This study investigates the factors influencing the differences between particulate inorganic carbon (PIC) export efficiency and PIC transfer efficiency across the global ocean. By integrating global PIC production estimates derived from satellite observations with PIC flux measurements from sediment traps, the author assesses spatial and seasonal variability and correlations in these metrics. Notably, the study finds no strong global correlation between PIC production and PIC flux, except in two key regions: the North Atlantic and the Southern Ocean. The author also introduces the concept of a divide between high- and low-latitude regimes, suggesting that temperate and subpolar regions exhibit higher PIC export efficiency compared to equatorial and subtropical areas.

The topic is timely and important, addressing the ocean carbonate pump, a key component of the global carbon cycle that remains poorly quantified. Exploring regional and seasonal variations in PIC dynamics, especially at different depths, offers valuable insights into carbon export processes and their controls.

However, the current manuscript falls short in several areas that must be addressed prior to publication:

Introduction: The literature review lacks recent references and fails to clearly frame the current study within the context of recent advancements. A more thorough and up-to-date overview of the state of knowledge is needed to establish the relevance and novelty of the research.

Author's response: *I considered Reviewer 2's attention to the lack of recent references in the new version, especially through comments/suggestions gave by Reviewer 2 in the specific comments below. I am grateful for the several reference suggestions gave by Reviewer 2. Please consider my answers/modification below.*

Results: The presentation of the results is at times unclear, making it difficult to follow the core findings. Clearer structure, better use of figures, and more direct links between observations and interpretations would significantly improve readability.

Author's response: *I considered Reviewer 2's attention to use of results/figure in the discussion and results presentation. More links between presented results/data/figure and discussed processes have been made in the new version (especially concerning Fig. 6 and 7). Please consider my answers/modification followed by Reviewer 2 specific comments below.*

Discussion: The discussion lacks specificity. It should better connect the results to the broader implications for the carbonate pump and global carbon cycling. Currently, the discussion reads as disconnected and somewhat speculative without robust support from the data.

Author's response: *I completely understand Reviewer 2's points (also raised by Reviewer 1). More links between presented results/data/figure and discussed processes have been made in the new version (especially concerning Fig. 6 and 7). Please consider my answers/modification followed by Reviewer 2 specific comments below.*

Section 4.4.1 & Section 4.4.2: These sections are indeed speculative and do not come directly from my analysis. However, the references listed support the hypotheses raised in the manuscript concerning the potential PIC dissolution inside aggregates and PIC "dissolution escaping" inside the fecal pellets. Most of study about carbonate pumps assume that PIC dissolution is associated with biological and ecological mechanisms, without explaining hypothetic mechanism:

Lines 43- 47: ". A large proportion of these CaCO3 produced in the euphotic zone is dissolved within the first 300m of the ocean (Sulpis et al., 2021, Feely et al., 2002; Milliman et al., 1999), ... This shallow dissolution is not yet clearly explained but considered to be associated to biological and ecological mechanisms (zooplankton and procaryotes mediated dissolution)."

In these 2 sub-sections, I propose potential processes, supported by references.

I also implemented some links to the results presented in the present study:

Lines 422-425: "However, PIC E_{eff} is higher at high latitude where fecal pellet contribution to gravitational pump is lower (Fig. 6b). This result suggests more complex mechanism and implication of plankton community phenology into the PIC E_{eff} control (see sections 4.4.3. and Fig. 7). In addition, PIC E_{eff} is higher at high latitude where phytoplankton aggregates contribution to gravitational pump is also higher (Fig. 6b), which suggest implication seasonal phytoplankton phenology."

Line 436-439: "This latitudinal variation of microzooplankton grazing pressure could partially explain the PIC E_{eff} and PIC Teff observed (Fig. 6). Annual higher grazing rates by microzooplankton are also expected in subtropical regions due to a low seasonal bias (Fig. 6a), leading to continuous grazing pressure from microzooplankton. This idea is also supported by the contribution of fecal pellet to the gravitational particles flux (Fig. 6b)."

Overall, the study has the potential to contribute meaningful insights to our understanding of oceanic carbon export mechanisms. However, I strongly recommend substantial revisions to improve clarity, coherence, and scientific rigour before it can be considered for publication.

