



## The Global Energy and Water Exchanges (GEWEX) Earth's Energy Imbalance Assessment

M. Hakuba, T. Boyer, S. Fourest, J. Carton, B. Meyssignac, G. Forget, S. Kato and many more  
OSTST 2023, November, 2023



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# Content

- Intro & Background
- EEI in CERES EBAF
- Phase 1 GEWEX EEI inter-comparison
- Systematic discrepancies across observing systems
- Workshop Recommendations

# WCRP GEWEX Data and Analysis Panel (GDAP)

## New Integrated Assessment on Earth's Energy Imbalance (EEI)

Leads: **Benoit Meyssignac** and **Tim Boyer**

### Background and goals:

- A range of EEI estimates are available, often with error bars that are difficult to robustly trace to measurement principles.
- GDAP assesses currently available EEI estimates from observations. Since the ocean stores ~90% of the total planetary heat uptake, the EEI assessment focuses on **intercomparing estimates of the time rate of change of ocean heat content** (ocean heat uptake). This first EEI assessment will focus on:
  - (a) Understanding the spread of global and regional ocean heat content and ocean heating rate among products.
  - (b) Determining systematic errors that depend on assumptions, models, and combined observations.
  - (c) Understanding the spread of uncertainties depending on the methods and formulae used.

<https://www.gewex.org/panels/gewex-data-and-analysis-panel/gdap-projects/>



## GEWEX-EEI: Objectives & science questions

<https://sites.google.com/magellium.fr/eeiassessment/>

### Objectives:

- Inter-comparison of EEI/OHC products with uncertainties, focusing on interannual to longer time scales.
- Provide overview on available data records, meta data and evaluation results.
- Inform on common robust EEI variability present in all EEI records and identify and explain inconsistencies among data records.
- Focus on EEI, but also Ocean Heat Content (OHC, J) and Ocean Heat Uptake (OHU,  $\text{Wm}^{-2}$ ).

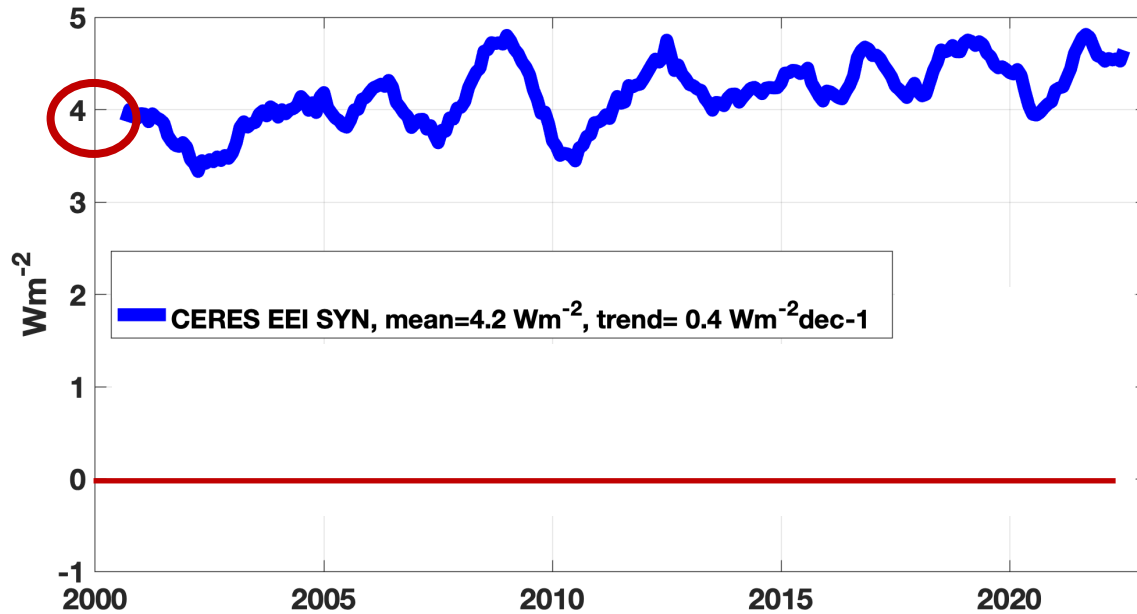
### Sciences questions:

- What are the uncertainties in the observed mean and temporal change in EEI for each product?
- How large are the differences in observed mean and temporal change across EEI/OHC products?
- Do the OHU records exhibit areas/periods of distinct quality and how can differences and limitations be explained?
- What is the quality of OHU products in the lowermost part of the ocean? At high latitudes?
- How do OHC/EEI estimates compare between **satellite, in situ** and **reanalysis/ocean state** estimates?

### Info & outcome:

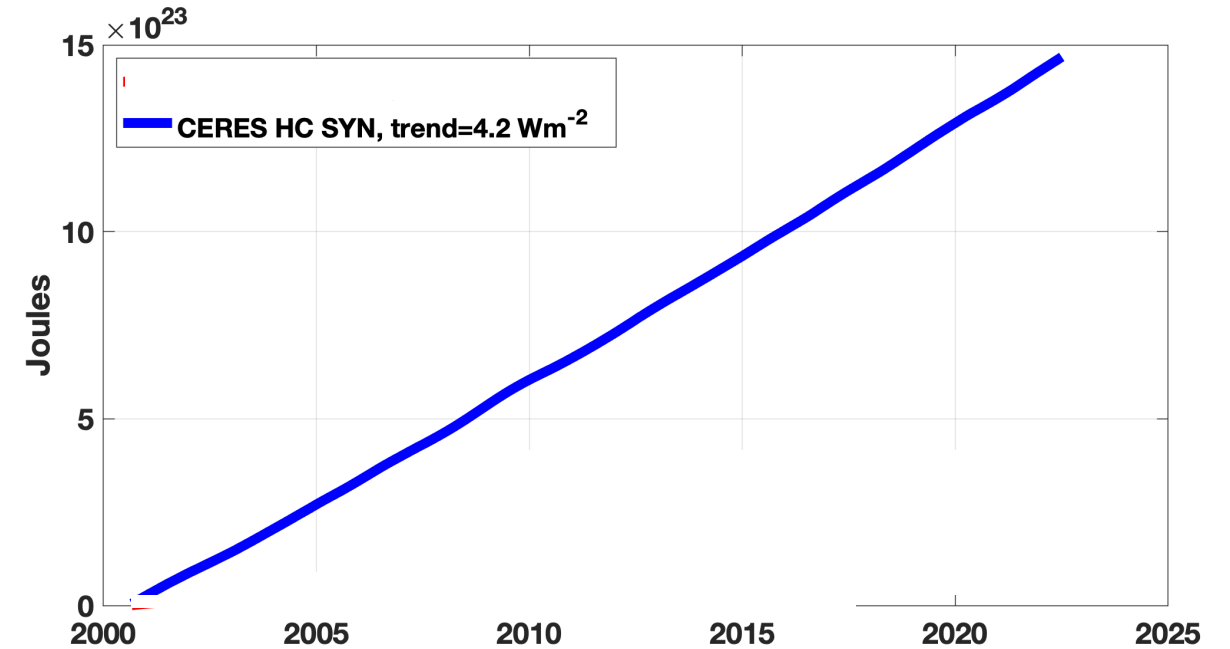
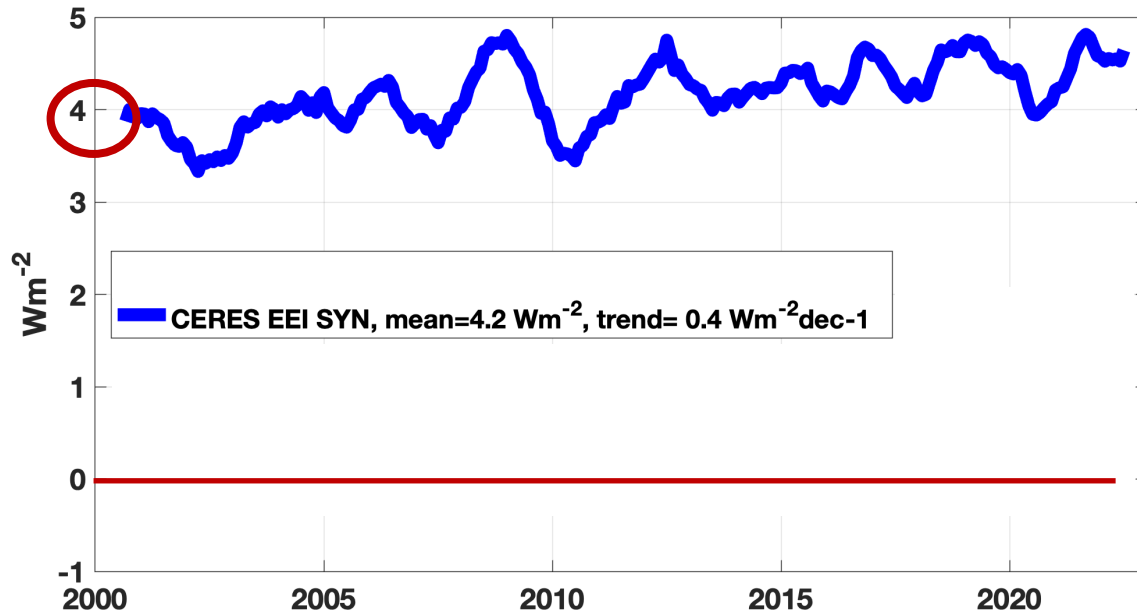
- This assessment will last a few years, with several workshops held.
- WCRP report on G-EEI delivered to GEWEX for revision and a summary paper.

