Closing the global mean sea level budget from altimetry, GRACE/GRACE Follow-On and Argo data (2005-present)

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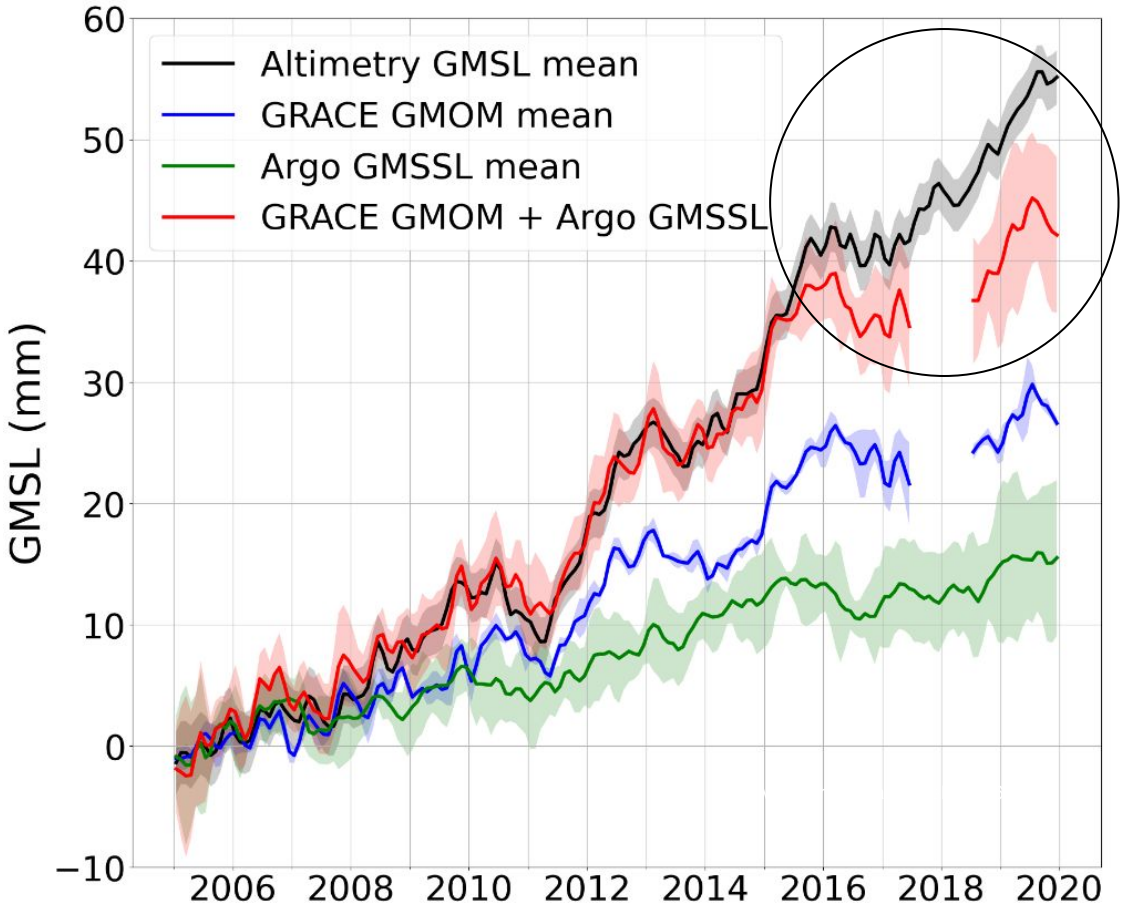
Sea level budget

