Monitoring the Ocean Heat Content & the Earth Energy Imbalance from space gravimetry and altimetry

Florence Marti (1), Alejandro Blazquez (2), Benoit Meyssignac (2), Michaël Ablain (1) , Jonathan Chenal (2,3), Robin Fraudeau (1), Rémi Jugier (1), Gilles Larnicol (1), Julia Pfeffer (1), Anne Barnoud (1), Marco Restano (4), Jérôme Benveniste (5), Gérald Dibarboure (6), François Bignalet-Cazalet (6)

(1) Magellium, France ; (2) LEGOS, CNES, France ; (3) ENPC, France ; (4) SERCO-ESRIN, Italy ; (5) ESA-ESRIN, Italy ; (6) CNES, France

living planet symposium BONN 23–27 May 2022

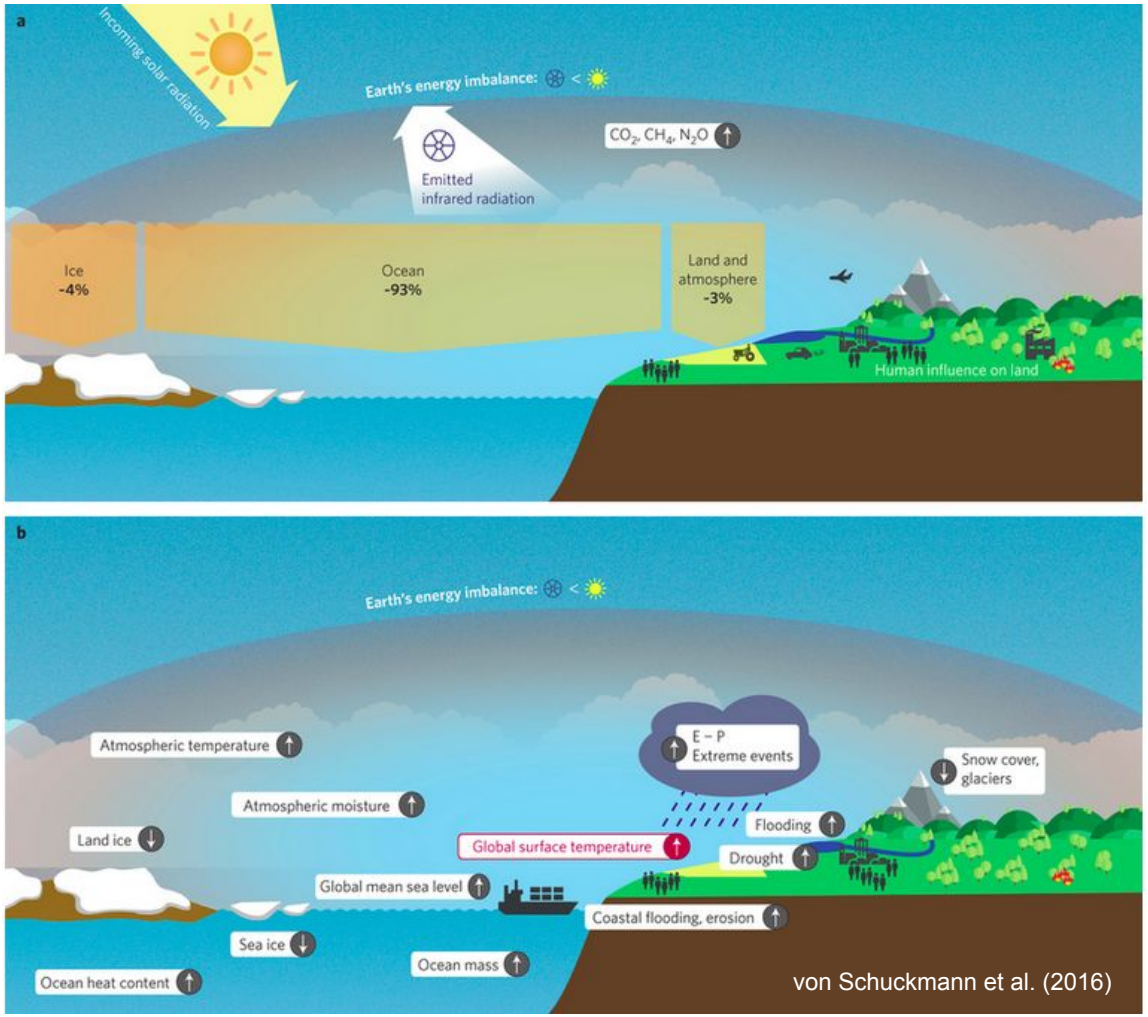
eo@magellium.fr earthobservation.magellium.com

Earth Energy Imbalance - overview

Earth energy imbalance (EEI) indicator provides a quantitative estimate of climate change. Recent studies suggest that the EEI response to anthropogenic greenhouse gases and aerosols emissions is 0.5-1 $W.m^{-2}$ (<< 340 $W.m^{-2}$ incoming solar radiation).

An **accuracy** of 0.3 $W.m^{-2}$ (ideally 0.1 $W.m^{-2}$) is necessary to assess the long-term mean EEI due to anthropogenic forcing at decadal time scales.

The ocean heat content (OHC) is a very good **proxy** to estimate EEI as ocean is the major heat reservoir (90% EEI).

