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# Global Sea-Level Budget and Ocean Mass Budget Assessment

## Initial results from ESA's CCI Sea Level Budget Closure (SLBC) project

### Summary

Studies of the sea-level (SL) budget are a means of assessing and understanding how sea level is changing and what are the causes.

**Closure of the total sea-level budget** implies that the observed changes of global mean sea level equal the sum of observed (or otherwise assessed) contributions, namely changes in **ocean mass** and **ocean thermal expansion**.

**Closure of the ocean mass budget** implies that the observed ocean mass change (OMC) equals assessed changes in mass from glaciers, ice sheets, land water storage, snow pack and atmospheric water content.

**Misclosure** of these balances indicates errors in some of the components or contributions from missing or unassessed elements in the budget.

### SLBC\_cci

ESA's Climate Change Initiative (CCI) has conducted a number of projects related to sea level, namely the Sea Level CCI project, the Greenland and Antarctic Ice Sheet CCI projects, the Glaciers CCI project and the Sea Surface Temperature CCI project.

The aim of the **CCI Sea Level Budget Closure project**, launched in April 2017, is to use the CCI data products, together with further data products provided by the project partners to re-assess the sea-level budget and ocean mass budget.

Specifically, the project further develops and analyzes products based on the CCI projects mentioned above in conjunction with data products from ocean profilers (e.g., Argo), GRACE-based ocean mass change assessments, and model-based data for glaciers and land hydrology. The work benefits from directly involving the expertise on the product generation for all the involved sea-level contributions.

### Initial Results

Here, we report on the initial assessment of global sea-level budget and global ocean mass budget closure. This initial assessment uses data products that were available by the beginning of the project.

In this presentation, we focus on the 2003–2015 (GRACE / ARGO) period. We consider the budget of the long-term trends as well as the budget of the overlaid interannual variations.

A special focus is on the account for uncertainties of the individual contributions, building on the expertise of all project partners. We find that **the budget is closed within uncertainties**. Systematic uncertainties in the ocean mass change estimates appear to dominate the uncertainty budget.

### Global Ocean Mass Budget

$$\Delta M_{\text{ocean}} = -\Delta M_{\text{glaciers}} - \Delta M_{\text{ice sheets}} - \Delta M_{\text{landwater}}$$