ΔGMSL = ΔGMSSL + ΔGMOM

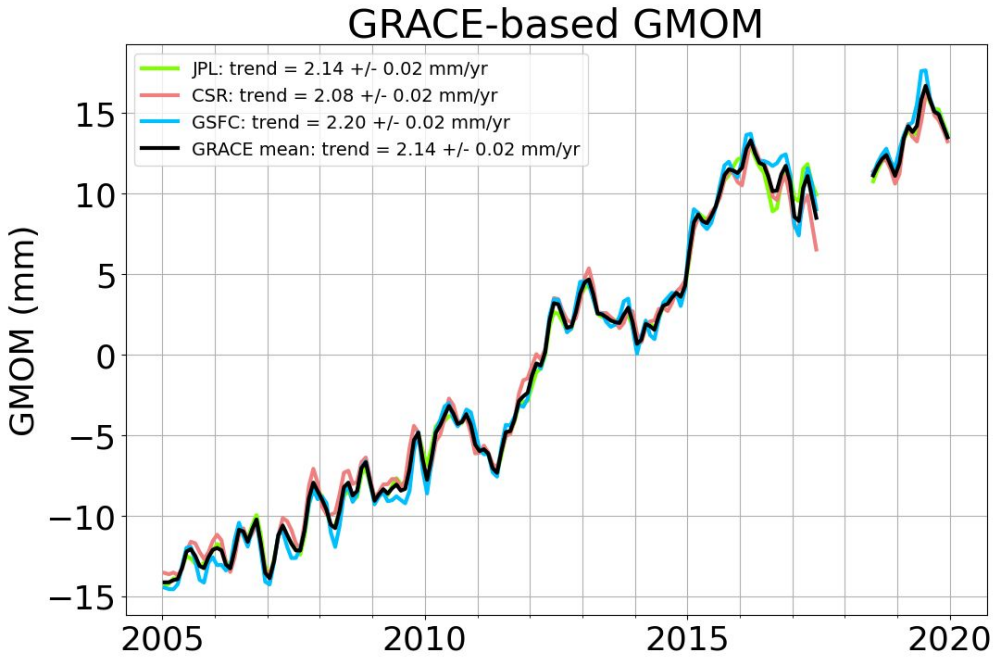
- **GMSL**: global mean sea level
- **GMSSL**: global mean steric sea level (thermosteric + halosteric)
- **GMOM**: global mean ocean mass

- The sea level budget was closed from 1993 to mid-2016 (e.g. Cazenave and the WRCP, 2018; Horwath et al., ESA CCI Sea Level Budget Closure project, 2020).
- Since 2016, the budget is no longer closed (Chen et al., 2020).
- Which sources of errors in any of the three components are responsible for the observed non-closure?