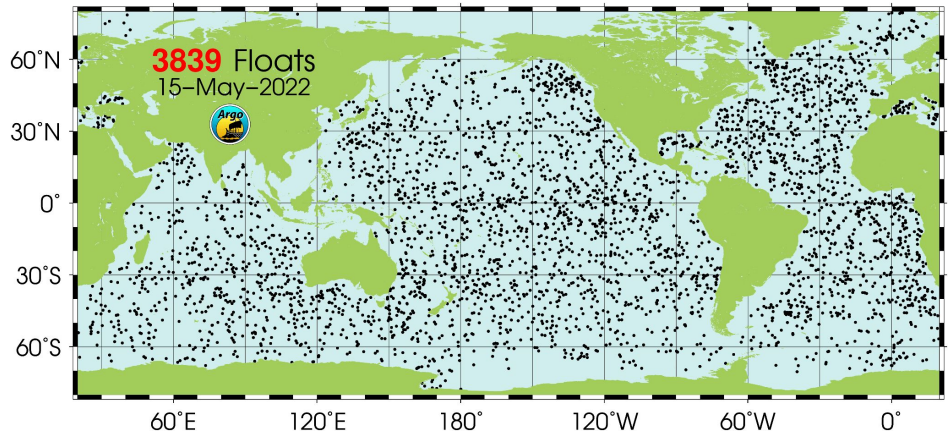


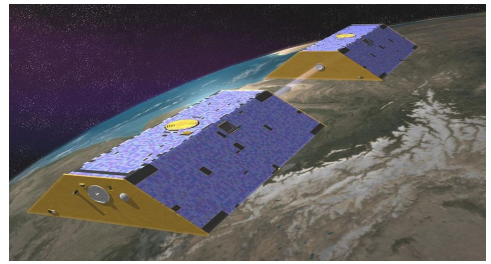
Different approaches

OHC can be derived from different approaches:

- in situ temperature/salinity profiles,
- space observations of the ocean surface net fluxes,
- ocean reanalyses,
- the measurement of the **thermal expansion of the ocean** from space based on differences between the total sea-level content derived from altimetry measurements and the mass content derived from gravimetry data (noted "**space-geodetic approach**").

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



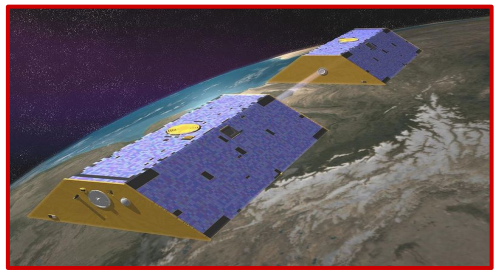


The physical principle

1 2 3 4

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

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

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

- Global ocean heat content change $\Delta GOHC = \sum_{i,j} \Delta OHC(i,j)$
- Earth energy imbalance $EEI \approx \frac{1}{\alpha} \frac{d\,GOHC}{dt}$

Monitoring the ocean heat content change and the Earth energy imbalance from space altimetry and space gravimetry, Marti et al., 2021
https://doi.org/10.5194/essd-2021-220

UPDATE

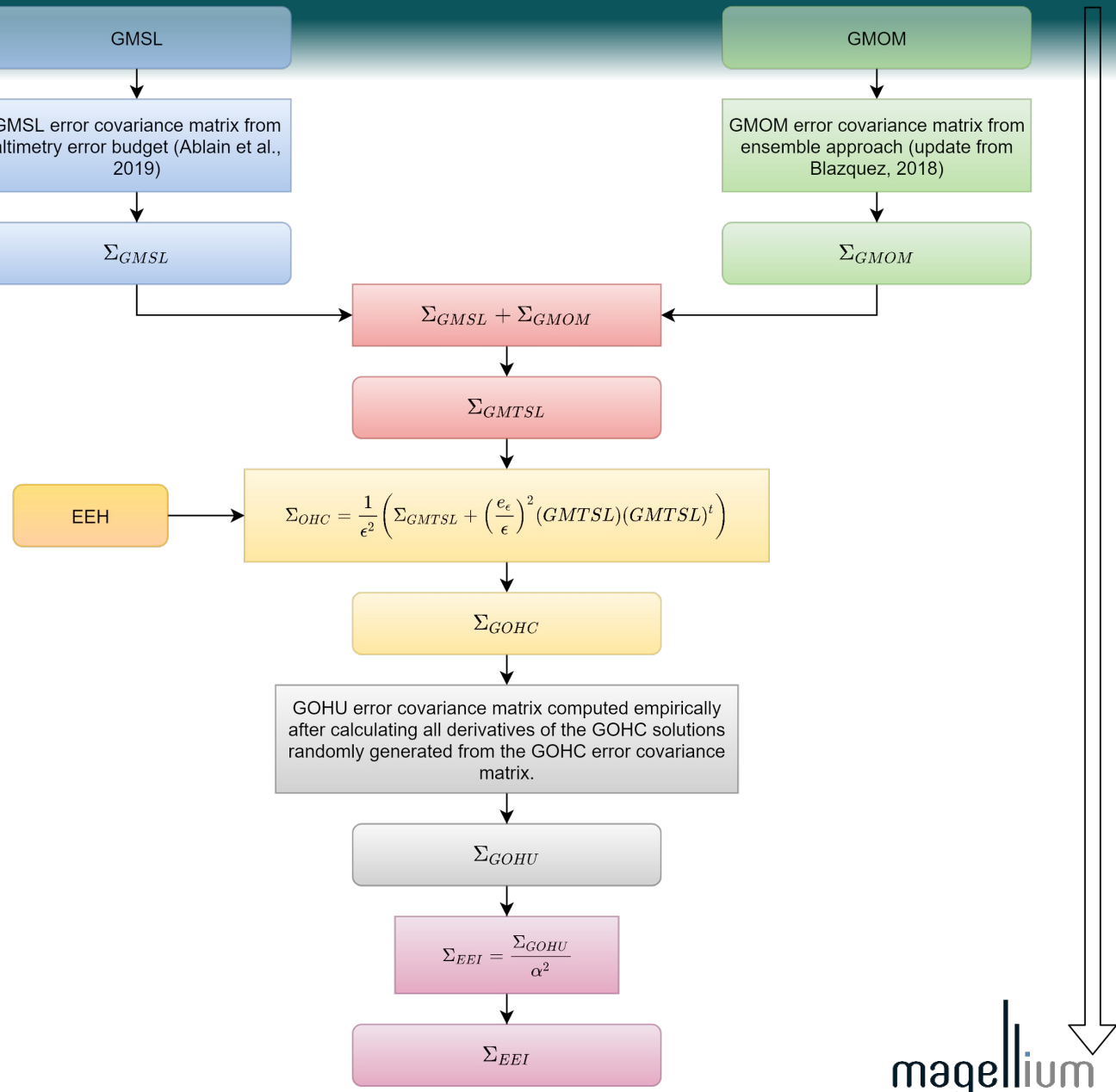
Methodology for the uncertainty estimation