# Excursion: EEI derived from CERES data



- Non-energy- balanced CERES SYN data record suggests mean EEI of  $4 Wm^{-2}$  due to mainly calibration uncertainty
- Not reconcilable with other estimates of EEI, radiative forcings and feedbacks

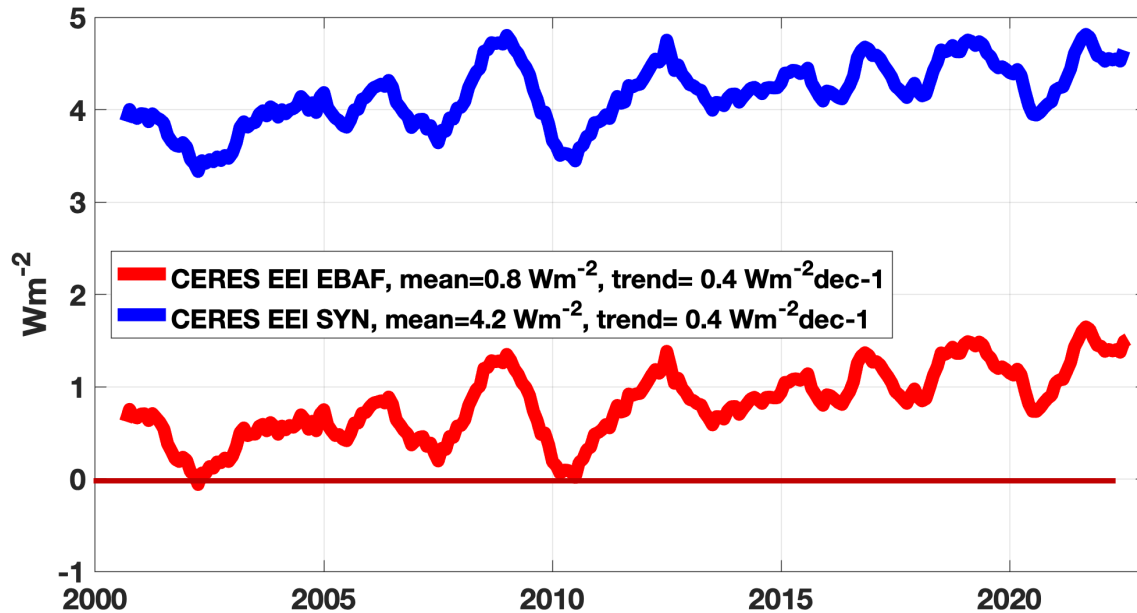
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- Cumulative EEI = Heat content change exceeds average OHC rates on the order of  $15 ZJ/yr$  by almost 1 order of magnitude ( $125 ZJ/yr$ ).

