Response to reviewer 2

We thank the reviewers for their thoughtful and constructive comments, which will help us improve the quality of our manuscript. Below we respond to each point raised, and indicate when changes will be made in the manuscript. Reviewer's comments are in Italic font and our responses are plane text.

Major Comments:

1. Biological vs. Sedimentological Signals:

The assumption that size-fraction partitioning reflects biological production differences between foraminifera and coccolithophores is plausible but deserves a more explicit discussion of potential confounding effects (e.g., selective dissolution, fragmentation, lateral transport). The authors should clarify whether assemblage data or size-specific calcification trends support the interpretation of biogenic variability.

We deliberately chose this location because we know, as mentioned L72 to L76, that during the time intervals studied, carbonate dissolution or fragmentation, as well as sediment disturbances, are negligible and that the $CaCO_3$ AR of each class size essentially reflects the biological production differences between foraminifera and coccolithophores. We are aware that there may be very slight fragmentation or carbonate dissolution, but that does not have to be obviously recognisable and may also not necessarily influence the findings. We will add a discussion on how dissolution or winnowing "would affect" the signal if they occurred. Fragmentation is the same as dissolution. We also should add that we agree that indeed assemblage composition data and size data would help us to understand exactly which biological factors are responsible for the variability. We intend to do this in the final paper. Thus, we will take up the aspects raised by the reviewer and incorporate them into our updated discussion, as a similar comment was also made by Reviewer 1.

2. Mechanisms of Orbital Response:

The manuscript convincingly shows that foraminifera and coccolithophores respond to different orbital frequencies and with differing phase relationships. However, the ecological or physiological mechanisms behind these responses (e.g., light dependence, seasonality, nutrient sensitivity) should be elaborated further. Drawing on trait-based frameworks or previous ecological modelling could help anchor these interpretations more firmly.

This is addressed in the last point of this document.

3. Assemblage Data:

The absence of plankton assemblage composition or species-specific trends is a limitation, particularly when interpreting variability in calcite flux. If such data exist from the same samples or nearby cores, even qualitative discussion would add significant value.

We will explore this in a new paper. There are no assemblages composition for the foraminifera but we have counts and we do have a distinction of species or groups of species for the coccoliths with counts. Added to this we have morphometric measurements, but all these data with their analyses and interpretations, given their importance, will be the object of a separate manuscript and publication.

4. Future Climate Relevance:

The discussion raises intriguing questions about the potential impact of future warming on pelagic carbonate production and ocean alkalinity. However, these speculations should be more tightly linked to modern observations or modelling results and framed more cautiously, acknowledging the complexity of projecting ecological responses from past analogues.

This is addressed in the last point of this document.

Specific Suggestions:

- *Justify the use of the 63 µm cutoff for foraminifera in greater detail, especially in light of evidence for small but non-negligible contributions from smaller foraminifera (Langer, 2008; Schiebel, 2002 may be of relevance.)*

We thank the reviewer for this helpful suggestion. We plan to add references on the topic of the use of the 63 µm cutoff for foraminifera and the possible associated bias in the revised material and methods L90 to L93.

- *Include uncertainty estimates (e.g., error propagation in $CaCO_3$ accumulation rate calculations) and statistical support (e.g., r^2 and p-values in regression plots).*

Regarding r2 and p values in regression plots, they are already included in figure 2.

- *Improve figure captions by clearly stating the methods used and adding key interpretation notes where appropriate.*

This will be done in the revised version of the manuscript, both in the main text and in the supplements.

- *Clarify the limitations of the SYRACO method more explicitly in the main text, particularly regarding the exclusion of aggregates or poorly preserved specimens.*

A sentence will be added in the revised material and methods, between L118 and L119, stating that the SYRACO device does not recognise aggregates or poorly preserved specimens, resulting in their exclusion from the final data. Nevertheless, the specimens are well preserved at the chosen location and the used protocol avoids aggregates, therefore, these scenarios remain rare.

- *Summarise key results from the supplementary wavelet analyses in a main-text synthesis figure (e.g., a matrix showing orbital periodicity detection across taxa and time intervals).*

This will be added in the revised manuscript.

Minor Points:

- Check grammar and conciseness in the discussion section. Examples:

- *L225-230: very long sentence – try to break it down into 2 sentences at least*

We thank the reviewer for pointing this out, we will rewrite it for the revised version of the manuscript as “According to the observations of the wavelet transform and $CaCO_3$ AR records vs time (Figures S1-S3), the foraminifera and the coccoliths are not responding to the same orbital parameter and not in the same way. The changes of $CaCO_3$ AR of the two groups do not seem to covary nor are they linked by any correlation, meaning that they are changing through the time without responding to the same forcing. This could also explain the different frequencies observed in the bulk $CaCO_3$ AR record (Cornuault et al., 2023): one frequency tracking coarse (foraminifera) and one frequency tracking small (coccolithophores) fraction."