Author's response: *I would like to thank Reviewer 2 for pointing out the weakness and the lack of clarity, coherence, and scientific rigor of the present manuscript. Supported by my justification and responses to comments raised by Reviewer 2 (detailed below), please consider the changes made to the manuscript for publication in Biogeosciences.*

Broader comments:

- The introduction should better explain the concept of the ballast effect. Currently, L33-34 hint at the effect of the carbonate pump of the soft tissue pump without explaining that PIC is a dense mineral, potentially increasing the sinking velocity of POM and thus carbon storage. Please, also explain that this is still a debated effect with evidence for and against it.

Author's response: *The concept of the ballast effect is introduced below; I also added evidence showing the controversial aspect:*

Lines 54-60: "It has been established that T_{eff} is not correlated with $CaCO_3$ export flux (Henson et al., 2012), but evidence from sediment trap collection suggests that coccoliths and coccospheres are transported more efficiently to depth when incorporated into fecal pellets or marine snow aggregates (Honjo, 1976; Pilskaln and Honjo, 1987). Indeed, the incorporation of biominerals (such as $CaCO_3$ and biogenic silica) induces a ballast effect (excess of density) on marine snow sinking velocity (Iversen and Ploug, 2010; Laurenceau-Cornec et al., 2020) and hence is expected to boost the BCP. However, it has been demonstrated that CaCO3 export flux in the upper ocean is not correlated with the transfer efficiency (Henson et al., 2012), hence the ballast effect hypothesis is still controversial."

In addition, section 4.1 in the discussion, the ballast effect is also disputed regarding the evidence for and against it.

- The introduction needs to use more up-to-date literature and better justify the aim of the study.

Author's response: *I thank Reviewer 2 for highlighting the lack of up-to-date literature. This aspect has been improved in the new manuscript version (I also included Reviewer 2's references suggestion listed in the comments below).*

e.g:

Guerreiro, C. V., Baumann, K. H., Brummer, G. J. A., Valente, A., Fischer, G., Ziveri, P., ... & Stuut, J. B. W. (2021). Carbonate fluxes by coccolithophore species between NW Africa and the Caribbean: Implications for the biological carbon pump. Limnology and Oceanography, 66(8), 3190-3208.

Ryan-Keogh, T. J., Thomalla, S. J., Chang, N., & Moalusi, T. (2023). A new global oceanic multi-model net primary productivity data product. Earth System Science Data, 15(11), 4829-4848.

Lacour, L., Llort, J., Briggs, N., Strutton, P. G., & Boyd, P. W. (2023). Seasonality of downward carbon export in the Pacific Southern Ocean revealed by multi-year robotic observations. Nature Communications, 14(1), 1278.

Poulton, A. J., Stinchcombe, M. C., Achterberg, E. P., Bakker, D. C. E., Dumousseaud, C., Lawson, H. E., Lee, G. A., Richier, S., Suggett, D. J., and Young, J. R.: Coccolithophores on the north-west European shelf: calcification rates and environmental controls, Biogeosciences, 11, 3919–3940, https://doi.org/10.5194/bg-11-3919-2014, 2014.

- The concepts presented in Figure 1 (and associated text) do not rely on current knowledge. It also does not match with Figure 3b.

Author's response: *Fig. 1 (opal vs $CaCO_3$ productive regime) has been removed in the new version, Fig. 1 was a big source of confusion and to a lesser extent contradictory statements suggested in the discussion and Fig. 3b. (Also, I think there is a confusion about which colors correspond to what…). Indeed, as explained by Reviewer 1, Francois et al. (2002) refer to the subtropics as $CaCO_3$-dominated systems in the context of opal versus calcium carbonate ballast regimes but not production.*

My point here was ecosystem dominated by blooming species (temperate regions with high seasonal amplitudes) are compared to annually productive regions (subtropics with low seasonable amplitude).

- The key results are not clearly highlighted and described with enough details in the results section. The discussion provides an interesting overview of the literature, but with no clear link to the results of the paper, which makes it challenging to see its use.

