Observation-based reconciliation of the Earth's Energy Imbalance budget constraint

A. Minière[1], K. von Schuckmann[1], J.-B. Sallée[2], M. Monier[1], P.-Y. Le Traon[1]

[1] Mercator Ocean International, Toulouse, France
[2] LOCEAN, Paris, France

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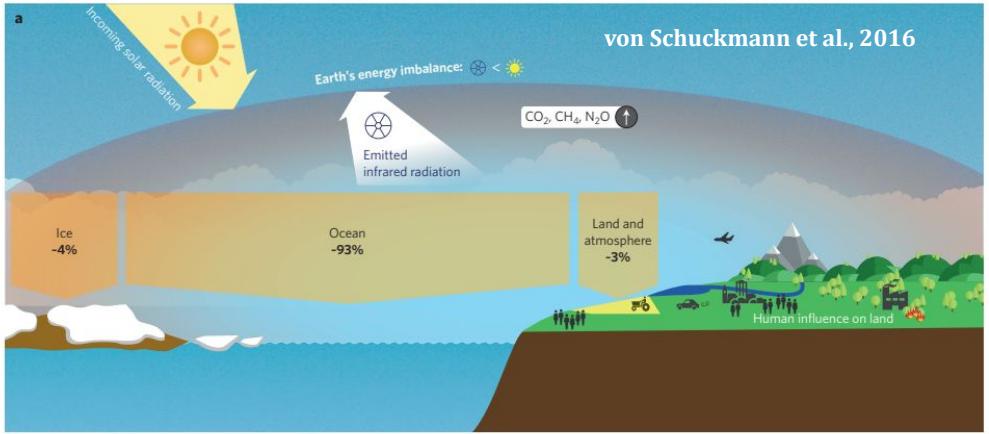
The EEI and the EEI constraint approach



- **Earth energy imbalance (EEI) = key variable of Climate Change**
- **EEI ~ 0.5-1 W/m^2**
- **Small values but huge implications !**