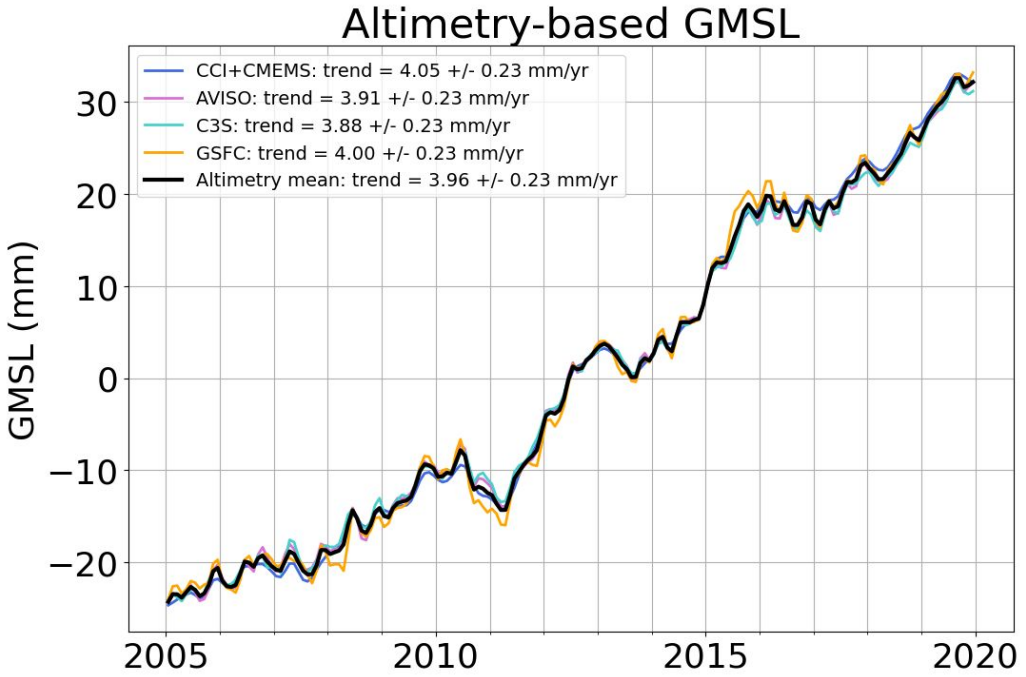
GRACE/GRACE Follow-On data

- We compare the GMOM estimates based on the Release 6 mascon solutions of the JPL, CSR and GSFC.
- From 2015, instrumental issues have affected the GRACE and GRACE-FO spacecrafts (battery power failures and loss of one of the two accelerometers).
- The change between the two GRACE and GRACE-FO missions could lead to a possible inter-mission bias even though no bias have been detected up to now (e.g. Velicogna et al., 2020; Landerer et al., 2020).
- Errors in altimetry and Argo data could also be responsible for the non-closure of the budget.

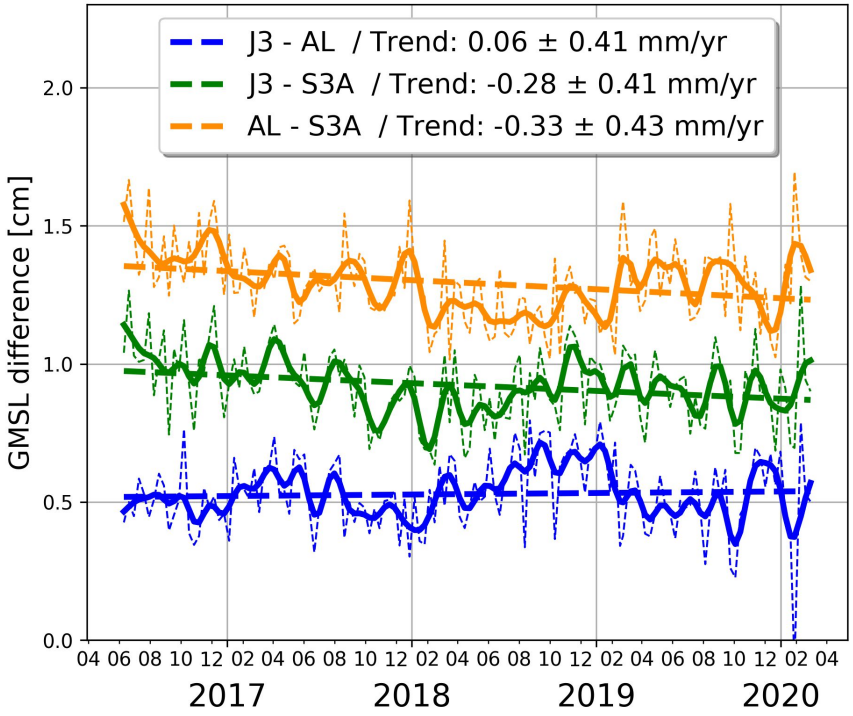


Altimetry data

- We compare altimetry-based GMSL estimates from four data providers.
- Trend differences lie within the 1-sigma uncertainty of 0.23 mm/yr obtained from the GMSL error budget (Ablain et al., 2019).
- Jason-3 mission was launched in January 2016 and its stability is debated. We investigate Jason-3 altimeter and radiometer stability by cross-comparison with other missions.