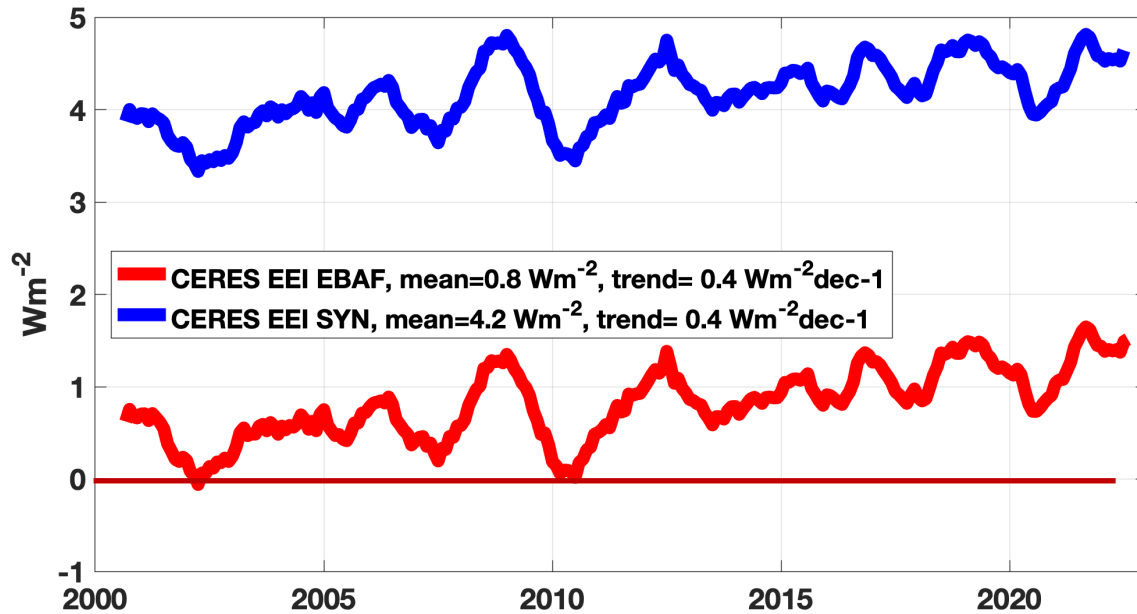
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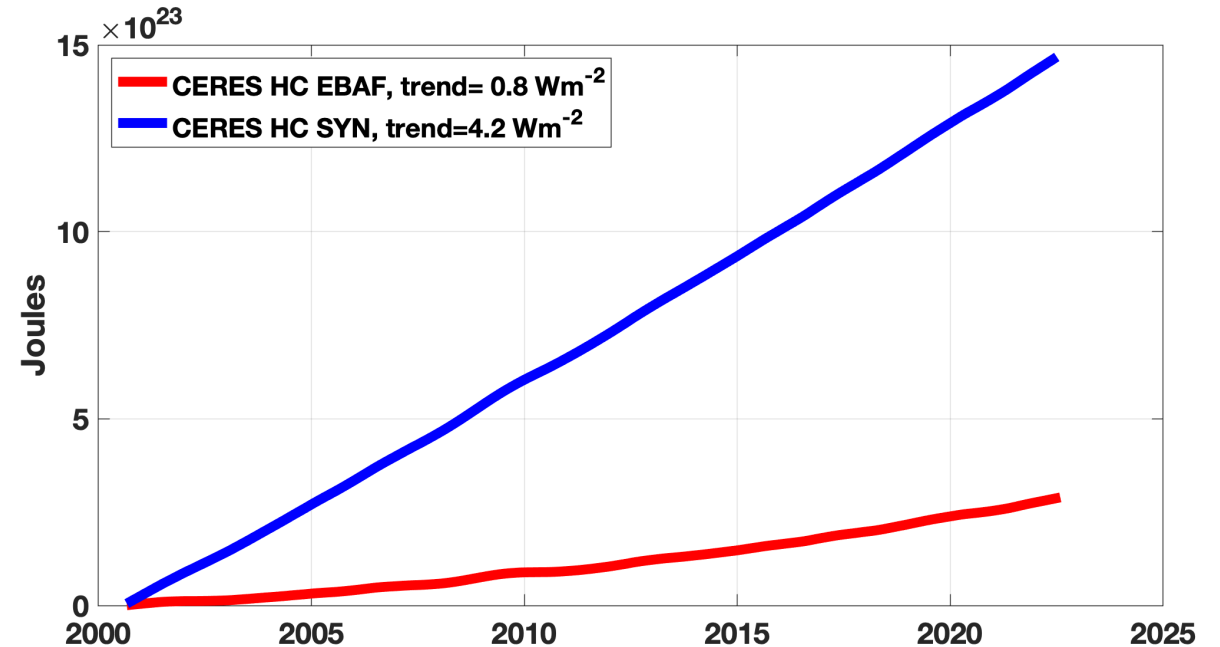
- CERES EBAF adjustment matches EEI average to heat inventory estimate (Johnson et al., 2016) and yields  $0.8 Wm^{-2}$  for above period.
- Temporal variability and trend are unaffected by correcting for this “offset”!



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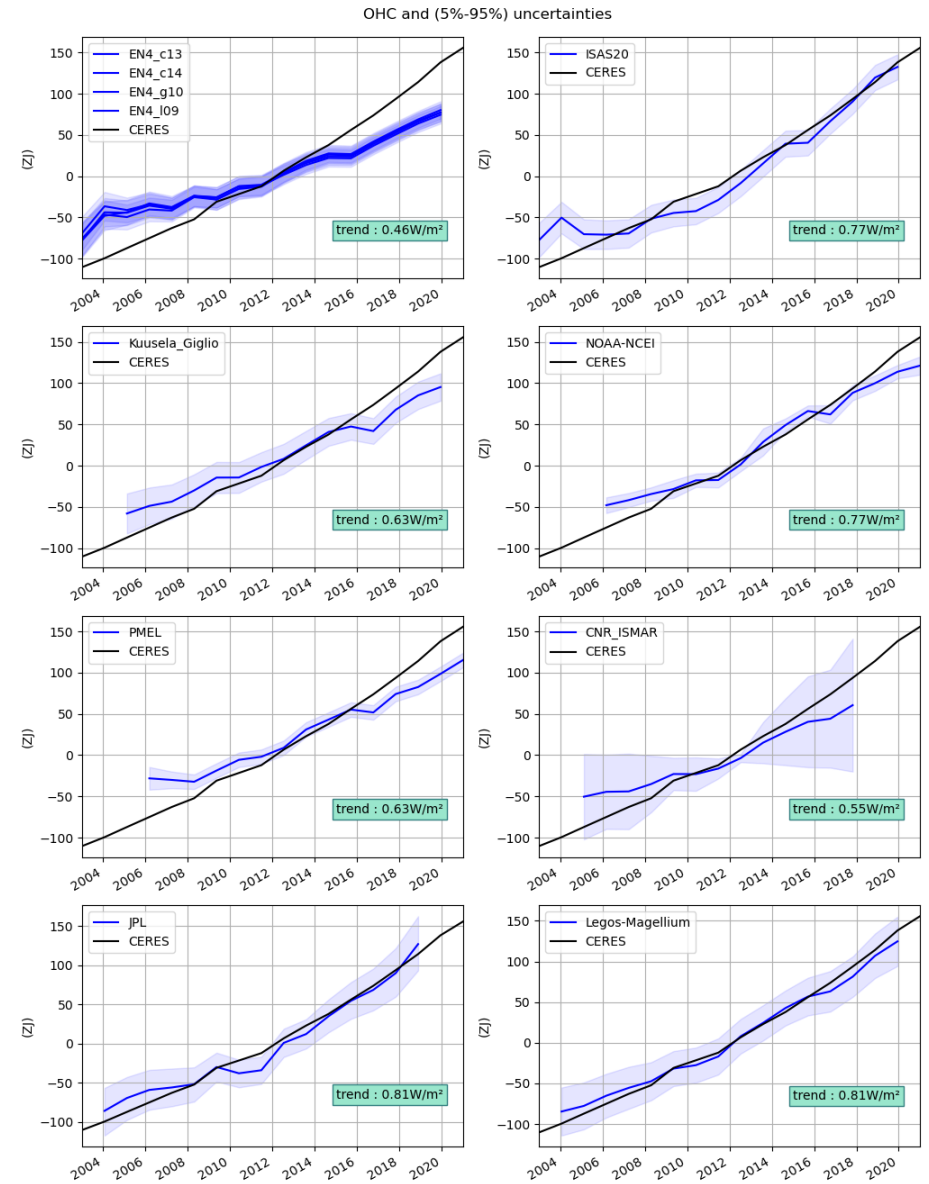
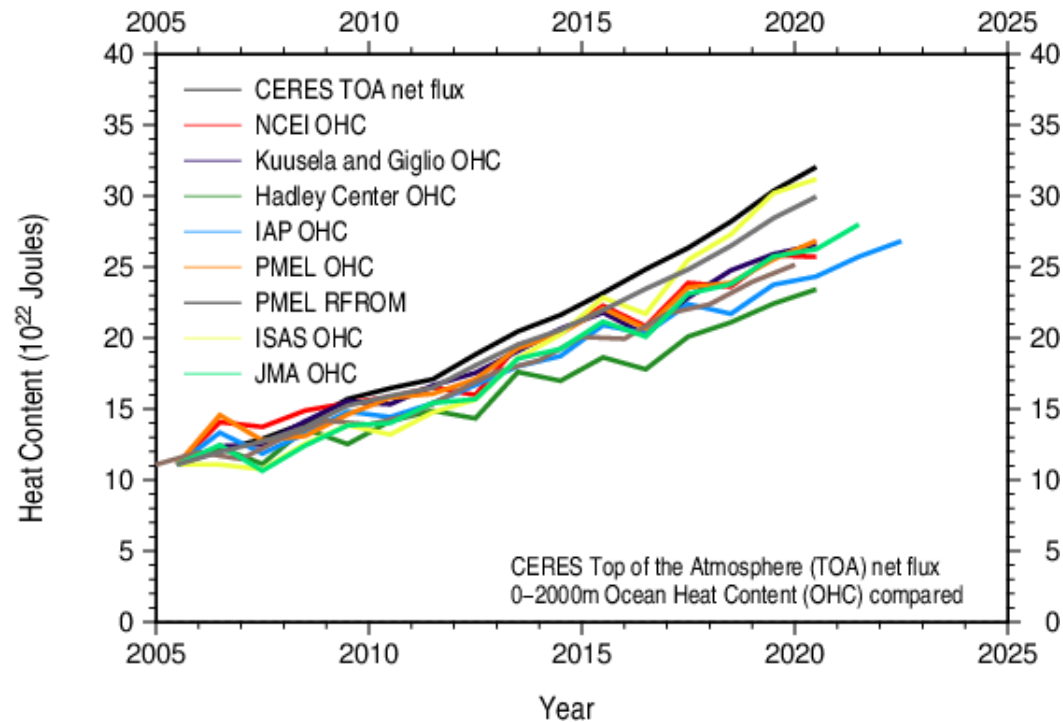


