

# Reconciling ocean mass change and GIA from satellite gravity and altimetry (OMCG)

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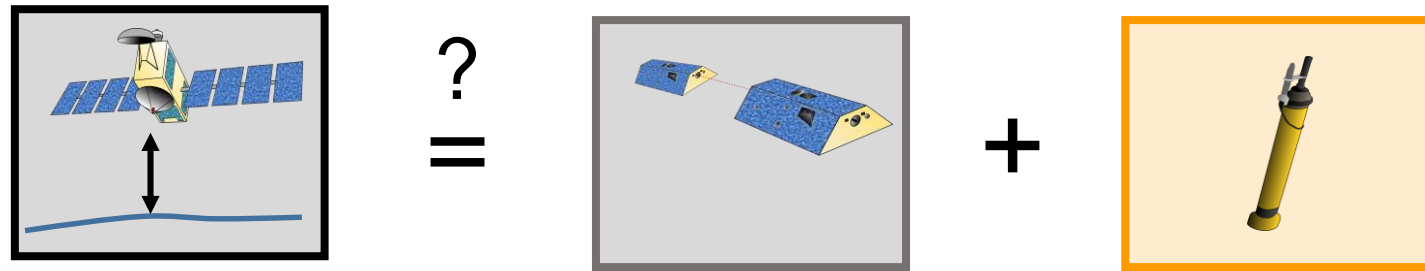
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# Motivation

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- Sea level budget: based on estimates of individual contributors, or by combining ocean mass and altimetry (ocean warming as residual).
- Mass change estimates from GRACE gravimetry have disagreed.
- This is an obstacle for (regional) sea-level budget assessments.



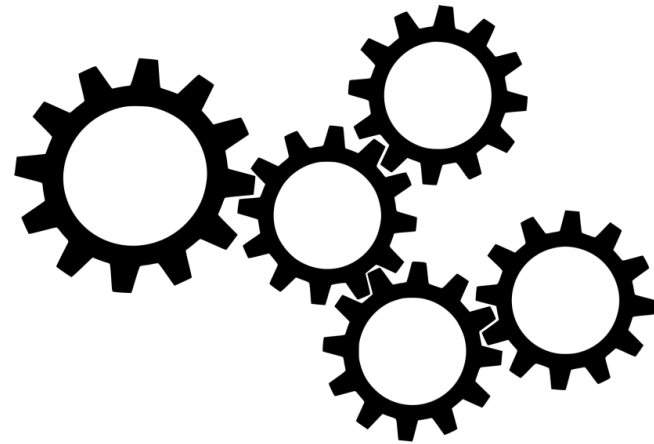
Issues addressed in this project:

- method issues in the GRACE data analysis
  - Consistency and misclosure at regional scale
  - errors in the correction for Glacial Isostatic Adjustment (GIA).
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# Reconciling **ocean mass change** and **GIA** from **satellite gravity** and **altimetry**

