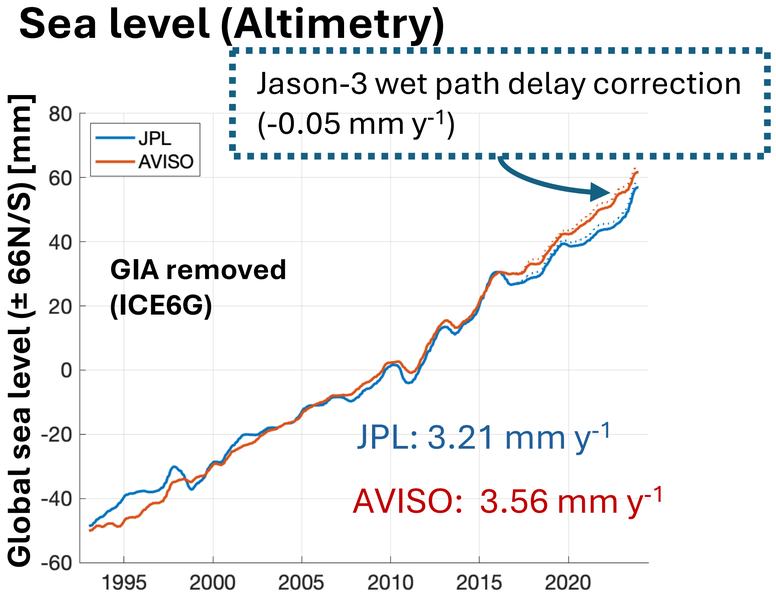
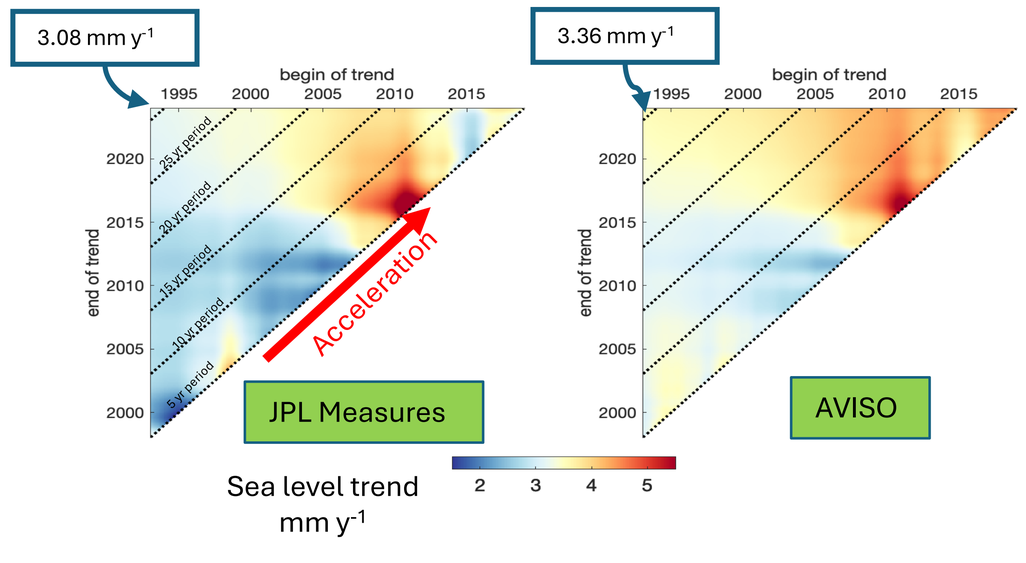
Sea Level Budgets using over 20 years of GRACE and 30 years of Altimetry data

Carsten B. Ludwigsen[1], Per Knudsen[1], Ole B. Andersen[1]
[1]DTU Space, Technical University of Denmark

Abstract Closing the sea level budget requires reconciling GRACE, GRACE-FO, altimetry, and terrestrial/ice mass contributions. Despite progress, inconsistencies remain (Wang et al., 2022; Barnoud et al., 2022), highlighting uncertainties in Earth's mass dynamics. Building on Ludwigsen et al. (2024), which validated two decades of GRACE with independent land surface mass estimates, we extend the analysis to the 30-year altimetry record to examine transient and long-term drivers of sea level change. Our results confirm strong agreement between GRACE and ocean mass reconstructions until 2020. Afterward, reconstructions show larger ocean mass increases, mainly due to underestimated precipitation over West Africa in ERA5, a bias confirmed by GRACE land mass data. Correcting for this improves model-observation consistency. Comparative analysis further indicates that discrepancies with steric-corrected altimetry stem largely from ARGO salinity drift and Jason-3 radiometer wet path delay, with smaller contributions from GIA and other biases.

