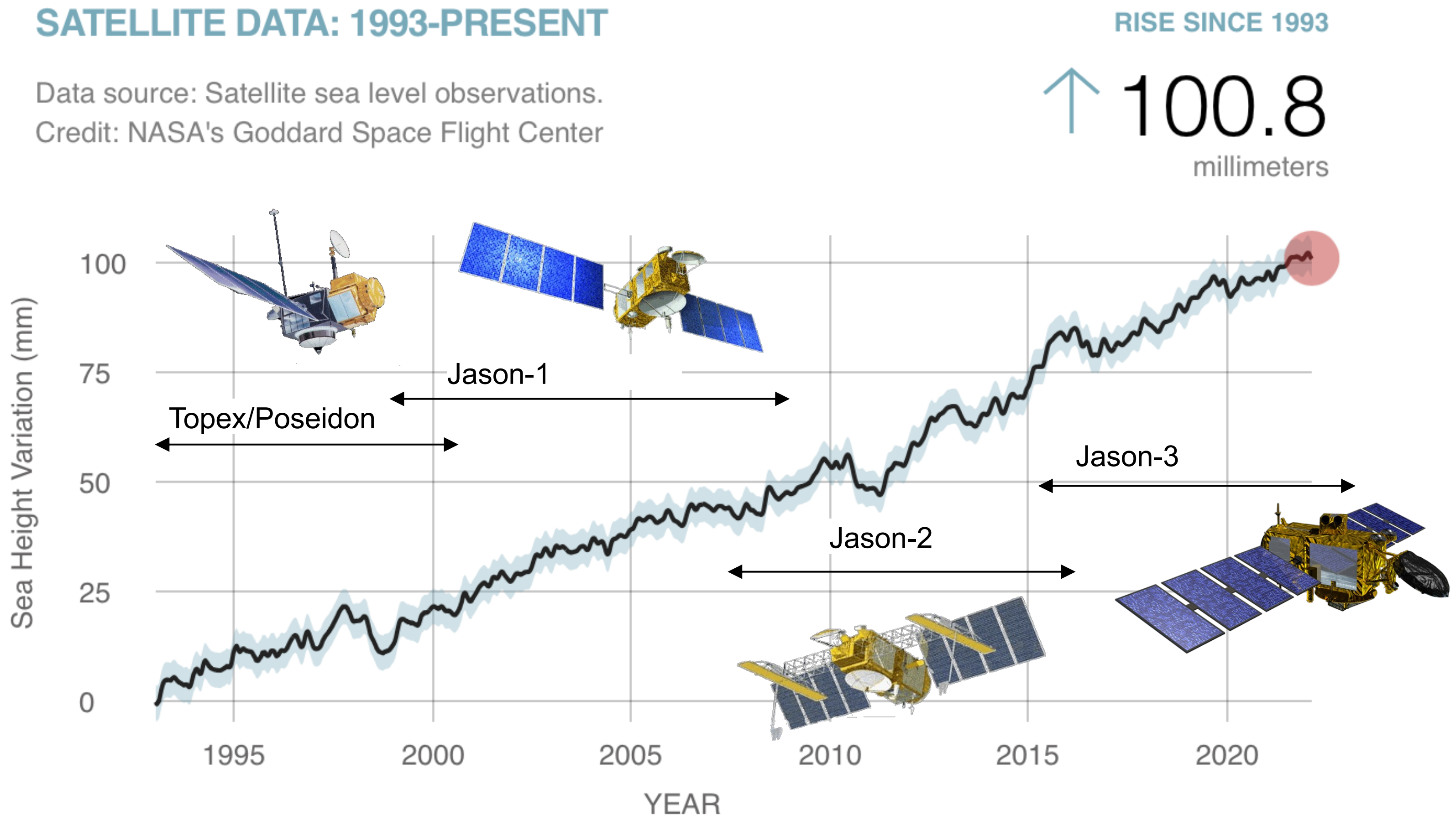
Carsten B. Ludwigsen and **Ole B. Andersen** (DTU Space)

Sea-level reconstruction of near-30 years of sea-level observations from altimetry

Altimetry oberved sea level change since 1993

Sea-level has risen more than 100 mm in the last 30 years.

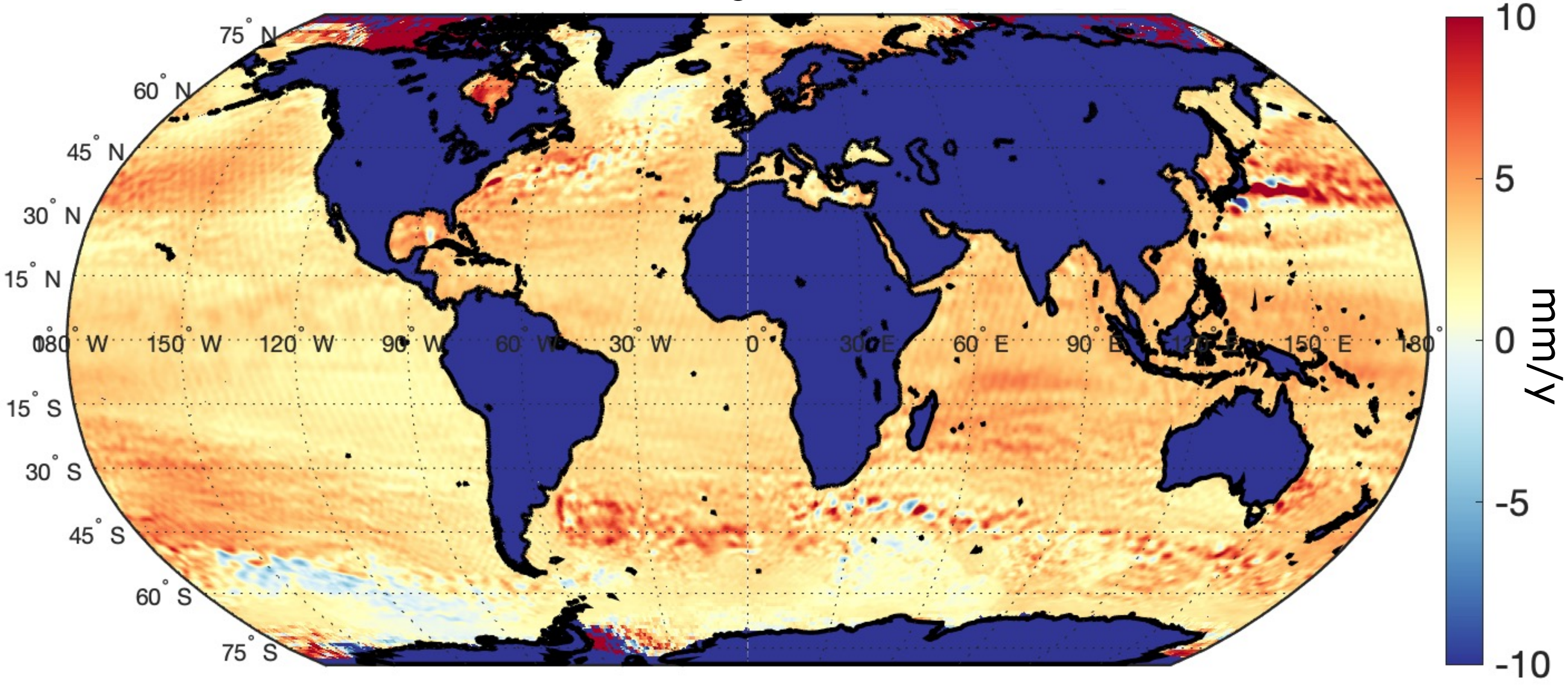


Altimetry oberved sea level change since 1993

Sea level rise pattern is not uniform.

Knowing what contributes to spatial and temporal sea level change is **essential for projecting sea level in the future.**

Gridded Sea Surface Height trend from 1993-2022



Source: NASA JPL, MEASURE2205

Observations of sea level change

Altimetry (various satellites 1993-now)

Sea surface height: **absolute sea level** (ASL) w.r.t. a geocentric reference.

GRACE (2002-2017) and GRACE-FollowOn (2018-now)

Gravemetri: observes **mass changes** on the earth (both land and ocean), which alters the geoid.

T/S profilers (since 1950's, ARGO 2001-now)

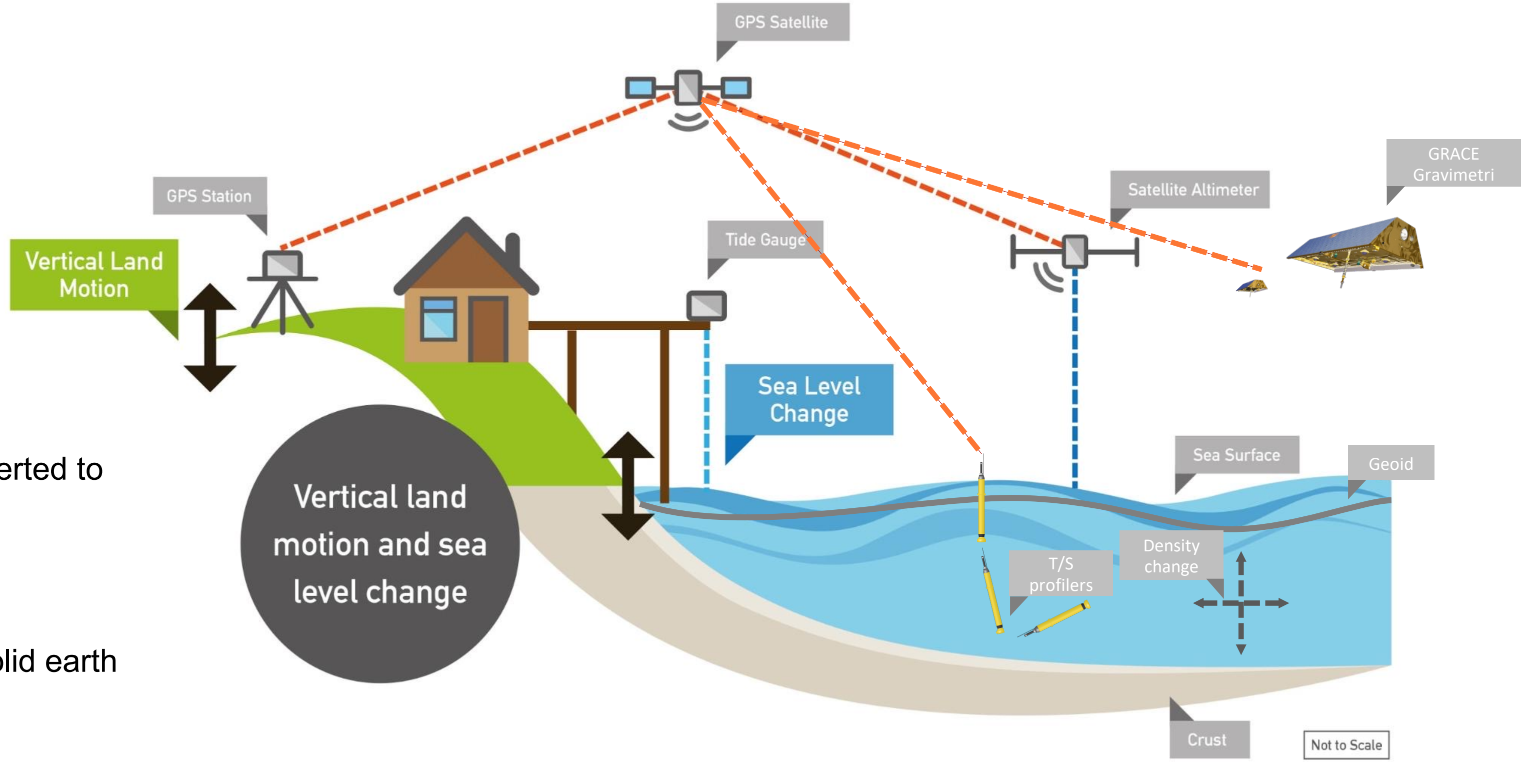
In-situ temperature and salinity measurements can be converted to changes in density changes, called **steric sea level**.

Tide-Gauges (since 18th century)

Relative sea level (RSL) – sea level relative to the coast/solid earth

GNSS (since 1990's)

Vertical land motion (VLM) – movement of the solid earth.
Difference between ASL and RSL



Altimetry (**absolute SL**) = GRACE (**mass**) + T/S profile (**steric**)
Altimetry (**absolute SL**) = Tide-Gauge (**relative SL**) + GNSS (**VLM**)

Observations of sea level change

Altimetry (various satellites 1993-now)

Sea surface height: **absolute sea level** (ASL) w.r.t. a geocentric reference.