**satellite  
gravity**

**satellite  
altimetry**



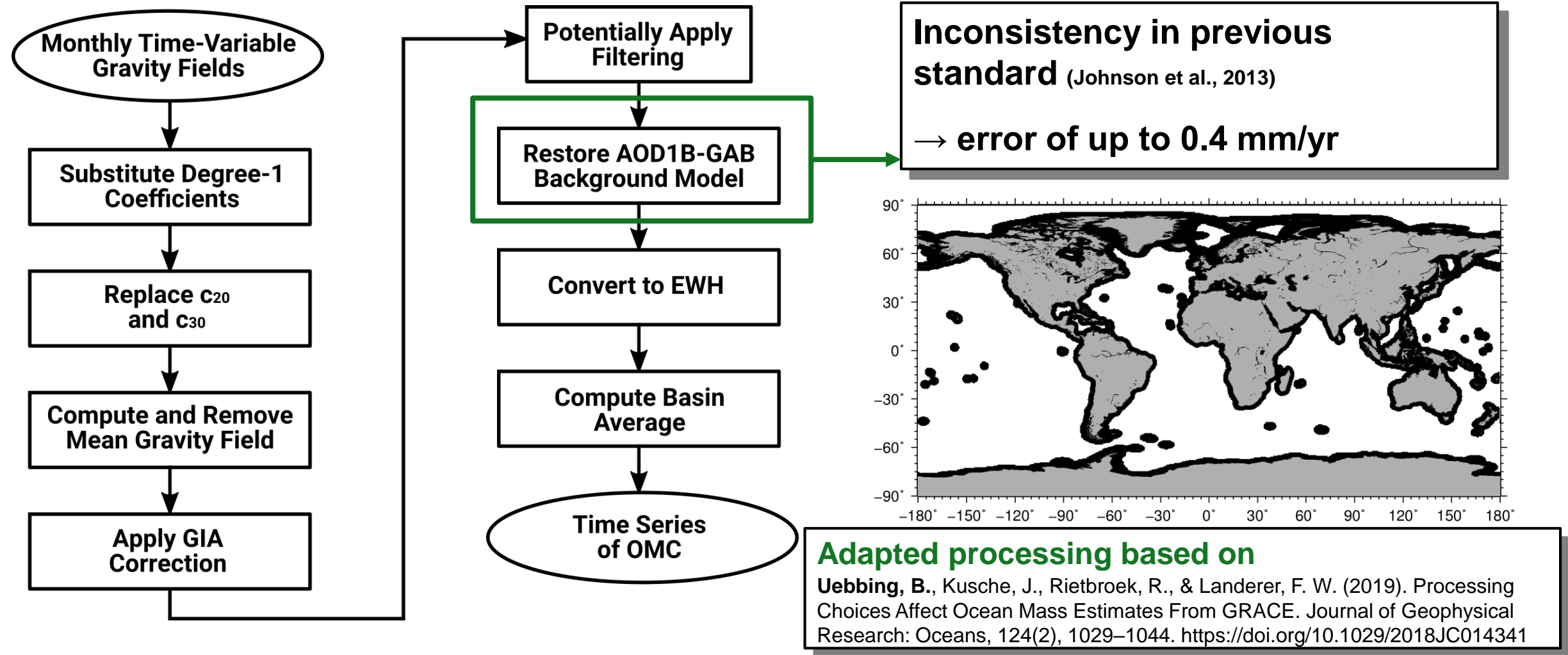
- Direct Method
- Inversion Method



**Ocean Mass  
Change (OMC)**

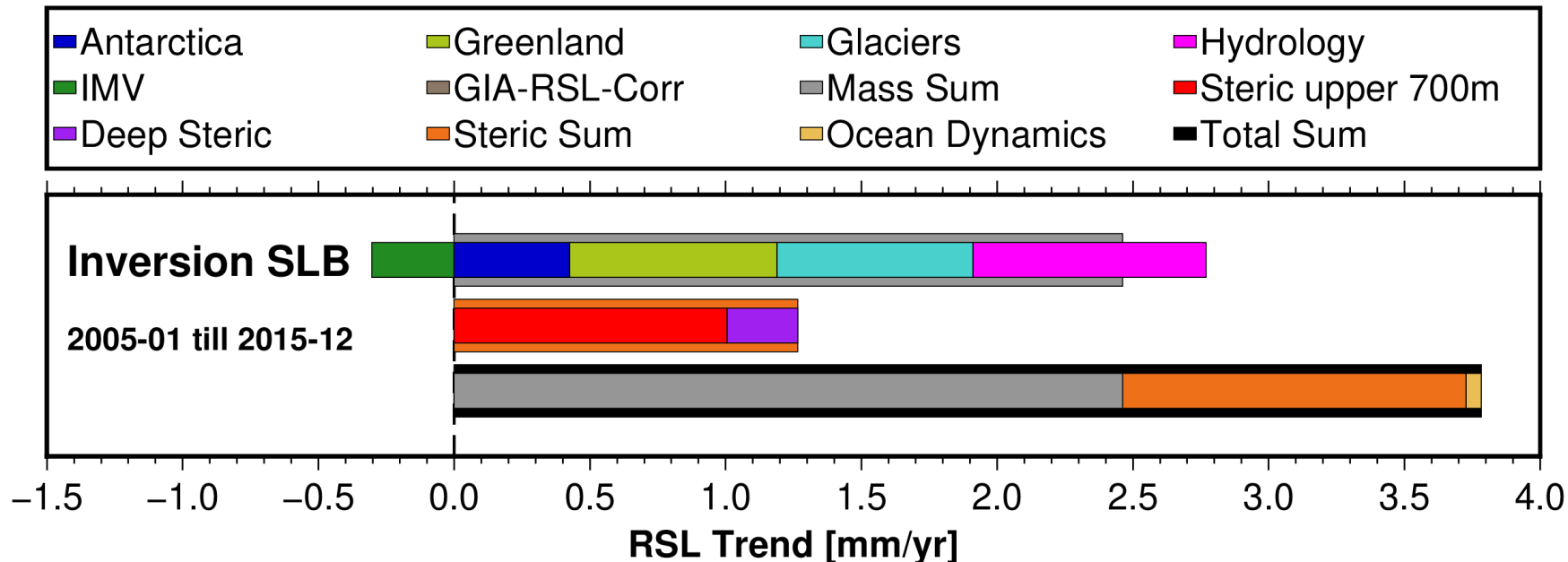
**Glacial Isostatic  
Adjustment (GIA)**

# Improved Ocean Mass Change from GRACE(-FO)



# Global Mean Sea Level Budget

- Inversion provides a consistently closed (within  $\sim 0.1$  mm/yr) SLB and additionally enables the derivation of mass and steric sub-budgets



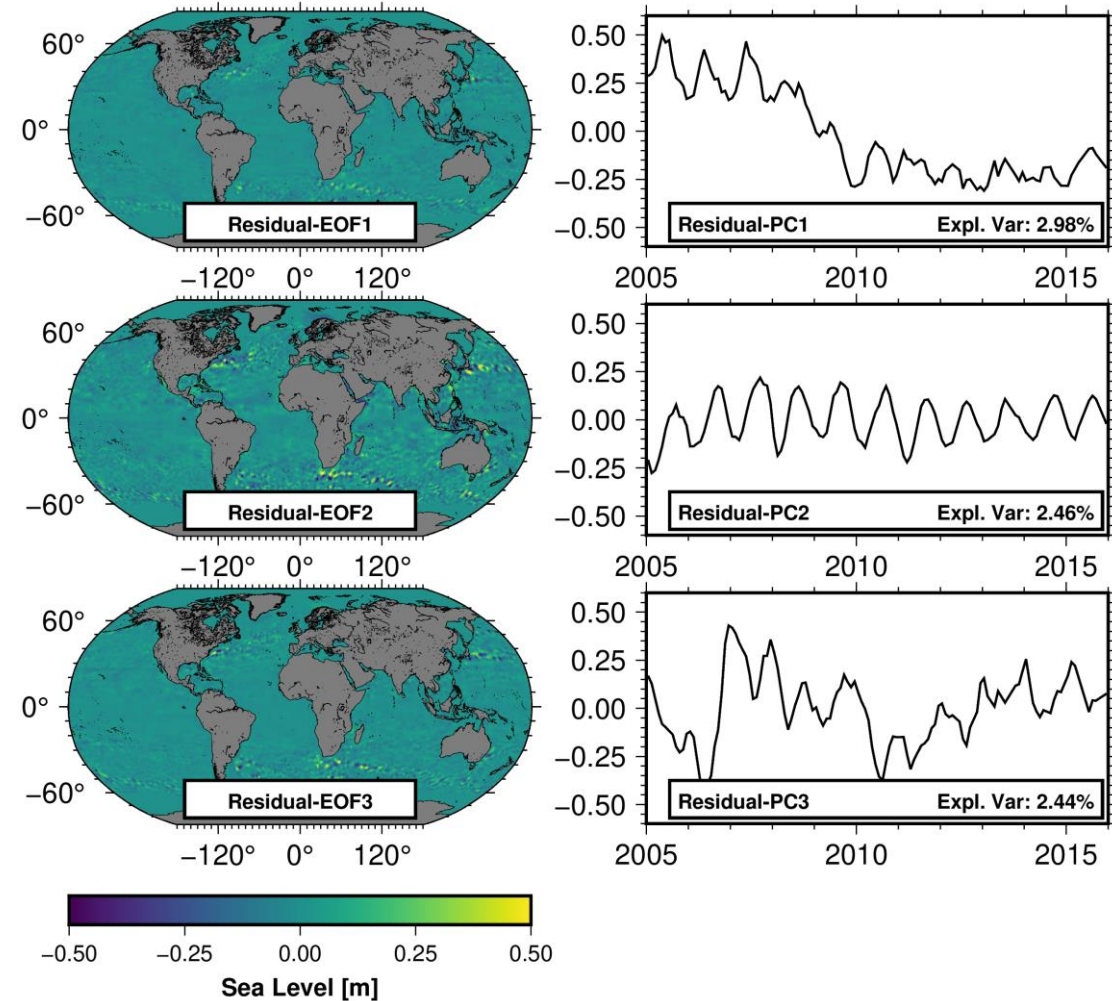
SL Component	2005-01 till 2015-12
Total	3.78
Steric	1.27
Steric (upper 700m)	1.01
Steric (below 700m)	0.26
Mass (sum)	2.46
Antarctica	0.43
Greenland	0.76
Glaciers	0.72
Hydrology	0.86
IMV	-0.30
Residual/Ocean Dynamics	0.05

