Monitoring the global ocean heat content from space geodetic observations to estimate the Earth Energy Imbalance

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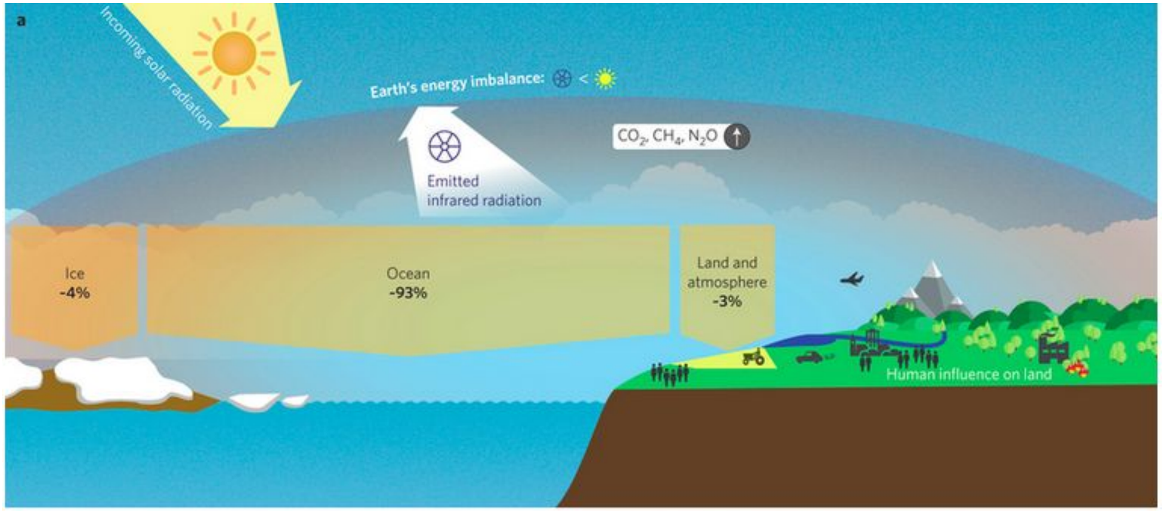
Overview

- ➔ The **Earth's energy imbalance (EEI)** provides a quantitative estimate of climate change

- ➔ Measuring the EEI is a challenge:
  - ◆ **~ 0.5-1 W/m²** versus **340 W/m²** of energy entering and leaving the top of the atmosphere
  - ◆ implies an uncertainty of **<0.3 W/m²** (90% CL) on a decadal scale for assessing variations in the EEI (< 0.1 W/m²/decade for the trend).
  - ◆ implies an uncertainty of **<0.1 W/m²** (90% CL) on a decadal scale to enable the effect of GHG reduction policies to be identified



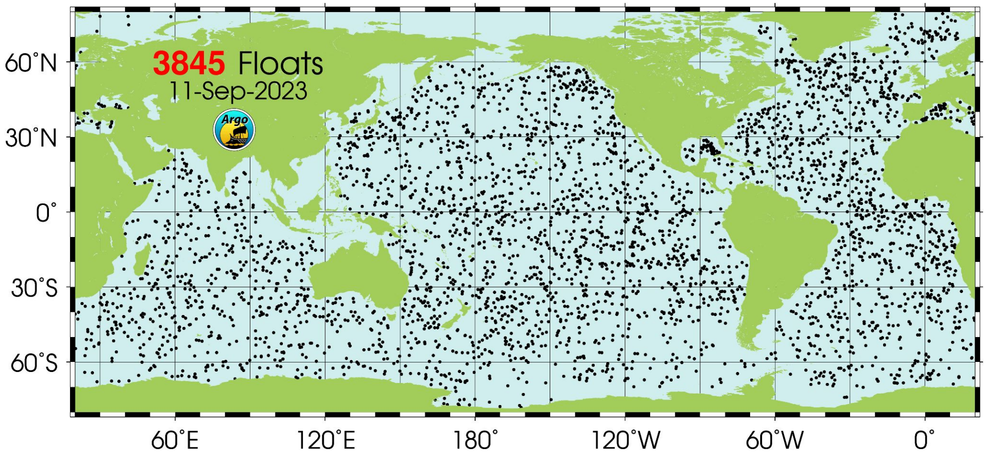
Overview

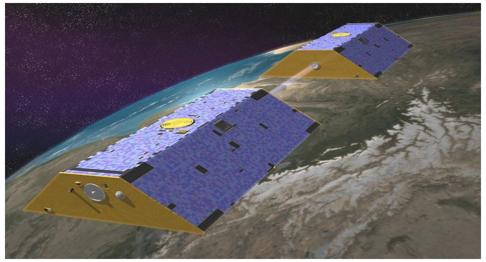
➔ The ocean heat content (OHC) is a very good **proxy** to estimate EEI as ocean is the major heat reservoir (91% of the EEI, from IPCC).