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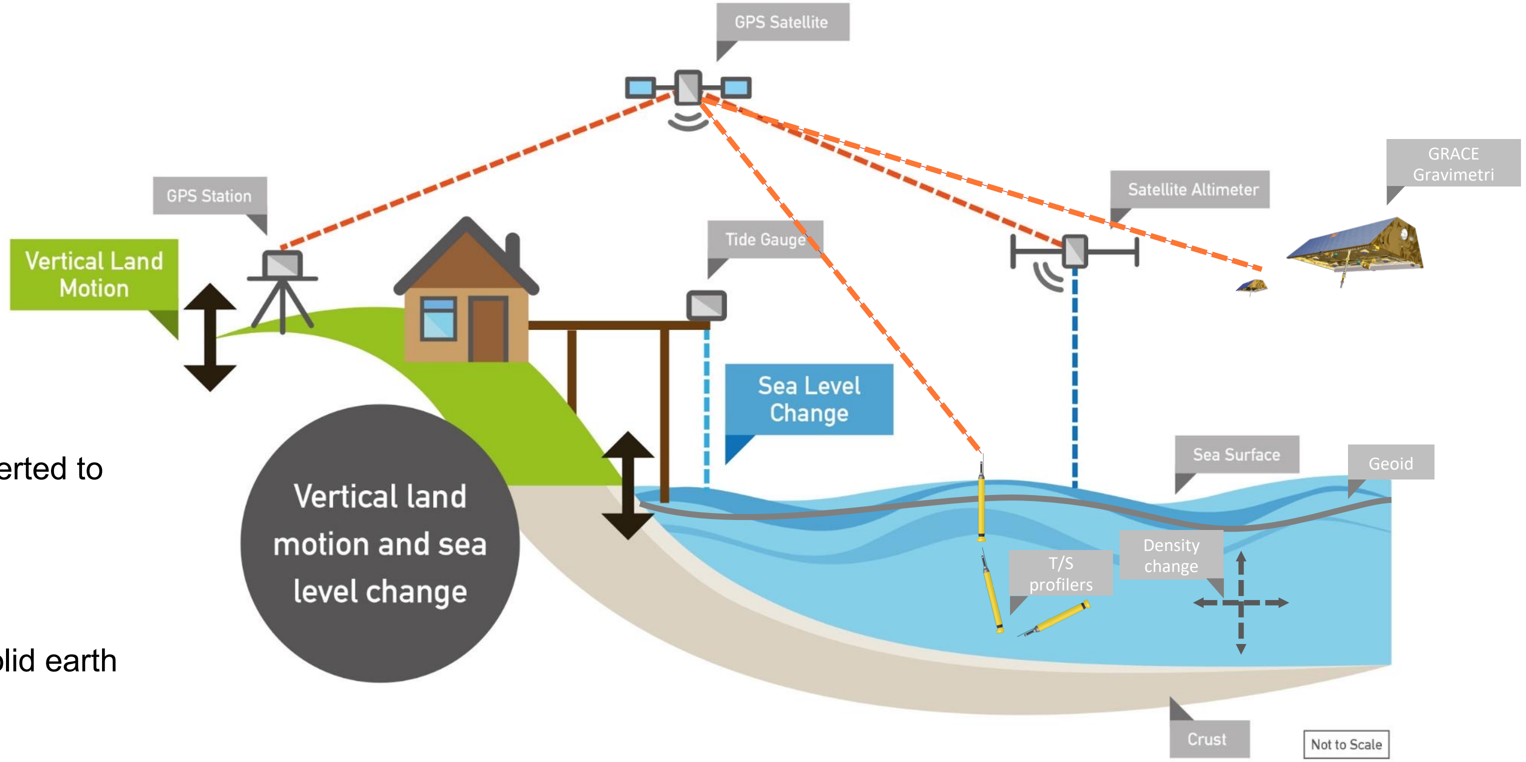


Only at **coastal locations** with GNSS/Tide Gauge combination

Altimetry (**absolute SL**) = GRACE (**mass**) + T/S profile (**steric**)

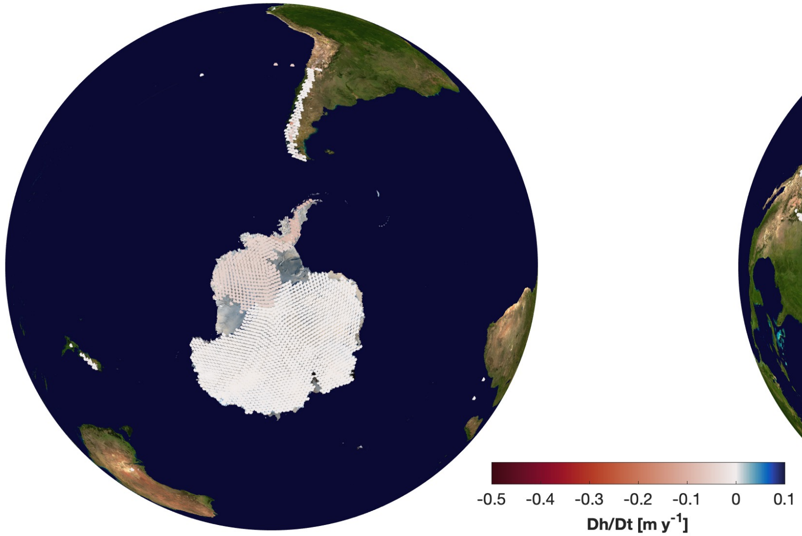
Altimetry (**absolute SL**) = Tide-Gauge (**relative SL**) + GNSS (**VLM**)

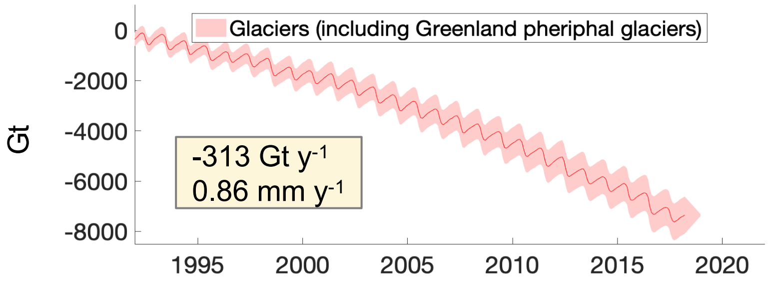
Reconstructing mass-driven sea level

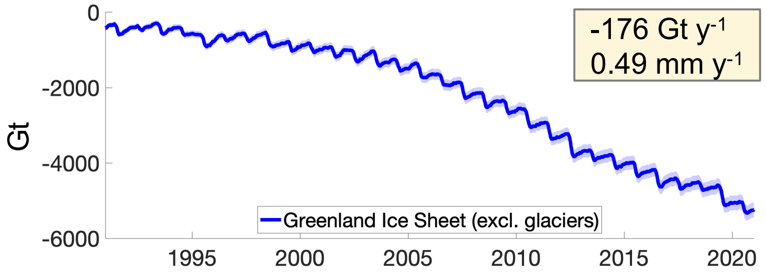
1992-2018

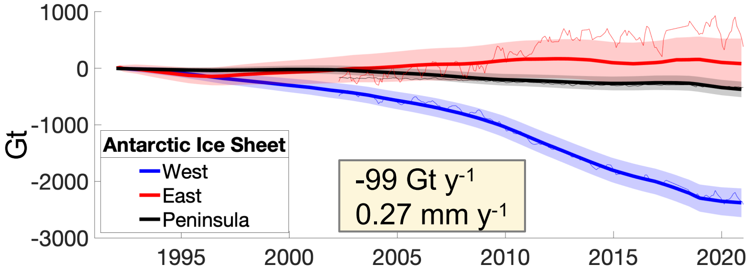
-118 Gt y^{-1}
~ 0.33 mm y^{-1} SLE*

-470 Gt y^{-1}
~ 1.30 mm y^{-1} SLE









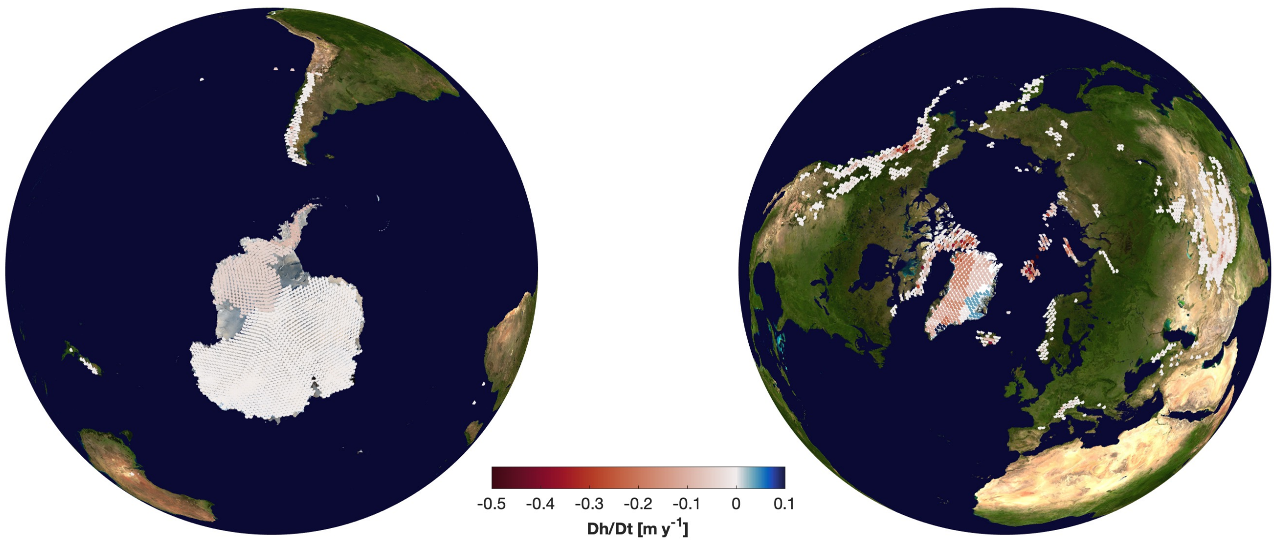
***SLE = global-mean sea level equivalent**

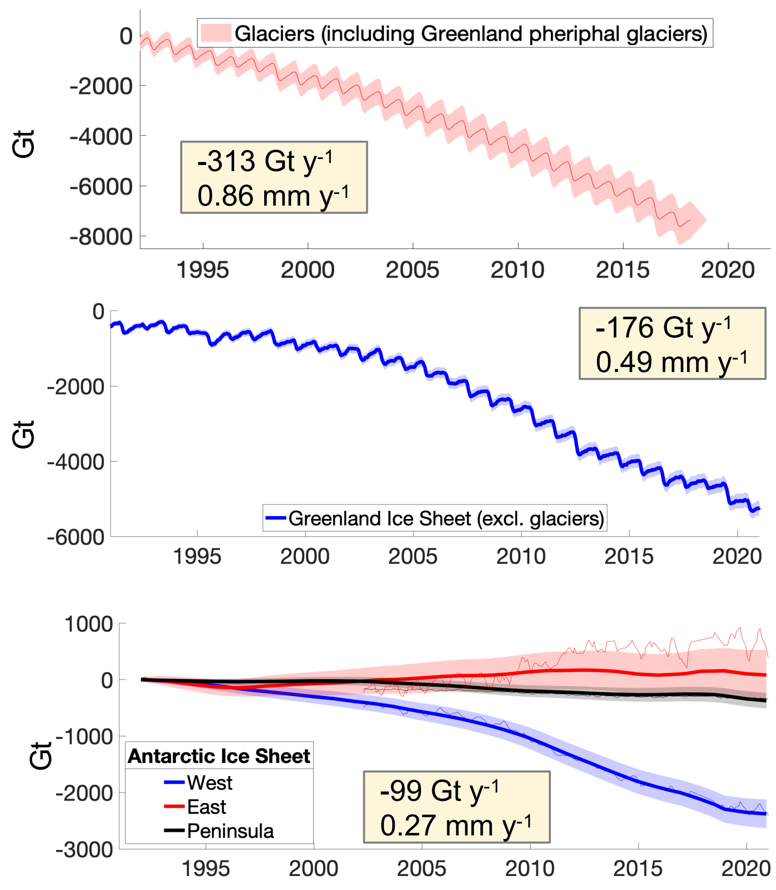
Reconstructing mass-driven sea level

1992-2018

-118 Gt y^{-1} ~ 0.33 mm y^{-1} SLE*

-470 Gt y^{-1} ~ 1.30 mm y^{-1} SLE





***SLE = global-mean sea level equivalent**

	Original spatial coverage	Original temporal coverage	Reference
Greenland	17 basins (Zwally basins)	Daily (1840-2022)	Mankoff et al, 2021
Glaciers	0.5x0.5 degree	Monthly (1901-2018)	Malles & Marzeion, 2021
Antarctic	3 regions (Peninsula, WAIS, EAIS)	Monthly (1992-2020)	IMBIE, 2021

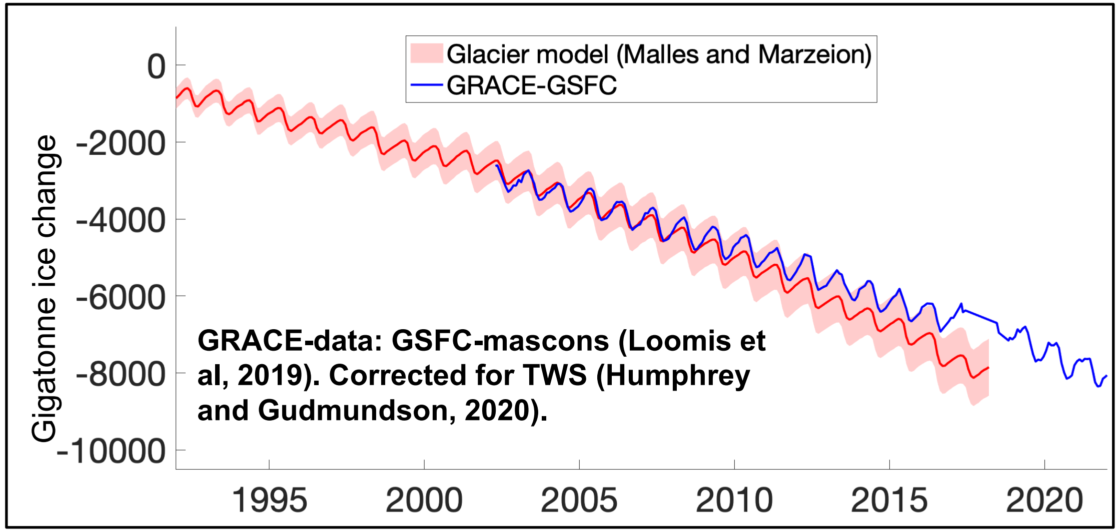
NB: Timeseries stops in 2018/2020.

Extension with GRACE observations.

Reconstructing mass-driven sea level

Original glacier data from glacial reanalysis model (based on Malles and Marzeion, 2021) in a 0.5x0.5 degree grid.