Novelty: estimation of the uncertainties based on a rigorous formal approach

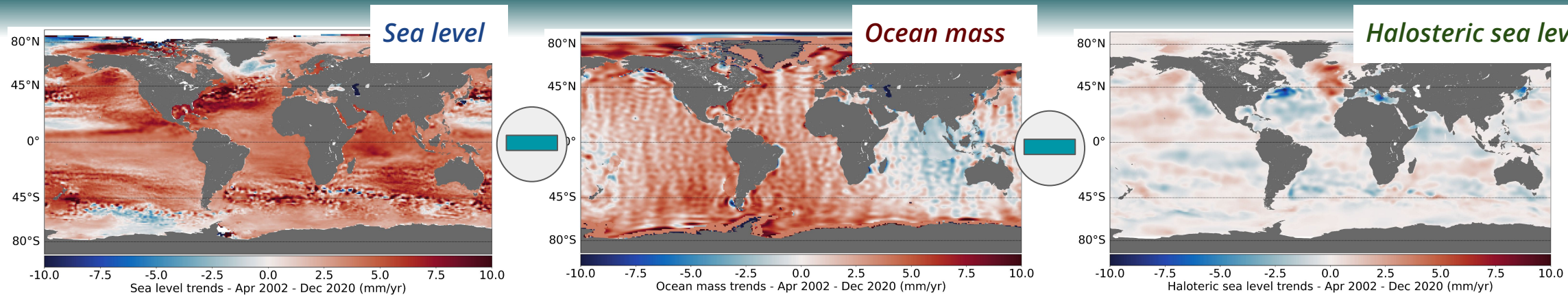
The uncertainties propagation has been specified **<u>at global scale</u>**:

- using error covariance matrices

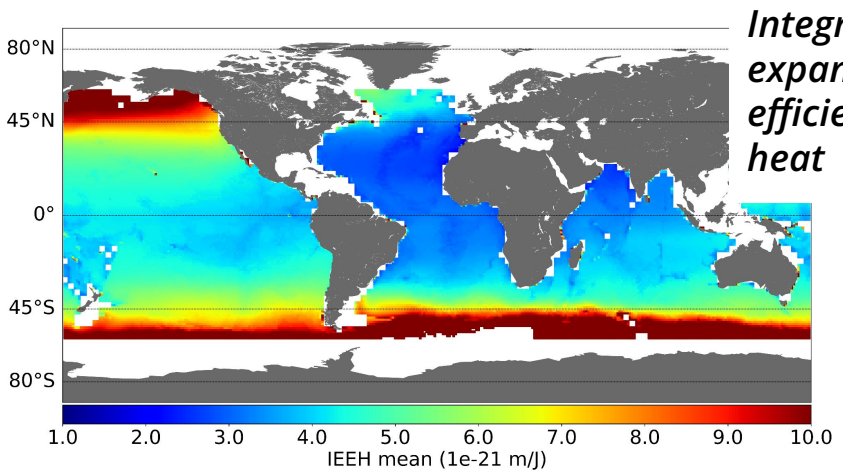
Error covariance matrix (∑) provides a full description of errors allowing the calculation of 1) trend uncertainties and 2) error envelop, etc.