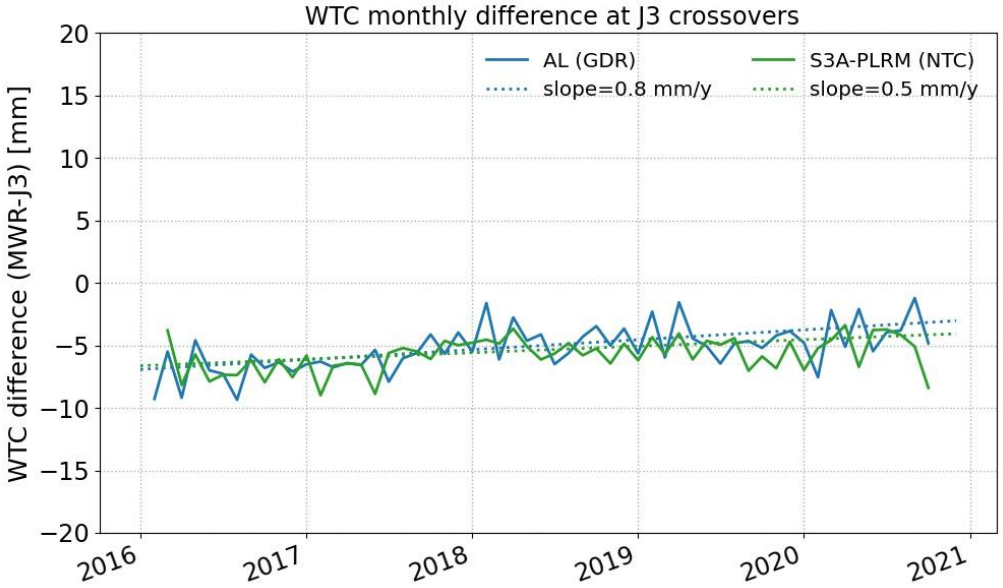
Stability of Jason-3 altimeter



- We compare Jason-3 with SARAL/AltiKa and Sentinel-3A PLRM altimeters, using the ECMWF wet tropospheric correction operational model.

➔ No significant relative drift is detected within a 1-sigma uncertainty of 0.4 mm/yr.

Stability of Jason-3 radiometer



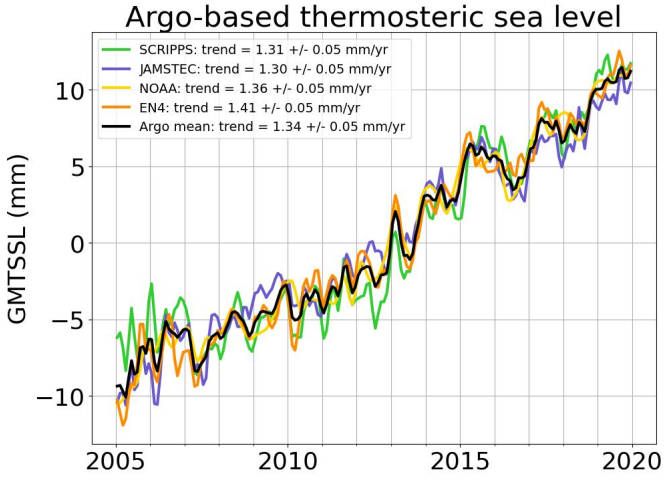
- The wet tropospheric correction (WTC) is a major source of uncertainty in the GMSL error budget (Ablain et al., 2019).
- Comparing Jason-3 with SARAL/AltiKa and Sentinel-3A radiometer WTC, we observe relative drifts of 0.8 mm/yr and 0.5 mm/yr respectively. These are upper-bounds for a possible drift of Jason-3 radiometer.
- These drifts are typical of radiometer WTC errors of 0.2 mm/yr taken into account in the GMSL error budget (Ablain et al., 2019), contributing to no more than 10 % of the budget error.

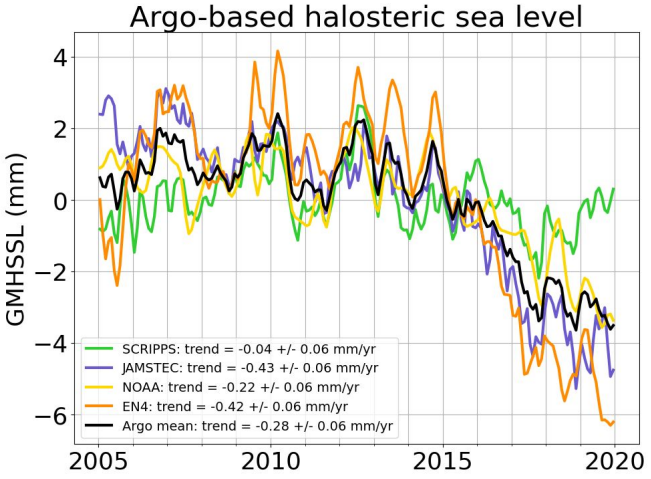
➔ Altimetry is unlikely to play a major role in the non-closure of the sea level budget.