GRACE estimates for glacier grid points (minus TWS) from GSFC 0.5-degree product (Loomis et al, 2020).



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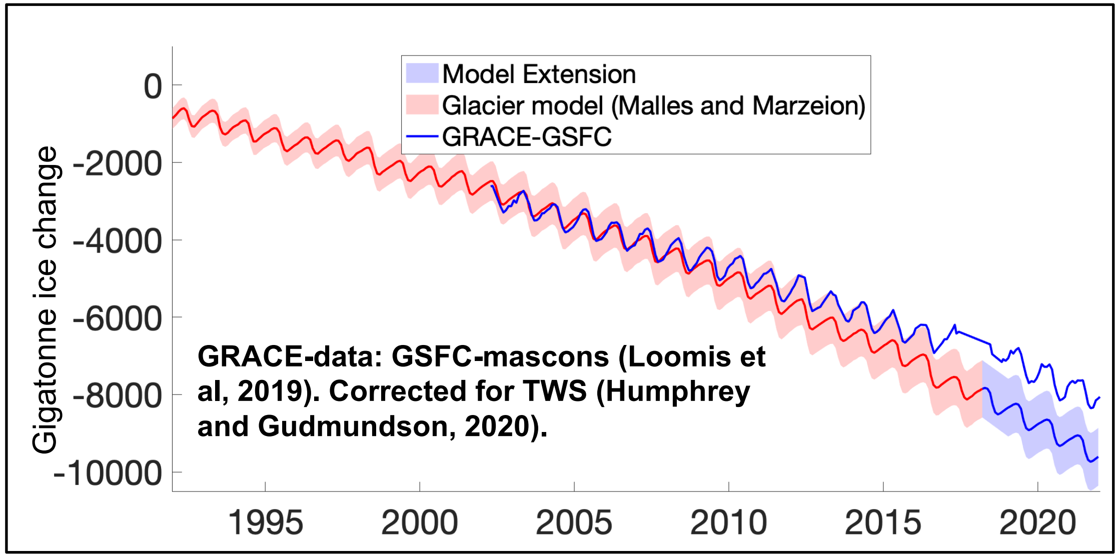
$$\alpha = \text{Glacier } \dot{\text{MB}}_{12-17} * \frac{\text{GR}\dot{\text{A}}\text{CE}_{18-21}}{\text{GR}\dot{\text{A}}\text{CE}_{12-17}}$$

$$\text{Glacier MB}_{18-21}\ (\text{Recon}) = \alpha * t + \text{Glacier MB}_{seasonal}$$



Reconstructing mass-driven sea level

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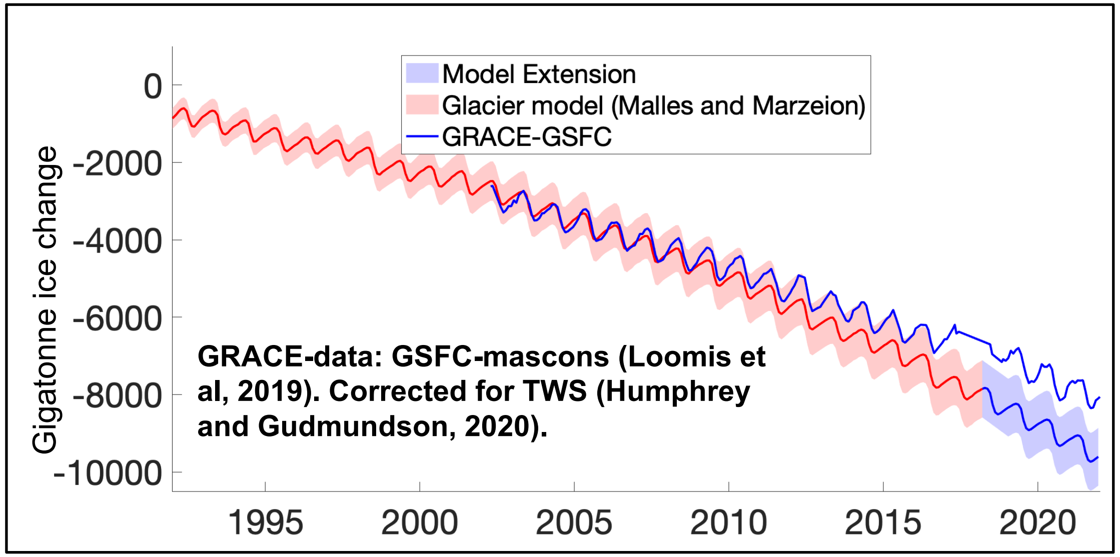
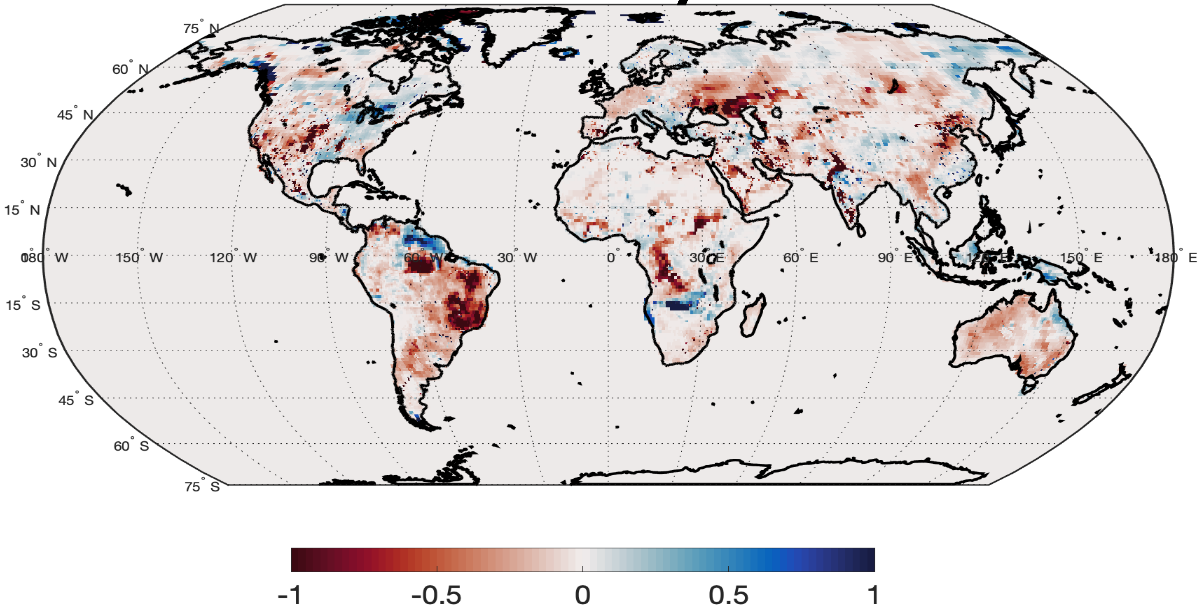


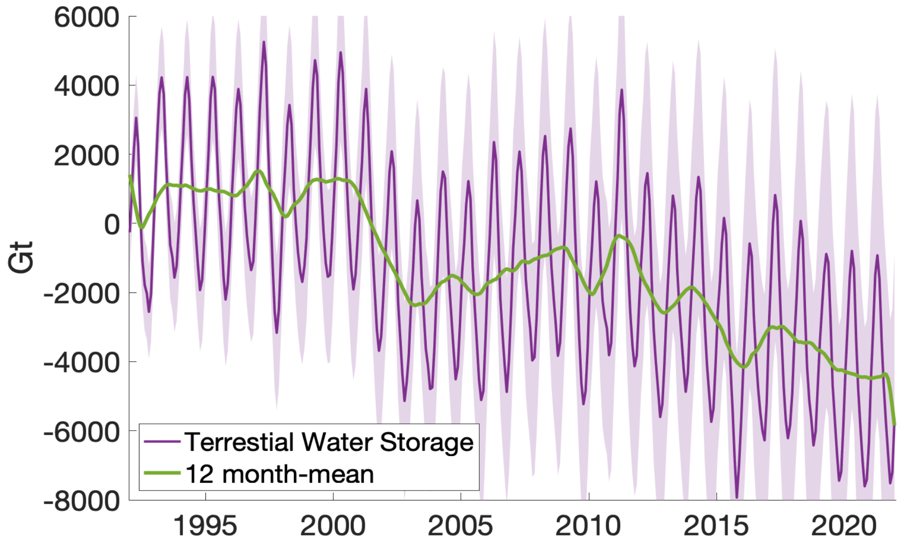
Same approach used for the Antarctic Ice Sheet (2020-2022) and Terrestial Water Storage (2019-2022)

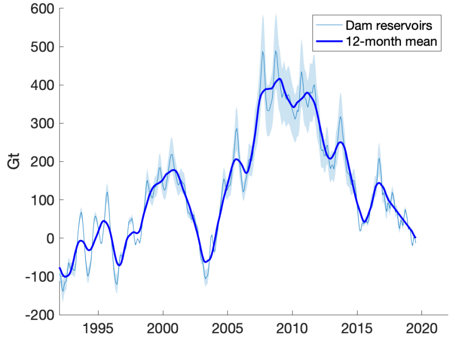
Reconstructing mass-driven sea level

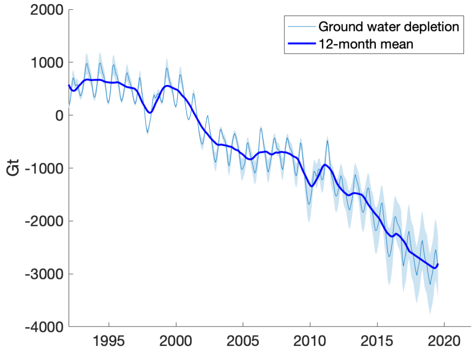
Terrestial Water Storage Change:

-194 Gt y^{-1}
~ 0.54 mm y^{-1} SLE



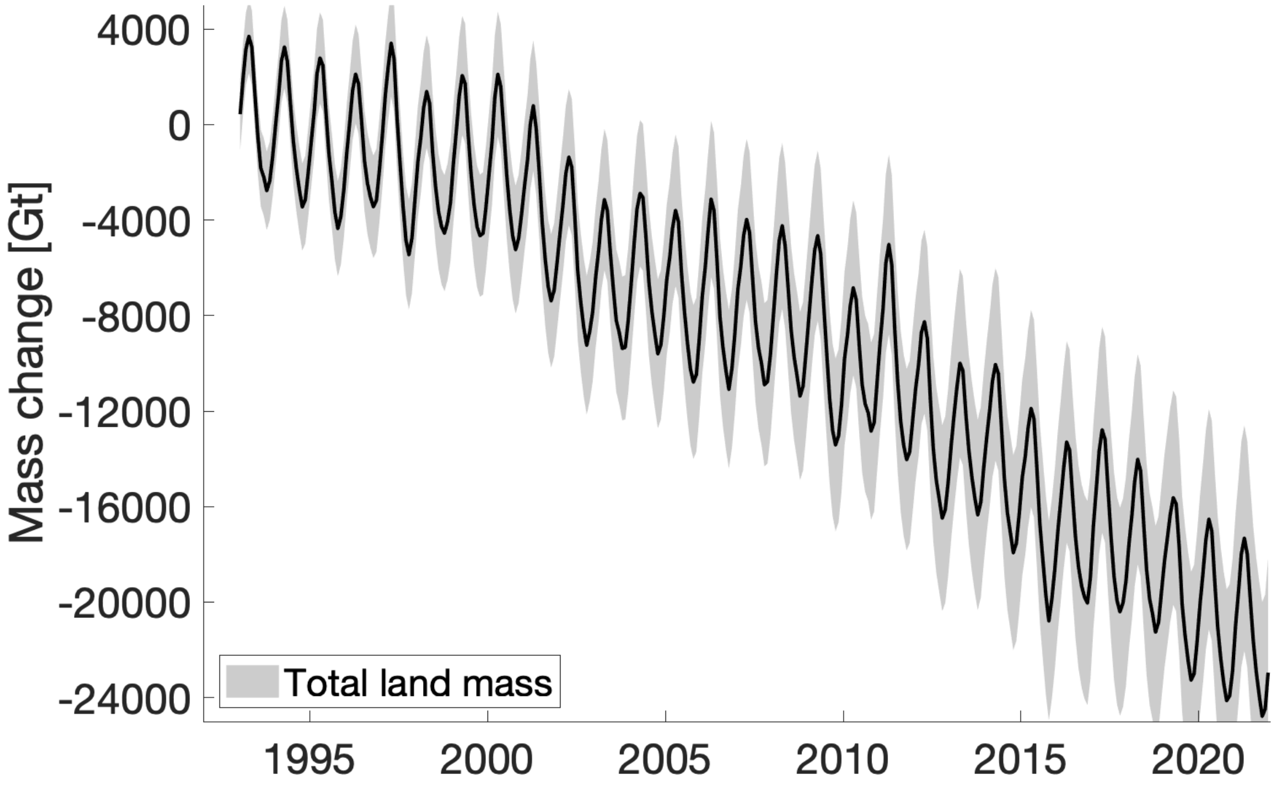




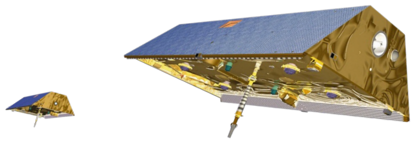


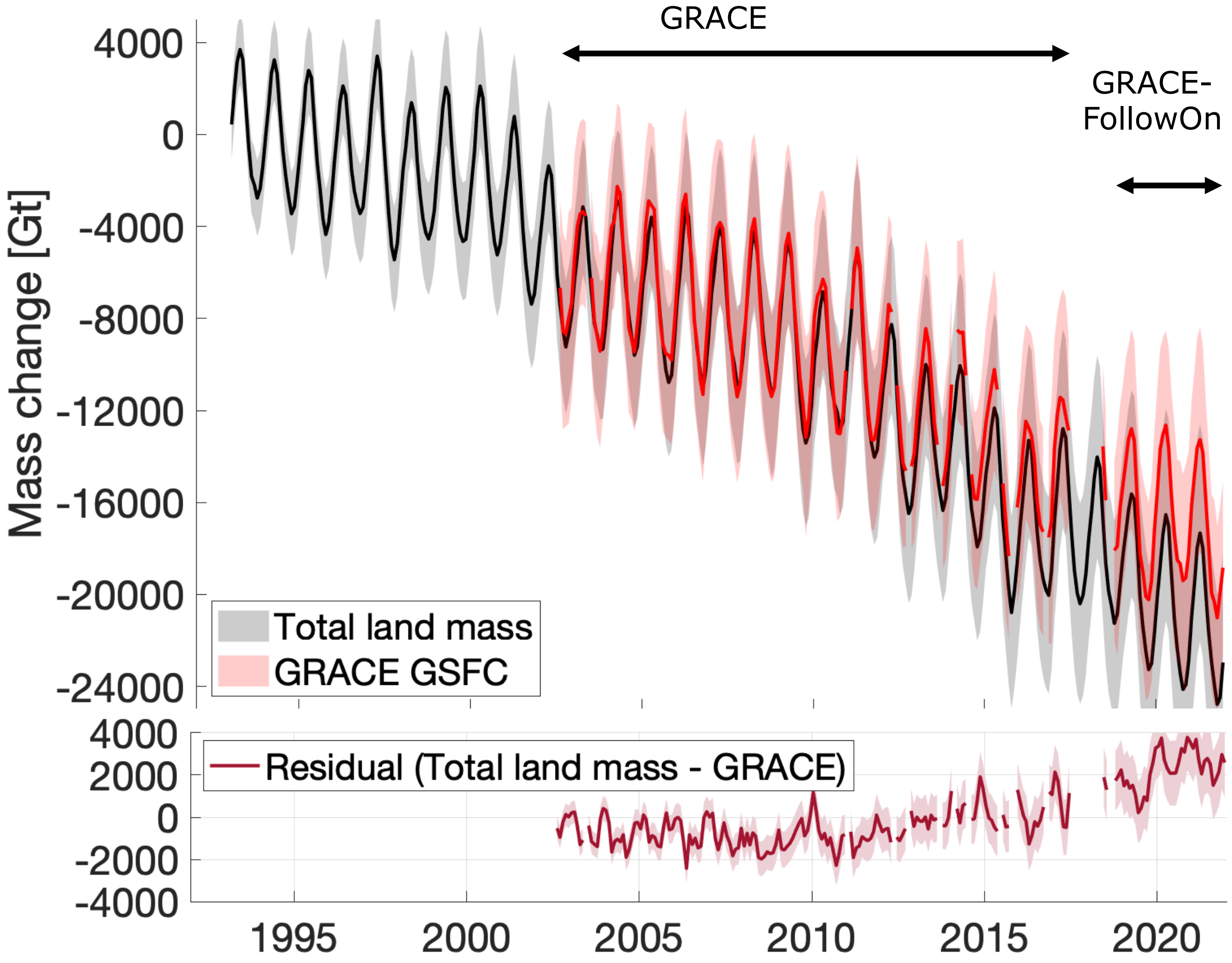
Natural TWS from GRACE-REC (Humphrey and Gudmundson, 2020).
Dam retention and Groundwater depletion from WaterGAP 2.2. (Müller-Schmied et al, 2020).
Extended from 2019 to 2022 with GRACE observations. TWS in glaciated areas is extended with linear regression.

Reconstructing mass-driven sea level

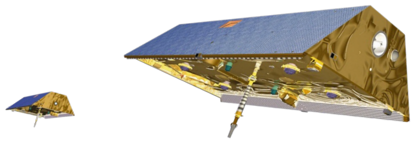


Reconstructing mass-driven sea level



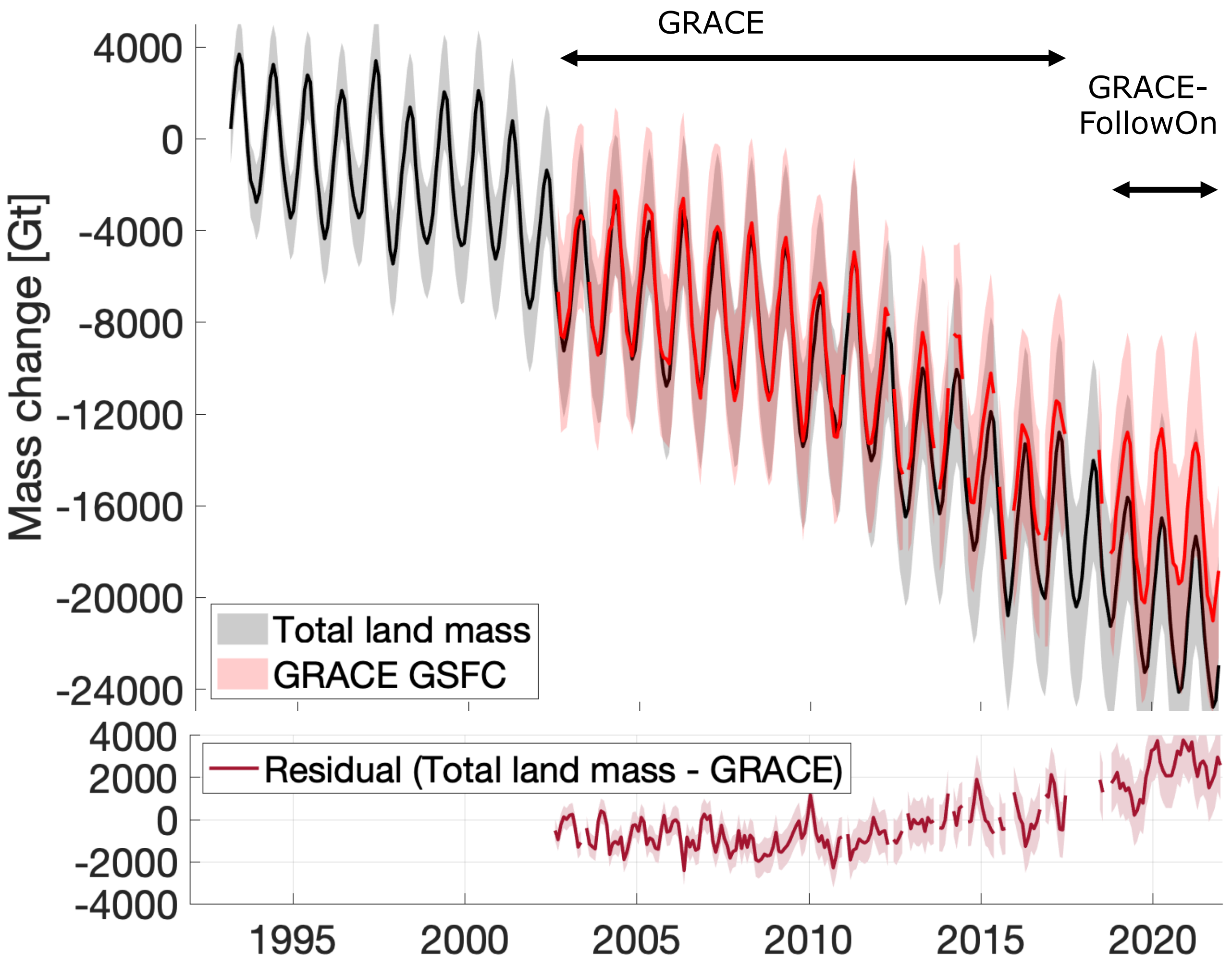


Reconstructing mass-driven sea level

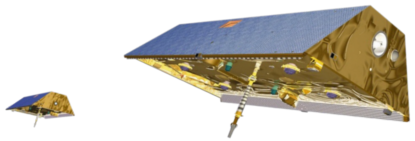


Mass budget deviates from GRACE.

Residual trend from
Jan 2015 – Dec 2021: ~500 Gt yr^{-1} / 1.39 mm yr^{-1}



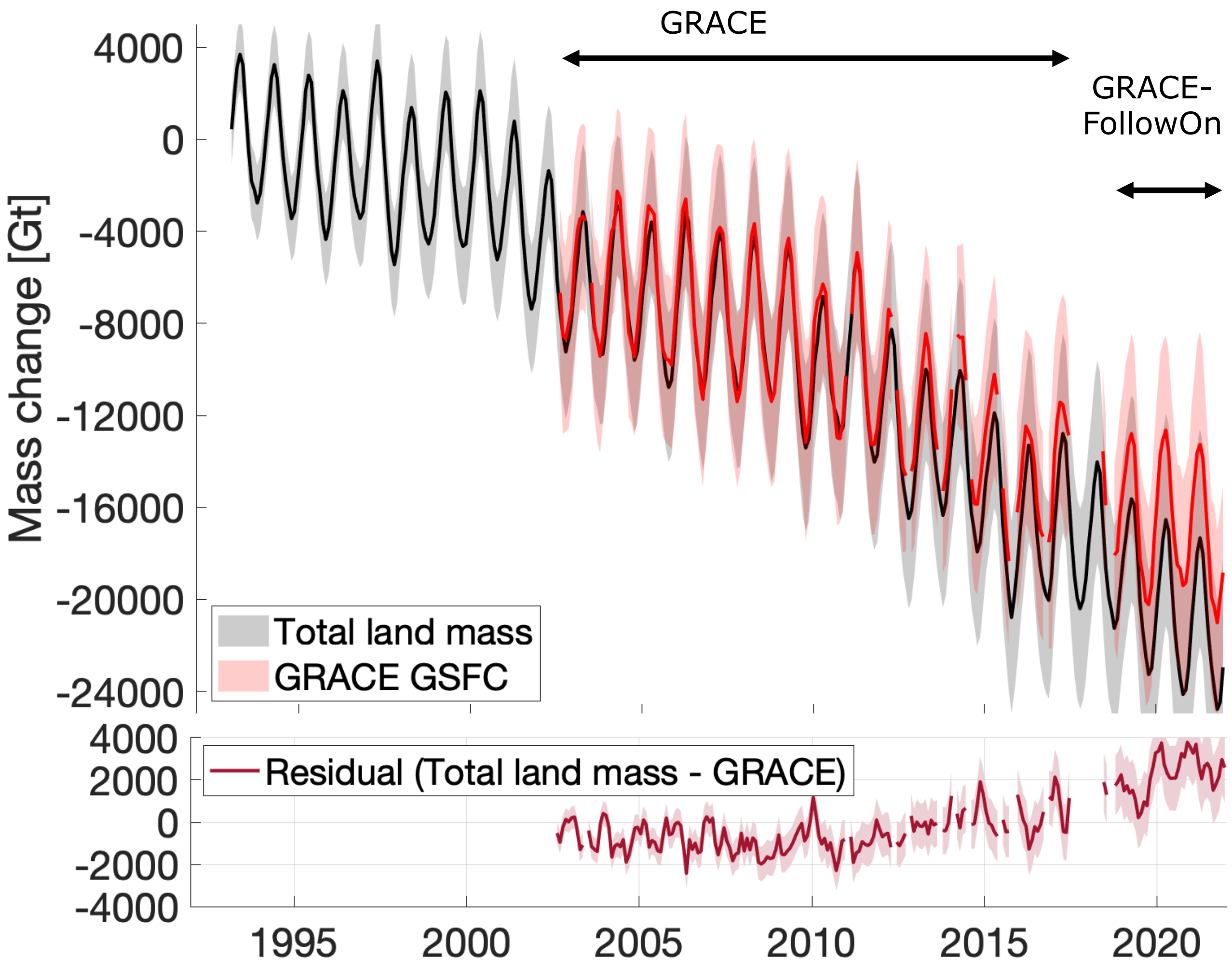
Reconstructing mass-driven sea level



Mass budget deviates from GRACE.

Residual trend from Jan 2015 – Dec 2021: ~420 Gt yr^{-1} / 1.16 mm yr^{-1}

Is GRACE the reason for non-closure of the sea level budget after 2016?