Results - Ocean heat uptake at local scales

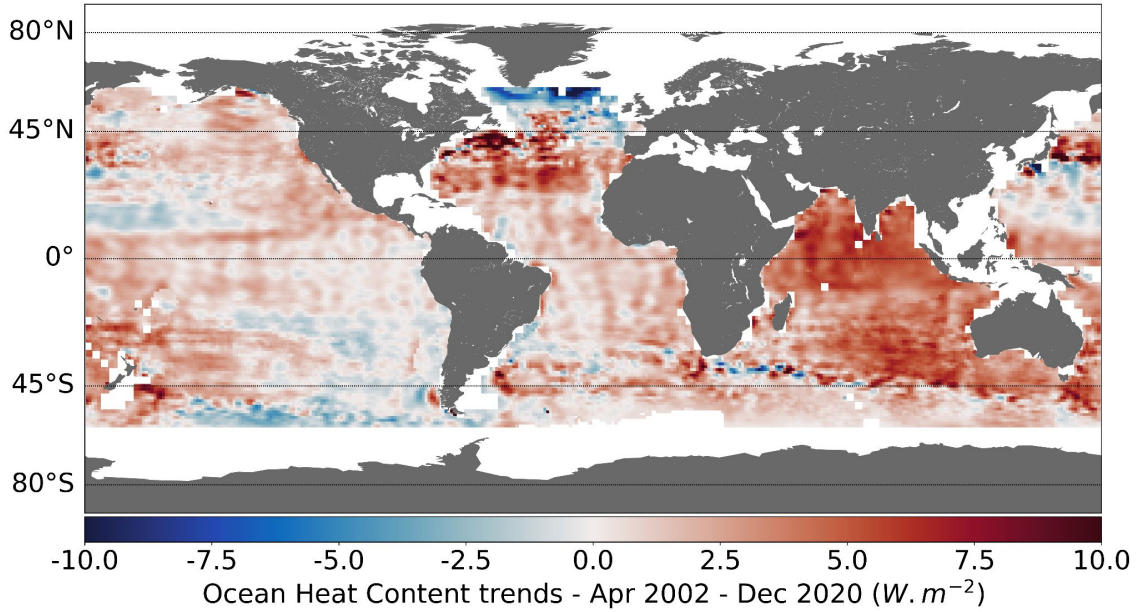


Step 1



Integrated expansion efficiency of heat

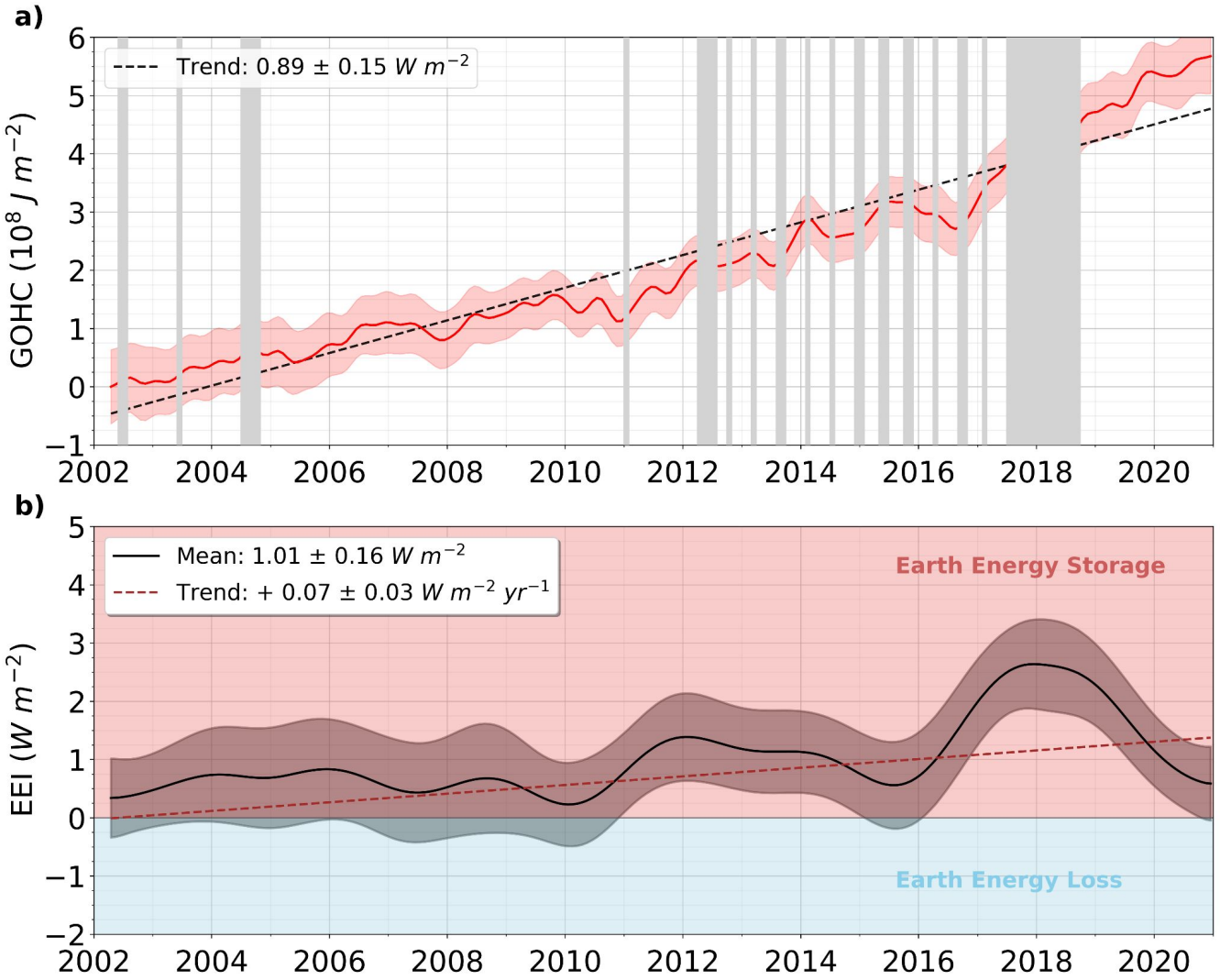
Step 2



Results - Global ocean heat uptake and energy imbalance

Step 3

Step 4



- Computation of the OHC/EEI climate indicators over the period April 2002 - December 2020 period:
  - EEI highlights a positive mean value of **+1.01 W.m^{-2}**
  - with an uncertainty of **0.16 W.m^{-2} (90% CL)**

Earth climate system is storing energy

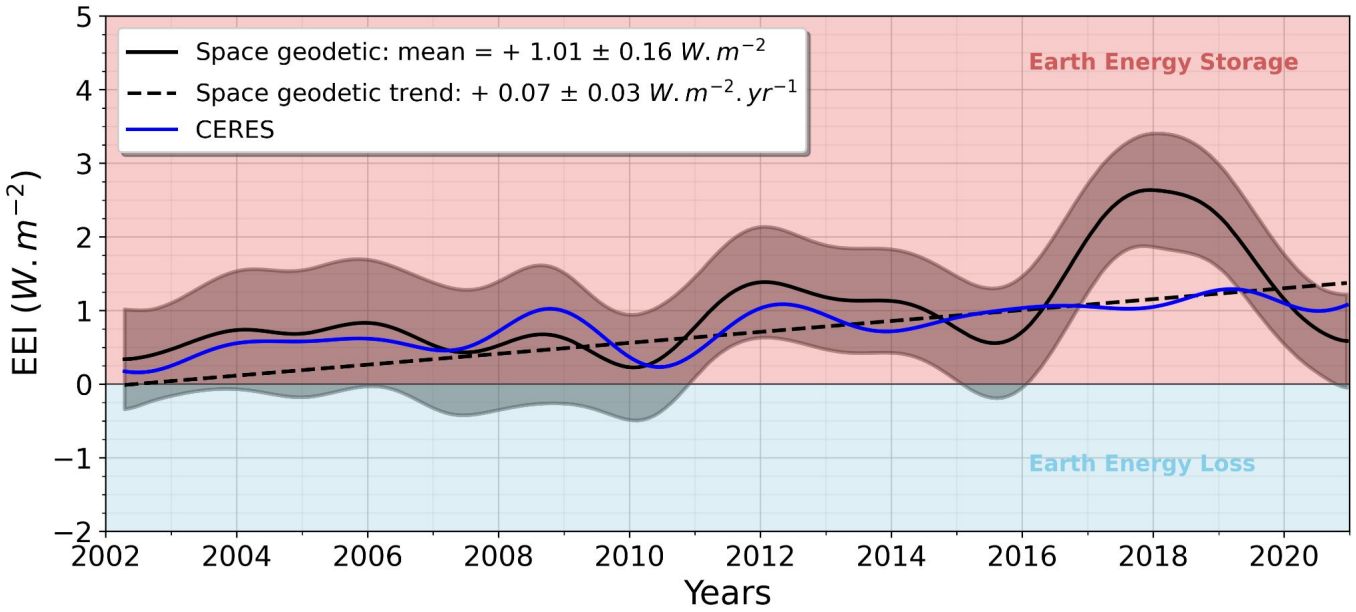
Assessment

- Comparison against results based on Argo in-situ measurements
- Ocean heat uptakes are **in agreement** within the uncertainty confidence level (90% CL) over 2005-2015