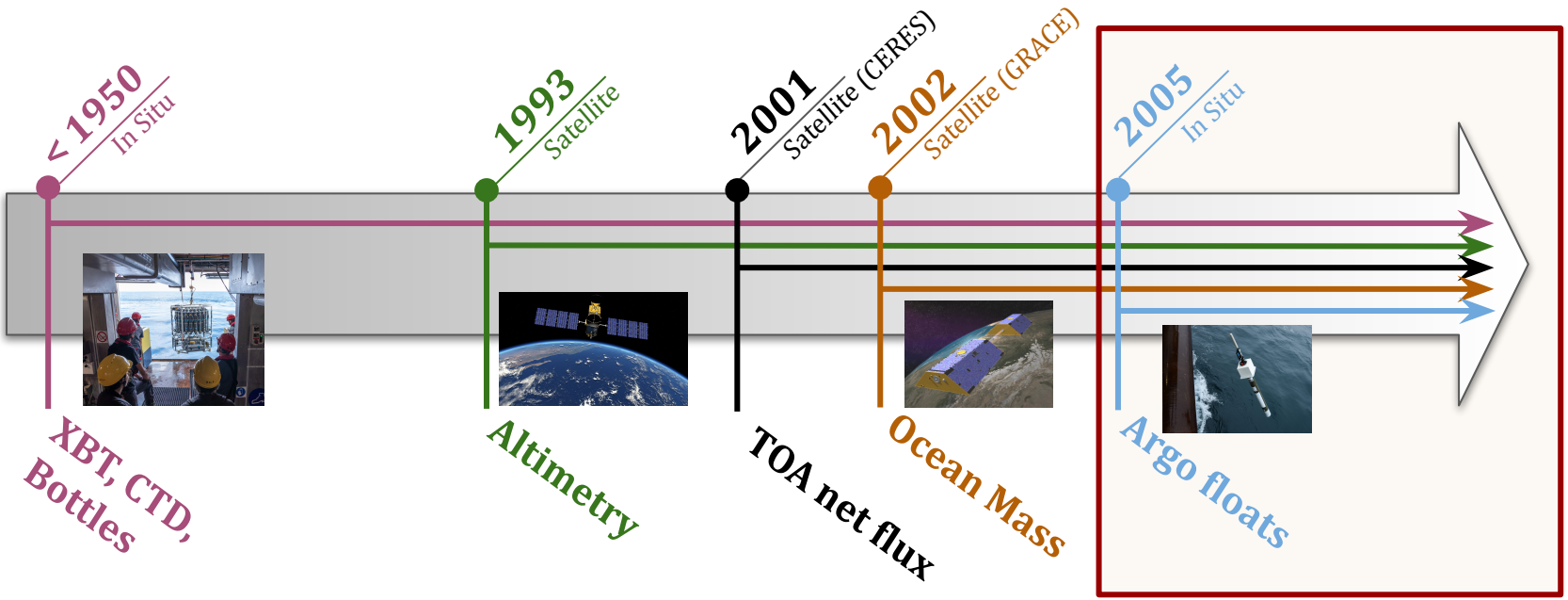
The EEI budget constraint

> 90% excess heat stored in the ocean ➔ Net radiative flux at top-of-atmosphere (**TOA**) and Global Ocean Heat Content (**GOHC**) changes are in phase at time scales ≥ 1 year

Loeb 2012, 2021 ; Palmer and Mc Neal, 2014 ; von Schuckmann et al., 2016

How do we estimate EEI?

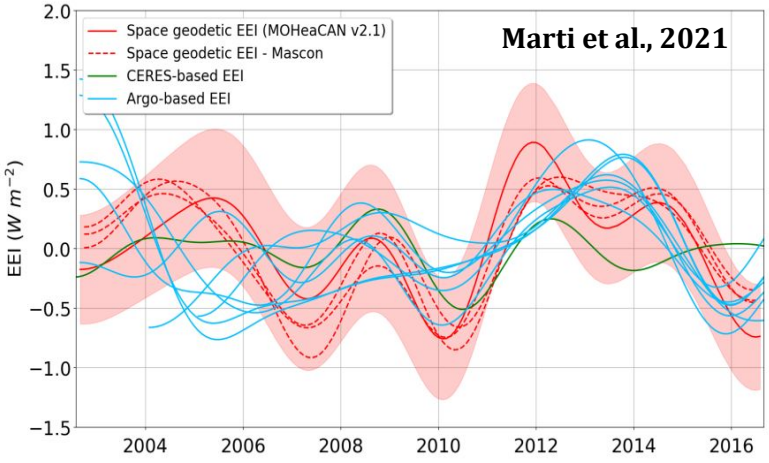
- **The Global Climate Observing System (GCOS)**

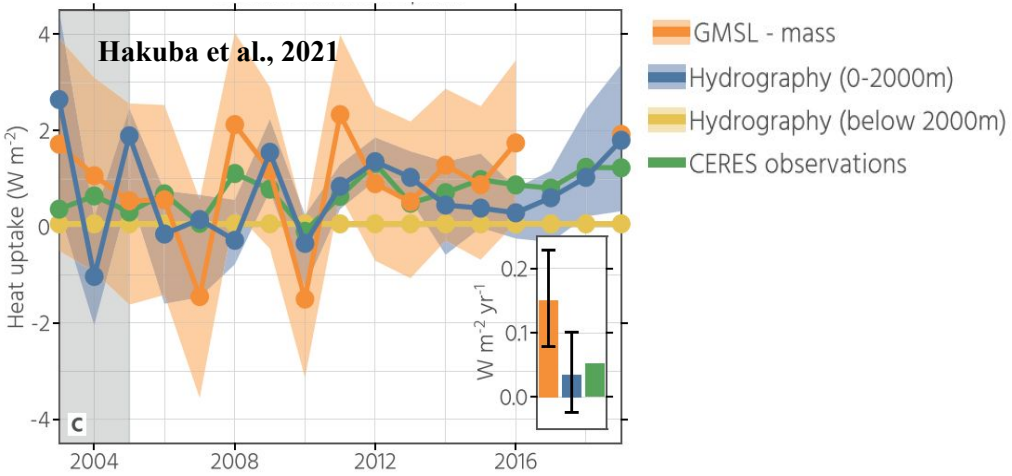


From 2005-onwards, all GCOS components are available for establishing the global EEI constraint, allowing for an in-depth evaluation of the state and change of the EEI over the past 16 years.