# Global Mean Sea Level Budget

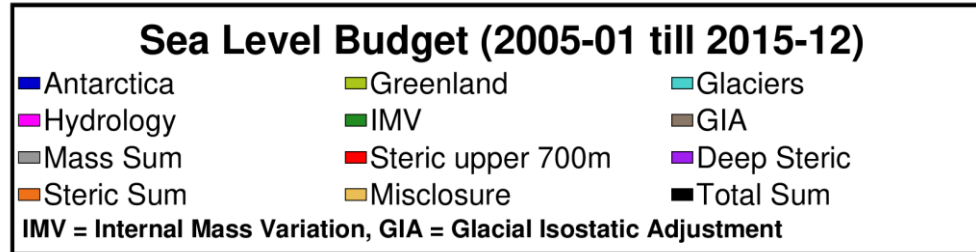
- Inversion provides a consistently closed (within  $\sim 0.1$  mm/yr) SLB and additionally enables the derivation of mass and steric sub-budgets
- No dominant residual signal left
  - Mainly (so-far) unmodeled ocean dynamics signals

PhD Thesis: Uebbing  
(2022)

Paper in prep.



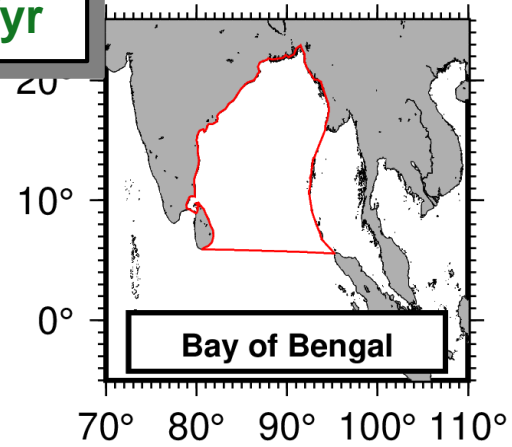
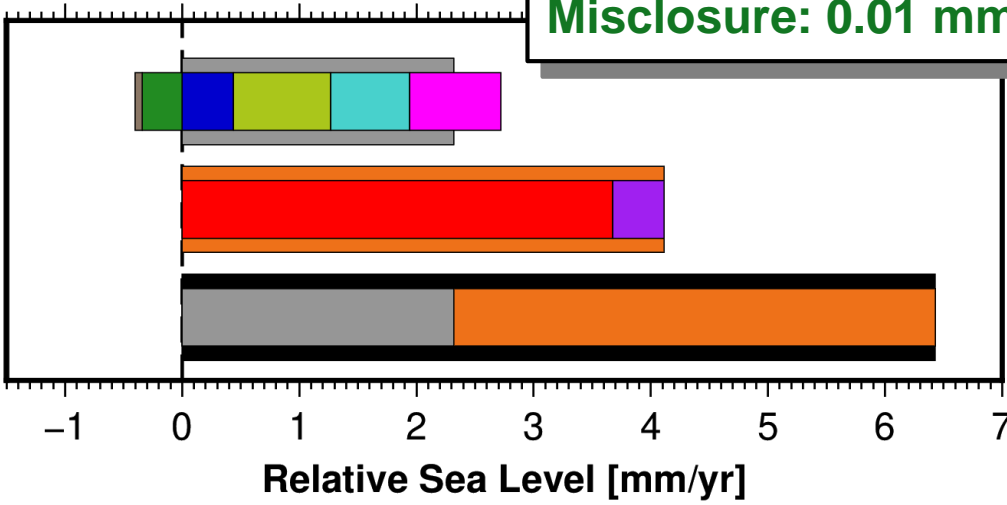
# Regional Sea Level Budget: Bay of Bengal