Data type	Depth range	GOHC trend ($W\ m^{-2}$)		EEI mean ($W\ m^{-2}$)	
		02/2002-12/2020	**01/2005-12/2015**	02/2002-12/2020	**01/2005-12/2015**
Satellite data from altimetry (C3S) and gravimetric (GRACE/GRACE-FO) missions	0-bottom	+0.89 ± 0.16	**+0.74 ± 0.20**	+1.01 ± 0.16	**0.78± 0.21**
Temperature and salinity profiles from 6 Argo datasets	0-2000m (with deep ocean contribution of +0.07 $W\ m^{-2}$)	+0.60 ± 0.05	**+0.59 ± 0.10**	+0.65 ± 0.08	**+0.61 ± 0.12**

Assessment

- Clouds and Earth's Radiant Energy System (CERES instruments)
  - Radiative fluxes at TOA
  - Accurate estimate of EEI variations
- Interannual signals of EEI are under investigation
  - Sensitivity to the spatial extent
  - Sensitivity to the filtering
- Need for a better estimation of uncertainties



Conclusions & future work

Waiting for your feedback

- Proof of concept of the space geodetic approach
  - Uncertainty propagation

- Perspective:
  - better understand and estimate EEI inter-annual variations
    - GEWEX EEI assessment
  - Improve the uncertainties characterisation to reach 0.1 W m^{-2} at inter-annual scales
  - Investigate on potential inconsistencies or anomalies in the input data
  - Extend the spatial and temporal coverage

- GOHC and EEI climate indicators freely available
  - Technical documentation
  - Publication: Marti et al., Monitoring the ocean heat content change and the Earth energy imbalance from space altimetry and space gravimetry, Earth Syst. Sci. Data, 2021.

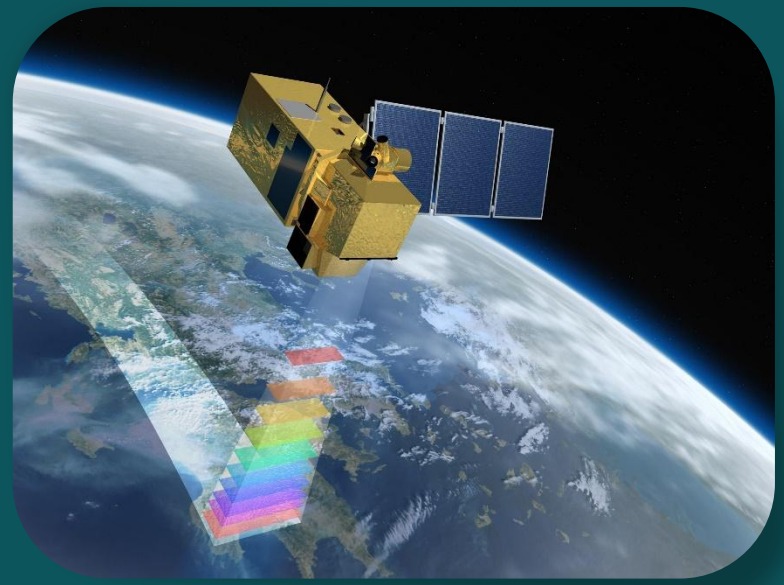
How to access the OHC/EEI product ?
Version 4.0 - available soon!
https://www.aviso.altimetry.fr/

florence.marti@magellium.fr

magellium
artal group

EARTH OBSERVATION
magellium artal group

Thank you for your attention.



earthobservation.magellium.com

eo@magellium.fr

References

- Ablain, M., Meyssignac, B., Zawadzki, L., Jugier, R., Ribes, A., Spada, G., Benveniste, J., Cazenave, A., and Picot, N.: Uncertainty in satellite estimates of global mean sea-level changes, trend and acceleration, Earth Syst. Sci. Data, 11, 2019, 1189–1202, https://doi.org/10.5194/essd-11-1189-2019

- Blazquez A, Meyssignac B, Lemoine JM, Berthier E, Ribes A, Cazenave A, Exploring the uncertainty in GRACE estimates of the mass redistributions at the Earth surface: implications for the global water and sea level budgets, *Geophysical Journal International*, Volume 215, Issue 1, 1 October 2018, Pages 415–430, https://doi.org/10.1093/gji/ggy293

- Marti, F., Blazquez, A., Meyssignac, B., Ablain, M., Barnoud, A., Fraudeau, R., Jugier, R., Chenal, J., Larnicol, G., Pfeffer, J., Restano, M., and Benveniste, J.: Monitoring the ocean heat content change and the Earth energy imbalance from space altimetry and space gravimetry, Earth Syst. Sci. Data, https://doi.org/10.5194/essd-14-229-2022

- Meyssignac B, Boyer T, Zhao Z, Hakuba MZ, Landerer FW, Stammer D, Köhl A, Kato S, L'Ecuyer T, Ablain M, Abraham JP, Blazquez A, Cazenave A, Church JA, Cowley R, Cheng L, Domingues CM, Giglio D, Gouretski V, Ishii M, Johnson GC, Killick RE, Legler D, Llovel W, Lyman J, Palmer MD, Piotrowicz S, Purkey SG, Roemmich D, Roca R, Savita A, von Schuckmann K, Speich S, Stephens G, Wang G, Wijffels SE and Zilberman N (2019) Measuring Global Ocean Heat Content to Estimate the Earth Energy Imbalance. Front. Mar. Sci. 6:432. https://doi.org/10.3389/fmars.2019.00432

- von Schuckmann, K., Palmer, M., Trenberth, K. *et al.* An imperative to monitor Earth's energy imbalance. *Nature Clim Change* **6,** 138–144 (2016). https://doi.org/10.1038/nclimate2876XX