Barnoud et al, 2021

Geophysical Research Letters

Research Letter | Full Access

Contributions of Altimetry and Argo to Non-Closure of the Global Mean Sea Level Budget Since 2016

Anne Barnoud, Julia Pfeffer, Adrien Guérou, Marie-Laure Frery, Mathilde Siméon, Anny Cazenave, Jianli Chen, William Llovel, Virginie Thierry, Jean-François Legeais, Michaël Ablain

First published: 26 June 2021 | https://doi.org/10.1029/2021GL092824 | Citations: 8

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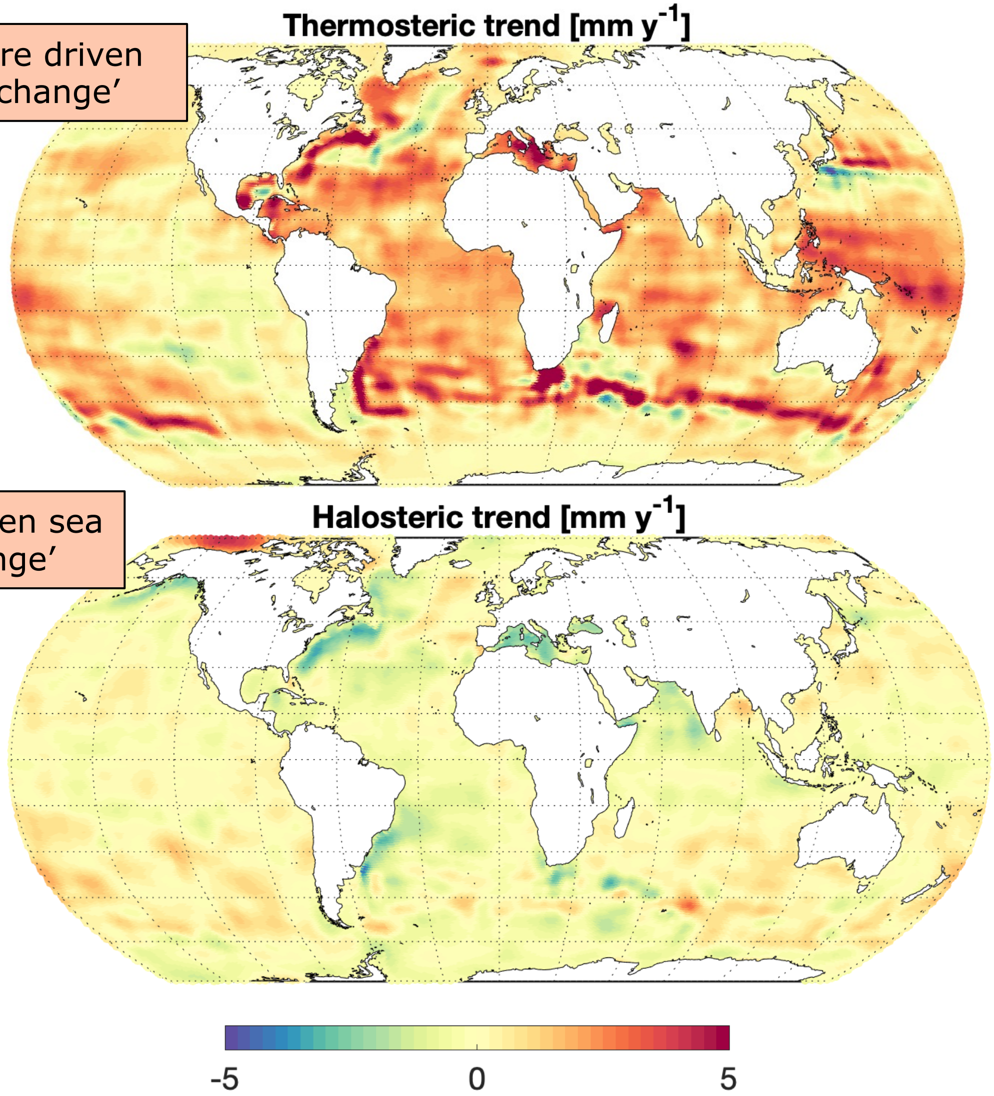
Abstract

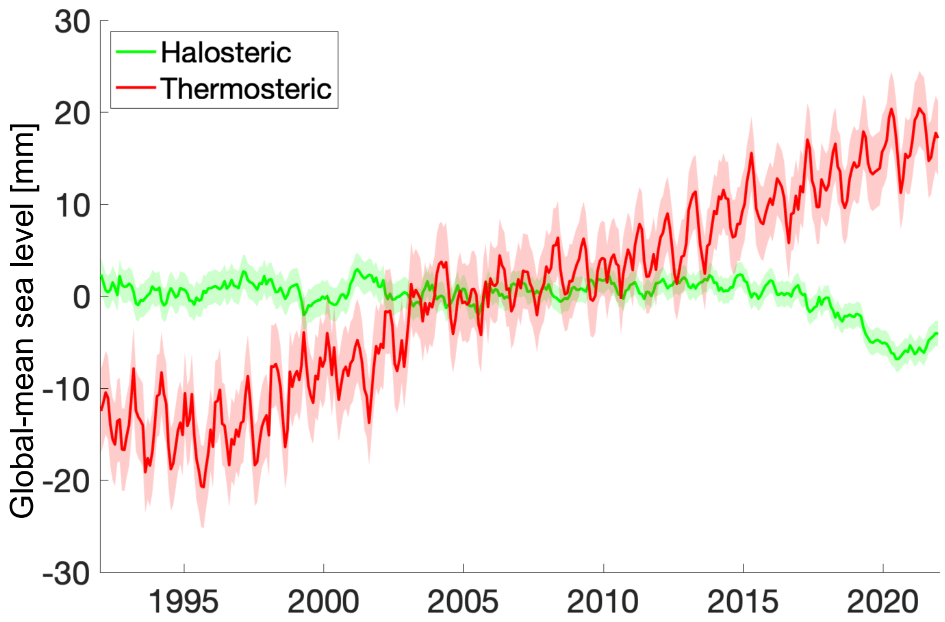
Over 1993–2016, studies have shown that the observed global mean sea level (GMSL) budget is closed within the current data uncertainties. However, non-closure of the budget was recently reported when using Jason-3, Argo and GRACE/GRACE Follow-On data after 2016. This non-closure may result from errors in the data sets used to estimate the GMSL and its components. Here, we investigate possible sources of errors affecting Jason-3 and Argo data. Comparisons of Jason-3 GMSL trends with other altimetry missions show good agreement within 0.4 mm/yr over 2016–present. Besides, the wet tropospheric correction uncertainty from the Jason-3 radiometer contributes to up to 0.2 mm/yr. Therefore, altimetry alone cannot explain the misfit in the GMSL budget observed after 2016. Argo-based salinity products display strong discrepancies since 2016, attributed to instrumental problems and data editing issues. Reassessment of the sea level budget with the thermosteric component provides about 40% improvement in the budget closure.

Steric sea level (calculated from EN4.2.2)

'Temperature driven sea level change'



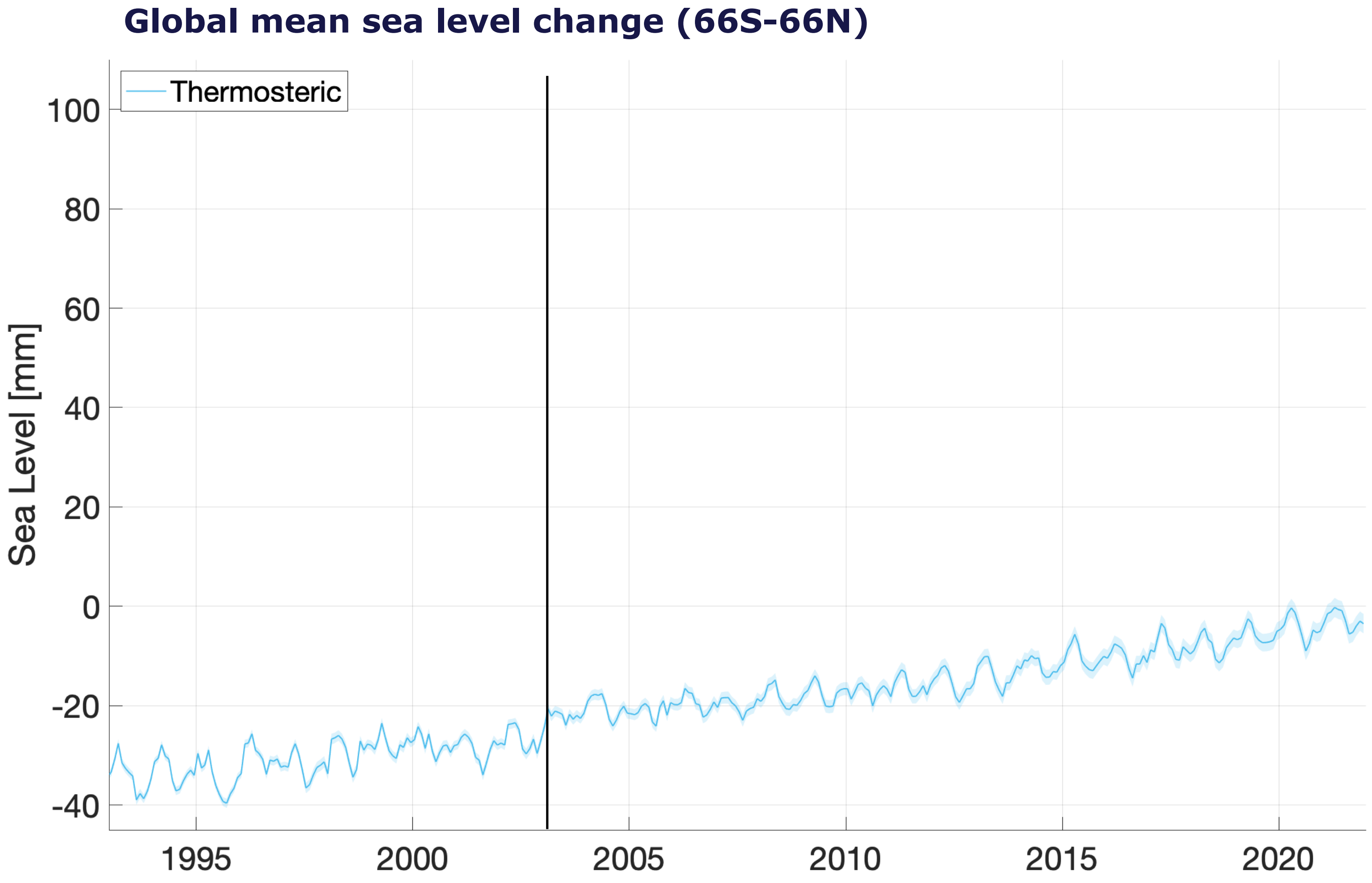
'Salinity driven sea level change'



Based on **monthly gridded ocean temperature and salinity** (depth range 0-5300 meters) from MetOffice (EN4.2.2) available from 1900-2022 (Good et al, 2013).

NB: Halosteric sea level should globally sum to zero (Gregory et al, 2019). Possible degradation of ARGO conductivity measurements after 2015 results in decline of halosteric sea level.

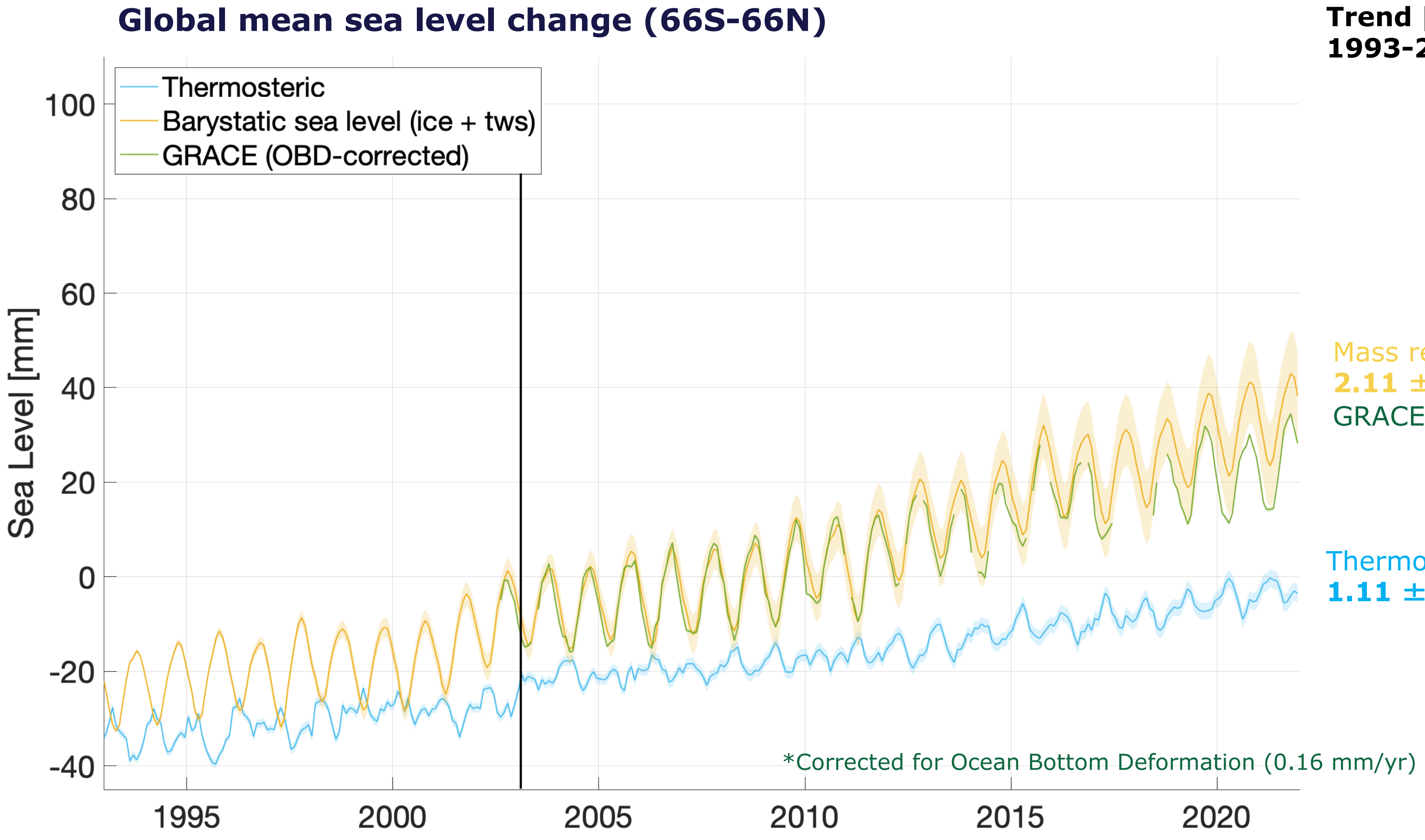
Reconstructed sea level change 1992-2021



