Review Referee #1

First of all, we would like to thank the reviewer for its relevant questions and comments that will help improve the manuscript, both in terms of content and form.

This manuscript presents analyses of a time-series of EEI using satellite and in situ data, and compares it to time-series from Satellite (CERES) and in situ only estimates. One issue with this manuscript is that the estimate is framed as being "from space geodetic observations" but the key IEEH parameter is estimated from in situ data of ocean warming. Without those in situ measurement of ocean warming, the method would not be feasible. This fact needs to be emphasized in the revised manuscript.

The space geodetic GOHC/EEI estimates are indeed not fully independent from in situ observations, however we opted to call the approach “space geodetic because ECCO data (here, or in situ observations in Marti et al., 2022) are only used to derive static information. The mean IEEH value (over 2005-2015) is assumed to be representative of the total study period (see also answer to question#6). In this study, we relied on the ECCO outputs to estimate the IEEH parameter, unlike Marti et al., 2022 for which IEEH was directly derived from in situ observations. We are aware that the ECCO model assimilates Argo and other observational datasets, here is why we chose to illustrate the consistency between the results at global scale within Table 1.

→ We will emphasise in the manuscript that the knowledge of the warming pattern relies on situ observations.

Also, in general, the in situ estimates are much more certain than the "space geodetic" estimate, which should be acknowledged more directly in revision.

In our approach we intended to characterise the uncertainties associated with the input data as well as possible and then propagate them to the GOHC/EEI. Details are provided in Marti et al., 2022. The obtained trend uncertainty range results of the current knowledge on the uncertainties.
The comparison of the GOHC trends obtained with our approach and from in situ observations (Figure 2) clearly illustrates that the uncertainties associated with in situ based GOHC trends are lower than those from the space geodetic approach. However, for SIO, EN4, JAMSTEC, ISAS20, NOAA, the GOHC were estimated from T/S gridded fields. In such a way, we are able to generate GOHC timeseries in a homogeneous way, by considering data over a same mask (the one described as in Von Schuckmann et al., 2023, hereafter called “GCOS mask”) for instance. On the other hand, no uncertainty associated with T/S data was accounted for. The uncertainty trend eventually corresponds to the formal error adjustment of a linear model with the OLS method . No time-correlated effects are taken into account, leading to a lower estimate of the realistic uncertainty. For CORA dataset (and ARMOR3D, but in the next version of the manuscript we decided to simplify it and remove ARMOR3D dataset as it results from a mixed method), we directly used the GOHC time series which is not characterised by any uncertainty. Here also, the uncertainty is given by the formal error adjustment of a linear model with the OLS method.
To sum up, most of the in situ derived GOHC trend uncertainties are underestimated as they omit potential time-correlated errors. Moreover, the uncertainty linked to deep

ocean contribution (we used here the Purkey and Jonhson estimate) is not taken into account. They are therefore not comparable to the other uncertainties. Consequently, the reduced uncertainty ranges do not mean in practice that the in-situ GOHC trends are more reliable than space geodetic GOHC trends. Work is currently on-going (see presentation by Cheng et al. “An update for IAP ocean heat content data and implications for EEI” in 2023) to provide a new estimate of the GOHC accounting for realistic uncertainties related to the measurement, the different biases, the climatology, the interpolation, and mapping method. See also answer to question 3.

→ we will modify Figure 2 (preview of next version of Figure 2 below) so that the results whose trend uncertainty corresponds to the formal OLS error without characterisation of the data uncertainties are not interpreted by the reader in the same way as other results.