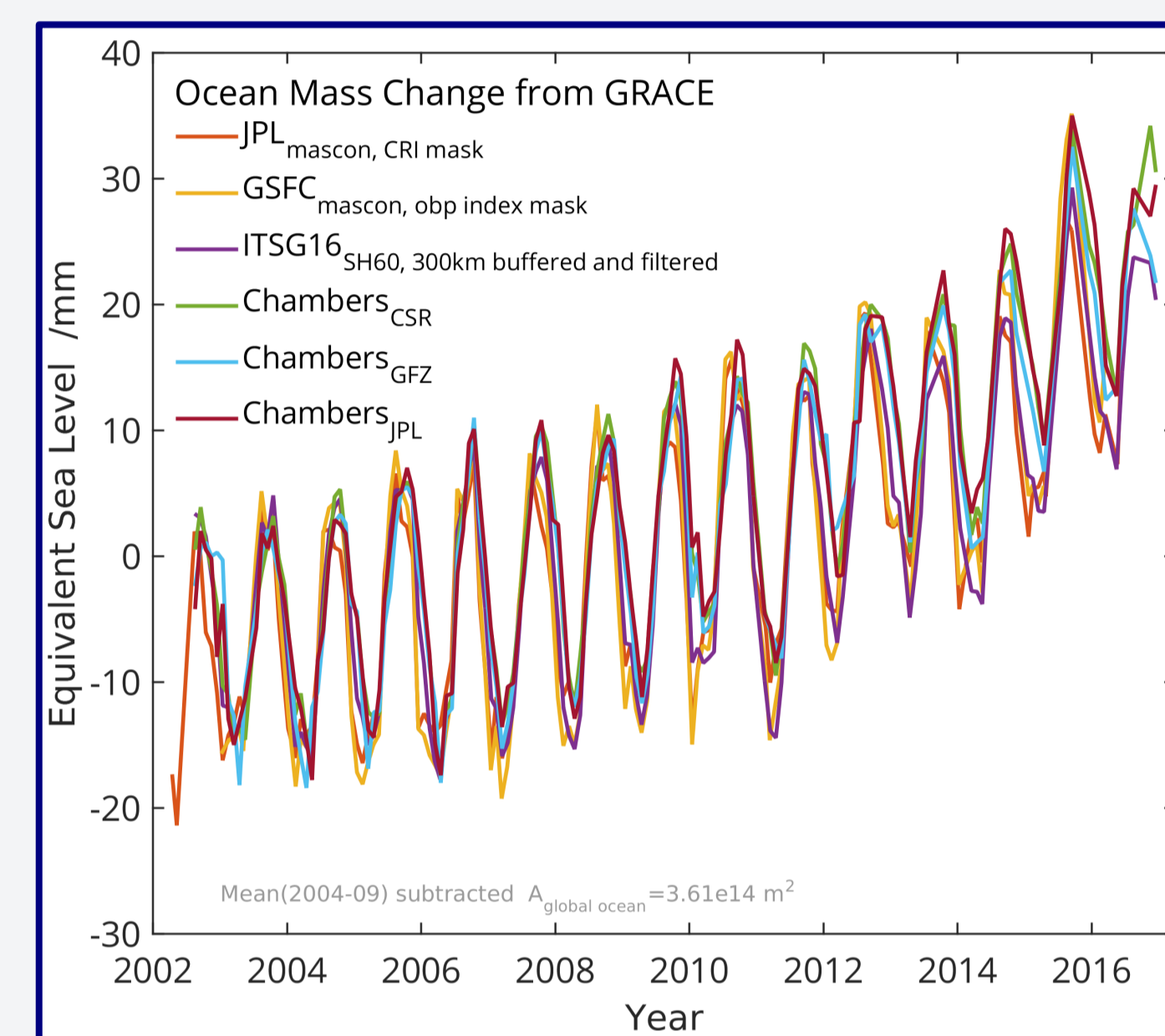


Fig. 1: Global ocean mass change from several GRACE solutions. Here, the seasonal signal is still included.