- EBAF heat content change is constrained to match heat inventory and is therefore not an independent estimate to compare with Argo etc. – but the EEI trend (left) and year-to-year variability (left) is!



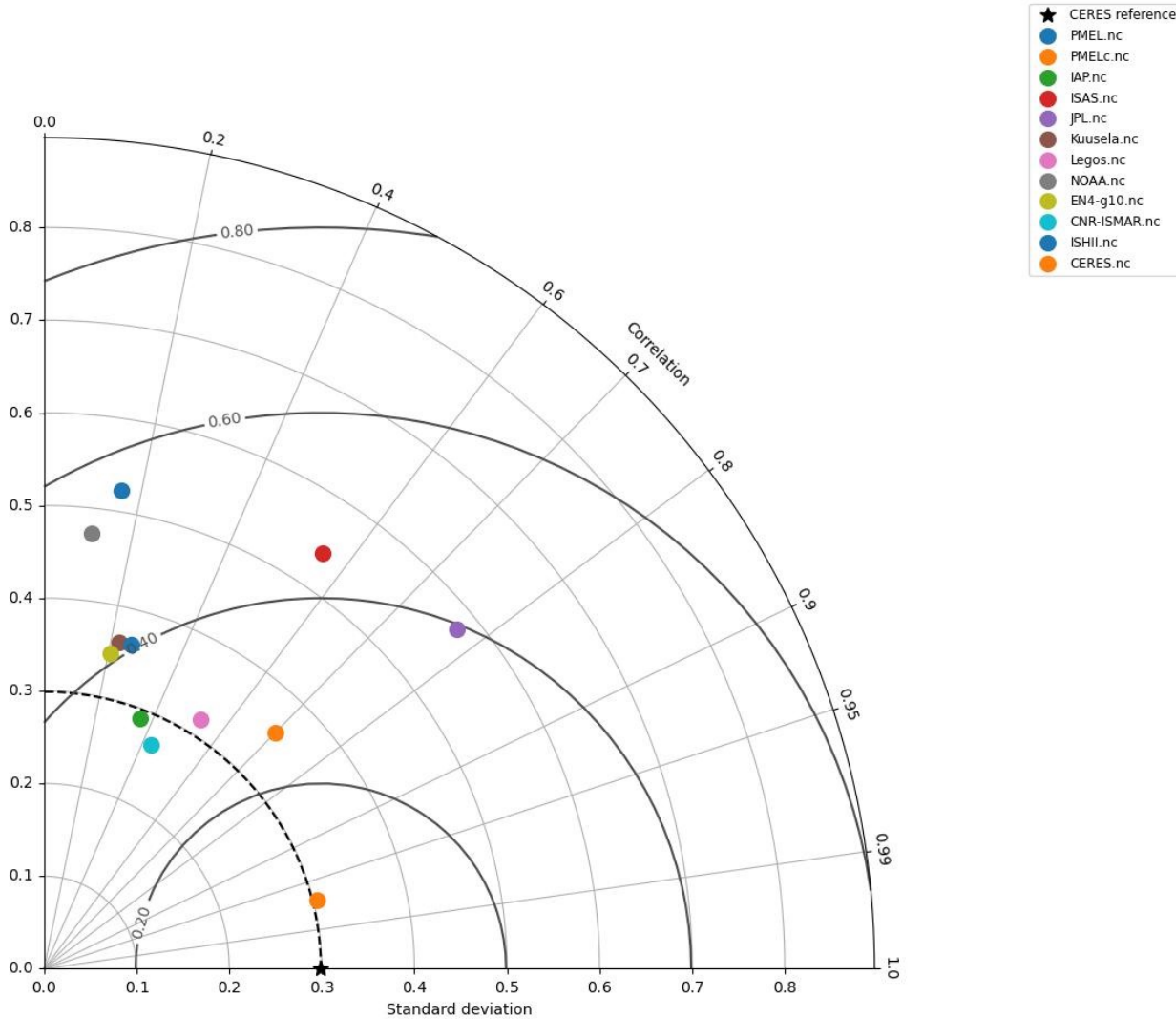
# GEWEX-EEI assessment

- Substantial spread in annual global OHC estimates can have various reasons:
  - Input data & Quality control
  - Mapping/interpolation techniques
  - Calculus: OHC & OHU derivation
  - Sampling, coverage, ocean mask