- *L223: "causing" instead of "making"?*

We will reword it for the revised version of the manuscript as "[…] time scale, resulting in a change of their relative contribution to the $CaCO_3$ AR bulk."

- *L227: "or be linked" instead of "or being linked"*

This will be modified as mentioned above.

- *L238: Define who/what "Their" is – coccolithophores? And how do we know their morphology changes with eccentricity? Provide a reference*

"Their" is indeed coccolithophores, it will be changed in the final version of the manuscript as "The coccolithophores morphological diversity […]". Regarding the reference, it is already there at the end of the sentence, L40: "(Beaufort et al., 2022)".

- *L241: Be more precise than "changed a lot"*

We thank the reviewer for highlighting this lack of precision, we will rewrite the sentence as: "We observe important differences of the orbitally forced variability within the different time intervals and different responses between the two groups."

- *L249: Expand on "This would reduce the ocean's carbon sink capacity", provide references, no need to capitalise ocean in this instance*

We thank the reviewer for this helpful suggestion. We will add a more detailed explanation of how we arrived at this conclusion by rewriting the lines L248, L249: "Can we expect a decrease in the role of the coccoliths in the surface ocean anthropogenic carbon absorption in the future with warmer climates? This would reduce the Ocean's carbon sink capacity (Ziveri et al., 2023)."

- *L250-253: Rewrite for clarity and define "that much"*

We will rewrite this portion for clarity and reword as follow: "Our results are in line with those obtained by Schwab et al. (2013) and Stolz and Baumann (2010) who find a high coccolith productivity during the MIS 5e, even if during this interval, the coarse fraction increased with such amplitude that there is a relative increase of the foraminifera fraction in the sediment."

- *L254: Use correct symbol for delta, e.g.* $\delta^{18}O$

This will be modified in the revised version of the manuscript.

- *L276 to end: Expand on why this is an issue*

We thank the reviewer for pointing this out, we will add a more extended explanation of why this is an issue by rewriting the end of the manuscript and breaking the sentences into three. First, we explain the effect of differential susceptibility, then, we explain the effect of different trace elements, finally, we explain the effect of different ballasting.

- Define all abbreviations (e.g., CBT, ETP) upon first use in figures and text.

This will be checked and added in the revised version of the manuscript.

- Include references to relevant recent studies on coccolithophore or foraminiferal responses to modern climate change, where discussing implications.

We thank the reviewer for this helpful suggestion. We will add a paragraph with recent references in coccolithophore and foraminiferal responses to modern climate change, and their possible path in the future. This will be added in the discussion to compare my data with and give context to the possible projections of our findings.

Modern climate change includes changes in pCO_2 (and CO_2 dissolved in ocean waters, resulting in changes of alkalinity), temperature (Globally, SSTs have risen by an average of 0.97°C (confidence interval: [0.77°C - 1.09°C]) between 1850-1900 and 2014-2023 (Forster et al., 2024)) and ocean pH (Intergovernmental Panel On Climate Change, 2021) and chemical conditions for calcification have become less favorable over the past 40 years (Bates and Johnson, 2023).

Regarding the coccolithophores, recent studies found a decreasing calcium carbonate production relative to growth with increasing p CO_2 (and decreasing CO_3^{2-} concentrations) in most areas (except for one E. huxleyi morphotype), with species-specific response. The PIC/POC ratio of coccolithophores decreases with increasing CO_2 (Gafar et al., 2018) and this modifies (marine) carbon cycle, regional carbon export and ocean-atmosphere CO_2 exchange feedbacks (Beaufort et al., 2011 -cultures-; Krumhardt et al., 2019 -models-). Coccolithophores become more abundant but less calcified as CO_2 increases with a tipping point in global calcification (changing from increasing to decreasing calcification relative to preindustrial) at approximately $\sim$600 μatm CO_2 (Krumhardt et al., 2019). With increasing temperature and surface ocean p CO_2, their calcification and growth rate decreases in most low and mid latitude regions, with possible increases in both of these responses in most high latitude regions." (Krumhardt et al., 2017) and some studies found coccolithophores blooms to be limited by temperature increase (Oliver et al., 2024). Furthermore, the time scale matters, as phytoplankton can adapt to temperature increases as long as they occur over the time scale of a century but when rapid and extreme events of temperature change are considered, the phytoplankton adaptive capacity breaks down and primary productivity plummets (Sauterey et al., 2023).