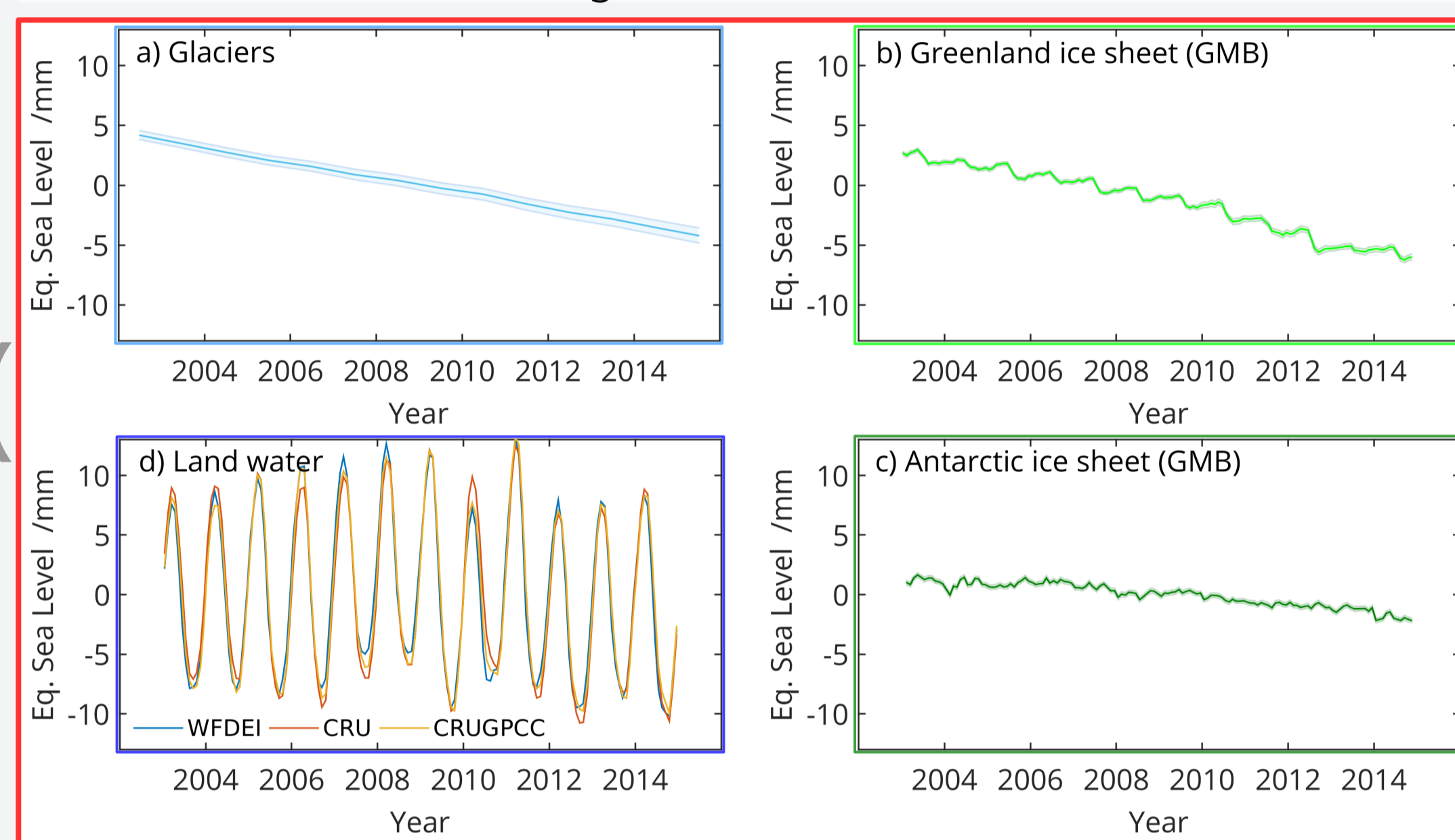


Fig. 2: Individually assessed contributions of components. Note the strong seasonal signal of the land water component. In this figure, mass loss means gain for the ocean.