What we know today: current use of the EEI constraint

- EEI constraint approach in recent literature





➔ How to assure a consistent comparison between EEI estimates from different products and GCOS components ?
What are the advantages of this constraint approach?

Implementing the EEI constraint approach

- **Product use: aspects to consider and recommendations**

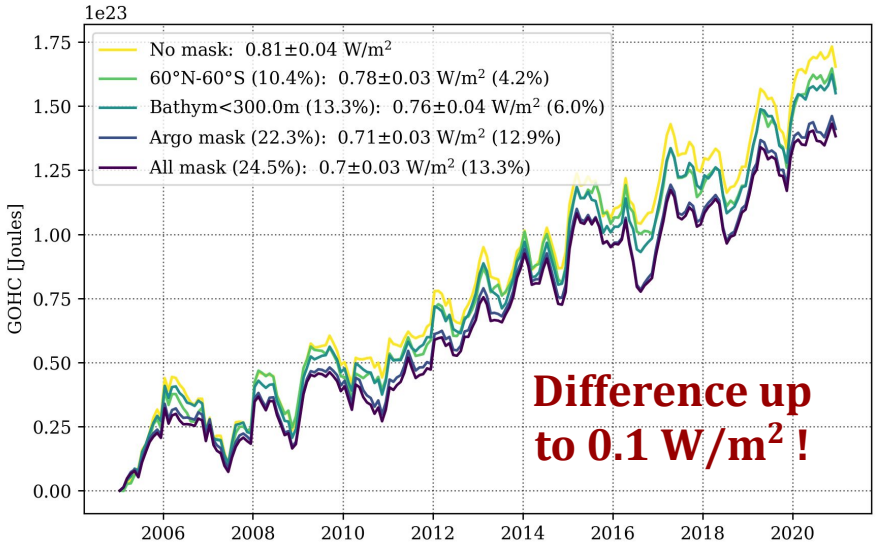
Ocean Heat Content products

Different pre-processing (e.g., Boyer et al., 2016) → **Ensemble Mean Approach**

Noisy at subannual scale (Trenberth et al., 2016) → **12-months rolling-trends and running-means rather than annual means**

Different ocean domain → **Common ocean mask**

GOHC over 0-2000m from IAP (Cheng et al., 2017) product



Implementing the EEI constraint approach

- 12-months in situ GOHC rates of change compared to TOA Net Radiative Flux

Ensemble Mean Approach

- ARMOR3D (Guinehut et al., 2012)
- CORA5.2 (Cabanes et al., 2013)
- EN4 (Good et al., 2013 ; XBT : Levitus et al., 2009)
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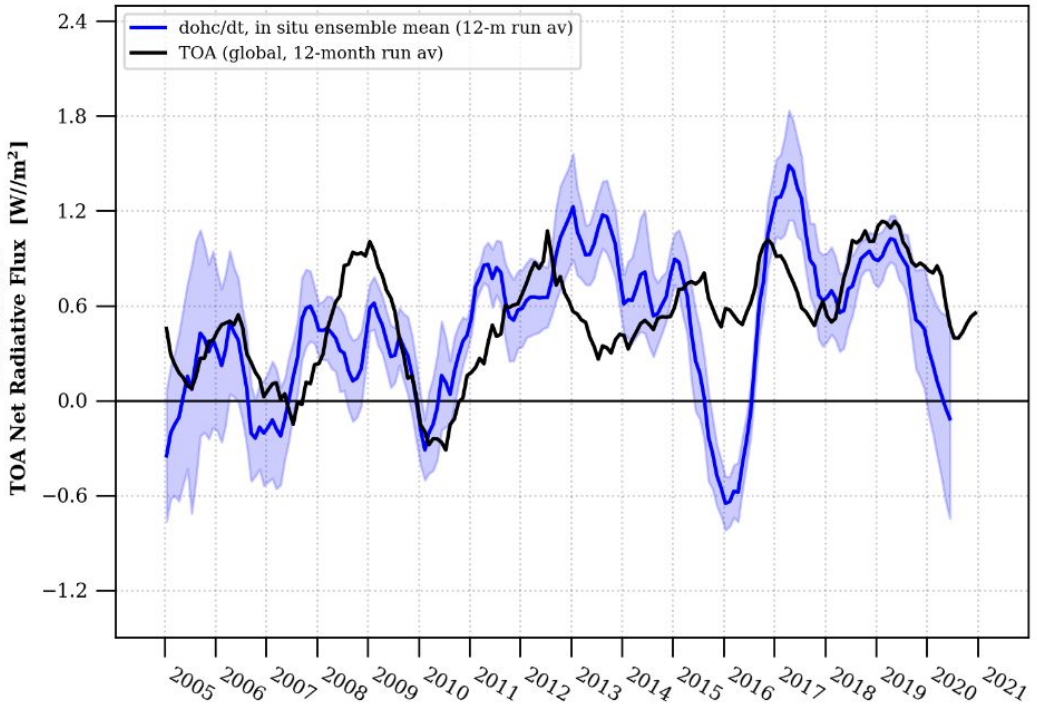
- CSIO/BOA (Lu et al., 2020)
- IPRC

