 period



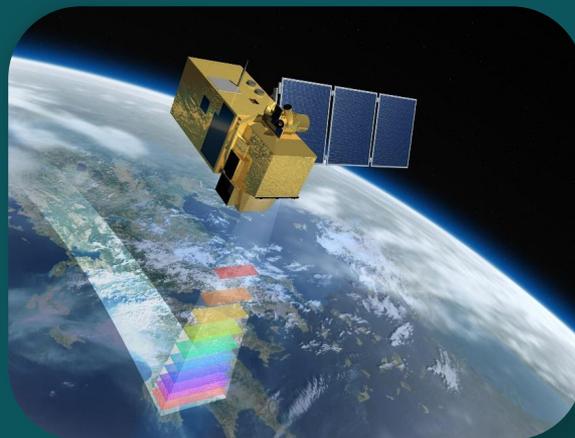
- WTC derived from water vapour CDRs allows:
 - to improve WTC stability : reduction of sea level trend uncertainty at global mean by 20 % over the 2001-2020 period
 - to detect drift on the current altimeter constellation : Jason-3 (corrected in last L2/L2P release), Jason-2 (not yet corrected)
 - work ongoing at regional scales
- For S6NG :
 - Use the WTC derived from water vapour CDRs to assess the MWR WTC: Cal/Val plan.
 - Provide stability requirements for S6NG MWR WTC based at least on the performance obtained with WTC derived from water vapour CDRs.

**The CDR-derived WTC is available on the AVISO+/ODATIS portal
for independent assessment:
<https://doi.org/10.24400/527896/a01-2022.018>**



Thank you for your attention.

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