➔ OHC can be derived from different approaches (Meyssignac et al., 2019) :
- ◆ in situ temperature/salinity profiles,
- ◆ space observations of the ocean surface net fluxes,
- ◆ ocean reanalyses,
- ◆ **"space-geodetic"** data using altimetric and gravimetric measurements

➔ **"space-geodetic"** approach is a potential candidate to meet the EEI **accuracy requirements: 0.1 W.m^{-2}** on the long term mean (>10 years).

Measuring Global Ocean Heat Content to Estimate the Earth Energy Imbalance, Meyssignac et al., 2019
https://doi.org/10.3389/fmars.2019.00432



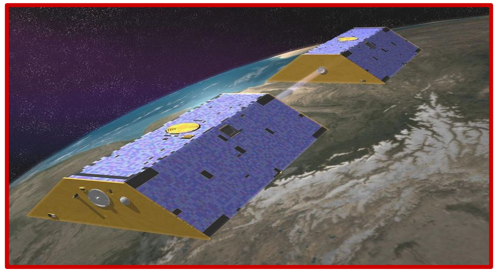


Space geodetic OHC & EEI: geophysical principle

1

➔ The space geodetic approach relies on the sea level budget equation:

$$\Delta SL_{total} = \Delta SL_{mass} + \Delta SL_{thermosteric} + \Delta SL_{halosteric}$$



https://argo.ucsd.edu

2

➔ Ocean heat content change is derived from the thermosteric sea level change.

$$\Delta OHC = \frac{\Delta SL_{thermosteric}}{IEEH}$$

3

➔ Global ocean heat content change

$$\Delta GOHC = \sum_{i,j} \Delta OHC(i,j)$$

4

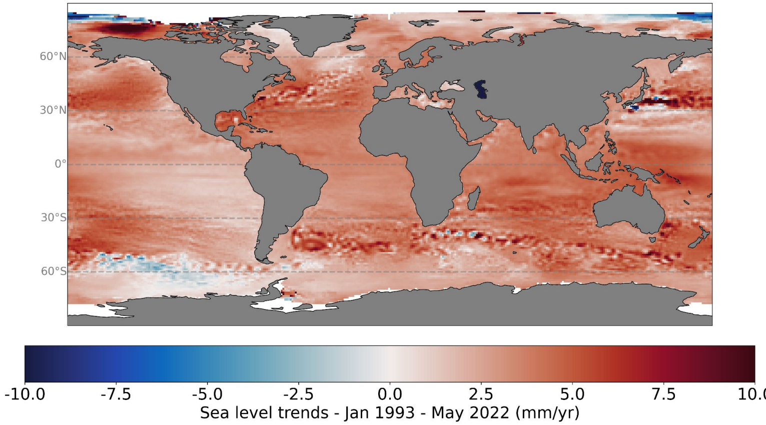
➔ Earth energy imbalance

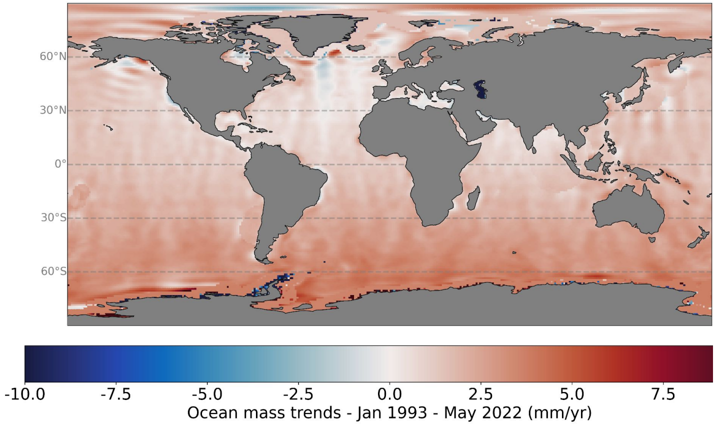
$$EEI \approx \frac{1}{\alpha} \frac{d\,GOHC}{dt}$$

Monitoring the global ocean heat content from space geodetic observations to estimate the Earth energy imbalance, Marti et al., 2023. https://doi.org/10.5194/sp-2023-26