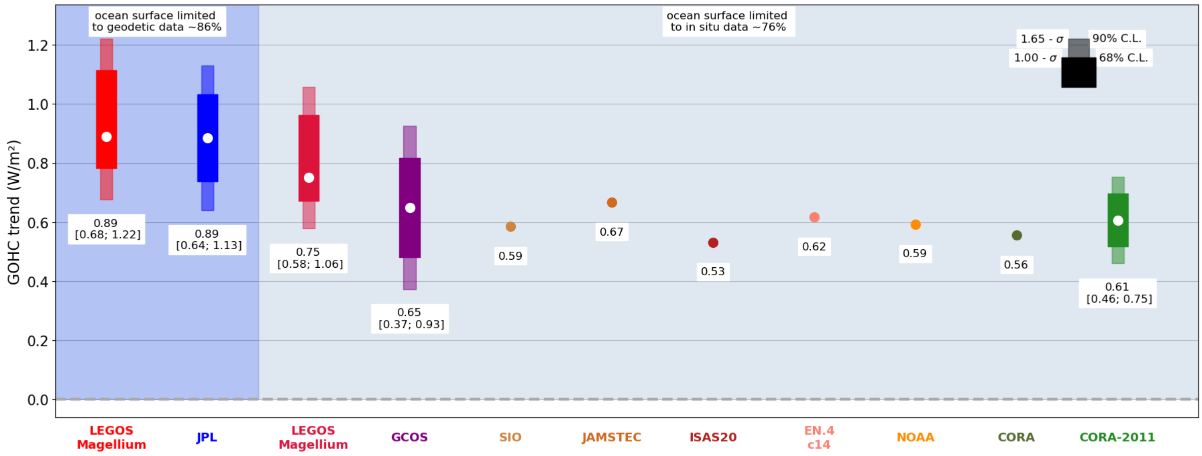

Figure R1-1: next version of the Figure 2 of the manuscript

Given these increased uncertainties, more mention of what the "space based" method might add to the in situ method in the revision might also be helpful.

→ In the data and method section, we will add a short sentence to stress on the fact that the space geodetic approach allows accessing information related to the whole water column.

→ We will clarify the different masks used in the paper. First, we will no longer refer to the “Argo mask” because it is confusing for the reader. Figure 2 will be divided into 2 parts as shown on the figure above. On the left, GOHC is estimated considering 86% of the ocean surface (equivalent to altimetry data availability), while for results on the right data was considered over the GCOS mask. Impact of the surface on the GOHC trend is strong and thus with this figure we will highlight one of the assets of the space geodetic approach, that is to say the large spatial coverage of the input data.

Comments follow indexed by line number (L) where possible.

1. L9-10. The word "trend" is not a correct choice. Consider changing to "mean value".

2. L10. The word "indicating" is not correct. The mean value does not indicate an acceleration. Perhaps change to "with an estimated acceleration of 0.29 W m-2 decade-1".

→ This will be corrected in the new version of the manuscript. We want to talk about EEI trend, and therefore acceleration in heat accumulation.

3. L23-29. In situ estimates relying mostly on Argo data are already there in terms of accuracy of 0.1 W m-2 on a decadal time-scale, at least starting from circa 2006 when Argo first achieved sparse near-global coverage. This fact should be indicated in the revised text.

As mentioned above, in the current manuscript the uncertainties associated with in situ based GOHC trends are indeed about 0.1 W/m² (at 90% confidence level) over 2005-2019. They are underestimated because they only correspond to the formal error adjustment of a linear model with the OLS method, where the potential time-correlated errors are not taken into account.
The paper from Von Schuckmann et al., 2023 illustrates that the trend uncertainty associated with in situ based GOHC data (here "GCOS") resulting from a community effort is comparable with the uncertainty range obtained with the space geodetic method (0.68 ± 0.3 W/m² over 2006-2020, full depth, 95% confidence level).
Cheng et al. "An update for IAP ocean heat content data and implications for EEI" showed early 2023 the first results of an ensemble approach for estimating uncertainty associated with GOHC (0-2000m) from in situ measurements. In slide 23, without uncertainty related to the mapping, they obtain σ: ~0.15 W/m² over 2000-2022, that is to say 0.25 W/m² (90% CL) over 20 years without considering the full water column.
These various elements do not allow us to conclude that the accuracy objective for the EEI study has been achieved with in situ measurements.

4. L51-56. The Roemmich and Gilson temperature and salinity maps include mitigation against the influence of salty drifters that appear to be largely effective at removing the halosteric bias error.

From Roemmich and Gilson we understand that this is the dataset from the SIO. Indeed, the SIO data could be used to remove the halosteric component, however these are only available from 2004 and cannot be used for our study which extends back in time to 1993.
→ eventually we might opt to remove the sentences related to recent instrumental drifts because it brings more confusion than clarifications to the reader.

6. L57-64. This is really the heart of the method, and reliance on Argo data to estimate the warming pattern and hence IEEH should be explicitly noted. Without in situ data to show where (at what temperatures, pressures, and salinities) the warming is taking place, the method uncertainties would be unacceptably large. So this is not really monitoring ocean heat content changes from space as the title implies! It requires monitoring the changes in situ to work with any accuracy. Also, ECCO is very poor at reproducing observed warming in the deep and bottom waters. It shows global cooling from 1992-2011 (e.g., Wunsch and Heimbach, 2014, J. Phys. Oceanogr.) whereas repeat hydrographic data (e.g. Purkey and Johnson, 2010) and Deep Argo float data show very definite warming in the global mean.

→ In the section Data and method, we will mention that the warming pattern is assessed from in situ observations.

On the time scale characteristic of the study, we do not expect any temporal variations associated with the warming pattern. This is already known at global scale (Kuhlbrodt and Gregory, 2012) and it can also be illustrated at regional scales with an Argo based product (see figure below) that the order of magnitude of the time variations associated to the regional IEEH are <4% in comparison with its mean value. This justifies why we used the IEEH temporal mean value, computed over 2005-2015 (Argo golden area), for our study over 1993-2022.
→ We will specify in the text the period we considered for the mean IEEH.

