Monitoring the Ocean Heat Content and the Earth Energy Imbalance from space: the MOHeaCAN product

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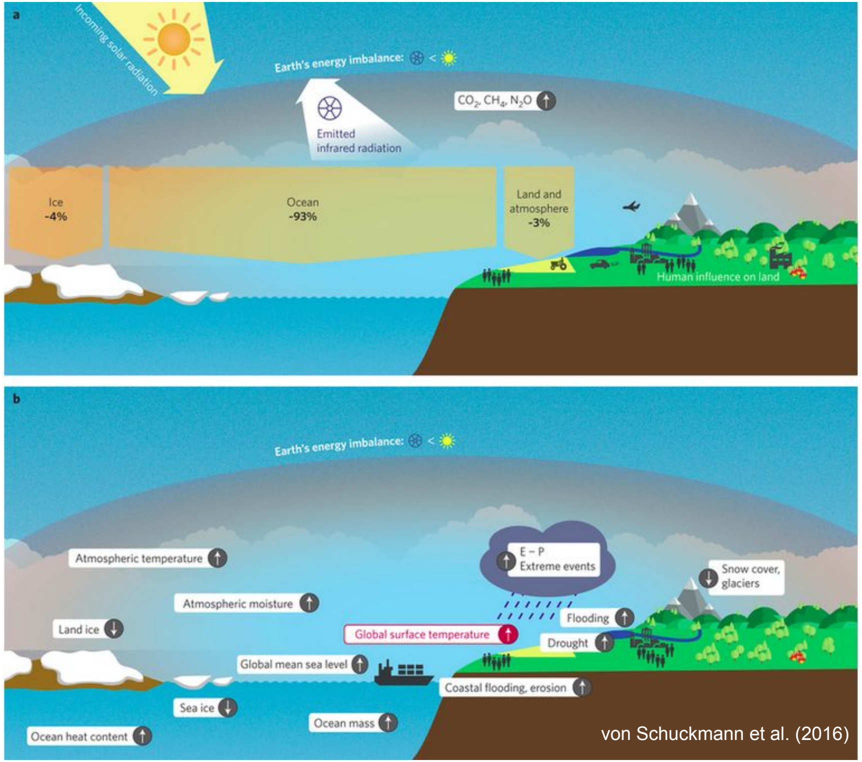
- ➔ Earth energy imbalance (EEI) indicator provides a quantitative estimate of climate change. Recent studies suggest that the EEI response to anthropogenic greenhouse gases and aerosols emissions is 0.5-1 W.m^{-2} (<< 340 W.m^{-2} incoming solar radiation).

- ➔ 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 (93% EEI)

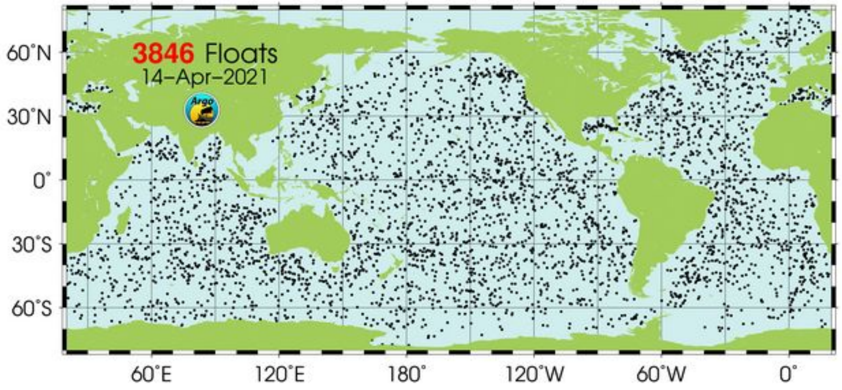


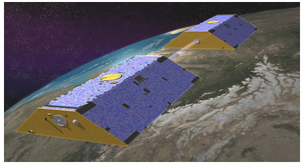
von Schuckmann et al. (2016)

Different approaches

➔ OHC can be derived from different approaches:

- the direct measurement of in situ temperature based on temperature/Salinity profiles (e.g. ARGO floats),
- the measurement of the ocean surface net fluxes from space observations,
- the estimate from ocean reanalyses that assimilate observations from both satellite and in situ instruments,
- **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 “altimetry-gravimetry”).**





The physical principle

➔ The "altimetry-gravimetry" approach relies on the Sea Level budget equation:

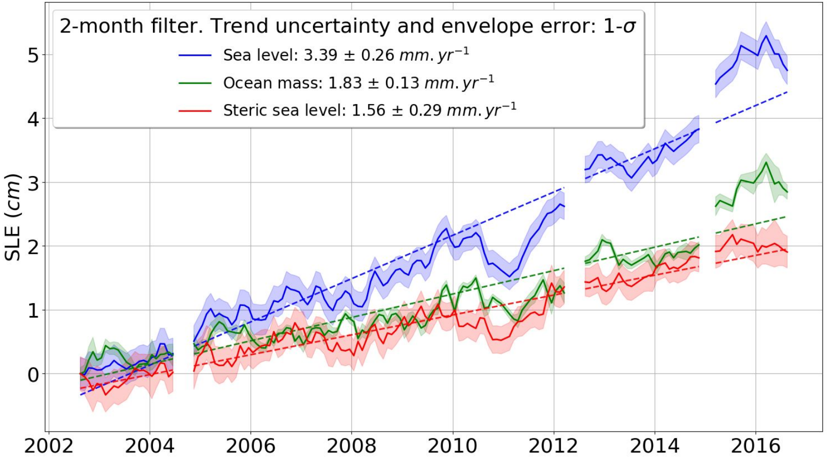
$$\Delta SL_{total} = \Delta SL_{steric} + \Delta SL_{mass}$$

At global scale, thermal sea level change is given by:

$$\Delta GMSL_{steric} = \Delta GMSL_{total} - \Delta GMSL_{mass}$$

➔ Processing of the climate indicators:

- Ocean heat content change $\Delta GOHC = \frac{\Delta GMSL_{thermosteric}}{\varepsilon}$
- Earth energy imbalance $EEI \simeq \frac{d\,GOHC}{dt}$



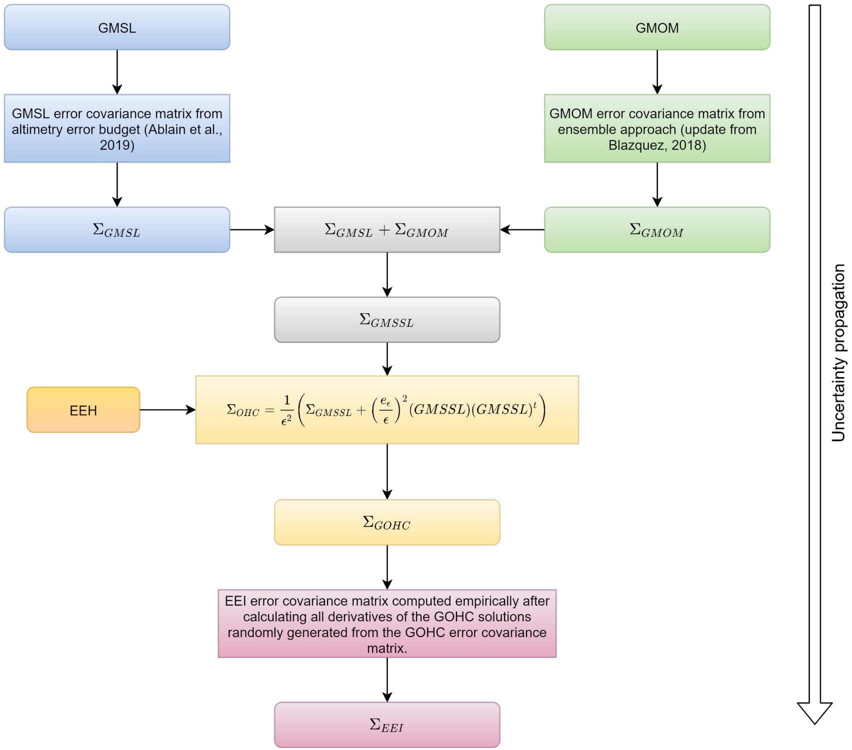
Global Mean Steric Sea Level (red curve) inferred from Altimetry Sea level (blue curve) and Ocean Mass from gravimetry data (green curve)

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

➔ **The uncertainties propagation has been specified at <u>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.