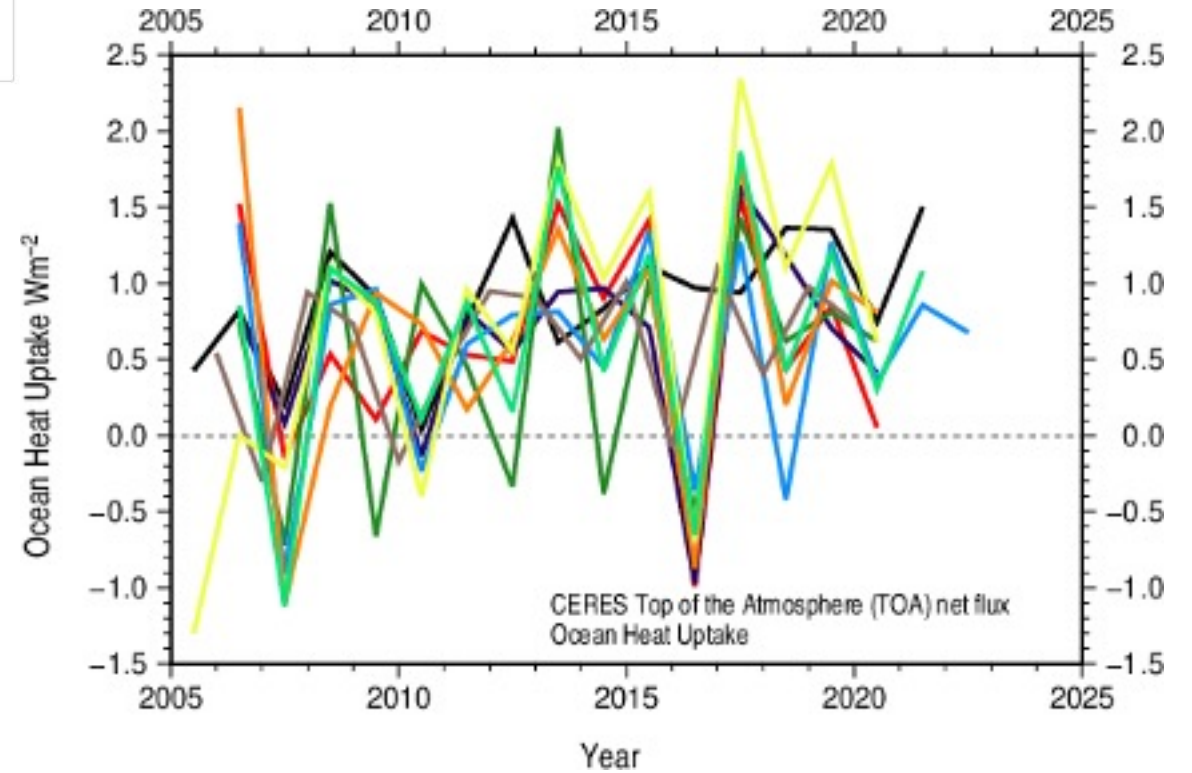
Satellite

# GEWEX-EEI assessment



Ocean heat uptake ( $dOHC/dt$ ) is expected to correlate with CERES net radiative flux at TOA at interannual and longer time scales.

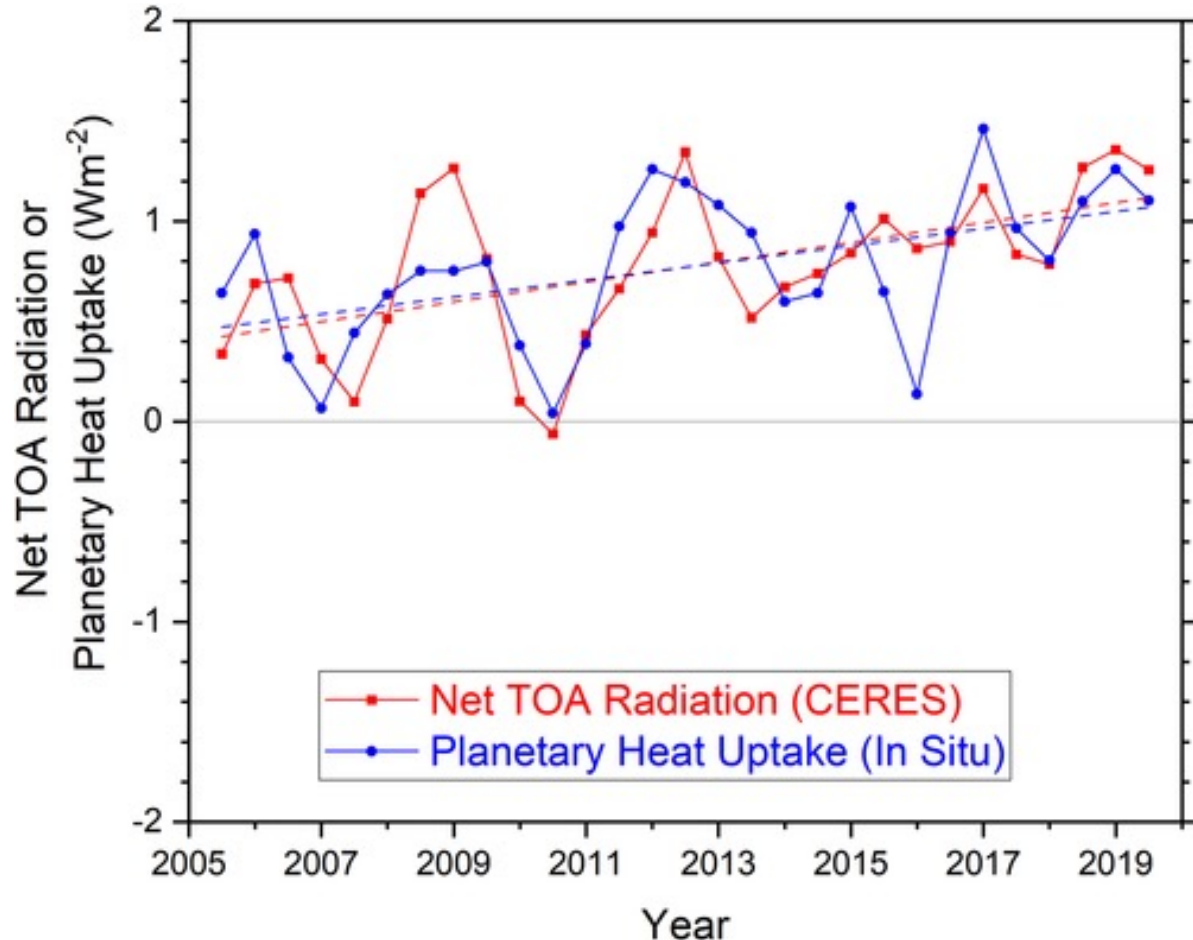
At first glance, OHU year-to-year variability from in-situ data does not match all to well with CERES EEI



T. Boyer

# GEWEX-EEI assessment

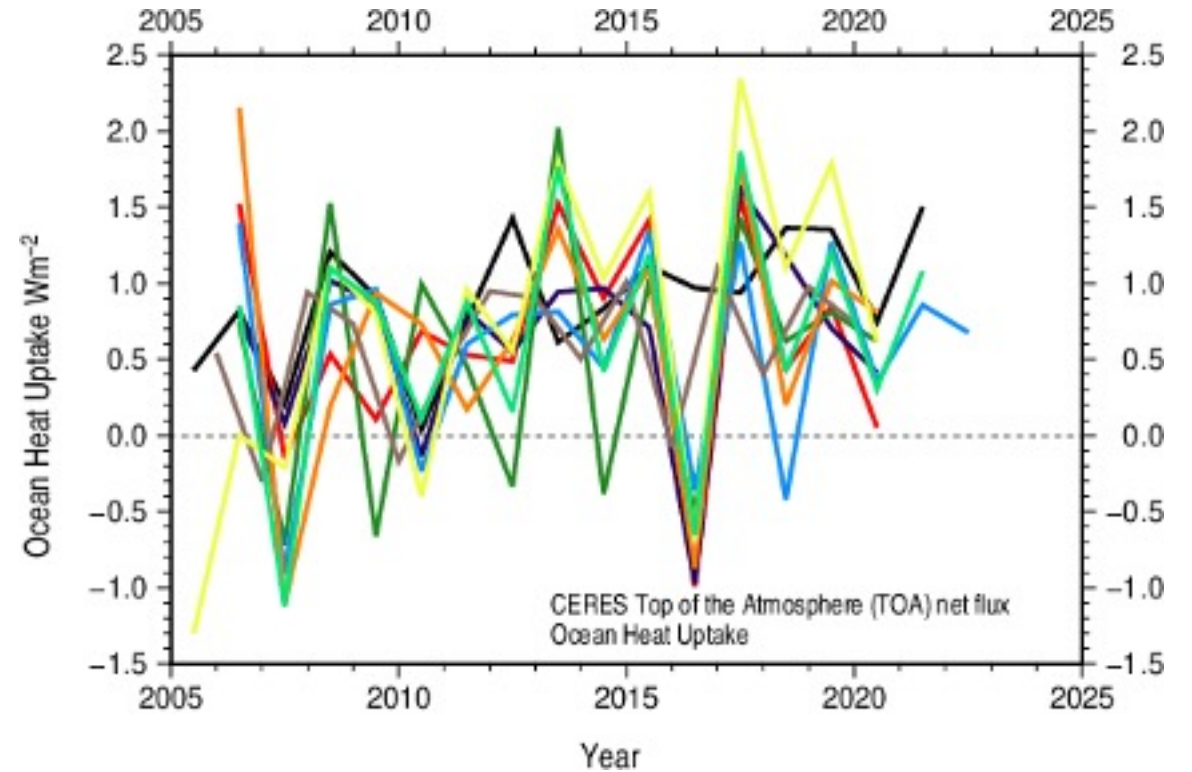
However, Very good agreement CERES EBAF EEI with PMEL combined OHU (in-situ + altimetry)