Space geodetic OHC & EEI: results at regional scales

Altimetric sea level grids (C3S)

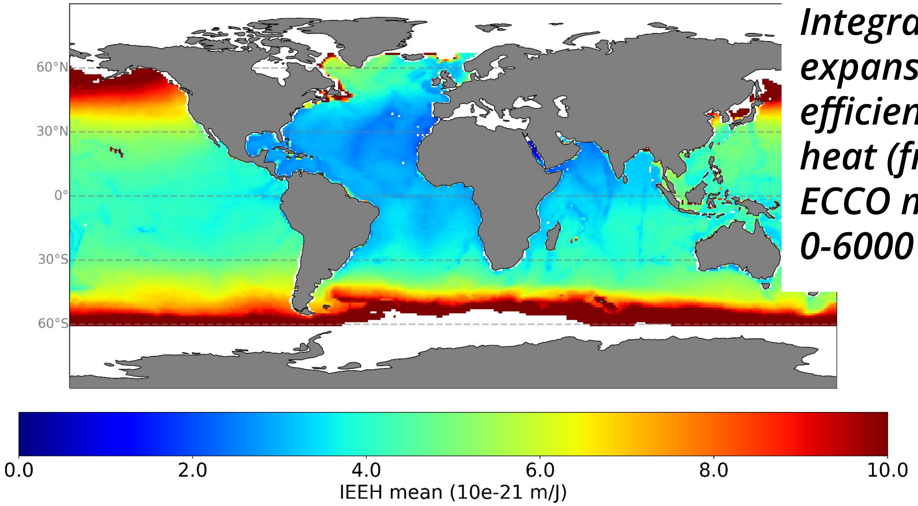




Manometric sea level grids

- *from GRACE(-FO) from 2002 (Blazquez et al., 2018)*
- *from individual land/atmosphere components before 2002 (slbc_cci)*

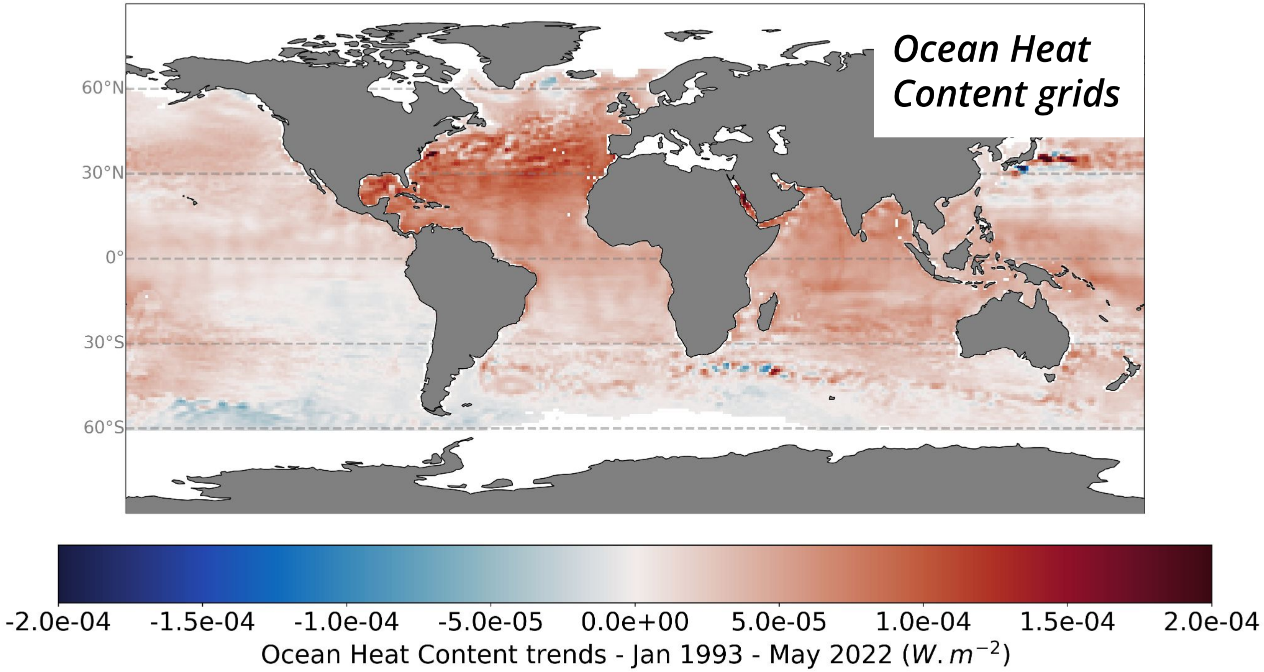
Step 1



Integrated expansion efficiency of heat (from ECCO model 0-6000 m)