Coccolithophore dynamics are expected to be driven by ocean warming and stratification, as evidenced by their poleward shift in response to rising sea surface temperatures (D'Amario et al., 2020; Meyer and Riebesell, 2015; Hutchins and Tagliabue, 2024), and the coccolithophore communities are described as varying with depth and latitude (Han et al., 2025). In recent years, high latitude regions are being potential refuges, with both coccolithophore and foraminifera expanding towards poles (Chaabane et al., 2024; Winter et al., 2014; Ying et al., 2024). The long-term stability of high latitudes is highly uncertain under continued warming, ocean acidification, and ecosystem restructuring (Guinaldo and Neukermans, 2025) and it is unknown if they will sustain prolonged darkness at higher latitudes, or water freshening trends in the high-latitude North Atlantic and Southern Oceans (Cheng et al., 2020).

Regarding the foraminifera, it has been shown that their response to ocean acidification and warming is species-specific and complex as well. Models show species-specific responses of planktonic foraminifera shell weight changes with increasing p CO_2, associated with drivers including (but not limited to) the carbonate system, which are likely different between ocean basins (Barrett et al., 2025). A weight reduction of some species has been observed between pre-industrial and post-industrial Holocene and recent data, with G. truncatulinoides experiencing the largest weight loss (32 %–40 %) followed by G. bulloides (18 % - 24 %) and N. incompta (9 %–18 %), evidence of a decrease in planktonic foraminifera calcification (Béjard et al., 2023). A 37.9 % decrease in total foraminiferal flux for the years 2014-2021 relative to the 1990s, has been observed accompanied by a 21.9 % overall reduction in calcium carbonate flux and a decrease in the relative abundance of subtropical species. The extremely rapid responses of foraminifera suggest that climate change is already having a meaningful impact on coastal carbon cycling and the observed decrease in particulate inorganic carbon (PIC) flux relative to particulate organic carbon (POC) flux may facilitate increased oceanic uptake of atmospheric CO_2 (Havard et al., 2024). They are projected to reduce their global carbon biomass between 8% (RCP6) and 11% (RCP8.5) by 2050 and between 14% and 18% by 2100 as a response to ocean warming and associated changes in primary production and ecological dynamics by 2100 relative to 1900–1950. That decline can slow down the ocean carbonate pump and create short-term positive feedback on rising atmospheric p CO_2 (Grigoratou et al., 2022; Ying et al., 2024).

The calcification seems to be depending on seawater density with a buoyancy regulatory function, and foraminifera bulk shell densities may serve as a seawater density proxy with calcification responding to the anthropogenically driven reductions in ocean density, with potential consequences for the carbon cycle (Zarkogiannis et al., 2025). Foraminifera acclimatization capacities are limited and insufficient to track warming rates and migration will not be enough to ensure survival (Chaabane et al., 2024). Certain species or strains may acclimate to future ocean pH and temperature (Rigual-Hernández et al., 2020; WestgÅrd et al., 2023), whereas others may perish or expand to new ecological niches where conditions are more suitable (Shemi et al., 2025), modifying the carbon export by the carbonate counter pump (Neukermans et al., 2023).

Satellite data are to be taken carefully, as it has been shown that high reflectance signal may relate to the presence of small biogenic opal particles or other unknown highly reflective particles, and be the reason of high satellite-derived PIC concentrations that are not apparent in the coccolith-based PIC data (Saavedra-Pellitero et al., 2025). A strong overestimation of PIC by sensor (and even more so by satellites) in surface waters colder than 1°C has also been found by Li et al. (2025). Ziveri et al. (2023) observe a decoupling of $CaCO_3$ production and export, with pelagic $CaCO_3$ production being higher than the sinking flux of $CaCO_3$ at 150 and 200 m, implying the remineralisation of large portion of pelagic calcium carbonate within the photic zone, explaining the apparent discrepancy between previous estimates of $CaCO_3$ production derived from satellite observations/biogeochemical modelling versus estimates from shallow sediment traps. The relative abundance of foraminifera to coccolithophores has been highlighted as an important factor that could lead to large changes in the amount of $CaCO_3$ exported from the surface ocean and thus the cycle of alkalinity (Ziveri et al., 2023).

The current study is and its conclusions regarding the possible response of pelagic calcifiers in the actual context of climate warming are coherent with previously published findings.

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