N. Loeb et al.: Satellite and Ocean Data Reveal Marked Increase in Earth's Heating Rate, 2021; **annual means at 6-months increments**

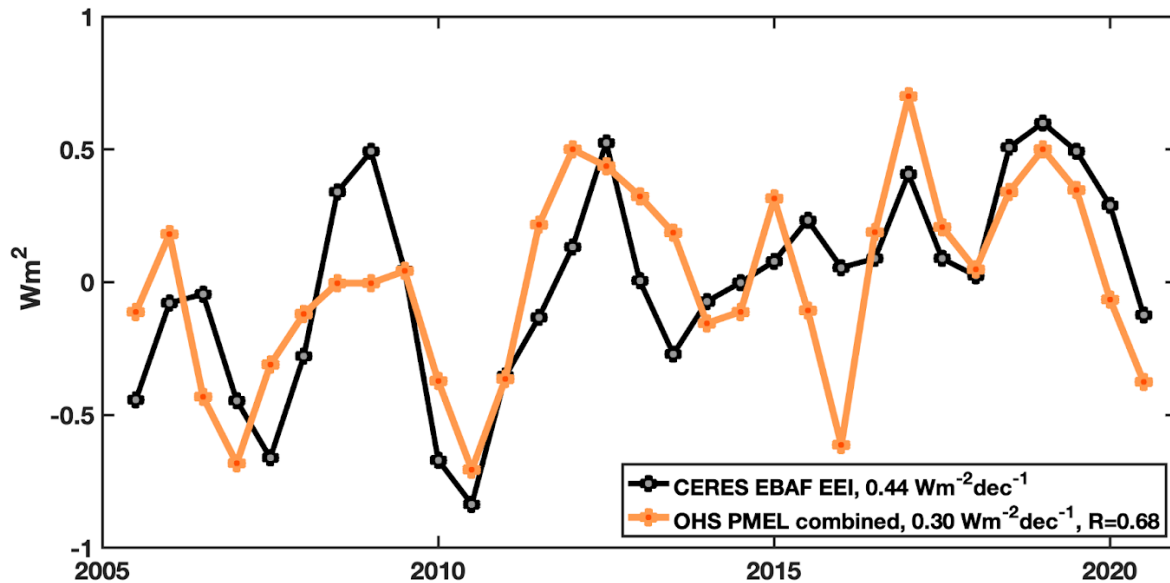
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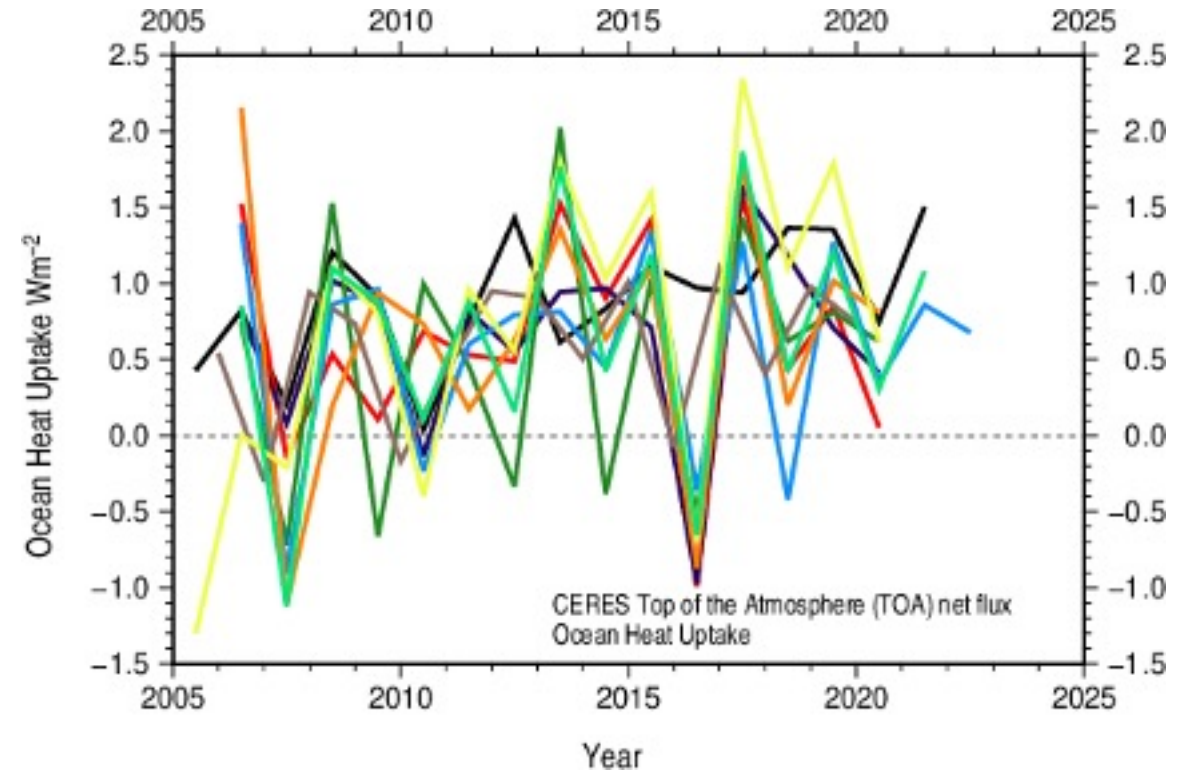
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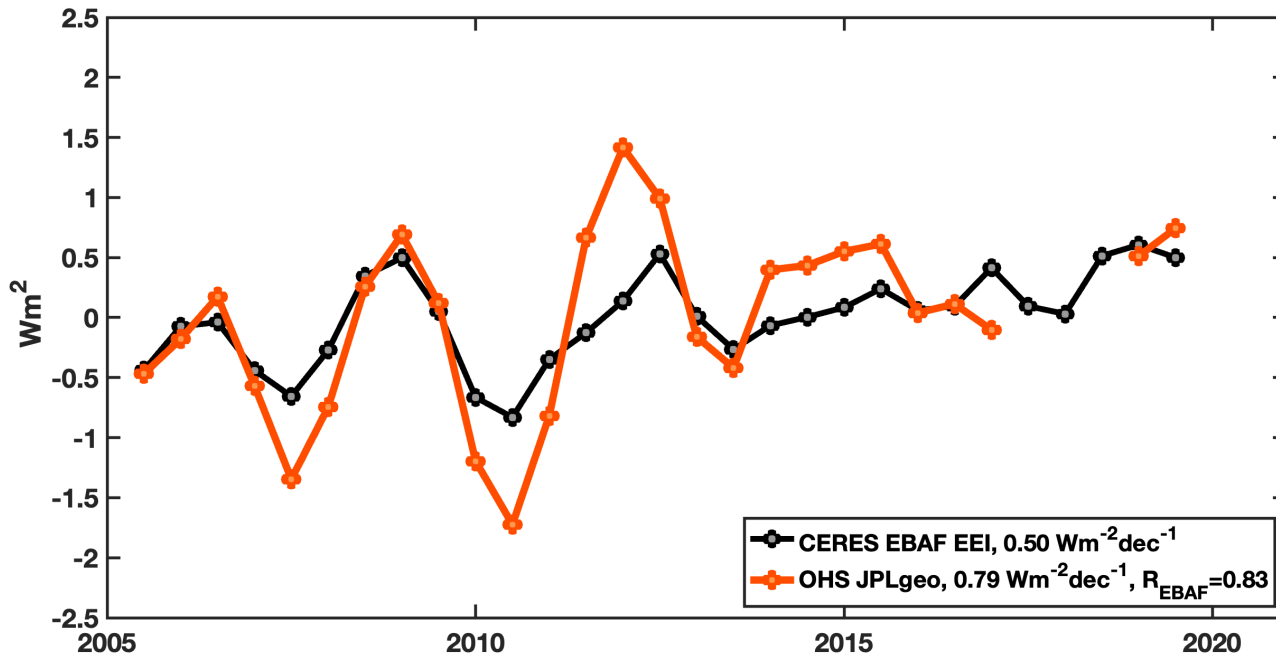