Sea level (Altimetry)

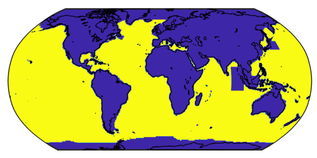




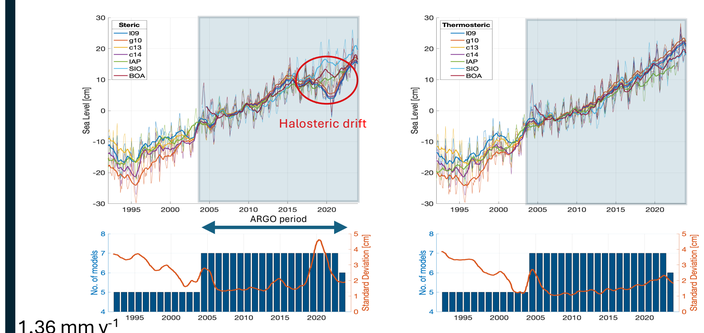
Both corrected for GIA and Jason-3 WPD

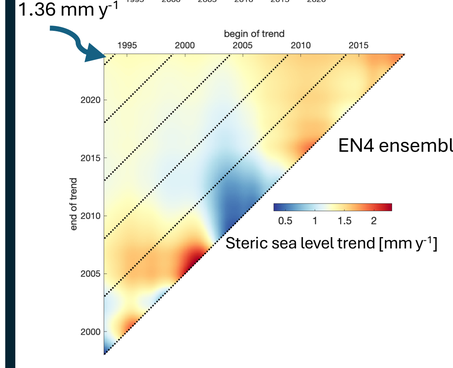
Signals of <1yr removed

Ocean mask applied (shallow (<100 m) coastal zones, high latitudes and areas around Sumatra and Tōhoku megathrust earthquakes)



Steric heights

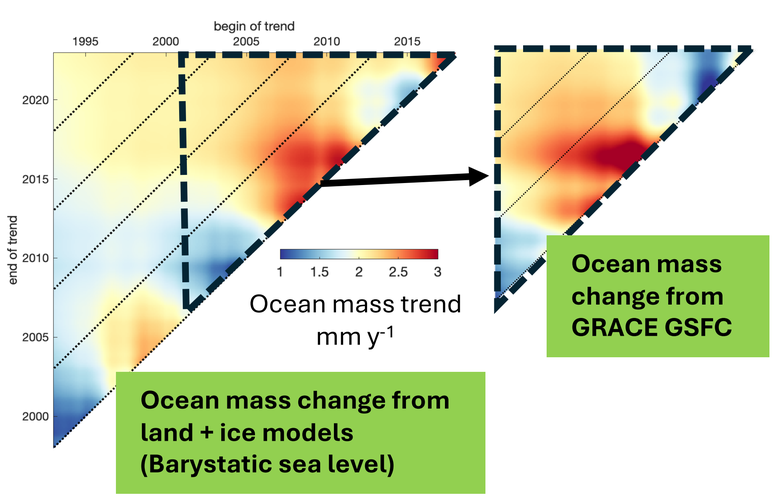




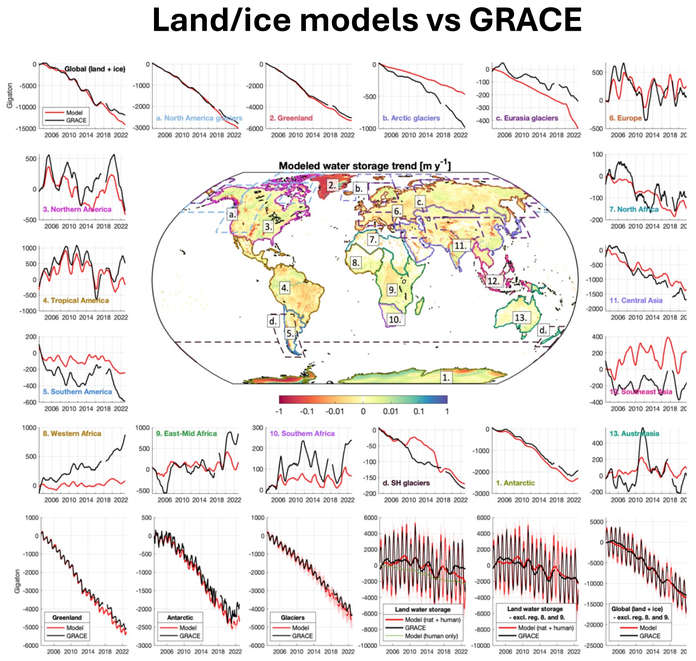
Corrected for halosteric drift.