Argo data

- We compare the Argo-based thermosteric and halosteric sea levels based from four sources.

- In global average, the halosteric sea level should be close to zero (Gregory and Lowe, 2000; Llovel et al., 2019). However, we observe a drop in the halosteric sea level, with high discrepancies between the datasets. Only the Scripps-based halosteric sea level remains close to zero. A drop in halosteric sea level would imply that the ocean is getting saltier, which is in contradiction with the melting of ice-sheets , glaciers and sea-ice which would be responsible for a global freshening of the oceans.





Errors in Argo salinity measurements

- Since 2015, several conductivity-temperature-depth sensors have drifted toward higher salinity values within 2 to 3 years after deployment (Wong et al., 2020).

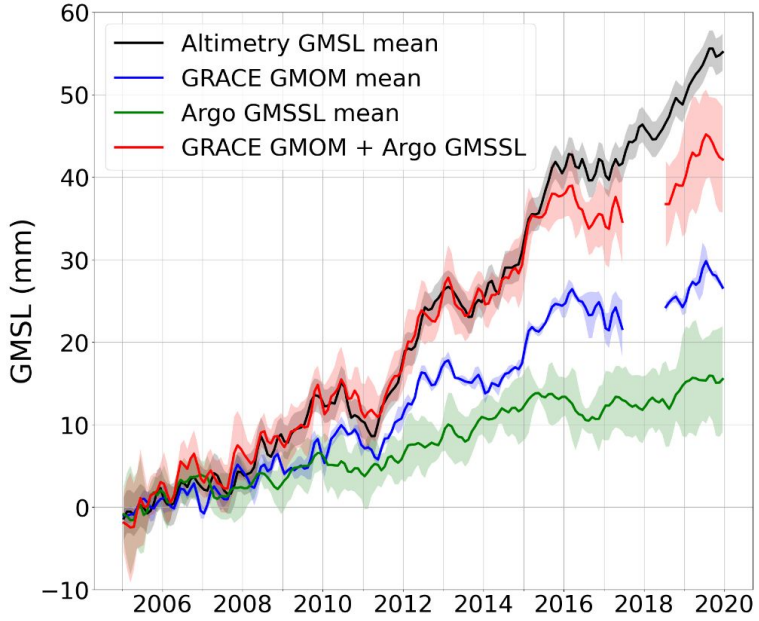
- Real time (RT) Argo data are provided within 24 hours after an automatic quality control. Several months are then required to provide delay mode (DM) data for which a manual quality control by an expert is required. For climate studies, the Argo project recommend to use only DM data.

- The differences in halosteric sea level between the four centers is likely due to their processing methods. JAMSTEC, EN4, NOAA and Scripps all include DM as well as RT data in the last four years. However, in the case of Scripps data, the RT profiles are adjusted to match the WOCE Global Hydrographic Climatology (Roemmich and Gilson, 2009), correcting the drifted salinity RT profiles.

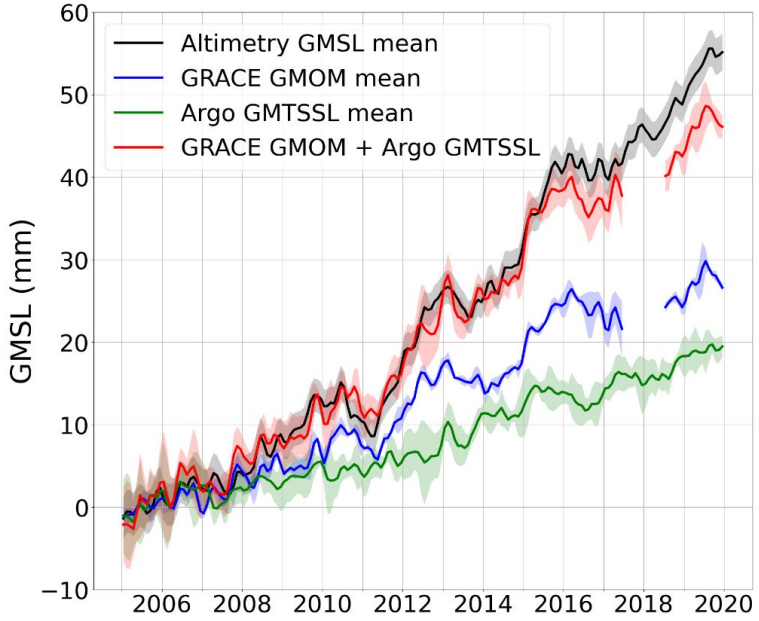
- As the global mean halosteric component is expected to be close to zero, we reassess the global mean sea level budget as the sum of the ocean mass and thermosteric component only.