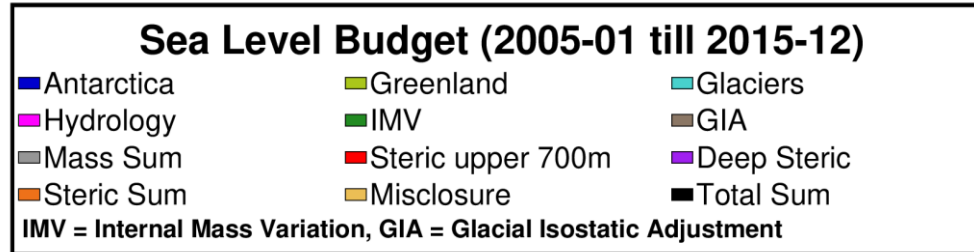
**Dominated by steric change**

**Small GIA contribution**

**Misclosure: 0.01 mm/yr**

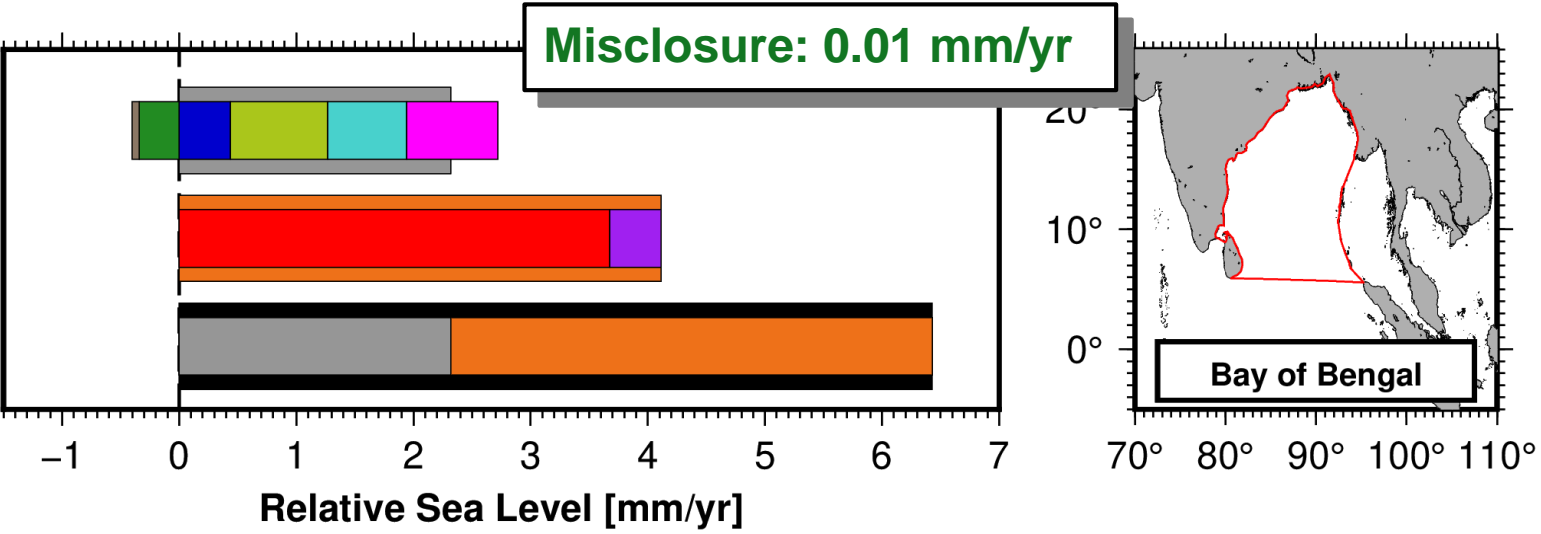


# Regional Sea Level Budget: Bay of Bengal



**Dominated by steric change**

**Small GIA contribution**



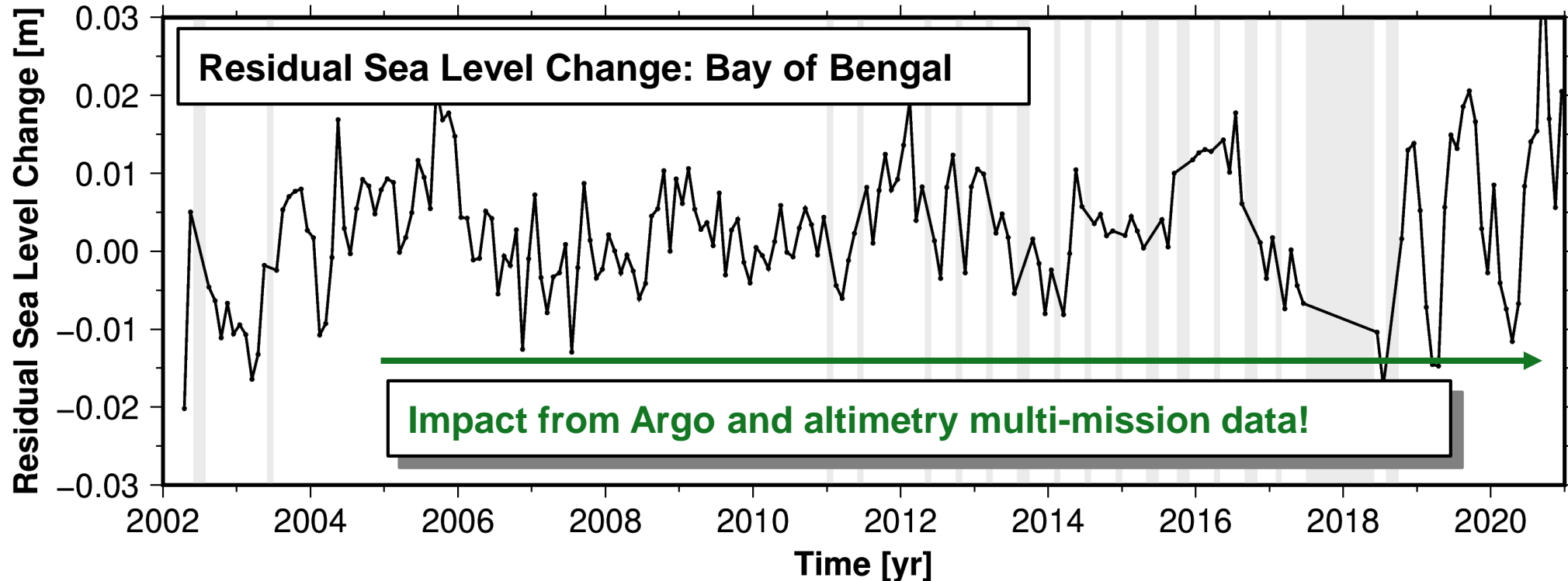
**Misclosure: 1.29 mm/yr (2002-04 till 2014-06)**  
 Kusche, J., Uebbing, B., Rietbroek, R., Shum, C. K., & Khan, Z. H. (2016). Sea level budget in the Bay of Bengal (2002–2014) from GRACE and altimetry. *Journal of Geophysical Research: Oceans*, 121(2), 1194–1217. <https://doi.org/10.1002/2015JC011471>