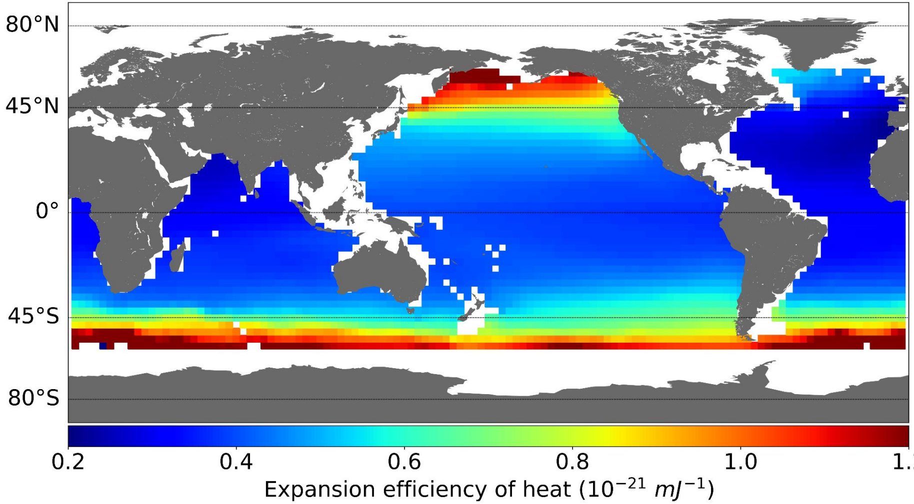
Expansion Efficiency of Heat

➔ **Estimation of the expansion efficiency of heat (EEH) at <u>regional</u> 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 2005-2016 period

➔ **New estimate of the global EEH:** ε = 0.15 ± 0.03 m.YJ^{-1}

EEH map defined on 3°x3° resolution grid



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

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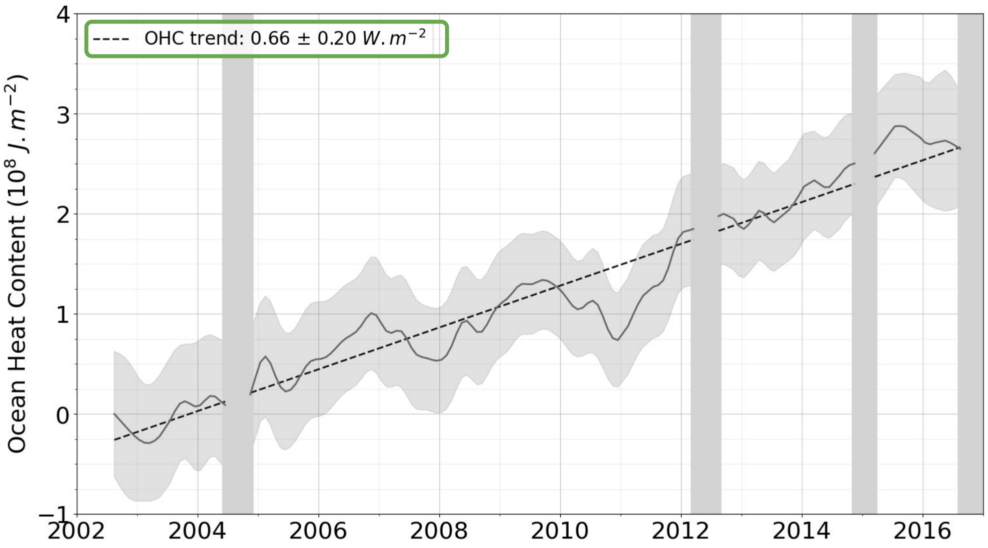
OHC change at global scale

➔ **Computation of the OHC/EEI climate indicators over the period August 2002 - August 2016**

- GRACE mission: April 2002 - October 2017



➔ Positive mean value (0.66 W m^{-2}): Earth climate system is storing energy

➔ Trend uncertainty: 0.20 $W.m^{-2}$ (90% CL)