In Situ

0-2000m, 60° N-60°S, bathym<300m masked

Ensemble Mean and Spread of In situ GOHC rates of change (12-month run av)

TOA Net Radiative Flux (12-month run av)
CERES EBAF TOA (Loeb et al., 2018)



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- 12-months in situ GOHC rates of change compared to TOA Net Radiative Flux

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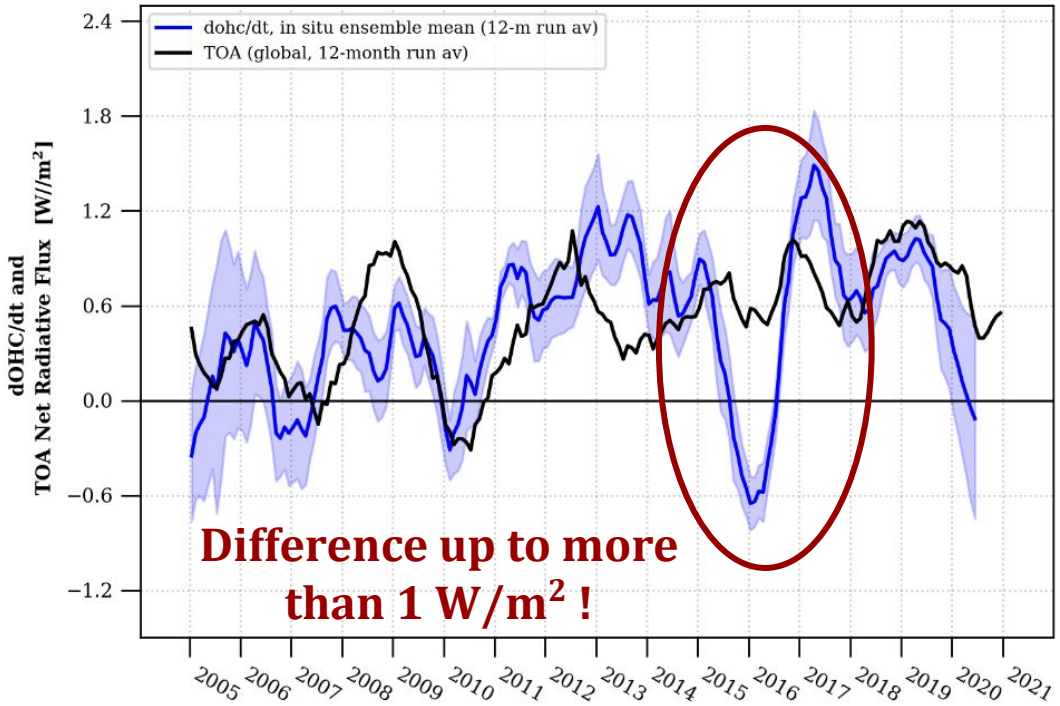
TOA Net Radiative Flux (12-month run av)

Why the budget does not close during 2015-2017 ?