Our update to Loeb et al., 2021; annual means at 6-months increments



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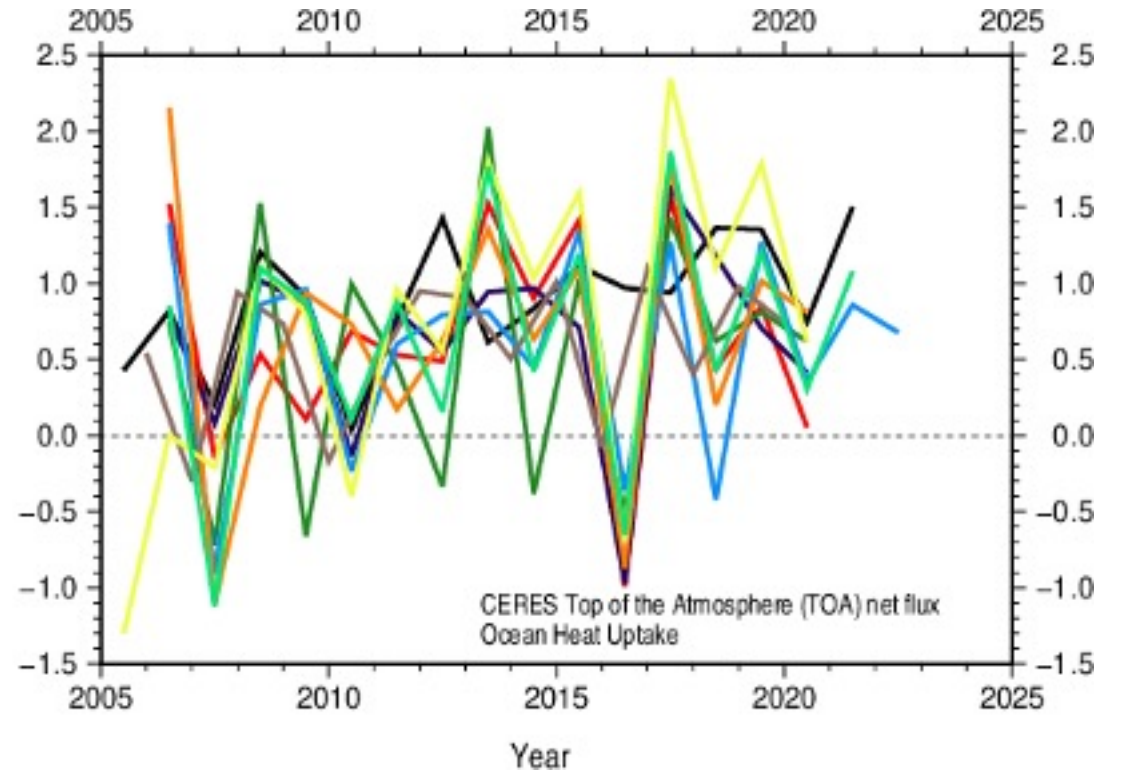
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Our update to Hakuba et al., 2021; satellite-based geodetic OHU, **annual means at 6-months increments**