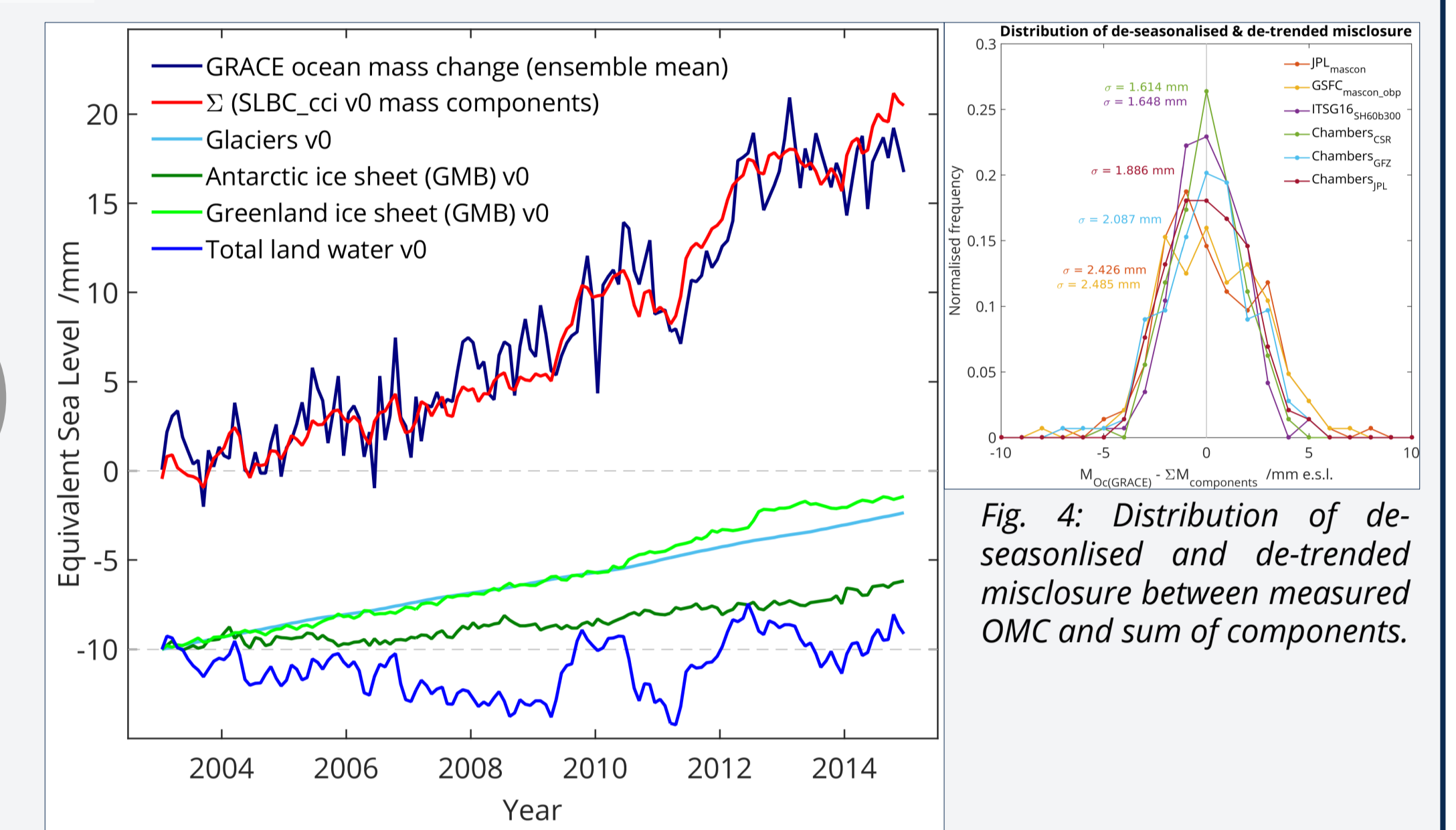


Fig. 3: Global OMC from GRACE (ensemble mean, dark blue, upper panel) and the sum of the individual components (red). For this figure, the seasonal signal has been removed.

### Global Sea-Level Budget

$$\Delta SL_{\text{observed}} = \Delta SL_{\text{ocean mass}} + \Delta SL_{\text{steric}}$$