Trend [mm/yr]
1993-2022 / 2003-2022

Thermosteric (EN4)
1.11 ± 0.12 / 1.05 ± 0.12

Reconstructed sea level change 1992-2021



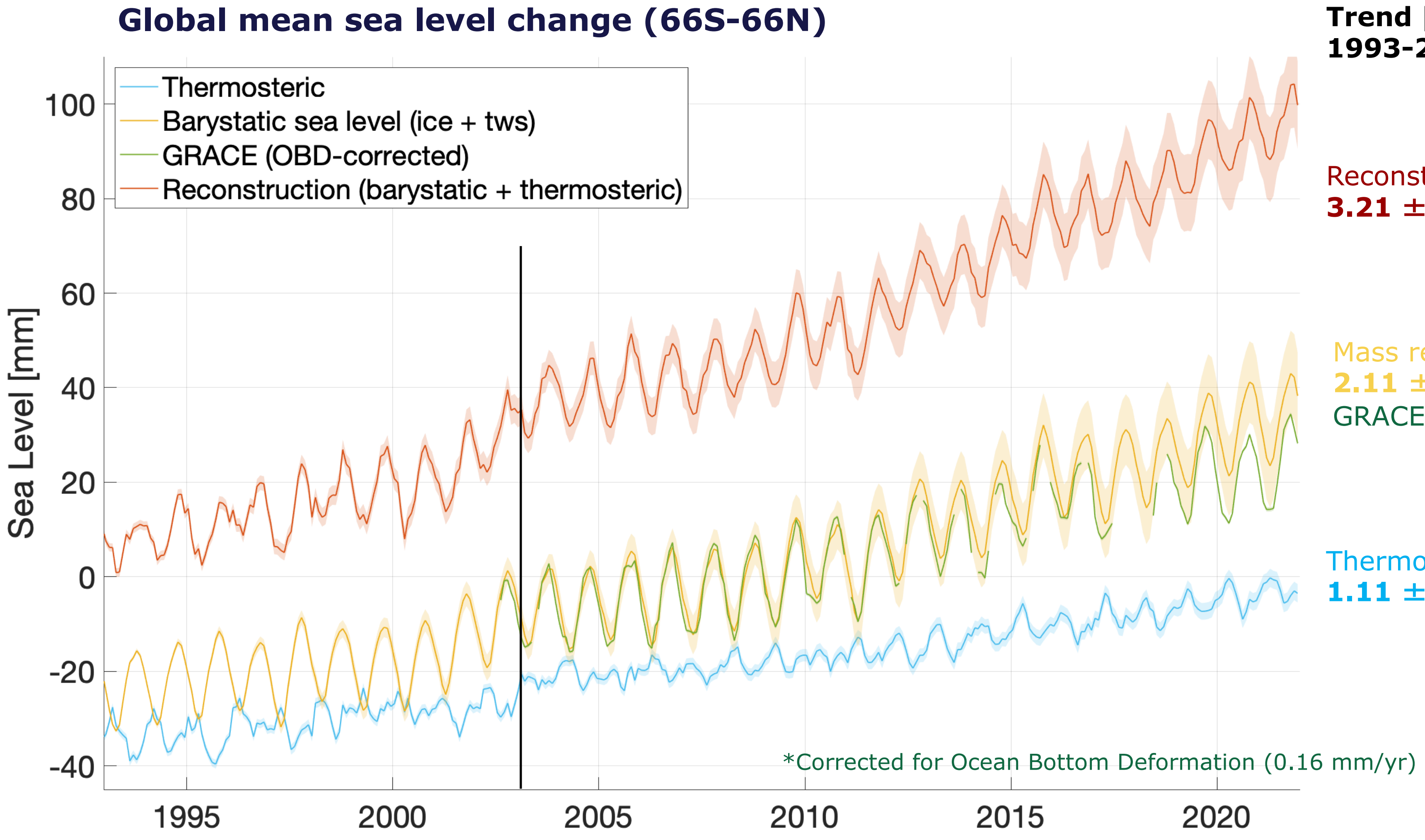
Trend [mm/yr]
1993-2022 / 2003-2022

Mass reconstruction
2.11 ± 0.25 / 2.43 ± 0.28

GRACE ocean mass (GSFC-mascons)*
/ 1.90 ± 0.08

Thermosteric (EN4)
1.11 ± 0.12 / 1.05 ± 0.12

Reconstructed sea level change 1992-2021



Trend [mm/yr]
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Reconstruction
3.21 ± 0.33 / 3.33 ± 0.38

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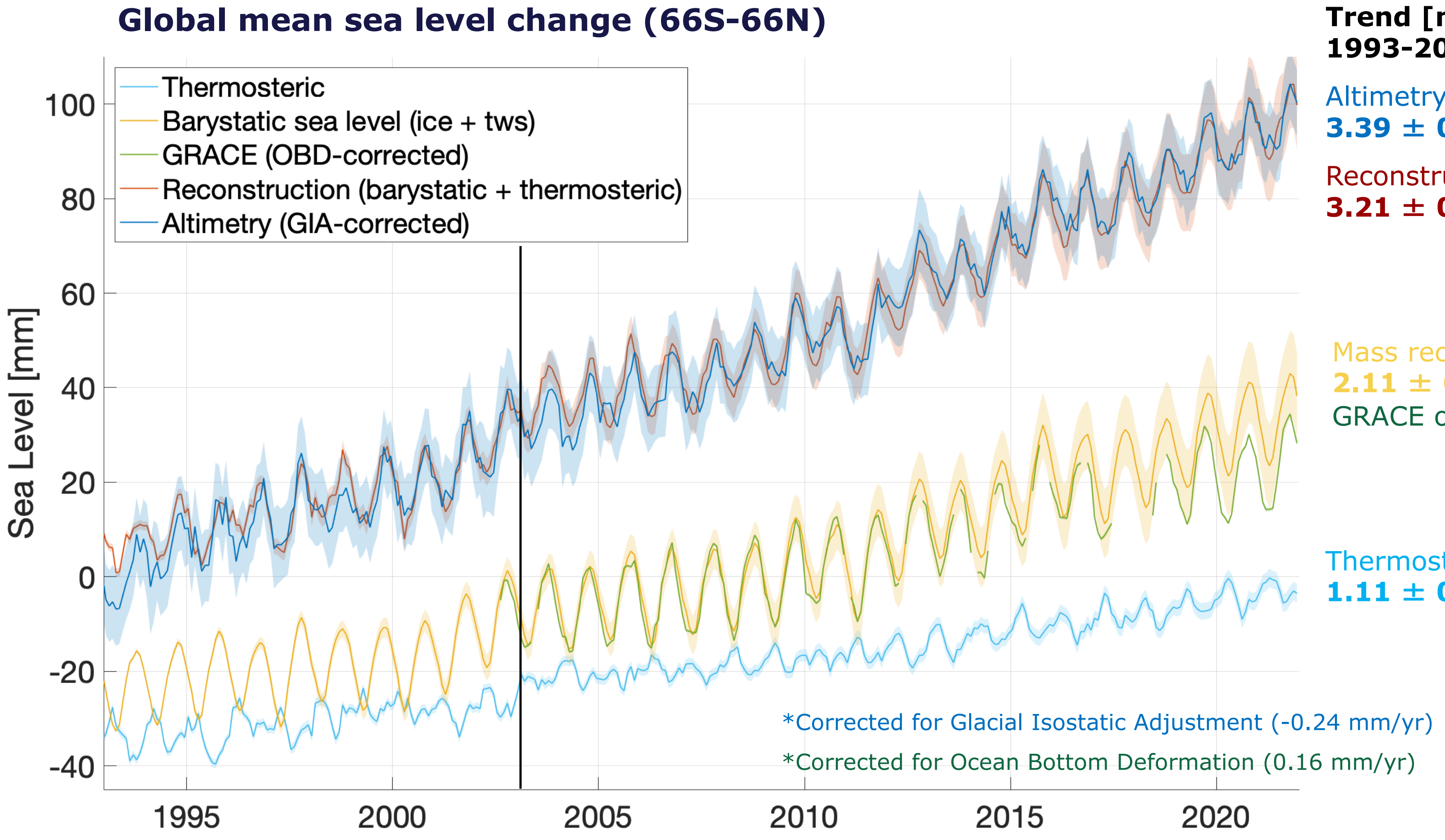


Trend [mm/yr]
1993-2022 / 2003-2022

Altimetry (JPL MEASURE 2205)*
3.39 ± 0.25 / 3.71 ± 0.28

Reconstruction
3.21 ± 0.33 / 3.48 ± 0.38

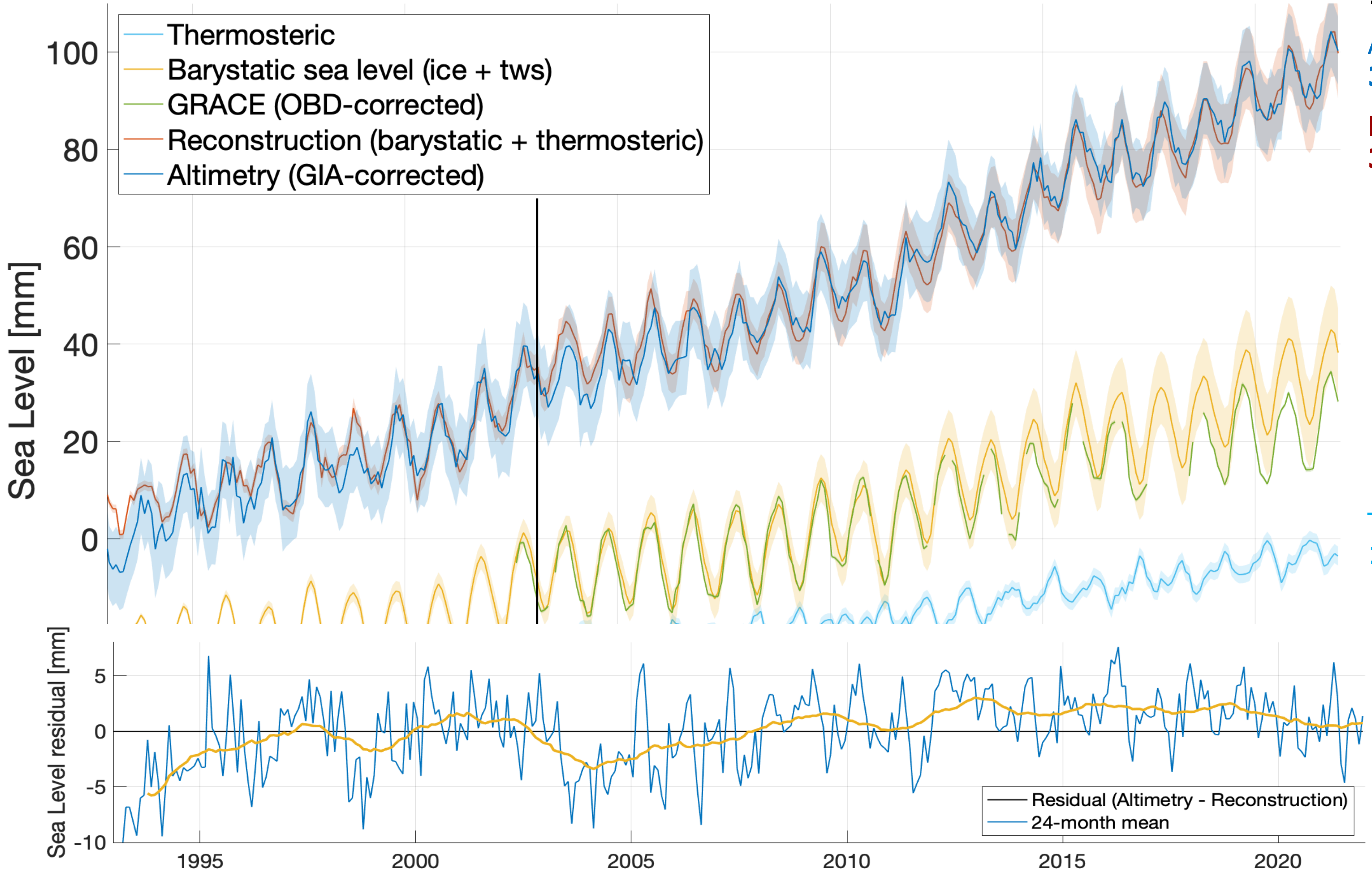
Mass reconstruction
2.11 ± 0.25 / 2.43 ± 0.28

GRACE ocean mass (GSFC-mascons)*
/ 1.90 ± 0.08

Thermosteric (EN4)
1.11 ± 0.12 / 1.05 ± 0.12

Reconstructed sea level change 1992-2021

Global mean sea level change (66S-66N)