Updated sea level budget

Using the total steric sea level



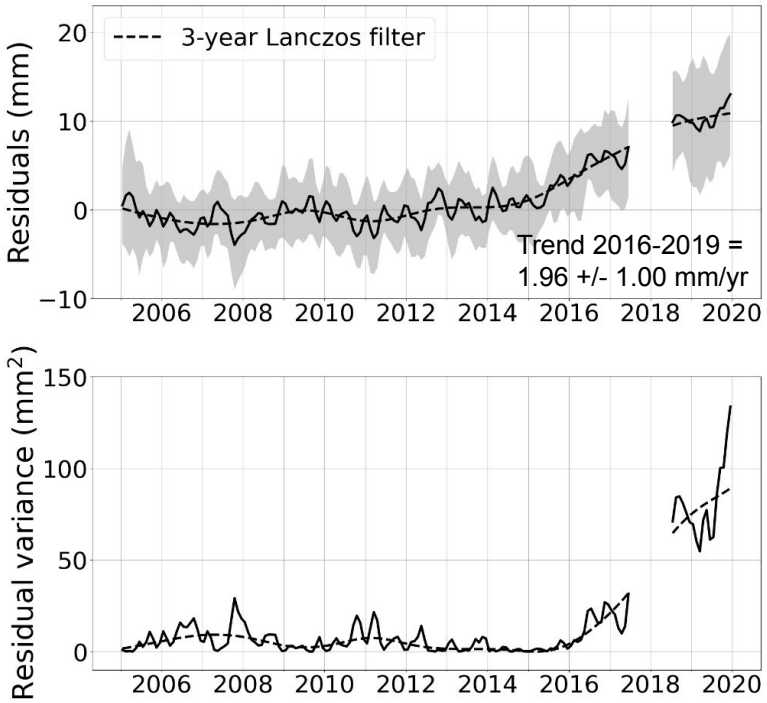
Using the thermosteric steric sea level



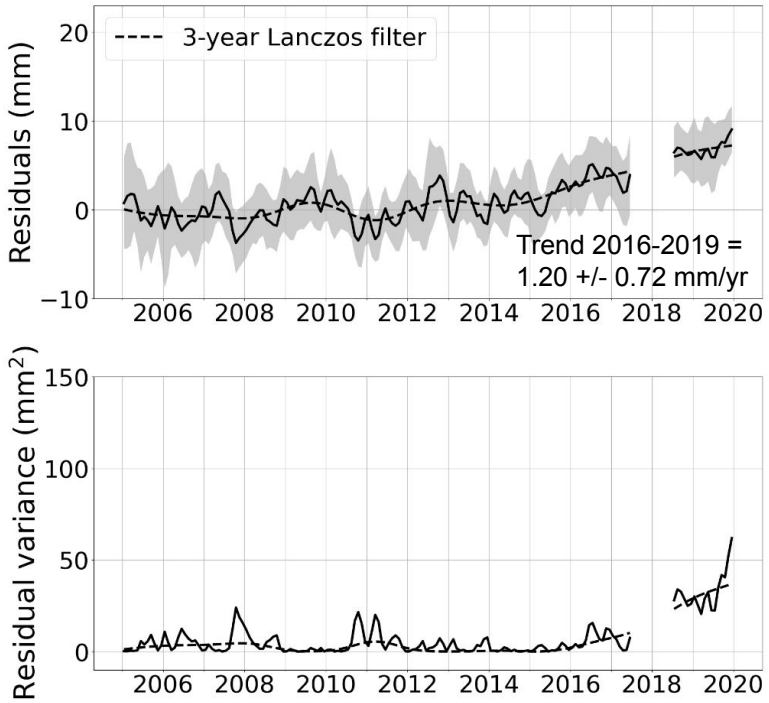
➔ Even though the budget is still not closed, the gap have been reduced by about 40% (see next slide for quantification).