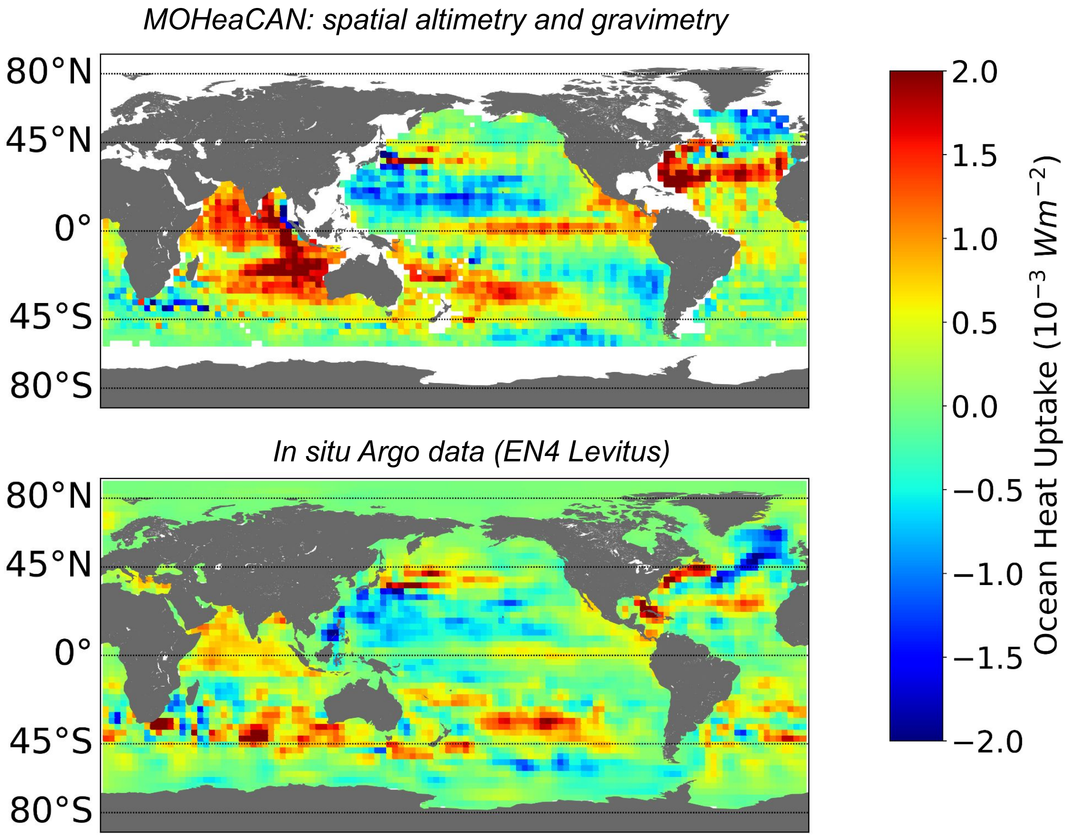
➔ Error envelop superimposed (1-σ)

➔ Comparison against in situ data (01/2005 - 12/2015)

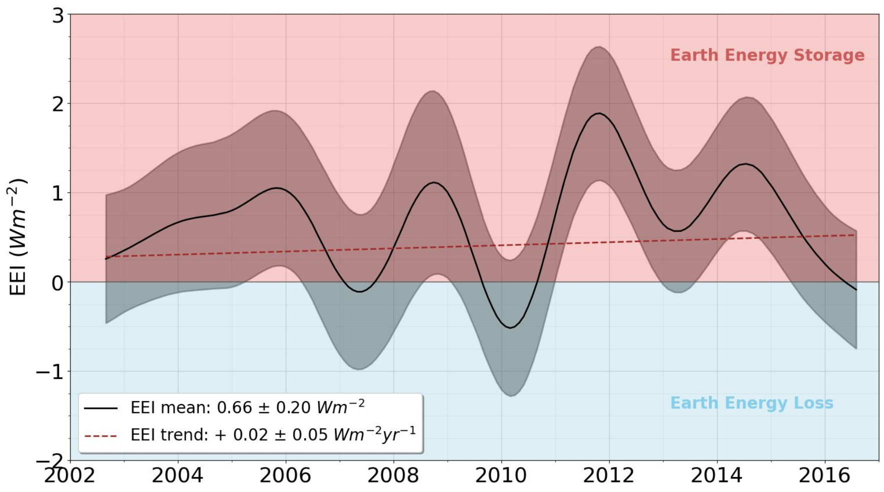
Data type	Depth range	GOHC trend (W m^{-2})
Temperature and salinity profiles from Argo network (average of 11 solutions)	0-2000m + deep ocean contribution of +0.07 W m^{-2}	+0.59 ± 0.13
Satellite data from altimetry (C3S) and gravimetric (GRACE ensemble mean based on spherical harmonic approach) missions	0-bottom	+0.67 ± 0.23

OHC change at regional scales

- ➔ OHC change estimated at regional scales for the first time
- ➔ Spatial patterns consistent with the main climate mode fingerprints
- ➔ Comparison to in situ data: good spatial coherence
- ➔ Preliminary results - limitations:
  - ◆ Halosteric signal is accounted for the OHC computation
  - ◆ OHC is provided on 84% of the ocean surface



EEI indicator



Evolution of EEI for periods higher than 3 years:

- ➔ Uncertainty envelop superimposed (1-σ)
- ➔ **Objective is to reduce the uncertainty level to identify what signals are related to anthropogenic forcing (≠ natural variability or error) ?**
- ➔ Interannual signals of EEI to be investigated
  - ◆ CERES space data