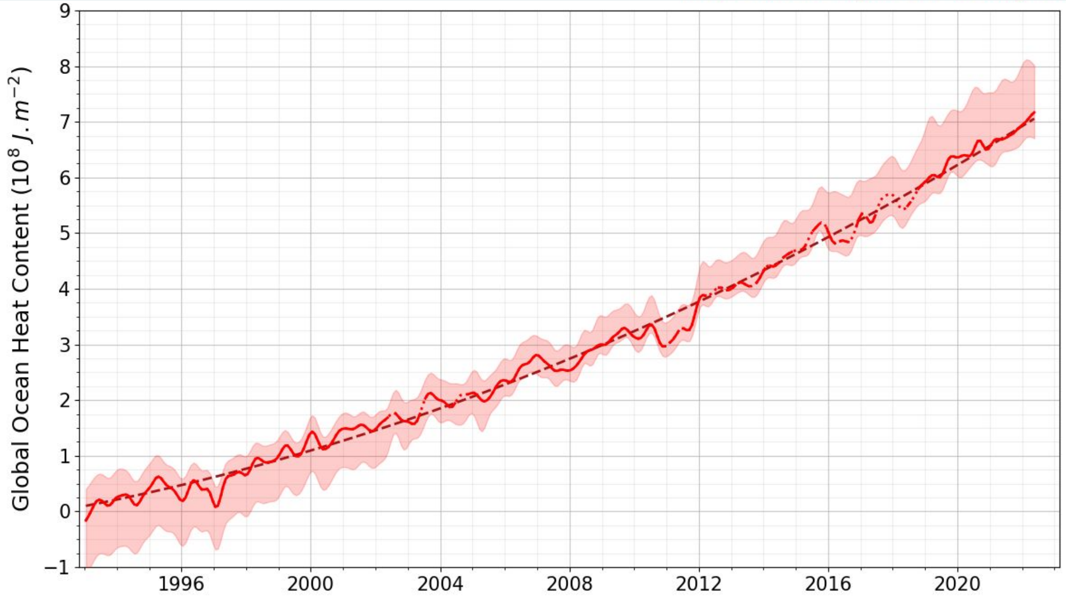
Step 2

Ocean Heat Content grids



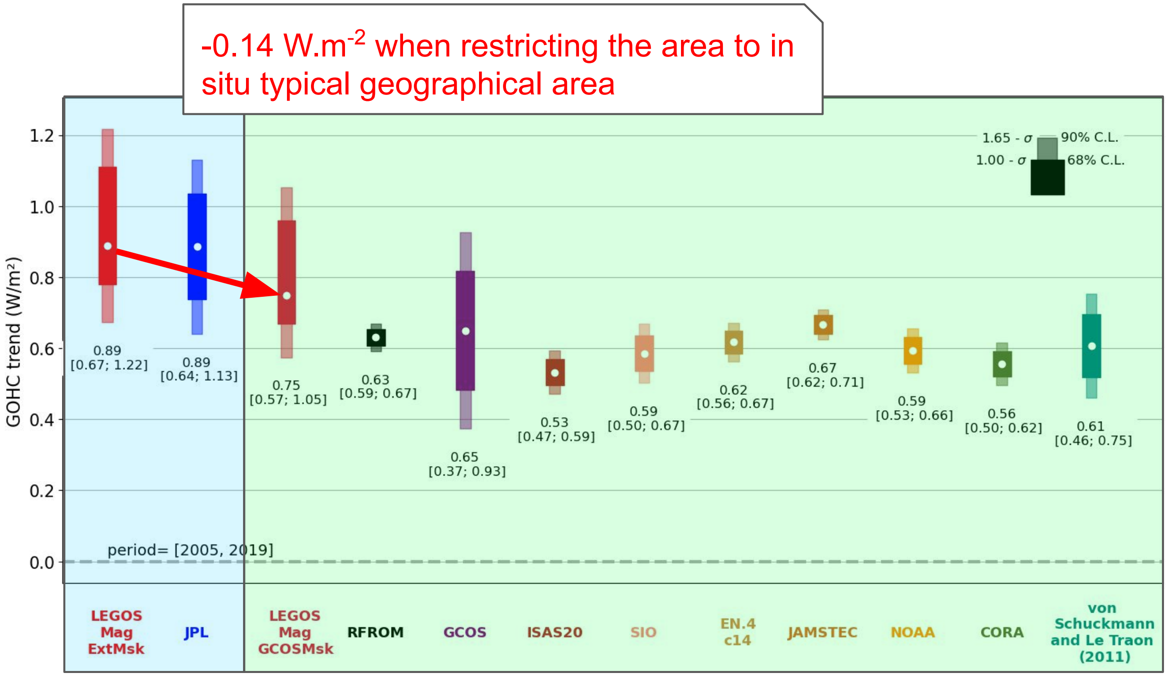
Space geodetic OHC & EEI: results at global scale