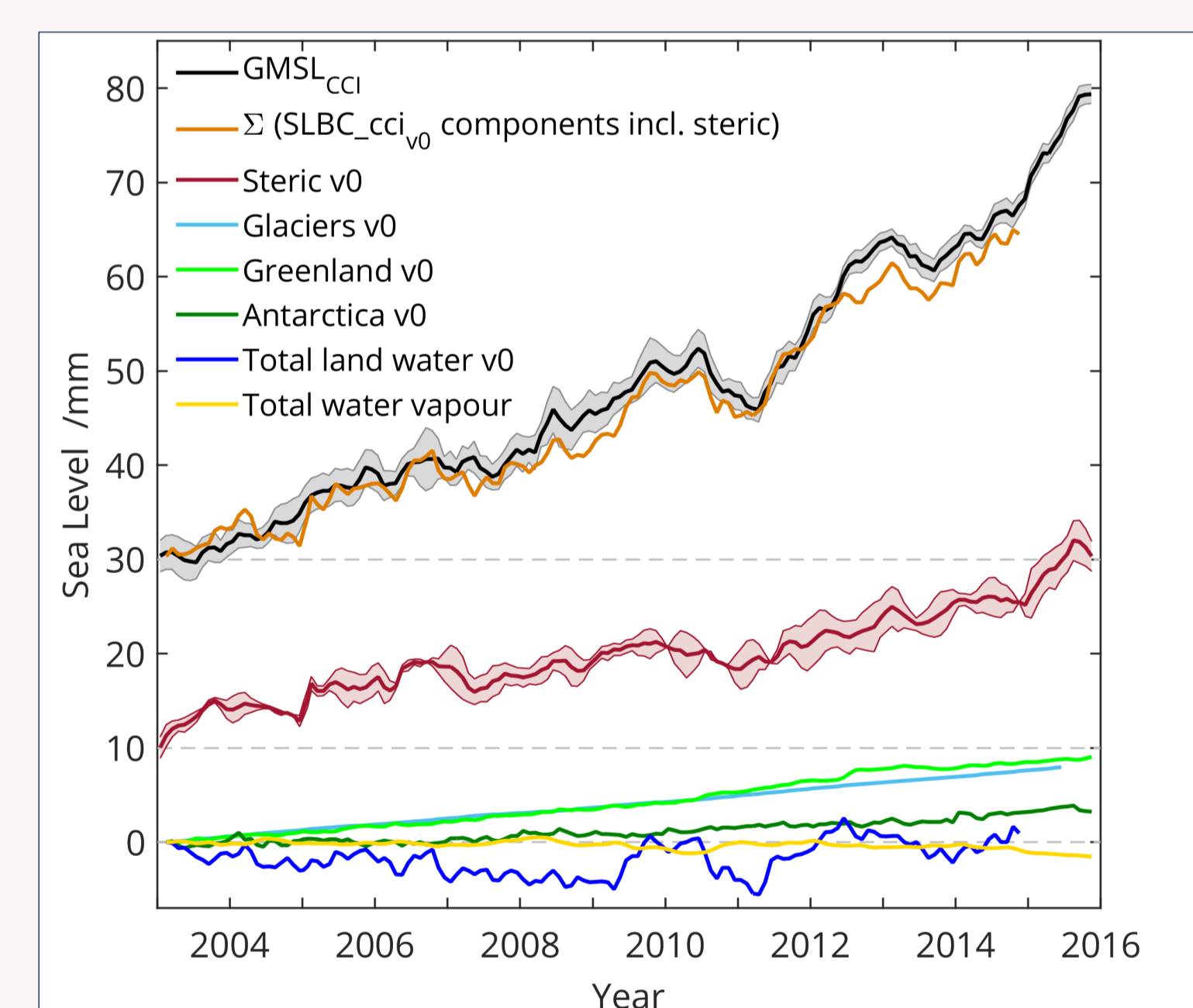


Fig. 5: The contributing mass components (lower set of curves) together with the steric expansion (dark red) add up to the orange curve. This is compared with observed sea-level change (black).

Table 1: Trends 2003–14/15 of components that contribute to the sea-level budget; with standard uncertainties.

SLBC_cci_v0 components	2003–2014 Trend mm/yr	2003–2015 Trend mm/yr
Glaciers	0.63 ± 0.04	0.63 ± 0.04
Greenland	0.77 ± 0.03	0.76 ± 0.03
Antarctica	0.27 ± 0.10	0.29 ± 0.10
Total Water Storage	0.17	0.17 (until 2014)
Water Vapour	-0.045	-0.07
<b>Σ components</b>	<b>1.80 ± 0.11</b>	<b>1.78 ± 0.11</b>
Steric	0.96 ± 0.09	1.14 ± 0.09
<b>Σ compon. incl. steric</b>	<b>2.75 ± 0.14</b>	<b>2.92 ± 0.14</b>