Implementing the EEI constraint approach

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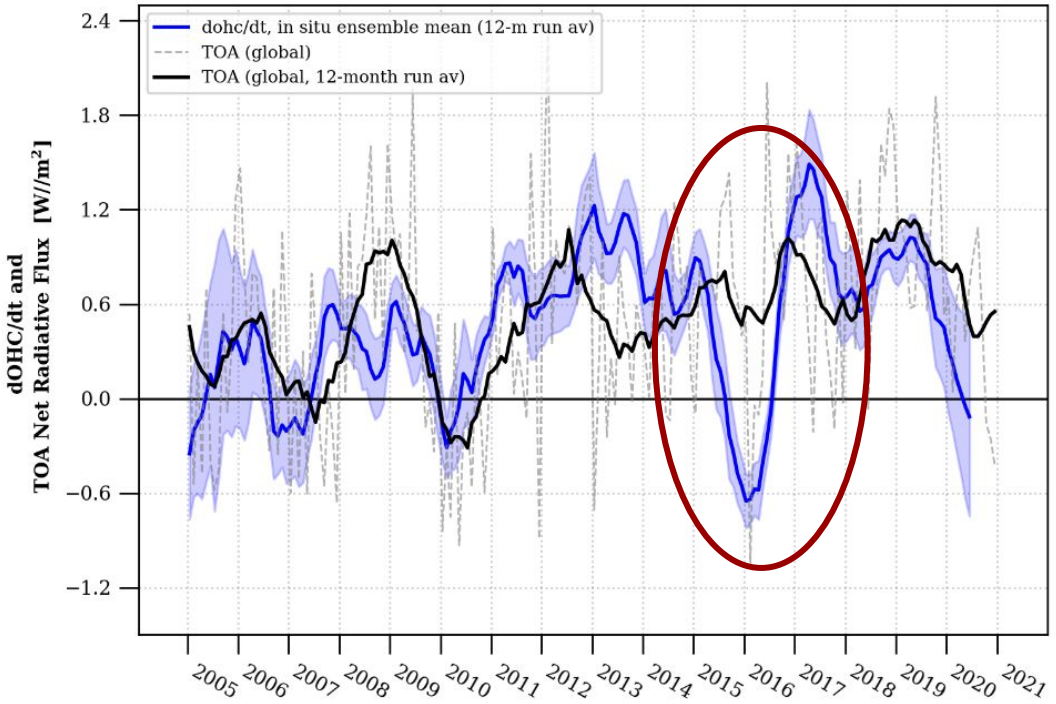
TOA Net Radiative Flux (12-month run av)

Monthly TOA Net Radiative Flux



Data processing artifact !

➔ **In situ GOHC changes and TOA in good agreement from 2005 onwards**

Year-to-year variations of EEI

- **EEI estimated from Sea Level Budget (Altimetry-GRACE)**

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IPRC

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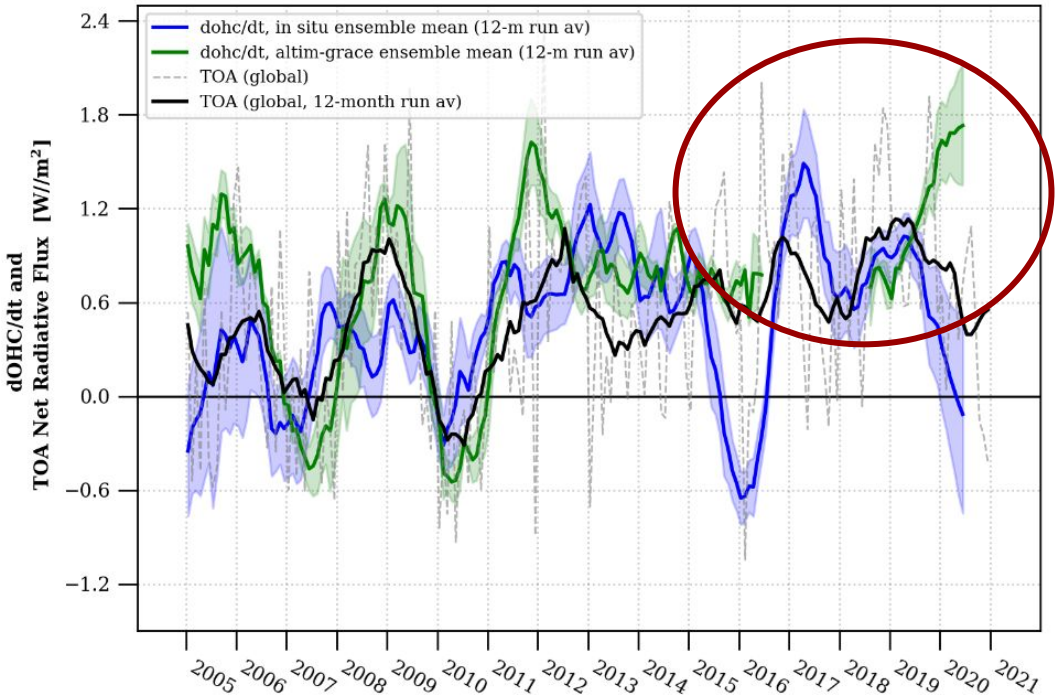
CMEMS/C3S - CSR