Step 3



- ➔ Space geodetic global OHC (1993-2022):
  - ◆ **Ocean heat uptake = 0.75 W.m^{-2}** within [0.61-1.04] at 90% confidence level
  - ◆ **Acceleration = 0.27 W.m^{-2}/decade** within [0.02-0.50] at 90% confidence level

- ➔ Assessment of the space geodetic GOHC (LEGOS-MAGELLIUM) trends over 2005-2019
  - ◆ using space geodetic GOHC from JPL
  - ◆ using several Argo-based datasets
  - ◆ using indicators delivered by CMEMS
  - ◆ selecting the same ocean surface



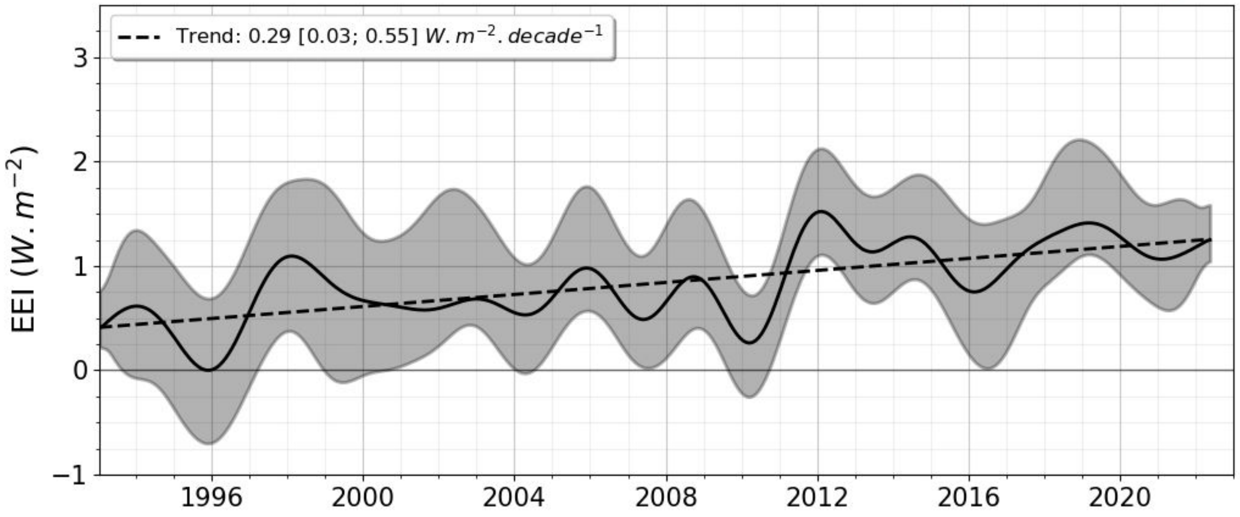
86% of ocean surface

76 % of ocean surface

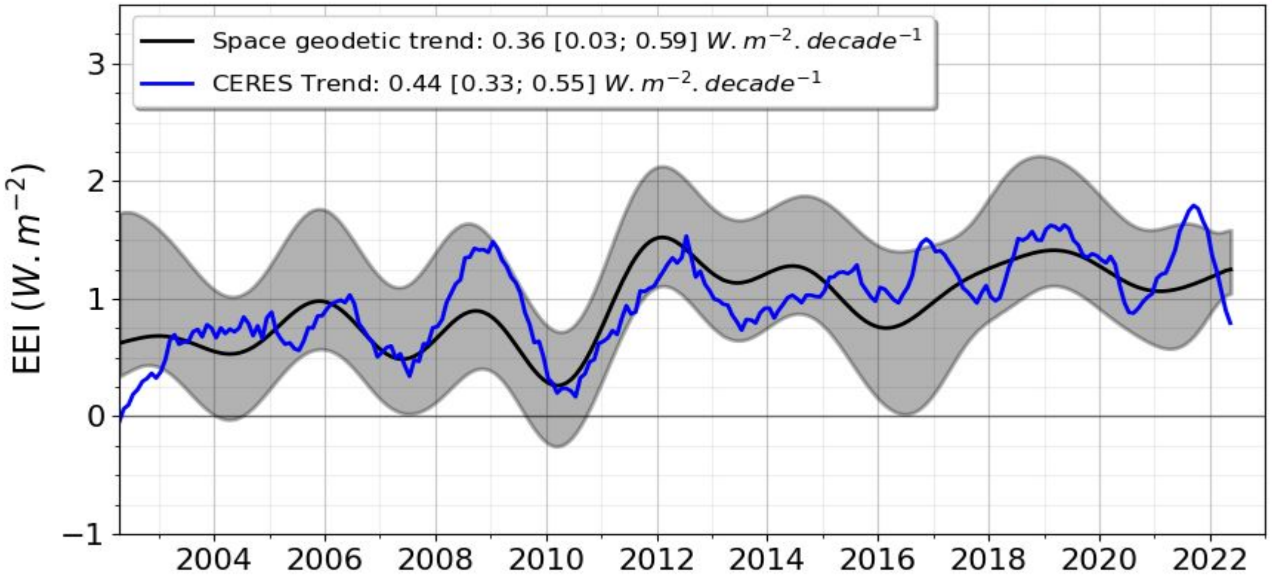
Space geodetic OHC & EEI: results at global scale

Step 4

- ➔ Space geodetic EEI (1993 - 2022)
  - **EEI mean = 0.83 W.m^{-2}** within [0.66, 1.15] at 90% confidence level
  - **EEI trend = 0.29 W.m^{-2} /decade** within [0.03, 0.55] at 90% confidence level



- ➔ Assessment of the space geodetic EEI (LEGOS-MAGELLIUM) by comparison with CERES measurements (2002-2022):
  - correlation: **R=0.70**
  - similar positive trends close to **0.4 W.m^{-2} /decade**