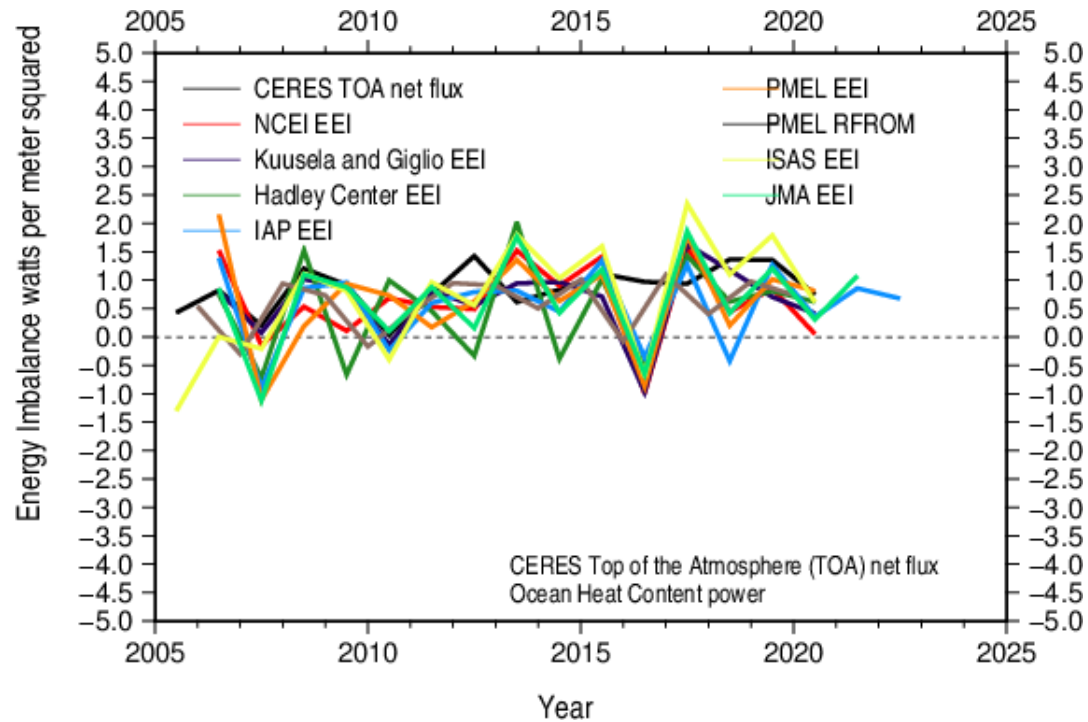
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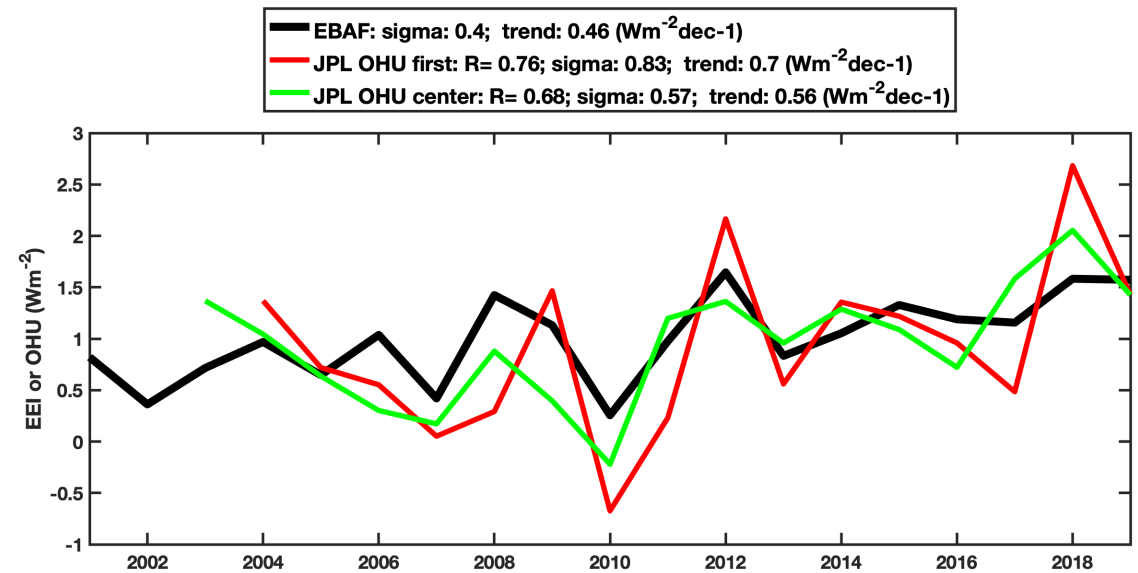


# GEWEX-EEI assessment

Results are sensitive to the derivation of OHU!  
Best practices need to be investigated.



Pretty good agreement with CERES EBAF EEI at 12-month intervals, but highly sensitive to methods.



# Systematic investigation into causes for discrepancies

- There is evidence that **spatiotemporal coverage/sampling of OHC** is essential for matching variability in CERES EBAF (higher correlation and comparable trends found for in-situ+altimetry and satellite-based products) and **causing OHU discrepancies.**
- Upcoming initiative: MapEval4OceanHeat (M. Palmer, D. Giglio, C. Domingues, D. Montelesan)
- Sensitivity of Global Upper-Ocean Heat Content Estimates to Mapping Methods, XBT Bias Corrections, and Baseline Climatologies (Boyer et al., 2016)
- International Quality-Controlled Ocean Database (IQuOD) v0.1: The Temperature Uncertainty Specification (Cowley et al., 2021)
- ...



## Workshop summary & recommendations

<https://www.wcrp-esa-eeia-2023.org/workshop-report>

B. Meyssignac, M. Hakuba, S. Kato, T. Boyer, J. Benveniste

**1. Continue EEI assessment efforts in support of society**

**2. Expand assessment efforts to the regional scale**

(includes efforts for generating gridded geodetic estimates and improved surface energy budget)

**1. Assess consistency of EEI variability across methods**

**2. Characterize uncertainty of OHC estimates from in-situ, reanalysis and ocean state modeling, satellite data**

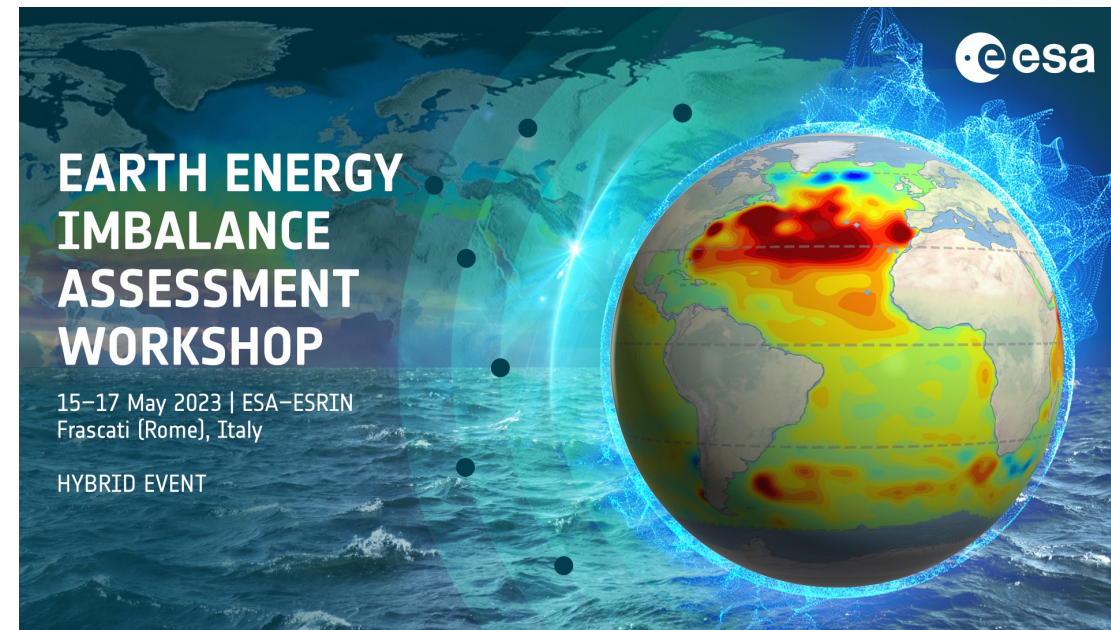
**3. Consider Hybrid OHC estimates to improve understanding of EEI variability and change**

**4. Define and implement best practices (e.g., OHC & OHU derivation on multiple time-scales)**

**5. Ensure continuity and intercalibration capabilities**

**6. Investigate the potential of novel observing system concepts**

**7. Attribute, understand and predict EEI changes**



# Conclusions

- GEWEX-EEI hopes to shed light on OHC discrepancies via systematic assessment of error sources across products and observing systems
- PHASE 1: intercompare global annual OHC from various groups 'as is' to document spread and inconsistencies
- “Best practices” needed to derive EEI/OHU for consistent comparison with CERES EBAF
- Regional estimates may serve to attribute global inconsistencies and help on the quest to better understanding of discrepancies in OHU and sea level budget
- Evidence that spatio-temporal sampling is indeed essential for portraying OHU variability consistently and that satellite data help to fill gaps; reanalysis and model comparison is in preparation.