**Misclosure (2002-04 till 2014-06): 0.42 mm/yr**



# Regional Sea Level Budget: Bay of Bengal



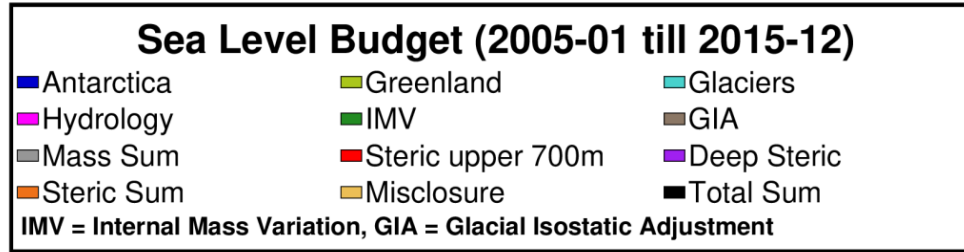
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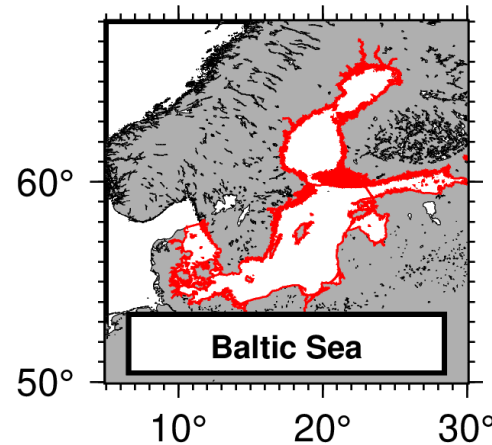
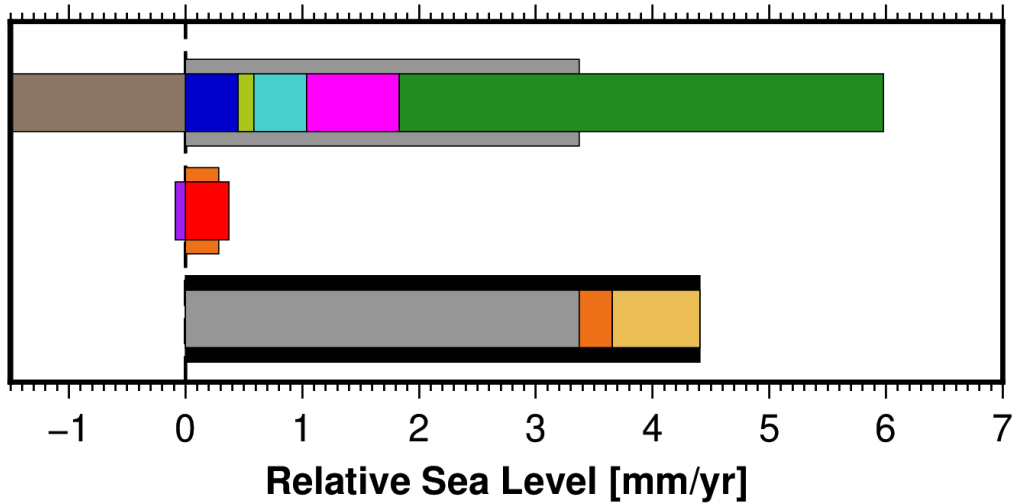
# Regional Sea Level Budget: Baltic Sea



**Dominated by mass change**

**Significant GIA contribution**

**Transport of water from the North Sea and the Atlantic**

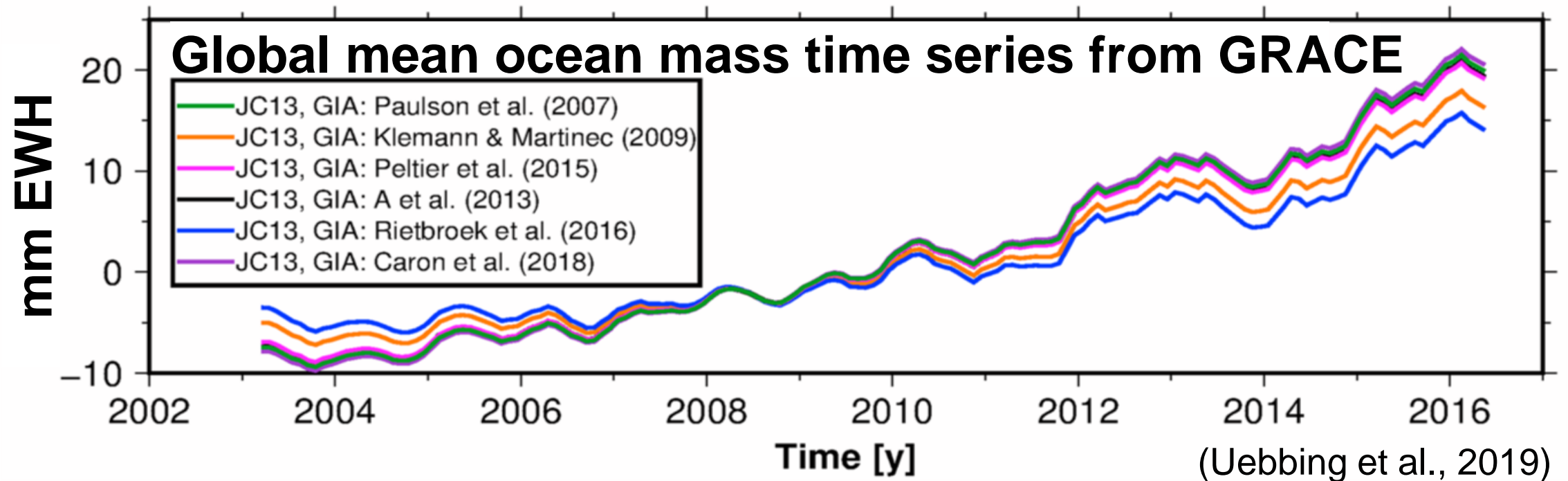


**Misclosure: 0.75 mm/yr**

**Unmodeled local effects and GIA model errors affect misclosure**

# Resolving Glacial Isostatic Adjustment (GIA)

- the **major difference** of up to  $\sim 0.7$  mm/yr between **ocean mass change** estimates is due to correction for **glacial isostatic adjustment (GIA)**