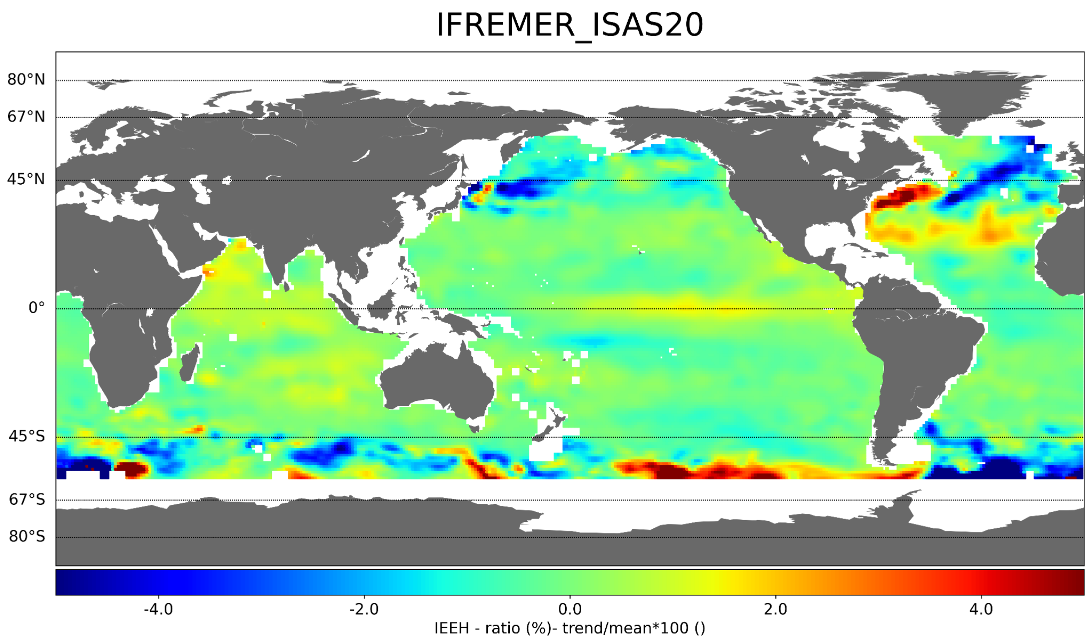

Figure R1-2 : temporal variations of the IEEH estimated from ISAS20 gridded T/S data over 2002-2020 (0-2000m) – ratio (%) IEEH trend over IEEH mean

Moreover, we found out that the choice of the in situ dataset has a very low influence on the IEEH value. In Marti et al, 11 in situ T/S solutions over 0-2000m were used to compute the global IEEH and it resulted in 0.145±0.001 m/YJ (90% CL), ie less than 0.7% discrepancy between global IEEH mean values.

In this study, we used ECCO to estimate the IEEH. ECCO is indeed subject to model drifts and bias of other observational systems (omissions errors), however consistent results have been obtained in the comparison of the IEEH means from the ECCO model and from in situ data. We assessed the discrepancies between the mean IEEH values over their common geographical area. Results at global scale are given in Table 1 (in the next version of the manuscript, global IEEHs in Table 1 will be estimated over the GCOS area and no longer on the Argo mask for clarity reasons). Results at regional scales are illustrated on the figure R1-3: we estimated the differences between regional IEEH derived from ECCO data and regional IEEH derived from T/S gridded fields based on in situ observations and provided by 2 centres (combination of ISAS20 and EN4.2.2.I09 data). Regional IEEH values correspond to the mean value (0-6000m) over the period April 2002-December 2020. The differences do not exceed 5% in the open ocean.