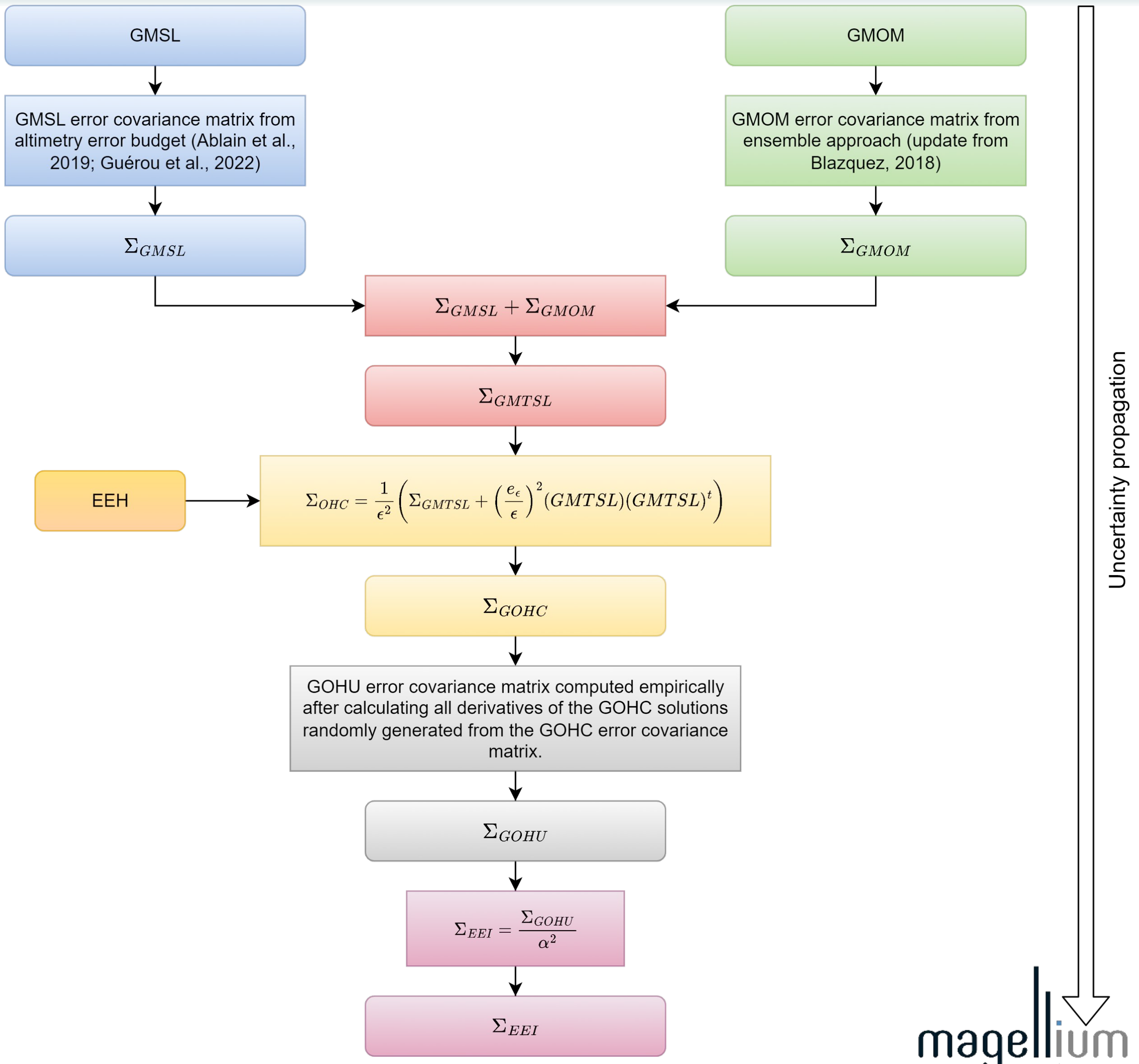


Space geodetic OHC & EEI: uncertainty estimates

➔ Uncertainties are propagated from input data until the OHC change and EEI calculation:

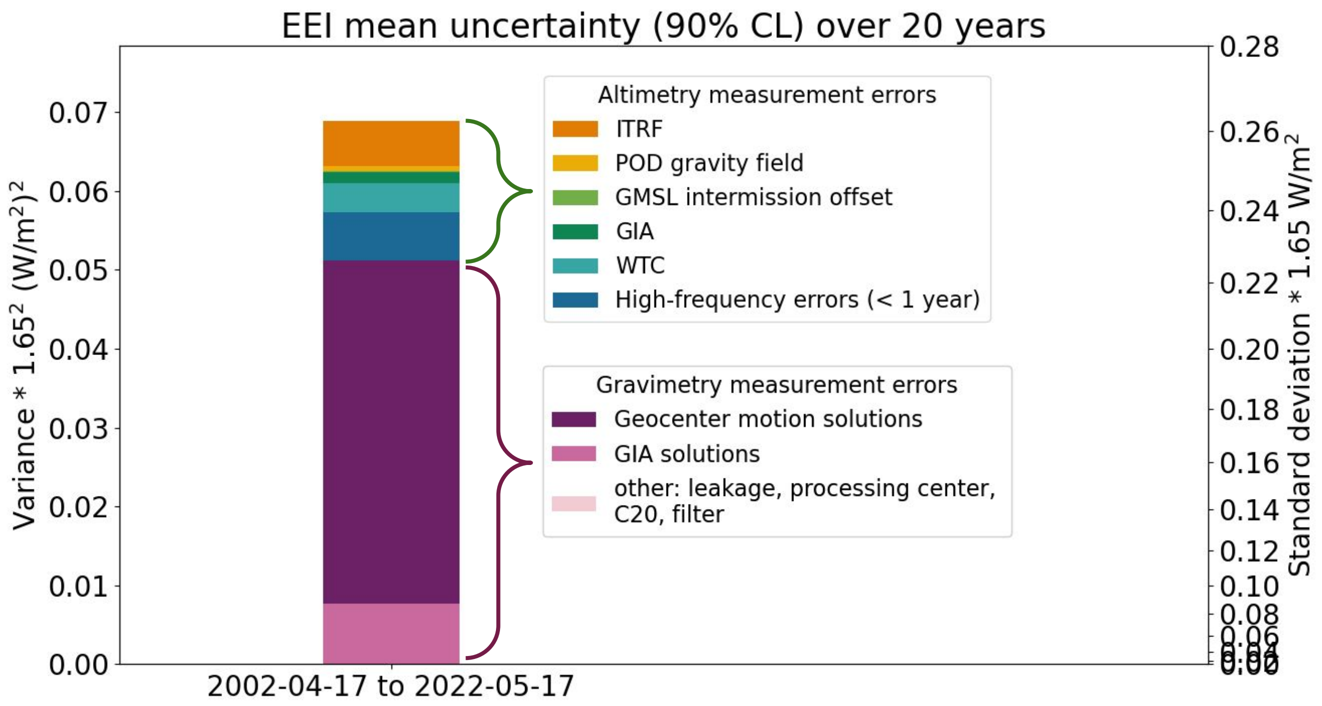
- based on error covariance matrix (∑) built from a characterisation of all major source of uncertainty
- trend/acceleration uncertainties derived from an OLS method where ∑ is taken into account (Ablain et al, 2009, 2019)