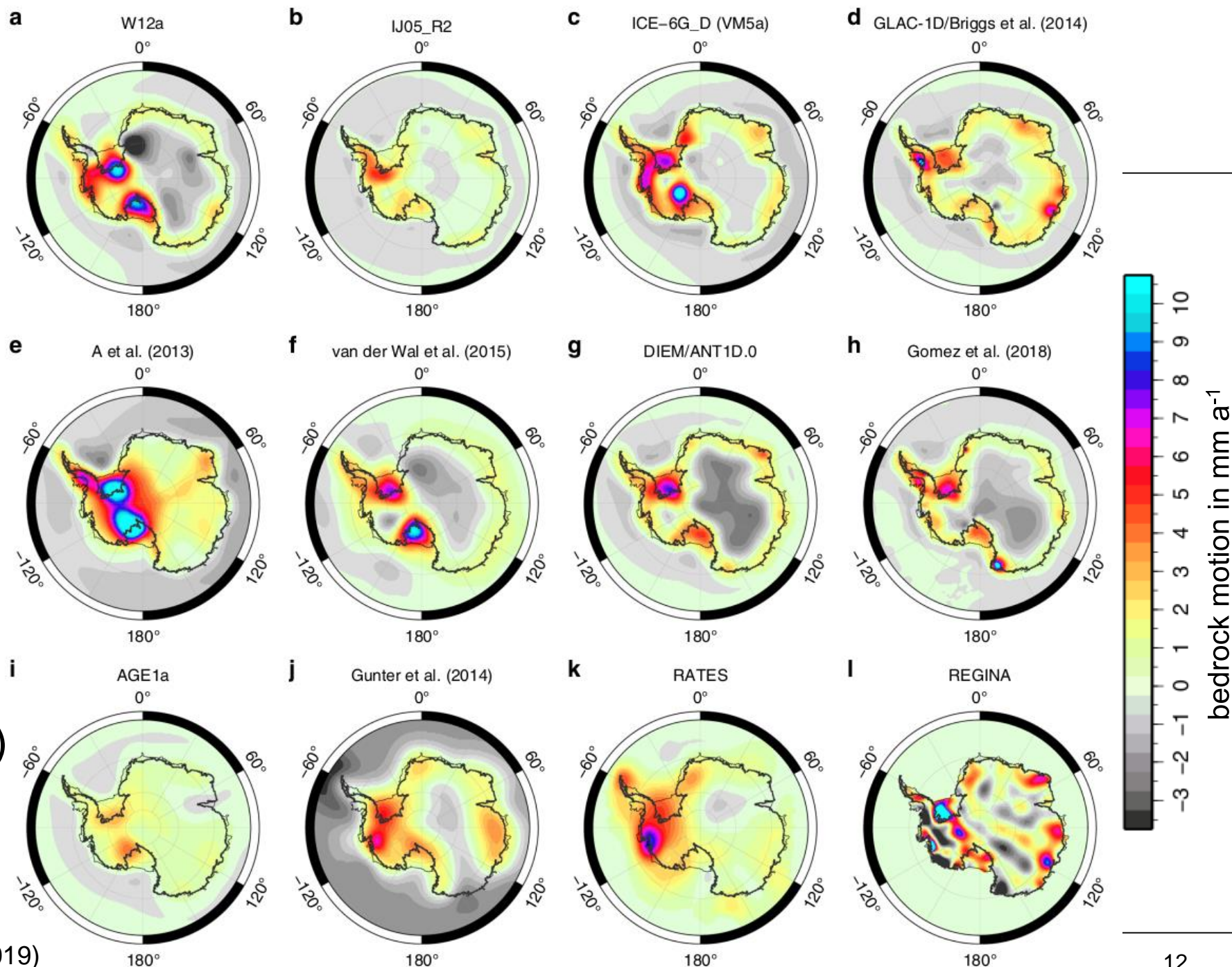


# GIA in Antarctica

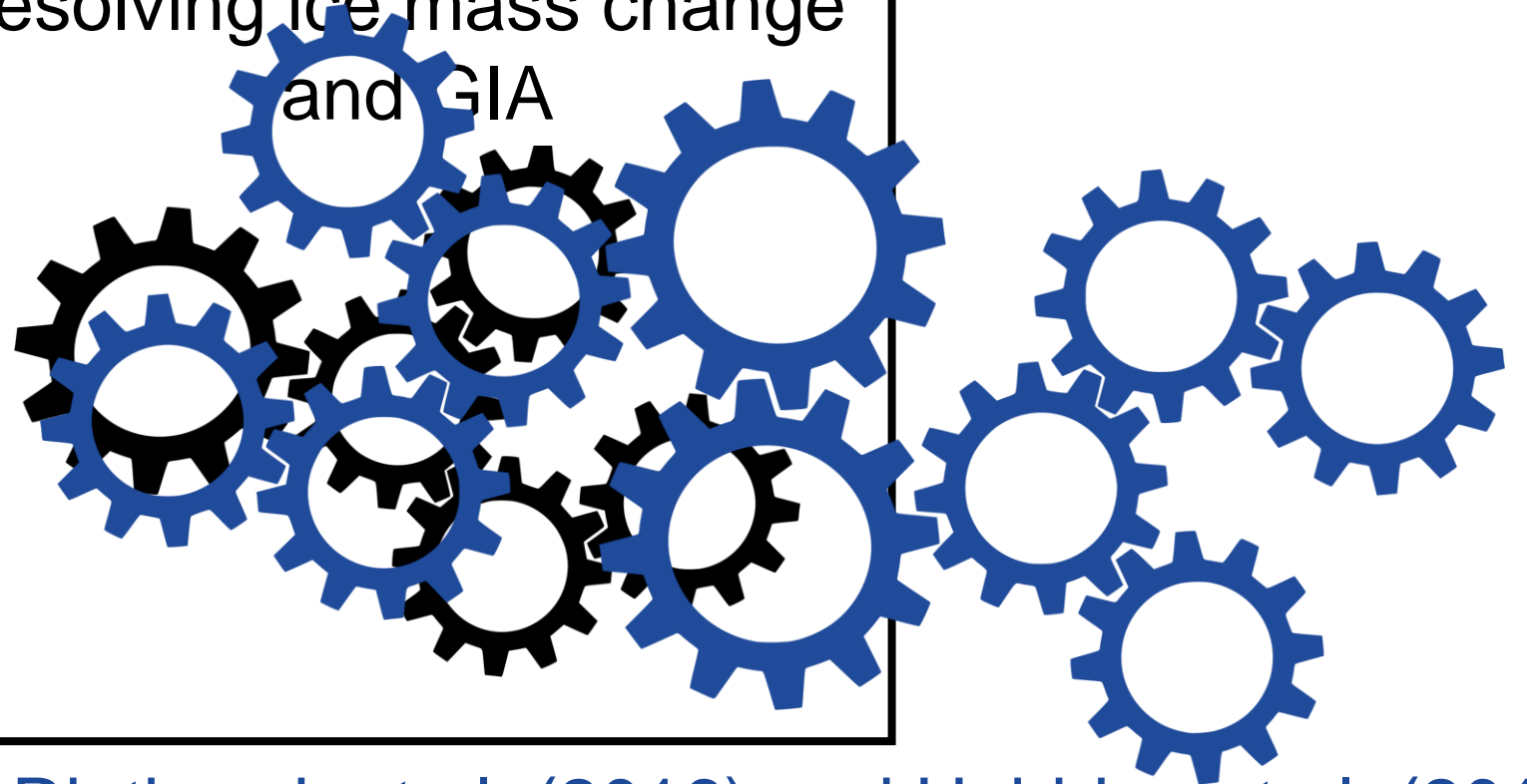
GIA mass effect:  
spread between  
**+3 and +81 Gt a<sup>-1</sup>**