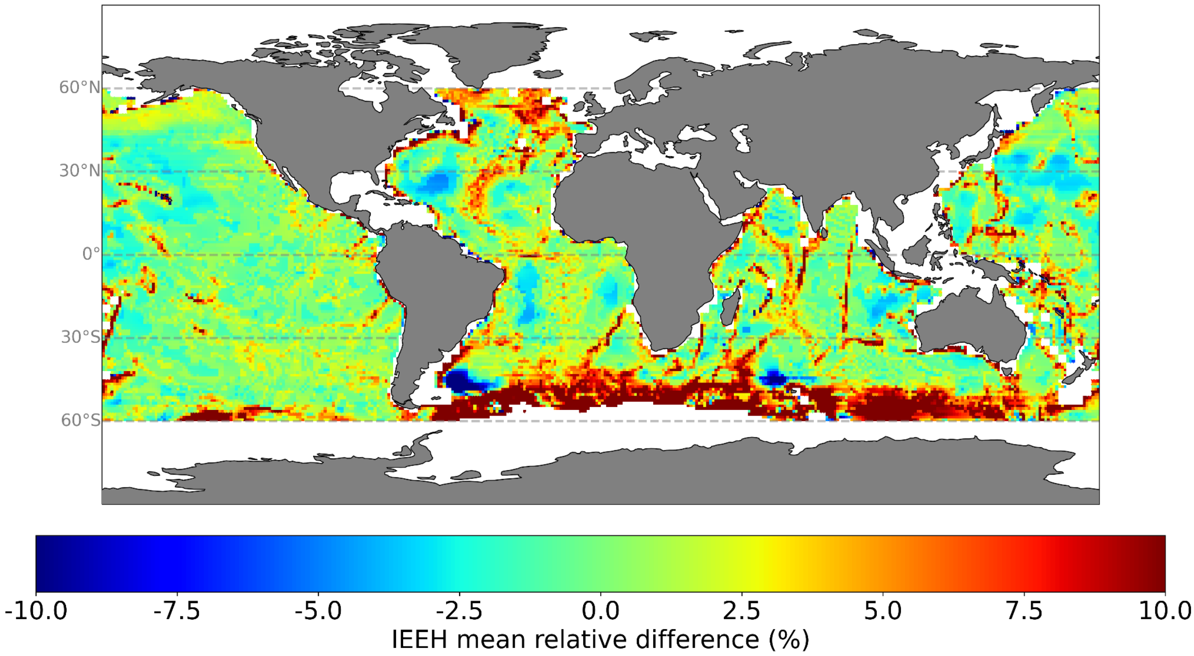

Figure R1-3: Comparison between regional mean IEEH, from ECCO and from in situ (ISAS20, EN4.2.2.I09) gridded T/S (0-6000m). Mean values are estimated over April 2002-December 2020.

7. L65 & L68. Superscript formatting was lost in the exponential numbers. Corrected;

8. L85-88. This portion of the manuscript requires a bit more exposition. Unless the filtering is strongly non-linear, it should not matter where it is done filtered regionally and then summed, or summed and then filtered.

We agree that filtering before or after summing should not impact. We however observed an impact on the EEI, the Lanczos filter that we are using is not perfectly linear (two lobes). There is no impact on the GOHC timeseries but when we differentiate the effect of this non-linearity is accentuated.

→ For ease of reading we will simplify this portion.

9. L89-99. Is the uncertainty of the IEEE coefficient included in the overall estimate? If not, please justify why that can be neglected. If it is, please describe that portion of the estimate.

The uncertainty associated with the IEEH coefficient was also used and propagated until the GOHC and EEI using error covariance matrices. The contribution of this uncertainty to the EEI mean uncertainty is negligible and represents <0.1% in variance. An additional study has shown that 75% of the EEI mean uncertainties (variance) are coming from uncertainties associated with the gravimetry data while the remaining part is due to altimetry sea level data.

→ in the text portion that describes the error covariance matrices computation, we will mention that the uncertainty associated with the IEEH had been propagated and eventually negligible compared to other uncertainties.

10. L95. Generally phrases like "Note that" or "Is is notable that" are superfluous and can be deleted. If it's not noteworthy, why put it in a manuscript? Deleted.

11. L116-118. Hasn't the geodetic series been filtered with a 3-year low-pass, so really the comparisons are only for signals with periods of about 3 years or greater?

→ “ both GCOS ensemble and OMIs are made up of yearly .. so that the derivative is made on a monthly time scale”: this portion needs to be clarified. We will explain in this portion that GOHC annual time series are used. They are then linearly interpolated to monthly time steps before applying the same method as applied for our product to compute the EEI. It will therefore mean that a 3 year low pass filter was applied to all time series.

12. L121-123. Please mention here that the CERES EBAF product mean EEI has been anchored with in situ estimate (including an ocean estimate that relies primarily on Argo data).

Thanks, you are right, it is important to mention it for the Figure 3.

→ We will add in the next version of the manuscript that CERES EBAF product mean EEI has been anchored with in situ product from Lyman and Johnson (2014).

13. L149. Generally sentences like "Figure x shows" are poor topic sentences, and duplicate figure caption. How about "Temporal variations of EEI derived from ....agree fairly well with those obtained from the GCOS yearly ensemble and CERES measurements (Figure 3)." Reformulated.

14. L150-161. Loeb et al. (2021) showed a pretty good agreement between an in situ estimate and CERES both for the acceleration of EEI, and the interannual correlation. Their correlation at 1-year resolution is comparable to those here at 3-year resolution.

→Thanks. Loeb et al., 2021 will be mentioned.

15. Figure 3 and discussion. It would probably be more interesting to the reader to compare trends over the portion of the record common to all three time-periods.

EEI trends over the common period 2000-2022 are given in lines 153-154, while EEI trends over individual availability periods are shown on Figure 3.

→ For the sake of clarity, we will review Figure 3 to display trends over the common period 2002-2022.