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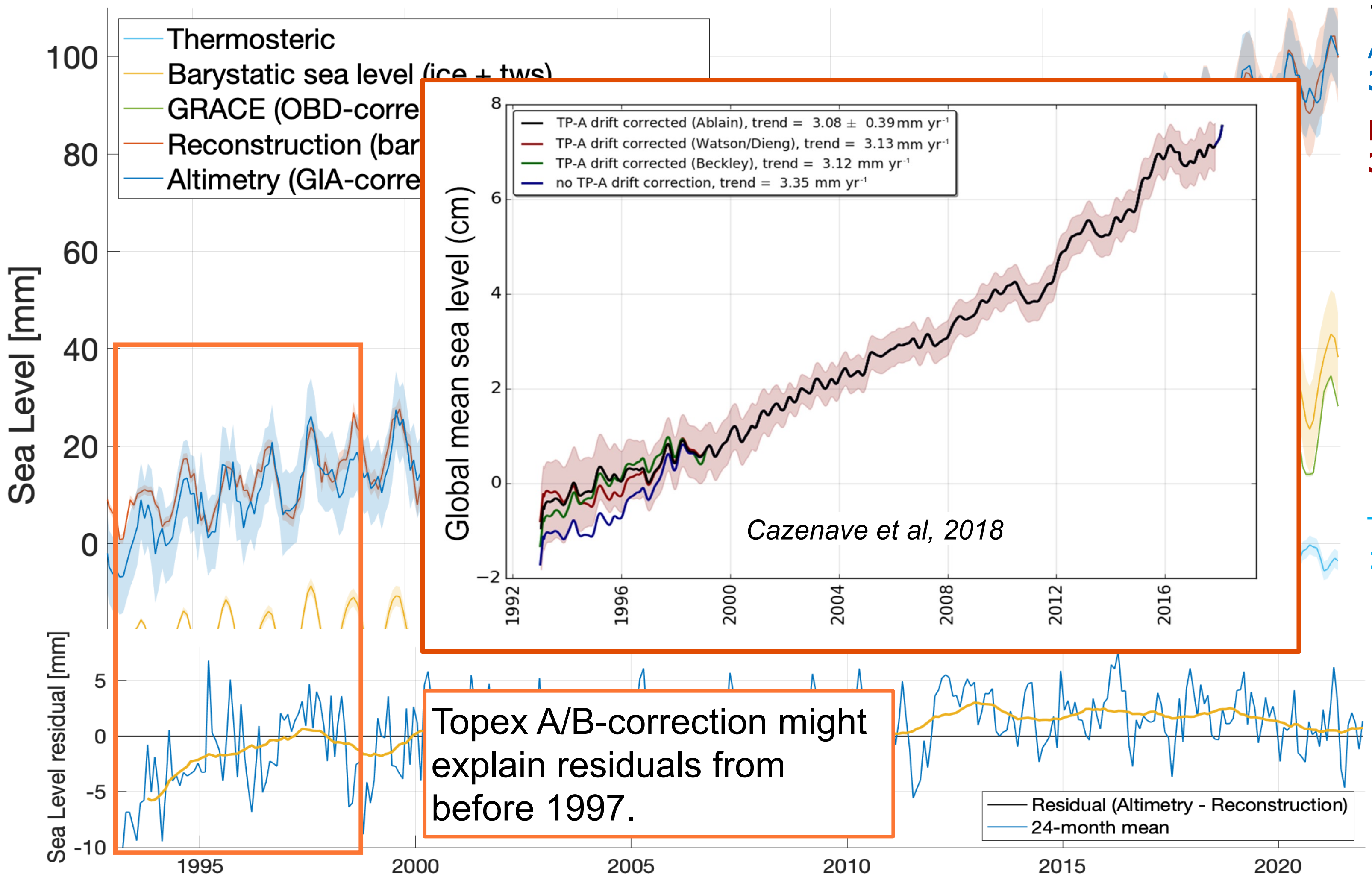
Residual trend
0.17 ± 0.41 / 0.22 ± 0.47

Reconstructed sea level change 1992-2021

Global mean sea level change (66S-66N)



Topex A/B-correction might explain residuals from before 1997.

Trend [mm/yr]
1993-2022 / 2003-2022

Altimetry (JPL MEASURE 2205)*
3.39 ± 0.25 / 3.71 ± 0.28

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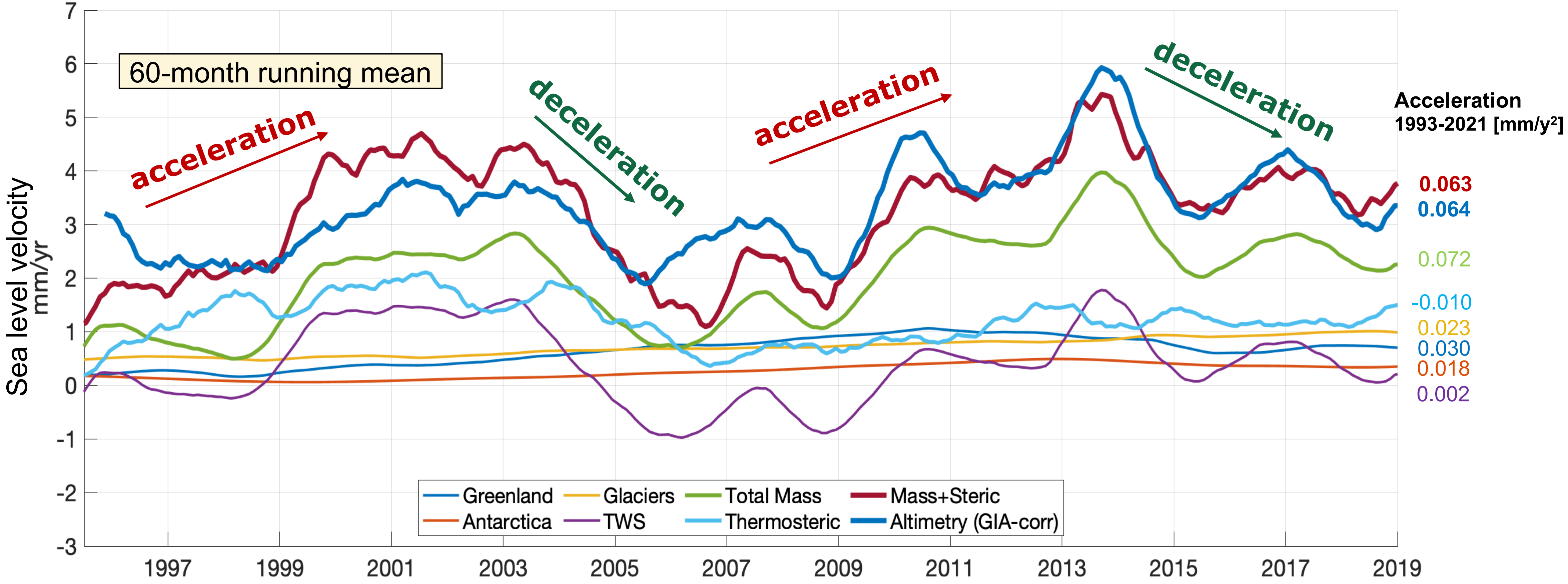
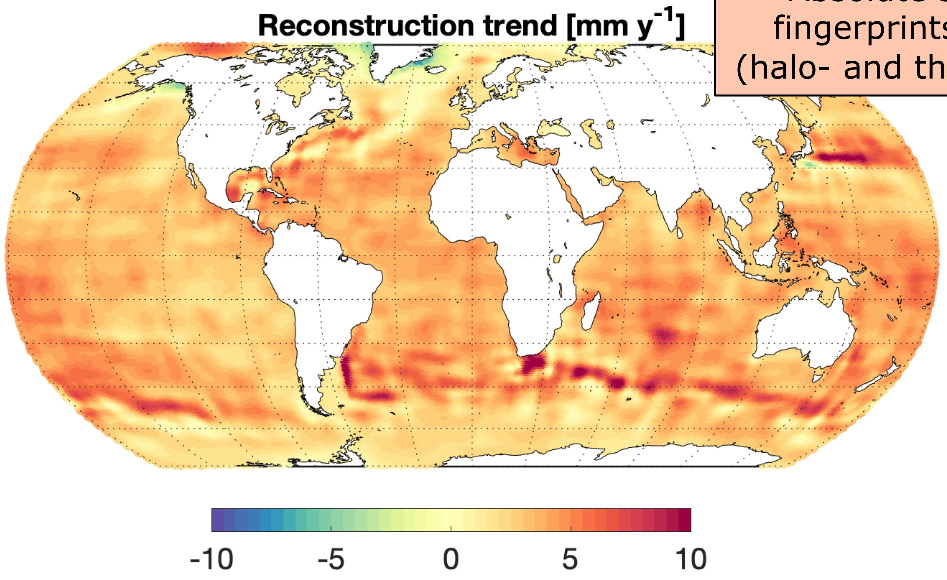
Residual trend
0.17 ± 0.41 / 0.22 ± 0.47

Reconstructed sea level change 1992-2021

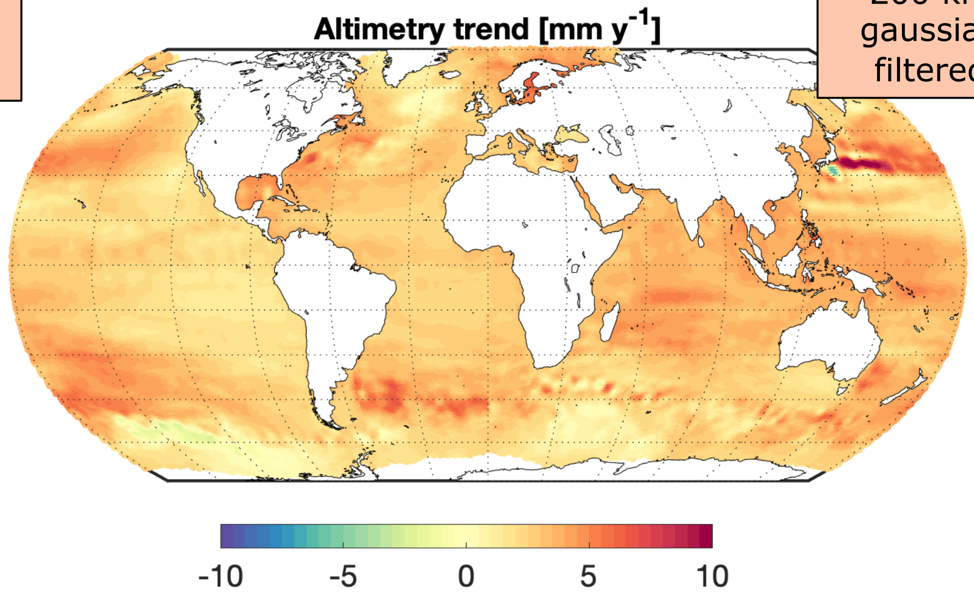
What drives sea level acceleration?



Reconstructed sea level change 1992-2021



Absolute sea level fingerprints + steric (halo- and thermosteric)

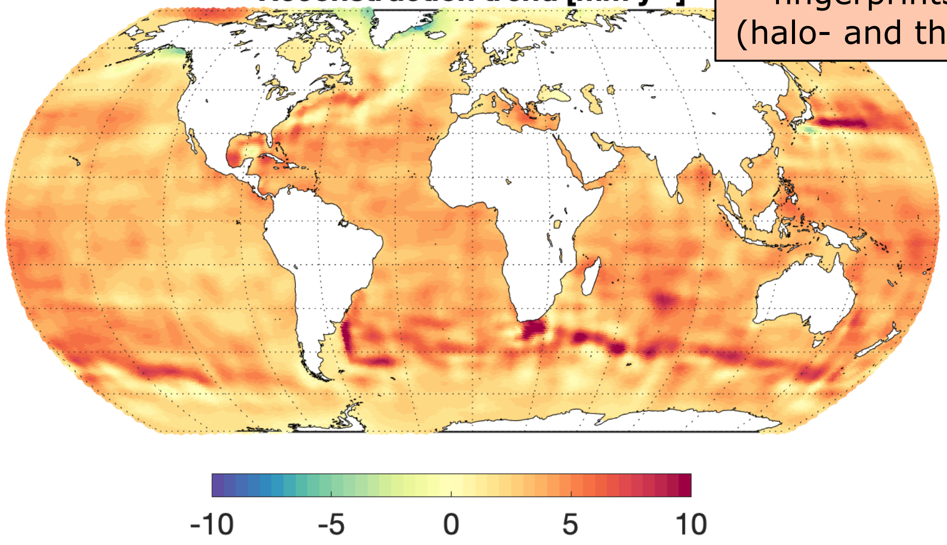


200 km gaussian filtered

Reconstructed sea level change 1992-2021

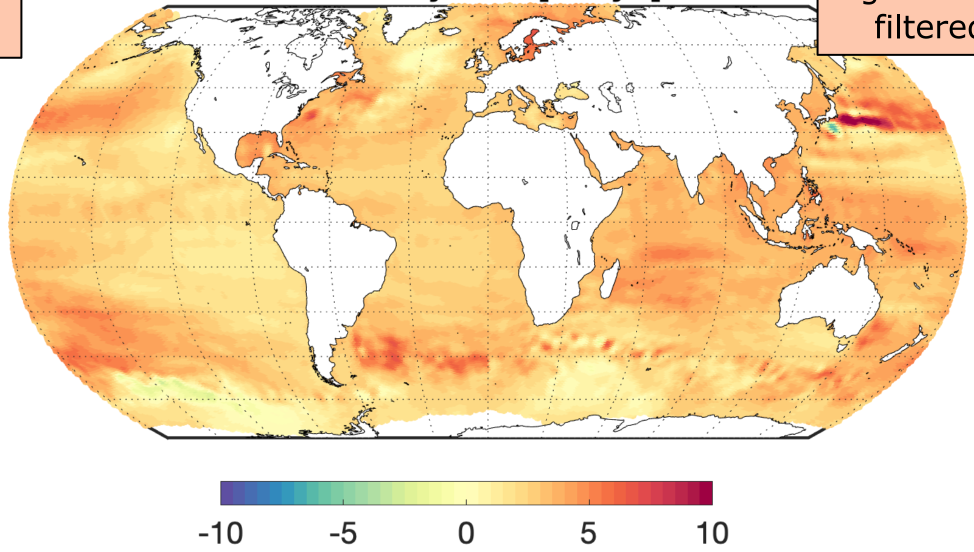
Reconstruction trend [mm y^{-1}]

Absolute sea level fingerprints + steric (halo- and thermosteric)

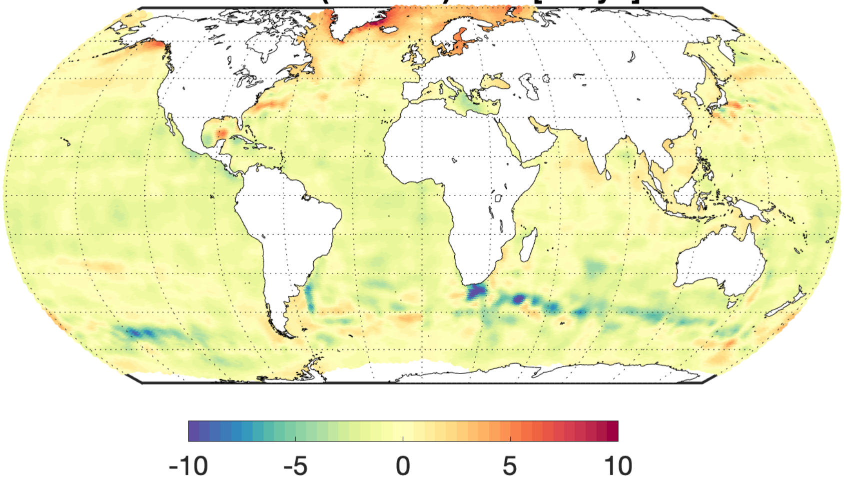


Altimetry trend [mm y^{-1}]