Antarctic ice mass  
balance (2003-2010):  
**-105 ± 51 Gt a<sup>-1</sup>**

(The IMBIE team, 2018)



global inversion for all  
sea level contributions  
framework (Uni Bonn)  
resolving ice mass change  
and GIA



cf. Rietbroek et al. (2016) and Uebbing et al. (2019)



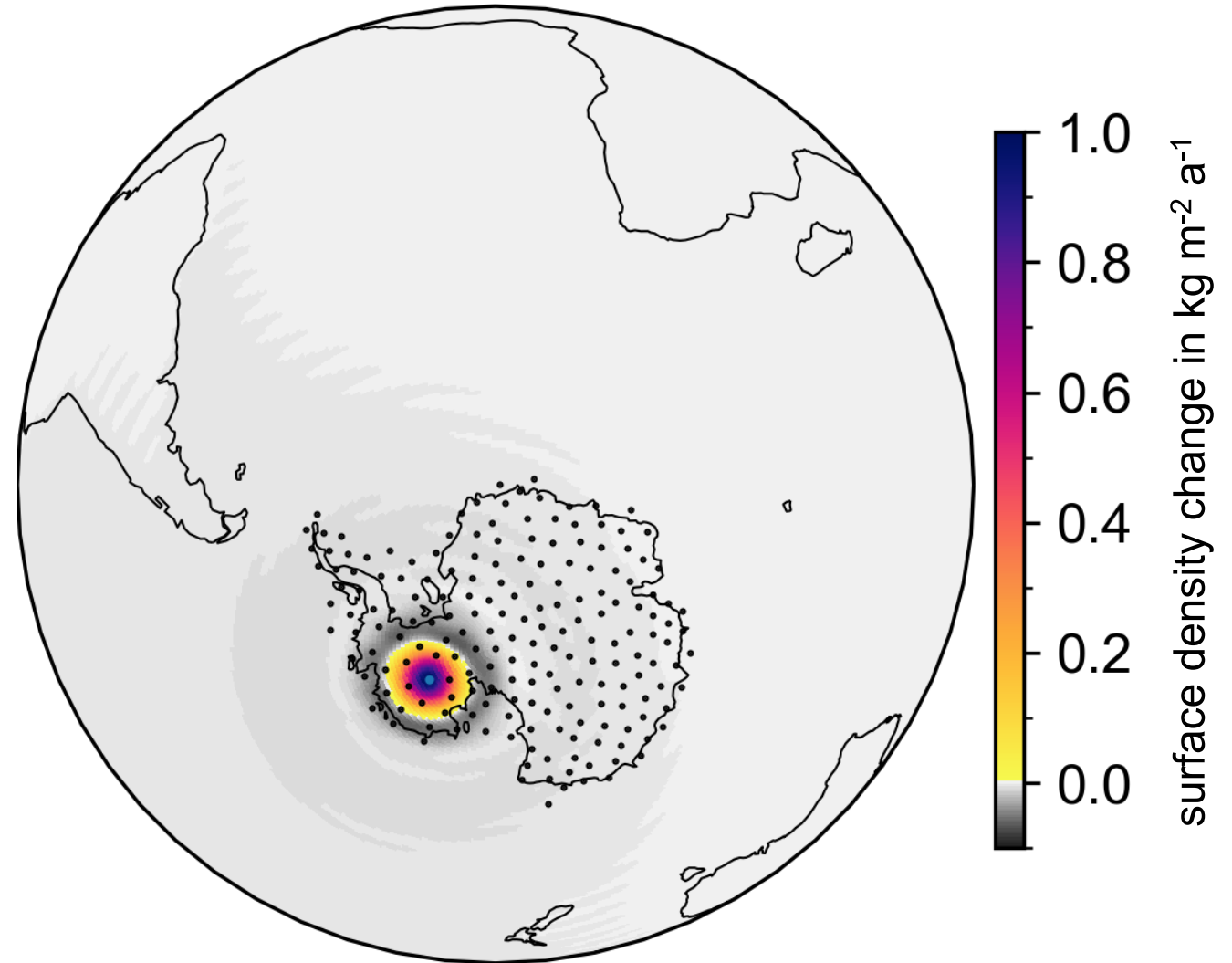
# GIA Parametrization

In Antarctica:

- allow to spatially resolve GIA without predefined patterns
- globally defined GIA patterns from local deglaciation impulses

Outside Antarctica

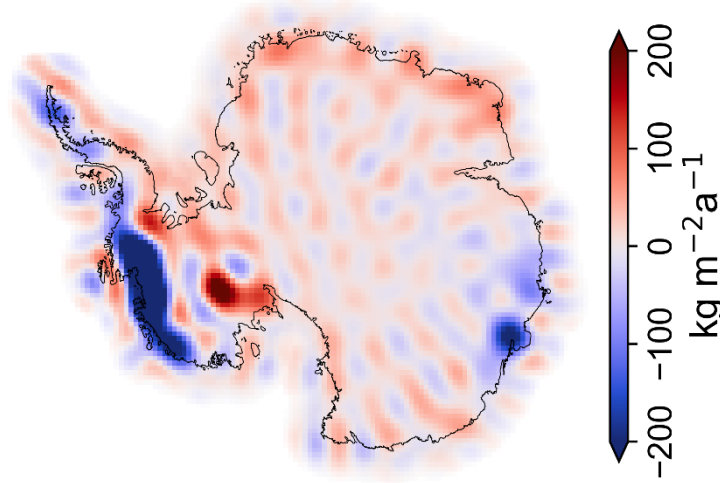
- 4 global fingerprints from regional ice histories (Greenland, Laurentia, Fennoscandia, and other)