Includes deep steric (2000-5400 m)

Land and Ice mass contributions to sea level (Ocean mass) vs GRACE



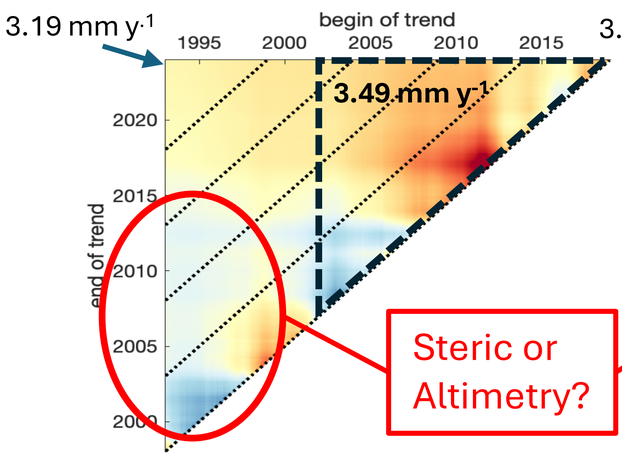
Land/ice models vs GRACE



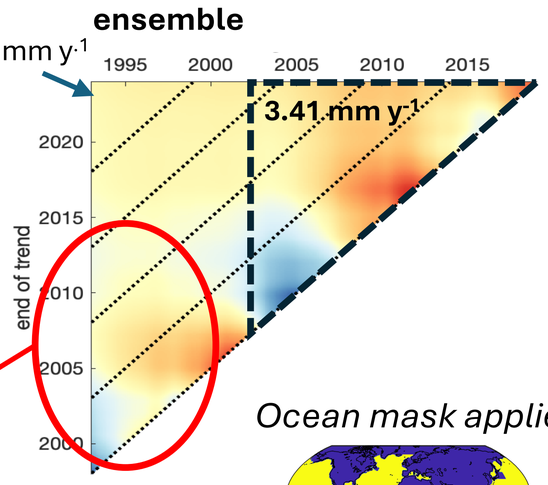
Model sources:
***Greenland**: Mankoff et al, 2021*
***Antarctic**: Imbie (spatially convoluted) and extended with GRACE-FO (2021-2022)*
***Glaciers**: Hugonnet et al, 2021 (extended with GRACE from 2019-2022) (To be replaced with GLAMBIE)*
***Terrestial Water Storage :** Müller-Schmied et al, 2023*

30-year sea level budget and 20-year ocean mass budget

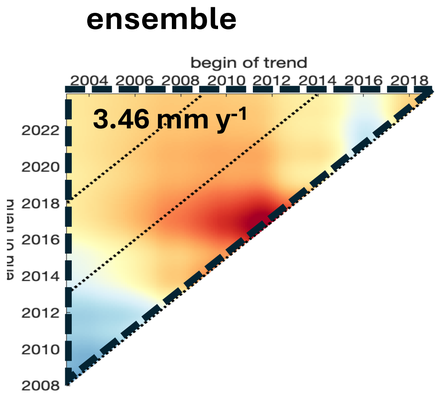
JPL Altimetry – GIA – *SFD**



Barystatic sea level + steric ensemble



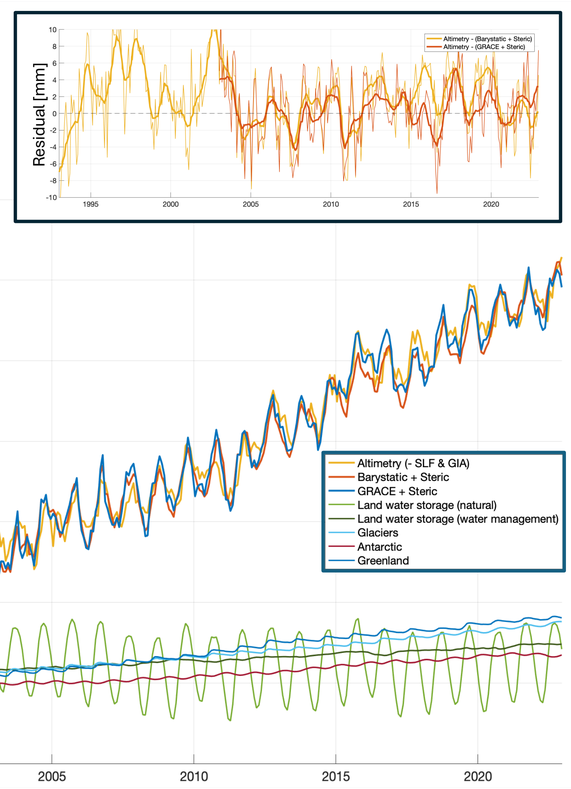
GRACE + steric ensemble



Ocean mask applied

Sea level trend mm y-1

***Sea Floor Deformation (uplift of the sea floor due to land/ice mass changes, 1993-2022 average 0.11 mm y-1)**



Conclusions

- The **global sea level budget can close but** depends on the choice of **steric and altimetry product**, and **ocean mask**.
- Disagreement between altimetry and steric components is larger before the ARGO era.
- Sea level change is accelerating → driven by ocean mass increase.
- Land/ocean mass is observed by GRACE is well-constrained with model estimates.
  → A ~1500 Gt gap post-2020 likely stems from unaccounted precipitation changes over Africa.

References

- Ludwigsen et al. "Global and Regional Ocean Mass Budget Closure since 2003." *Nature Comms., 2024*
- Ludwigsen et al. "Gridded and Timeseries Data Related to **Global and Regional Ocean Mass Budget Closure since 2003**." *Technical University of Denmark, 2024* [Dataset]