Altimetry-GRACE



➔ **Indirect GOHC estimate (satellite):**
could the 2017-2018 data gap impact the constraint ?

Absolute value of EEI at decadal scale

- 2005-2020 GOHC tendencies

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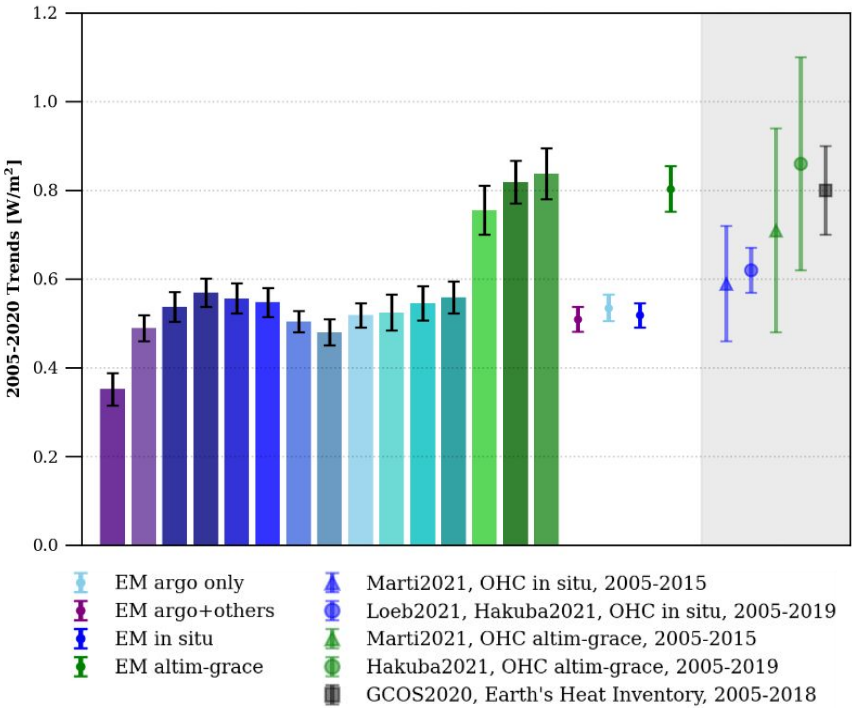