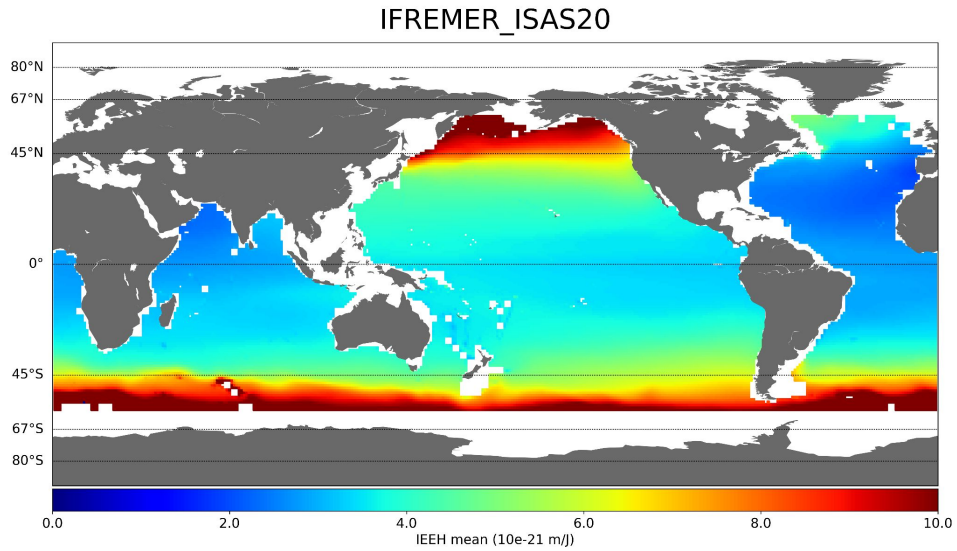
Appendices - (Integrated) Expansion Efficiency of Heat

- As a extensive variable, global (I)EEH cannot be derived from local (I)EEH
- At global scale, EEH and IEEH are identical.

$$EEH_t = \frac{trend(GMTSSL(t))}{trend(GOHC(t))} \qquad IEEH(t) = \frac{TSSL(t)}{OHC(t)}$$

Meyssignac, B., Padilla Polo, S. and Blazquez, A.: Accurate estimate of the Expansion Efficiency of Heat (EEH) coefficient at global and regional scales, In preparation

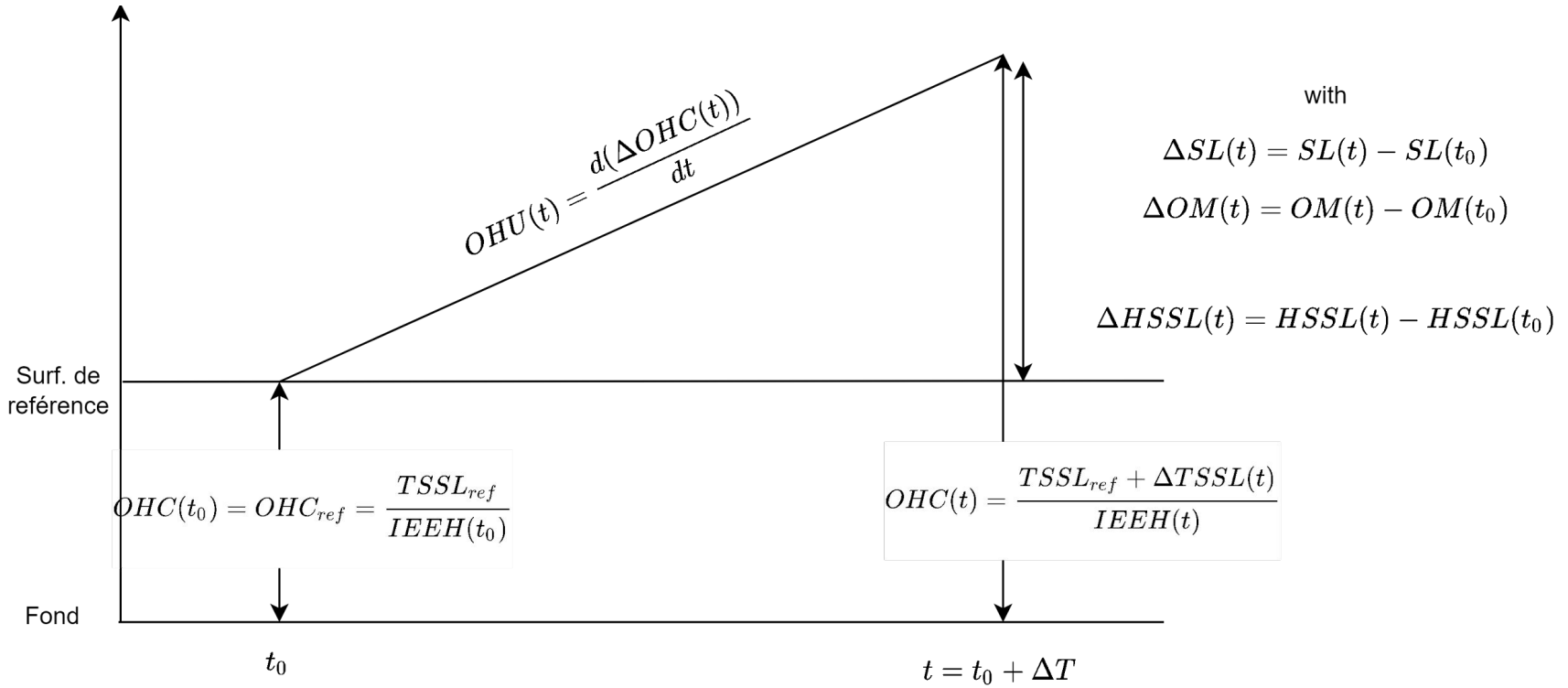
- Estimation of the integrated expansion efficiency of heat (IEEH) at local scales
  - From monthly 3D in situ temperature and salinity fields based on 11 various Argo solutions.
  - Use of the thermodynamic equation of sea water TEOS-10 to compute the ratio SSL/OHC in each cell at each timestep
  - Restrictive mask (no high latitudes, no enclosed-seas)
  - Representative of the 0–2000 m ocean column over the 2005-2015 period



At local scale, EEH is not defined for every cell. We use the IEEH approach.