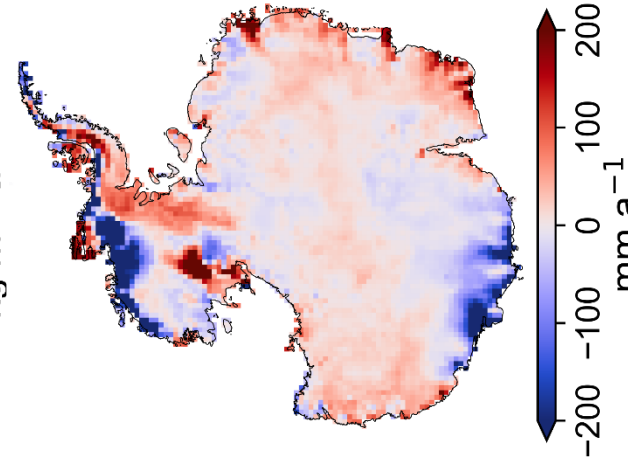
# Joint global inversion for Antarctic Ice Mass Change and GIA

## Input Data:

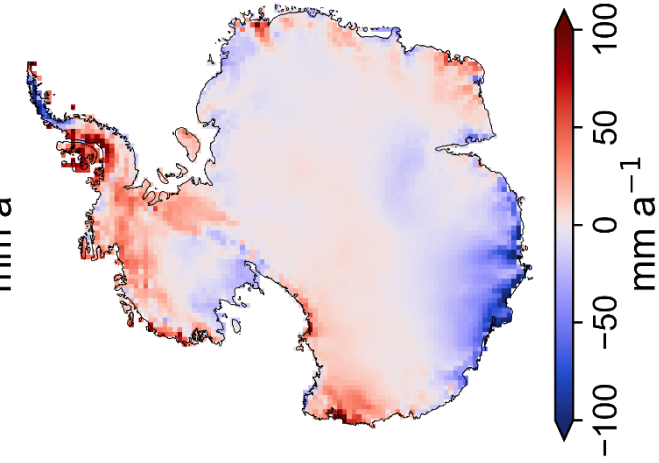
GRACE/GRACE-FO



CryoSat-2 Altimetry

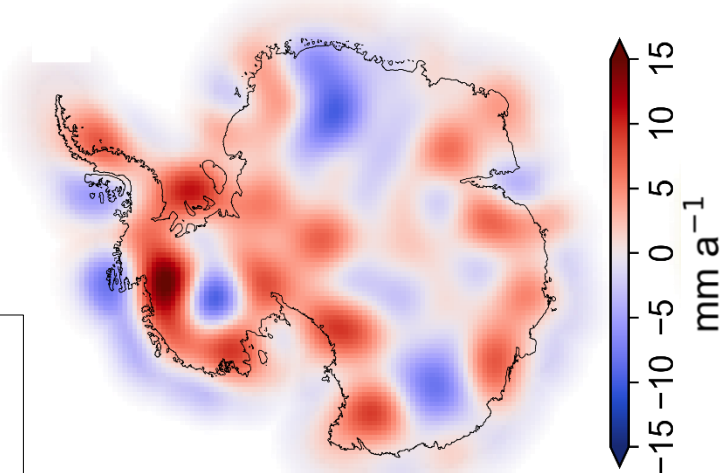


modelled Firn Air Content



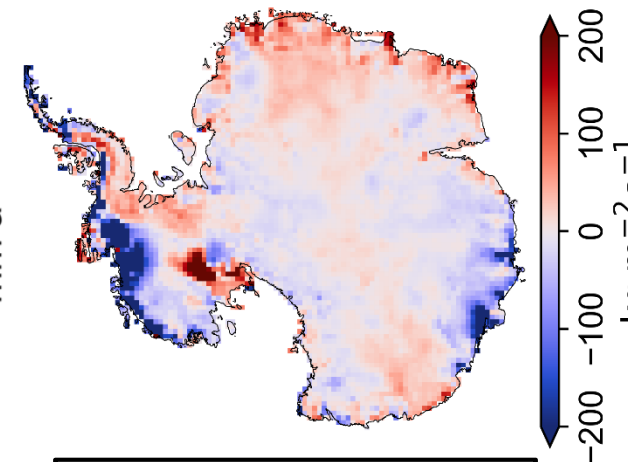
## Estimates:

GIA Effect



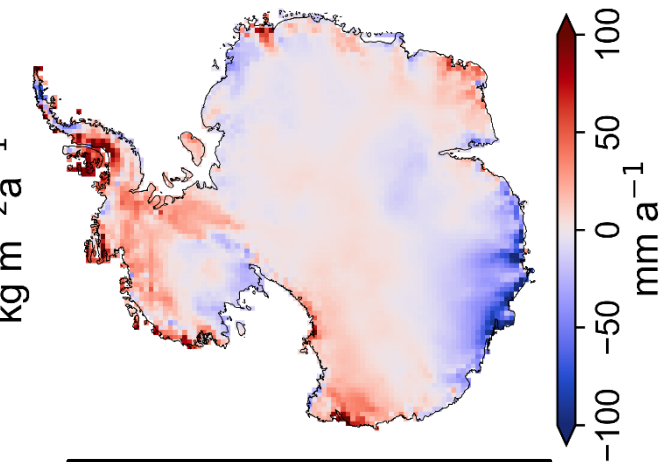
**$+86 \pm 21 \text{ Gt a}^{-1}$**

Ice Mass Change



**$-144 \pm 27 \text{ Gt a}^{-1}$**

estimated Firn Air Content



**$+13 \pm 18 \text{ km}^3\text{a}^{-1}$**

- Willen et al. (2020)
- Willen et al. (2021)
- Willen et al. (2022)
- Willen et al., in prep.)

# Conclusions

- Previous difference between methods of GRACE analysis traced back to methodological inconsistencies
- Global inversion provides a consistently closed (globally within  $\sim 0.1$  mm/yr) sea-level budget and enables the derivation of mass and steric sub-budgets at regional scale
- Using additional data over ice sheets allows to co-estimate GIA without relying on GIA models. This promises more accurate ocean-mass change and ice-mass change estimates within the global inversion.