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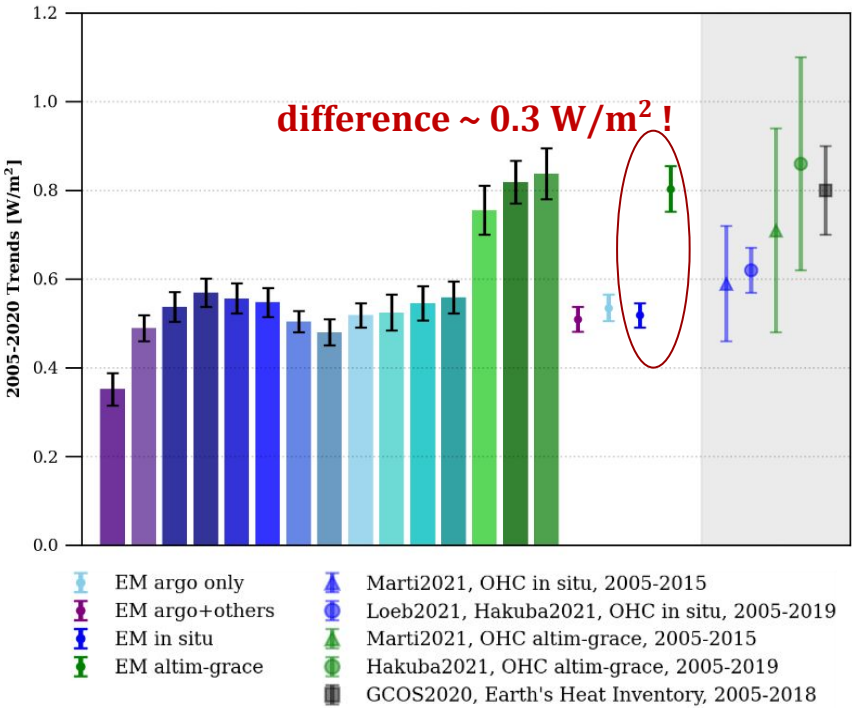
Why do satellite GOHC estimate show higher trends ?



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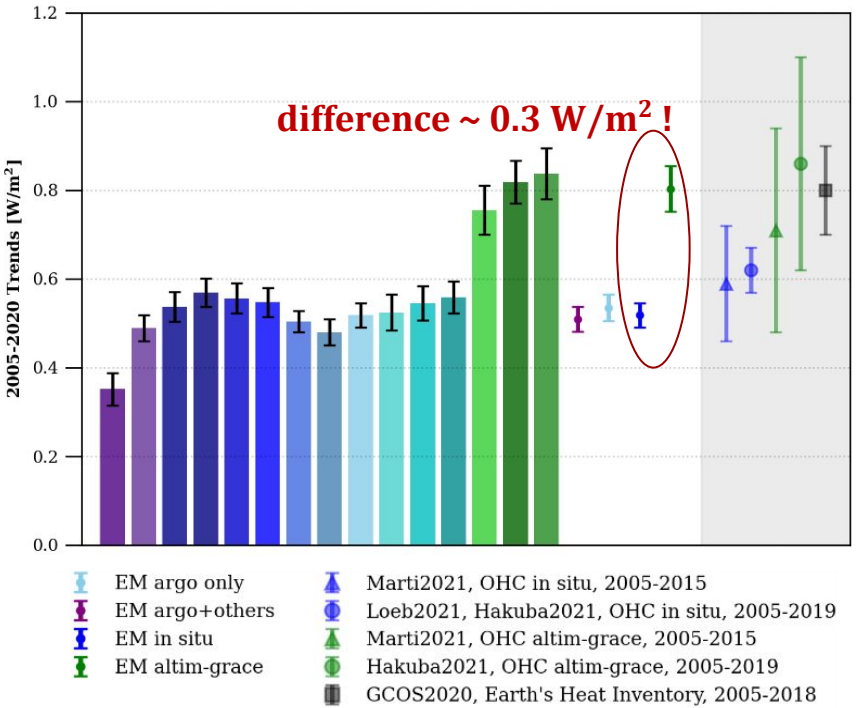

Why do satellite GOHC estimate show higher trends ?

➔ **Since 2016: Non-closure of the Sea Level Budget** (Barnoud et al., 2021; Chang et al., 2022)