Appendices - OHC change computation

$$\Delta OHC(t) = \frac{TSSL_{ref} + \Delta SL(t) - \Delta HSSL(t) - \Delta OM(t)}{IEEH(t)} - \frac{TSSL_{ref}}{IEEH(t_0)}$$



with

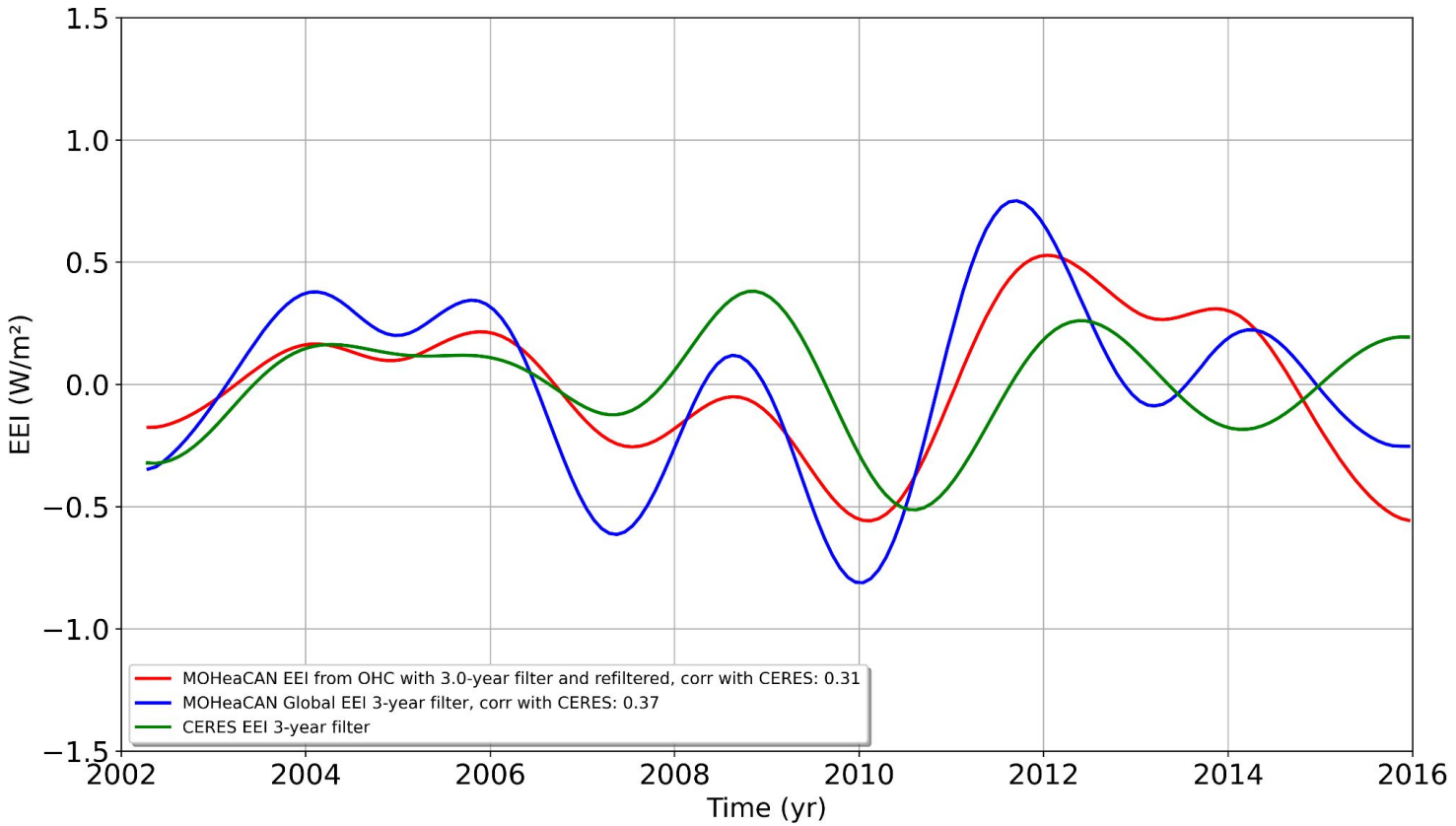
$$\Delta SL(t) = SL(t) - SL(t_0)$$

$$\Delta OM(t) = OM(t) - OM(t_0)$$

$$\Delta HSSL(t) = HSSL(t) - HSSL(t_0)$$

Appendices - EEI sensitivity to filtering

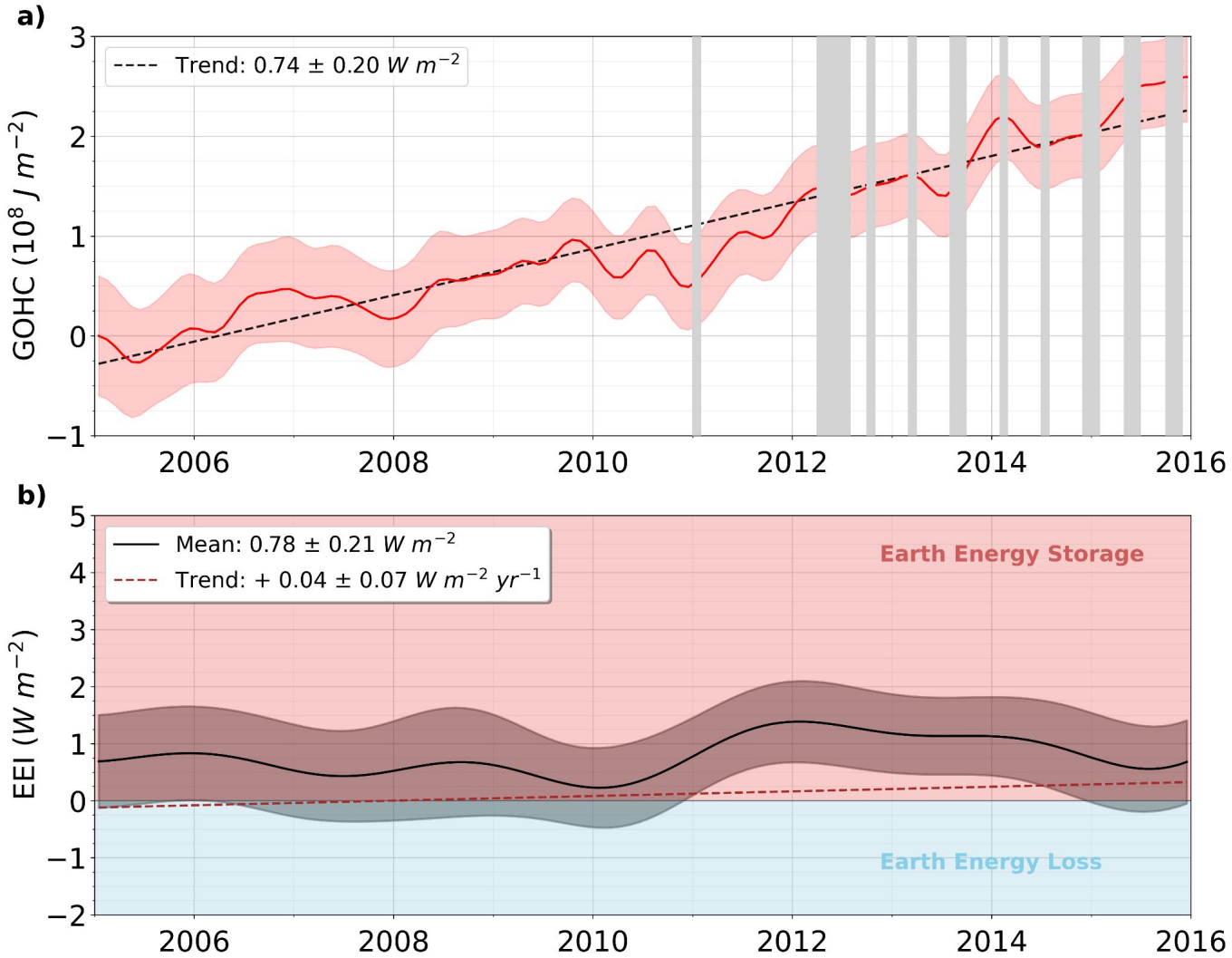
- En vert : EEI CERES après avoir filtré les hautes fréquences à 3 ans (Lanczos)
- En bleu et rouge : EEI géodésique spatial (avec HS V1.5.1)
  - En bleu : après avoir filtré les HF du GOHC à 3 ans