Sea level budget residuals

Using the total steric sea level



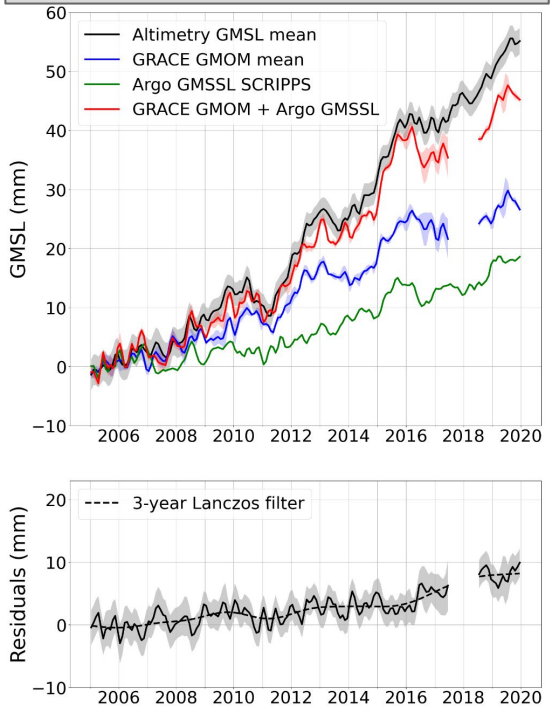
Using the thermosteric steric sea level



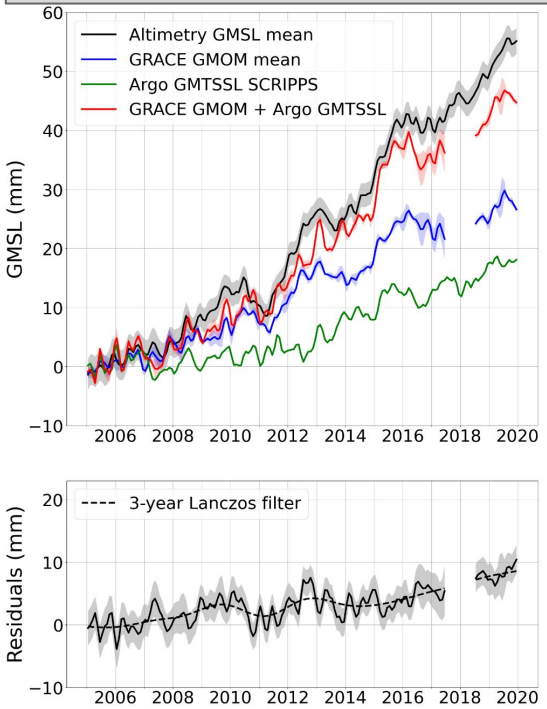
➔ Over 2016-2019, the residual trend is reduced by about 40 % using the thermosteric component only instead of the total steric.

Sea level budget with Scripps Argo data

Using the total steric sea level



Using the thermosteric steric sea level



➔ Scripps Argo data, with a halosteric component close to zero, appear more robust than the other Argo datasets used in this study.

Conclusion

- The global mean sea level budget is not closed after 2016 from altimetry, Argo and GRACE/GRACE Follow-On data.

- Errors in Argo salinity measurements are responsible for about 40 % of the non-closure of the budget since 2016. Sea level budgets should be done with the thermosteric component only or with the steric sea level obtained from Scripps data.

- Jason-3 altimeter and radiometer are unlikely to play a major role in the remaining budget error.

- Further investigations should be done to get robust uncertainty estimations of the three components (e.g.: calibration of altimetry with tide-gauges, deep ocean contribution with the deep Argo array).

Reference: Barnoud, A., Pfeffer, J., Guérou, A., Denneulin, M.-L., Siméon, M., Cazenave, A., Chen, J., Llovel, W., Thierry, V., Legeais, J.-F. and Ablain, M. (2021). Contribution of altimetry and Argo to non-closure of the global mean sea level budget since 2016. In revision.

Acknowledgments

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