Conclusions & Perspective

- ➔ Proof of concept of a new altimetry/gravimetry approach
  - ◆ Ocean heat uptake consistent with in-situ datasets
  - ◆ Uncertainty propagation
- ➔ OHC and EEI climate indicators freely available (Aviso website)
  - ◆ https://doi.org/10.24400/527896/a01-2020.003
  - ◆ Algorithm Theoretical Basis Document & Product User Manual
  - ◆ Peer review paper in preparation
- ➔ Perspective :
  - ◆ to better understand and estimate EEI inter-annual variations
  - ◆ improvement of uncertainties characterisation to reach 0.1 W m^{-2} at inter-annual scales
  - ◆ extension of temporal time series (e.g. use of GRACE-FO mission)
  - ◆ extension of spatial coverage (e.g. extrapolation of EEH grid)

Waiting for your feedback

Thanks!
Any questions? →florence.marti@magellium.fr

References

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Supplementary material

➔ **Comparison / validation against other datasets over the period January 2005 - December 2015**

- GOHC trends (or mean EEI) in agreement within error bars (90% CL)

Data type	Sources	Depth range	GOHC trend ($W\ m^{-2}$)
Temperature and salinity profiles from Argo network	Average OHC solutions provided by several international groups	0-2000m + deep ocean contribution of +0.07 $W\ m^{-2}$	$+0.59 \pm 0.13$
Combination of in situ data (Argo network) and reanalyses	Ocean heat content from CMEMS (Ocean Monitoring Indicator)	0-700m	$+0.60 \pm 0.25$
Satellite data from altimetry and gravimetric missions	Sea-level grids from C3S: Ensemble of 216 solutions based on spherical harmonic approach	0-bottom	$+0.67 \pm 0.23$
Satellite data from altimetry and gravimetric missions	Sea-level grids from C3S: Ensemble of 3 solutions based on mascon approach (JPL, CSR, GSFC)	0-bottom	$+0.52 \pm 0.21$

Monitoring the ocean heat content and the Earth energy imbalance from space altimetry and gravimetry missions, Marti et al, in preparation.

Supplementary material

Focus on uncertainties:

- ➔ Sea level - Ablain et al., 2019: error budget approach
- ➔ Ocean mass - update of Blazquez et al., 2018 : ensemble based on spherical harmonic approach. Solutions derived from different centers and a large variety of choices for post-processing corrections:
  - ➔ the geocenter motion,
  - ➔ oblateness of the Earth,
  - ➔ atmosphere ocean dealiasing,
  - ➔ filtering of the noise responsible among other for the characteristic stripes of GRACE gravity data,
  - ➔ leakage from continental signals over the oceanic domain,
  - ➔ glacial isostatic adjustment (GIA).

Source of errors	Error category	Uncertainty level (at 1σ)
High-frequency errors: altimeter noise, geophysical corrections, orbits	Correlated errors ($\lambda = 2$ months)	$\sigma = 1.7$ mm for TOPEX period $\sigma = 1.5$ mm for the Jason-1 period. $\sigma = 1.2$ mm for the Jason-2/-3 period.
Medium-frequency errors: geophysical corrections, orbits	Correlated errors ($\lambda = 1$ year)	$\sigma = 1.3$ mm for the TOPEX period $\sigma = 1.2$ mm for the Jason-1 period. $\sigma = 1$ mm for the Jason-2/-3 period.
Large-frequency errors: wet troposphere correction	Correlated errors ($\lambda = 5$ years)	$\sigma = 1.1$ mm over all the period ($\Longleftrightarrow$ to 0.2 mm yr^{-1} for 5 years)
Large-frequency errors: orbits (gravity fields)	Correlated errors ($\lambda = 10$ years)	$\sigma = 1.12$ mm over the TOPEX period (no GRACE data) $\sigma = 0.5$ mm over the Jason period ($\Longleftrightarrow$ to 0.05 mm yr^{-1} for 10 years)
Altimeter instabilities on TOPEX-A and TOPEX-B	Drift error	$\delta = 0.7$ mm yr^{-1} on the TOPEX-A period $\delta = 0.1$ mm yr^{-1} on the TOPEX-B period
Long-term drift errors: orbit (ITRF) and GIA	Drift error	$\delta = 0.12$ mm yr^{-1} over 1993–2017
GMSL bias errors to link altimetry missions together	Bias errors	$\Delta = 2$ mm for TP-A/TP-B $\Delta = 0.5$ mm for TP-B/J1, J1/J2, J2/J3.