Absolute value of EEI at decadal scale

- 2005-2015 vs. 2005-2020 GOHC tendencies

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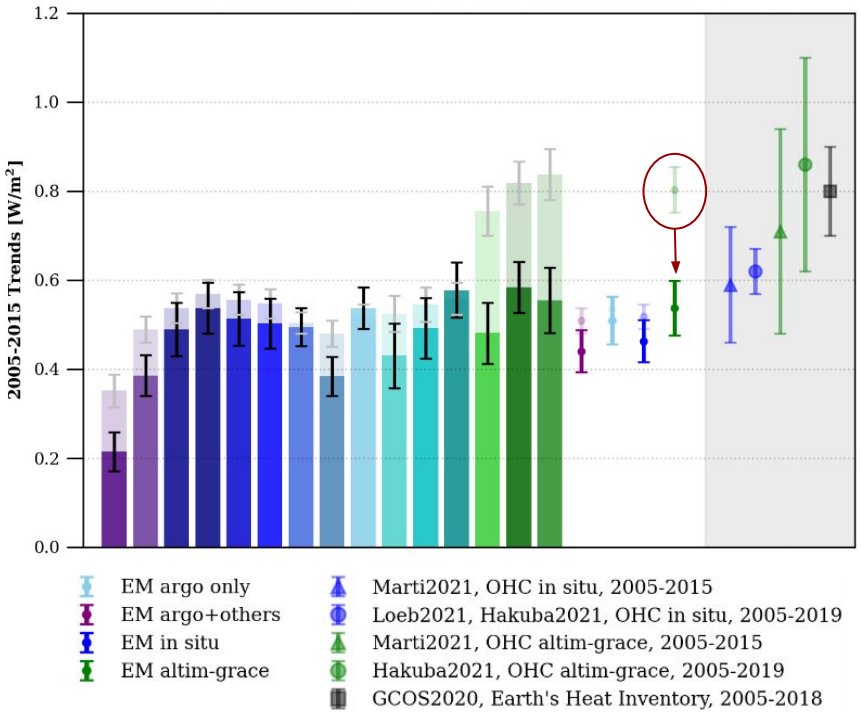
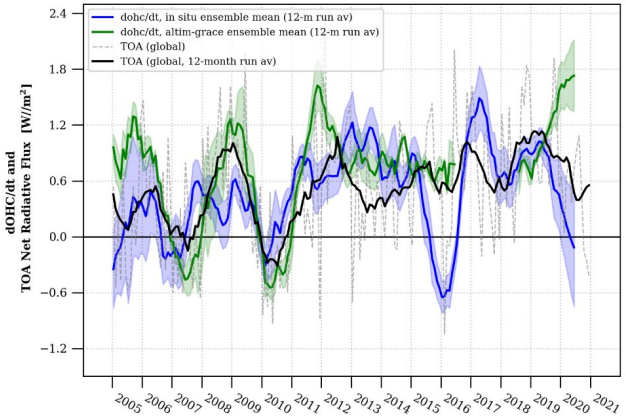
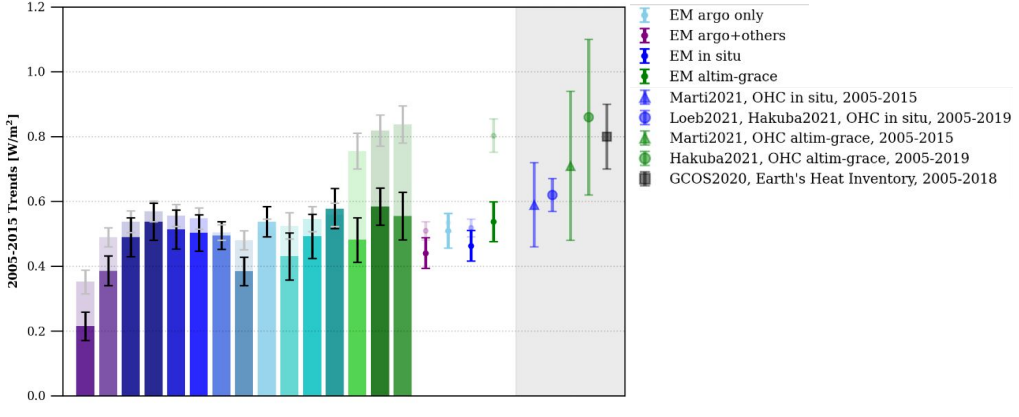


➔ **2005-2015 : EEI budget closed through GCOS components !**

Conclusion & Perspectives





- ✓ Improved implementation of the observational EEI constraint achieved at **annual** and **decadal** scales, provided that all GCOS components are **carefully evaluated and processed** (to avoid any mis-interpretations)
- ✓ EEI constraint approach suggests that **further evaluation is needed** for **reconciling the sea level budget** from 2016 onwards
- ✓ This approach might be used as **new opportunities to evaluate different ocean products**

➔ **Further efforts needed to improve the quantification of EEI uncertainty**

Thank you for listening!

aminiere@mercator-ocean.fr