$$\hat{\beta} = N(\beta, (X^t X)^{-1}(X^t \Sigma X)(X^t X)^{-1})$$



Space geodetic OHC & EEI: results at global scale

- Contribution of error sources to the uncertainty of the EEI mean (2002-2022):
  - **25% due to the errors in altimetry data** divided into:
    - WTC stability (21%)
    - High frequency GMSL errors (34%)
    - ITRF (33%)
    - others - POD, GIA, offset (12%)
  - **75% due to the errors in gravimetry data** divided into:
    - geocenter solutions (85%)
    - GIA corrections (15%)
    - others - leakage, processing center, geocenter motion, C20, filter (< 0.2 %)
- Similar results on the global ocean heat uptake



Conclusions

Space geodetic data is a reliable approach to provide accurate GOHC and EEI estimates:

➔ Assessment performed with independent dataset :
  - GOHC trends in agreement with Argo products and CMEMS indicators over the same surface ocean
  - Similar EEI interannual variations and EEI trend with CERES data

➔ Complementary to Argo data:
  - Over the total water column: Argo ocean heat uptake corrected by **+ 0.07 W.m^{-2}** (Purkey & Johnson, 2010)
  - Larger ocean surface available (86%) : **+ 0.14 W.m^{-2}** in ocean heat compared to the GCOS ocean mask (76%)

➔ Uncertainties calculated with a rigorous approach:
  - Low uncertainties overs 20 years: **0.27 W.m^{-2}** in the EEI mean at 90% confidence level
  - With higher contribution of gravimetry measurements: **~75%**

Space geodetic data should continue to be improved to get closer the 0.1 W.m^{-2} requirement on the EEI at decadal scale:

➔ Reducing errors: wet troposphere correction (alti) , ITRF solutions (alti), geocenter solutions (gravi), GIA solutions (gravi), …

➔ Improving error and uncertainty characterisation: GMSL errors < 1 year (alti), geocenter solutions (gravi), ….

LEGOS-Magellium product (*) is available on ODATIS/AVISO portal: https://www.aviso.altimetry.fr

(*) DOI = 10.24400/527896/a01-2020.003

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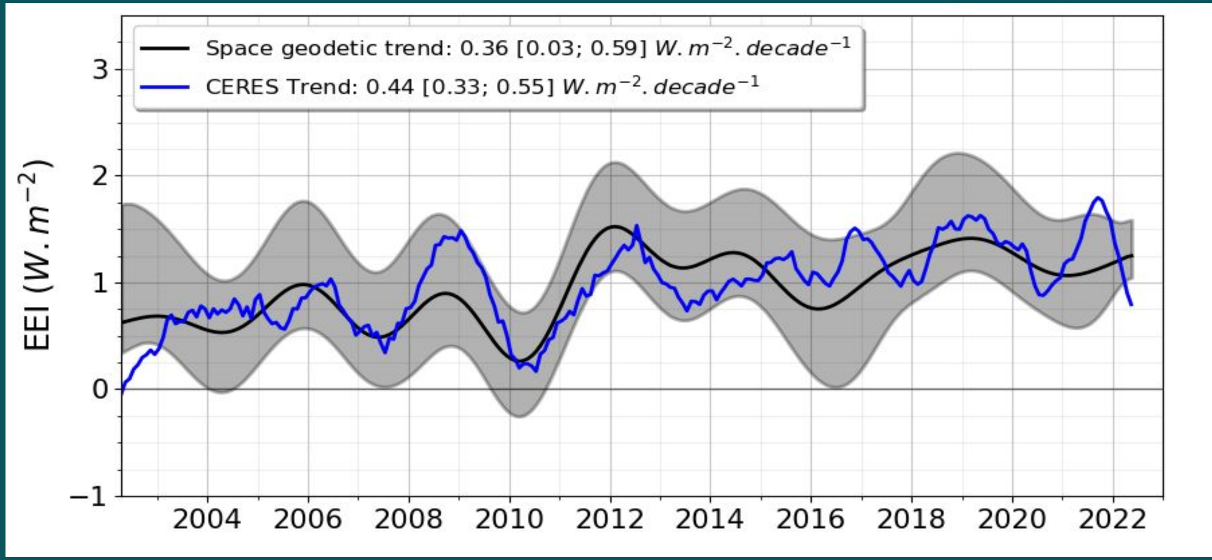
Thank you for your attention.



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