  - En rouge : après avoir filtré les HF des OHC locales à 3 ans, puis refiltré les HF résiduelles du GOHC à 3 ans



Results - Global ocean heat uptake and energy imbalance

Step 3

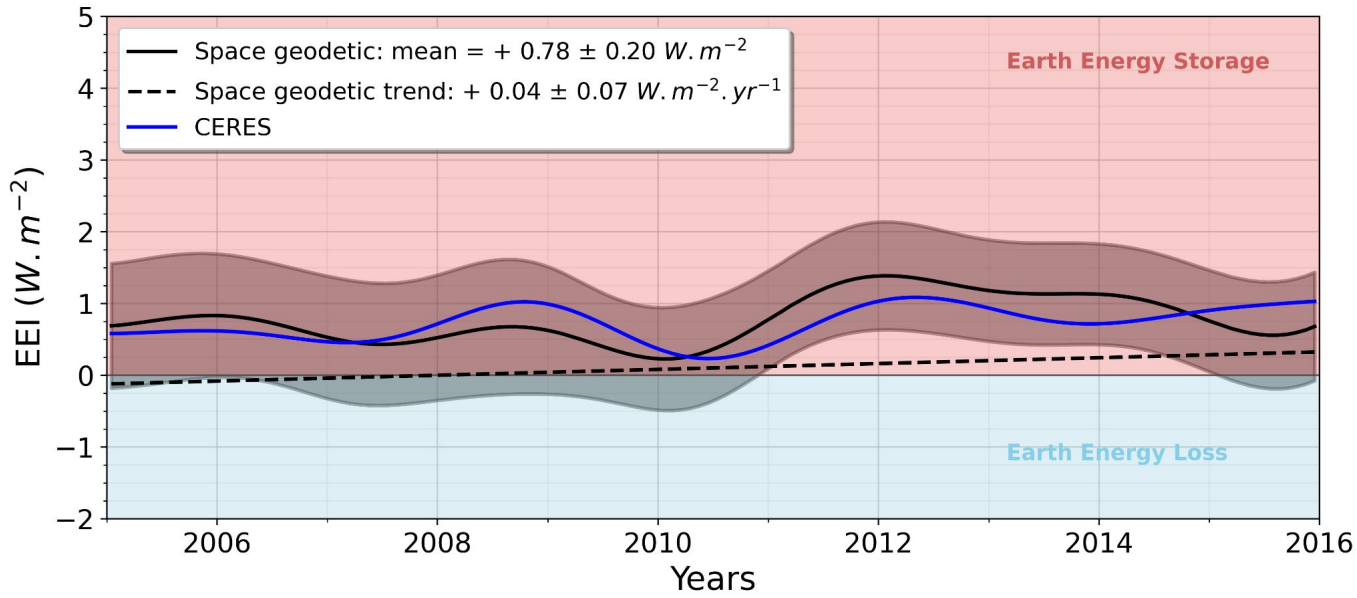
Step 4



- Computation of the OHC/EEI climate indicators over the period January 2005 - December 2015 period:
  - EEI highlights a positive mean value of **+0.78 W.m^{-2}**
  - with an uncertainty of **0.21 W.m^{-2} (90% CL)**

Earth climate system is storing energy

Assessment



- January 2005 - December 2015
- CERES mean : 0.78 W/m²
- Space geodetic mean : 0.78 +/- 0.20 W/m²