200 km gaussian filtered



Residual (alt-recon) trend [mm y^{-1}]



Reconstructed sea level change 1992-2021

Reconstruction trend [mm y^{-1}]

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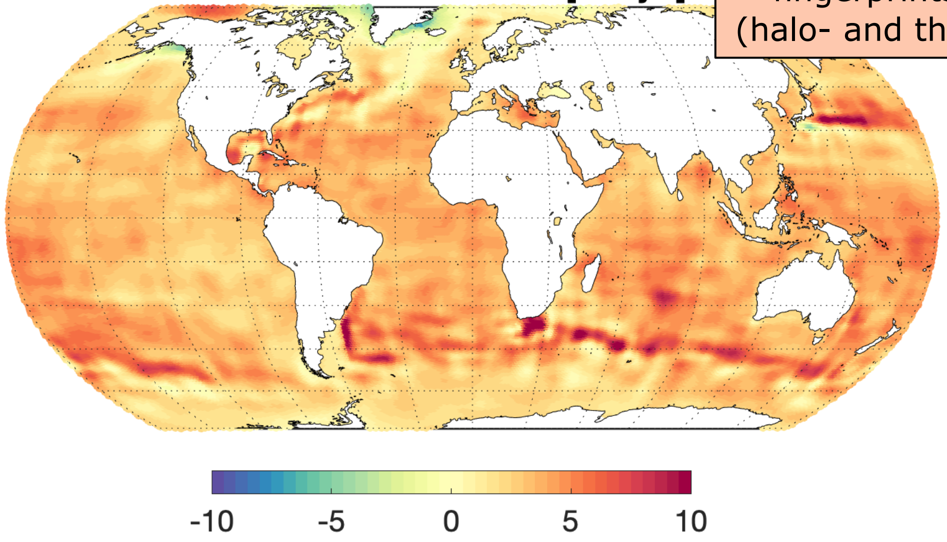
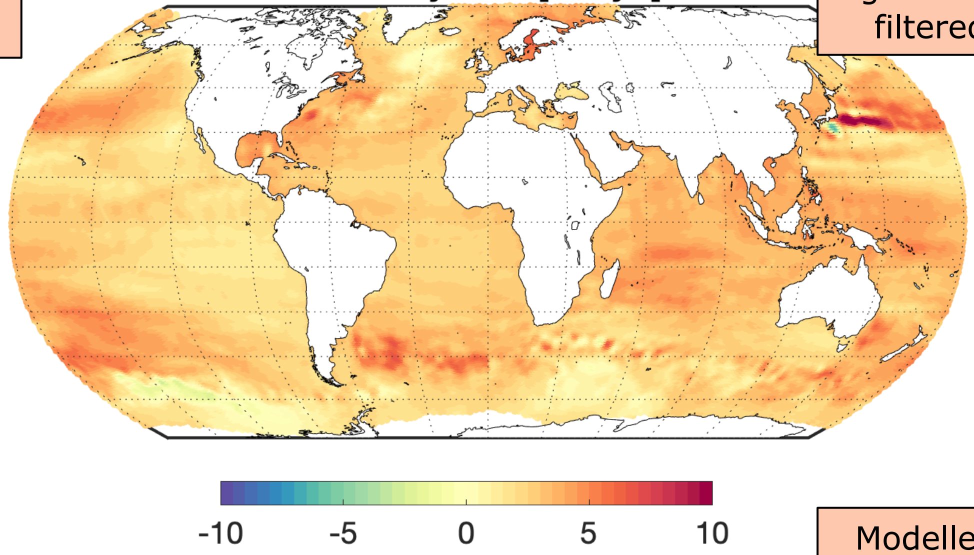
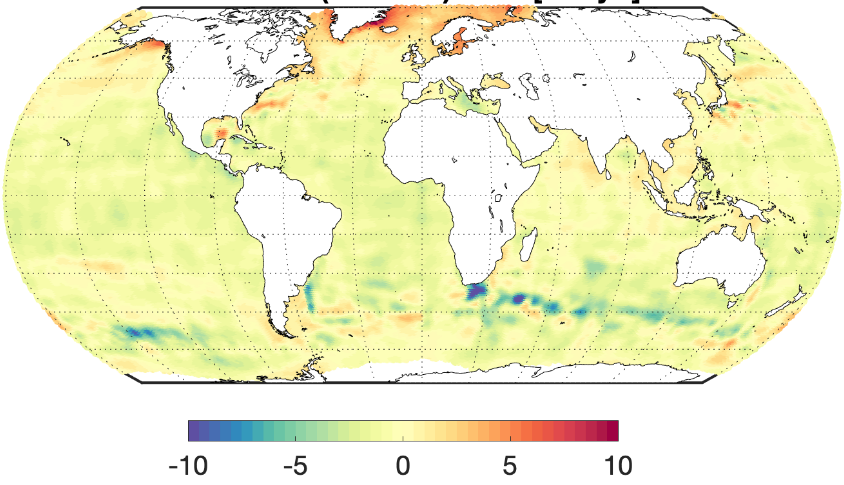


Altimetry trend [mm y^{-1}]

200 km gaussian filtered

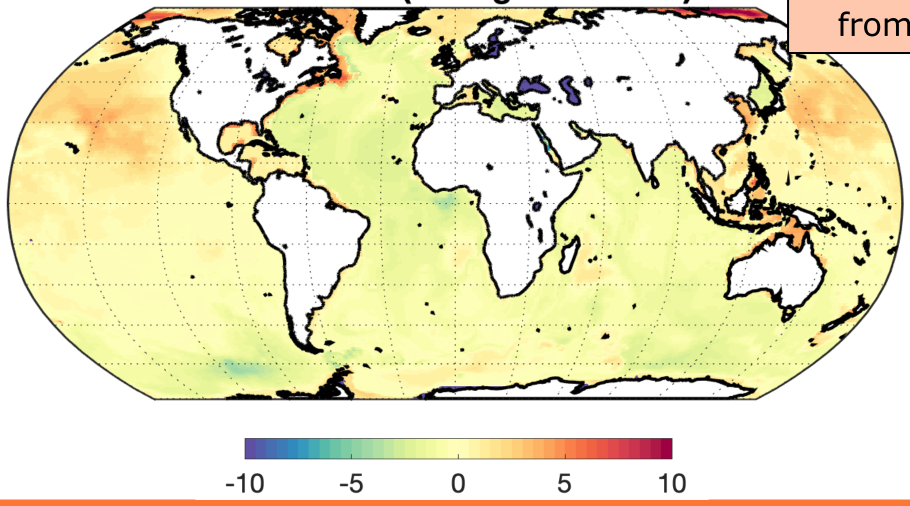


Residual (alt-recon) trend [mm y^{-1}]

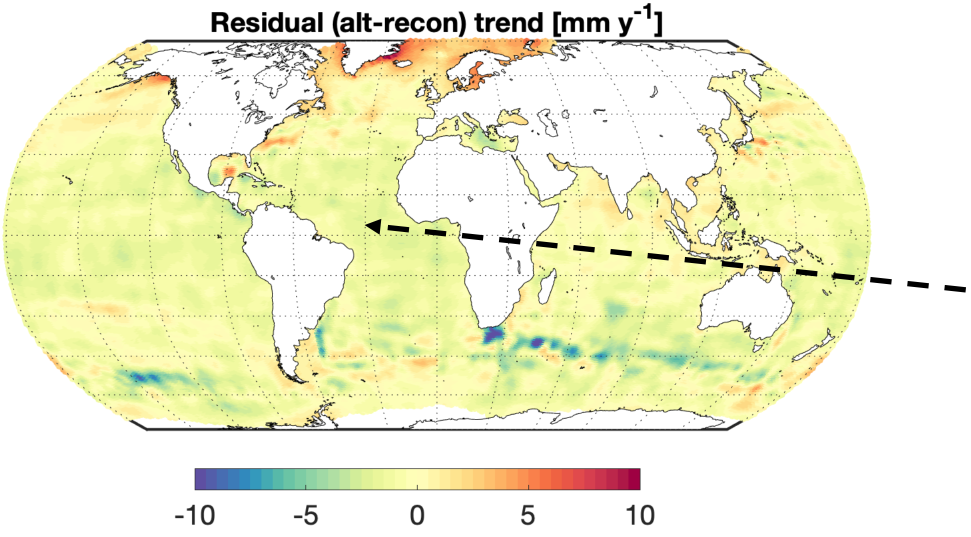


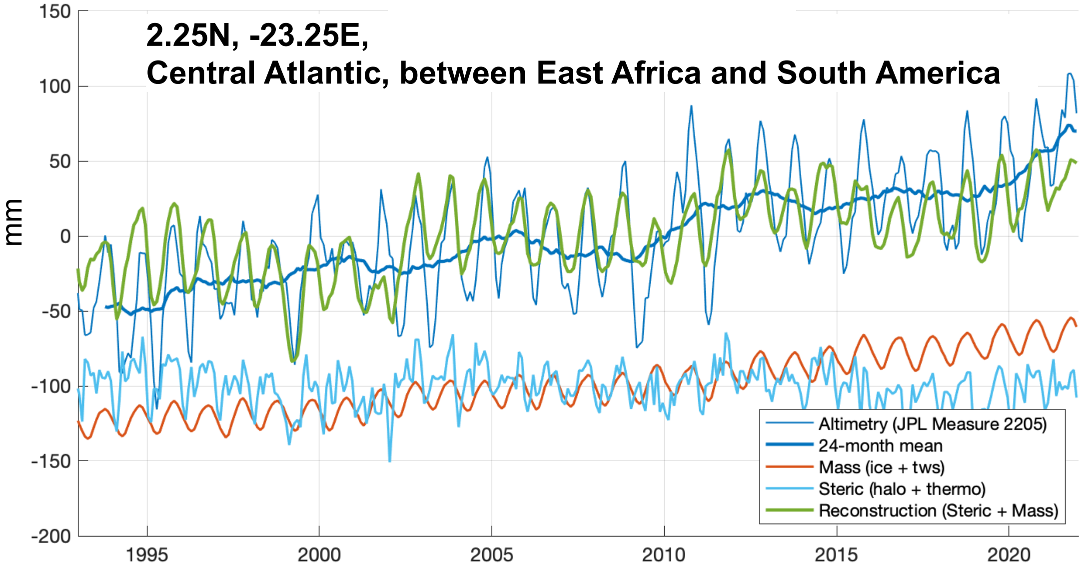
ECCO OBP (zero-global mean)

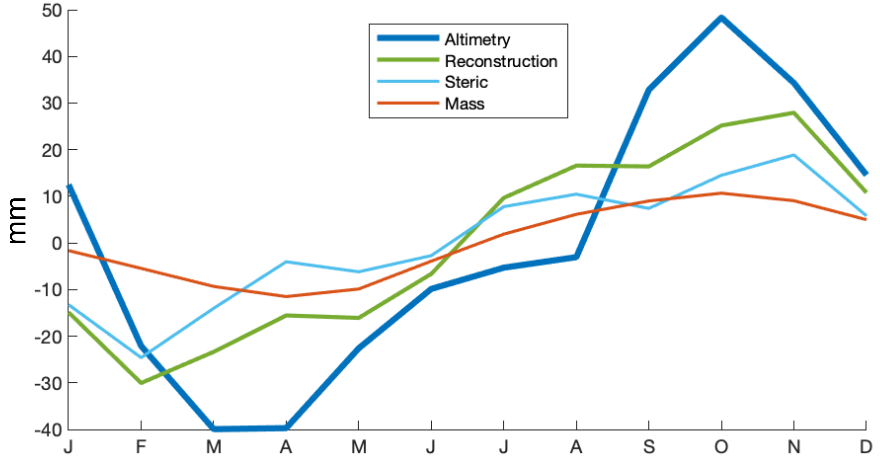
Modelled dynamic sea level change from 1992-2017



Reconstructed sea level change 1992-2021







Conclusions and outlook

- A monthly reconstruction in a 0.5-degree grid of every individual contribution to sea level change from 1992 to 2021. **Will be updated in late 2022 to have full 30 years sea level timeseries.**
- The **global-mean sea level trend and acceleration from 1993 to 2021** is reconstructed from the individual, independent contributions, however, the mass budget needs more investigation, in particular after 2015.
- Large deviations between mass-driven sea level reconstruction and GRACE after 2015.
- Dynamic OBP from ECCO-reanalysis explains some of the residual. More important in coastal zones.

Data	reference	link
Greenland	Mankoff et al, 2021	https://doi.org/10.22008/FK2/OHI23Z
Glaciers	Malles and Marzeion, 2021	https://doi.org/10.5194/tc-15-3135-2021
Antarctic	IMBIE team, 2021	https://doi.org/10.5285/77B64C55-7166-4A06-9DEF-2E400398E452
Terrestial Water Storage	Humphrey and Gudmundsson, 2019	https://doi.org/10.6084/m9.figshare.7670849
Ocean temperature and salinity (EN4.2.2)	Good et al, 2013	https://www.metoffice.gov.uk/hadobs/en4/
Altimetry (JPL MEASURE 2205)	Fournier et al, 2022	https://podaac.jpl.nasa.gov/dataset/SEA_SURFACE_HEIGHT_ALT_GRIDS_L4_2SATS_5DAY_6THDEG_V_JPL2205
GRACE (GSFC Mascons)	Loomis et al, 2019	https://earth.gsfc.nasa.gov/geo/data/grace-mascons
ECCOv4r4b	Fukumori et al, 2021	https://www.ecco-group.org/products-ECCO-V4r4.htm