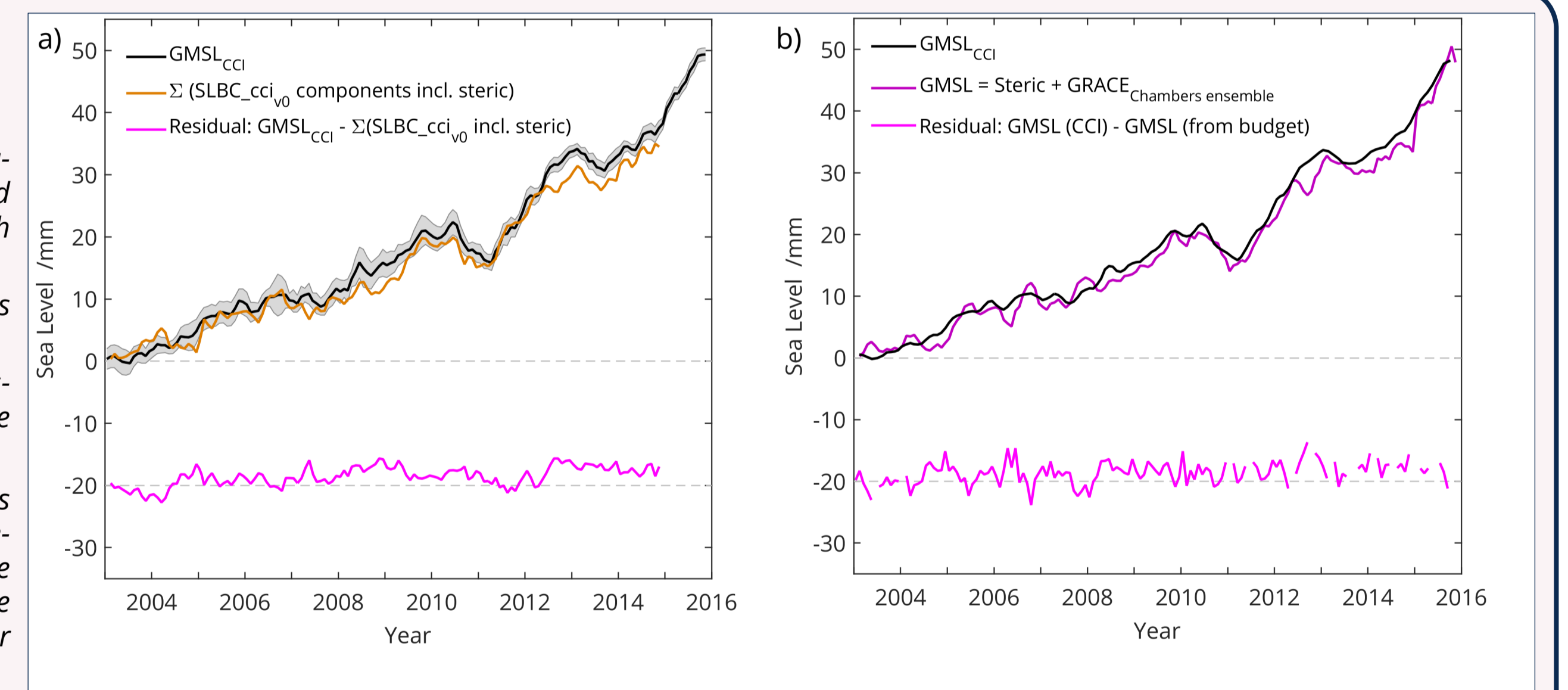
Table 2: GMSL trend budget 2003–14/15; with standard uncertainties. Cf. Figure 6a.

SLBC_cci_v0 GMSL budget closure	2003–2014 Trend mm/yr	2003–2015 Trend mm/yr
Observed GMSL	2.99 ± 0.40	3.36 ± 0.40
<b>Σ compon. incl. steric</b>	<b>2.75 ± 0.14</b>	<b>2.92 ± 0.14</b>
<b>Residual</b>	<b>0.24 ± 0.42</b>	<b>0.44 ± 0.42</b>

Fig. 6: Global mean sea-level budget of observed GMSL (black curves) with respect to:

- sum of components (orange) and
- the observed mass- and steric change (purple).

Residuals are plotted as pink curves below, respectively. In (b) only the Chambers ensemble mean is displayed for reasons of clarity.



Ocean mass change component from GRACE solutions		2003–2015 Trend mm/yr	2003–2015 Trend Residual: GMSL(observed) - GMSL(steric+GRACE) mm/yr		
SLBC_cci (initial, v0.3)	JPL mascon	1.70	SLBC_cci (initial, v0.3)	JPL mascon	0.50
	GSFC mascon	1.84		GSFC mascon	0.39
	ITSG16 SH60 300 km b&f*	1.51 ± 0.35 +?		ITSG16 SH60 (300 km buffered & filtered*)	0.67 ± 0.54 +?
Chambers	CSR Spherical Harmonics	2.05	Chambers	Ensemble mean	0.15
	JPL Spherical Harmonics	1.95			
	GFZ Spherical Harmonics	2.10			
	Ensemble Mean	2.03			

Tables 3 & 4: Global OMC trends from different GRACE solutions (left) and their misclosure with the observed GMSL (right). Cf. Figure 6b.

### References

- A collection of survey papers is freely available in the Surveys of Geophysics 2017, 38(1), special issue "ISSI Workshop on Integrative Study of the Mean Sea Level and its Components".
- Chambers, D.P., Cazenave, A., Champollion D., Dieng, H., Llovel, W., Forsberg, R. von Schuckmann, K., Wada, Y. (2017): Evaluation of the Global Mean Sea Level Budget between 1993 and 2014. *Surv. Geophys.* (2017) 38:309–327, DOI 10.1007/s10712-016-9381-3
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