Author's response: *I completely understand Reviewer 2's points (also raised by Reviewer 1). Please consider the change made to the new manuscript version (detailed below).*

Specific comments:

L28: Replace “In other hand” with “On the other hand”

Author's response: *The change has been made.*

Lines 27-28: “On the other hand, calcified phytoplankton…”

L32-34: Misconception that “CaCO3 is composed of carbon” and thus transport carbon to the deep ocean. This is in line with my general comment about the ballast effect. CaCO3 sinking has the effect of transporting alkalinity from the ocean surface to the deep and mediates POC settling via the ballast effect. Please, can you amend accordingly?

Author's response: *Indeed, I meant that calcifiers are not only made of inorganic carbon but also organic carbon (cells and living tissues). The sentence has been modified.*

Lines 32-33: "Even though calcification contributes to the release of CO_2 (counter effect), all planktonic calcified organisms (such as coccolithophores, foraminifera and pteropods) transport also POC to deep waters through gravitational settling"

Alkalinity transport occurs if $CaCO_3$ is dissolved at some point.

L36-37: Add Neukermans et al. (2023) for a reference directly comparing Coccolithophores with other planktonic calcifiers contribution to PIC.

Neukermans, G., Bach, L. T., Butterley, A., Sun, Q., Claustre, H., & Fournier, G. R. (2023). Quantitative and mechanistic understanding of the open ocean carbonate pump-perspectives for remote sensing and autonomous in situ observation. Earth-Science Reviews, 239, 104359.

Author's response: *The reference has been added (as well as Le Moigne et al., 2014, about Thorium-234 activity)*

Lines 35-37: "...are the most widespread techniques to quantitatively estimate a sinking flux, both in terms of time and geography (Savoye et al., 2006, Le Moigne et al., 2014, Neukermans et al., 2023)."

Line 39: "considered dominant at global scale (Knecht et al., 2023, Neukermans et al., 2023)."

L38-39: The statement that coccolithophores "uptake more carbon in high-light, stratified, and low-nutrient surface waters (Balch et al., 2011; Krumhardt et al., 2017)", which implies that coccolithophores preferentially grow in subtropical gyres, does not match common understanding and the used citations here. Both references (and others) highlight high coccolithophore PIC in the northern part of the Southern Ocean (referred to as the "Great Calcite Belt"), which is due to Emiliania huxleyi's blooming characteristics. Same for the statement "In low latitudes, which are CaCO3-productive regions" (L60).

Author's response: *Indeed, this sentence is contradiction with common understanding of coccolithophore ecological niche and global distribution pattern.*

I meant to say that low latitudes (subtropic gyre), are annually $CaCO_3$-productive regions compared to temperate areas (with high seasonal amplitude and blooming event). This statement included all calcifiers (Foraminifers, Pteropods as well), moreover, *coccolithophore diversity is higher in low latitude (Winter et al., 2014). It sounds maybe too controversial regarding Gephyrocapsa (Emiliania) huxleyi bloom dynamic at the global scale (e.g. North Atlantic and in the Great Calcite Belt of course). I change the tone of the sentence about coccolithophore ecological niche.*

Lines 39-42: "In the global ocean, coccolithophores form mesoscale blooms in high-latitude oceans (Brown and Yoder, 1994; Balch et al., 2005), which are associated with high rates of calcification (Poulton et al., 2007, 2014, Balch et al., 2011; Krumhardt et al., 2017, 2019)."

Line 64: "In low latitudes, which are annually $CaCO_3$-productive regions"

Winter, A., Henderiks, J., Beaufort, L., Rickaby, R. E., & Brown, C. W. (2014). Poleward expansion of the coccolithophore Emiliania huxleyi. Journal of Plankton Research, 36(2), 316-325.

Poulton, A. J., Stinchcombe, M. C., Achterberg, E. P., Bakker, D. C. E., Dumousseaud, C., Lawson, H. E., Lee, G. A., Richier, S., Suggett, D. J., and Young, J. R.: Coccolithophores on the north-west European shelf: calcification rates and environmental controls, Biogeosciences, 11, 3919–3940, https://doi.org/10.5194/bg-11-3919-2014, 2014.

L41: Please use more recent literature, which you can find in Krumhardt et al. (2019).

Krumhardt, K. M., Lovenduski, N. S., Long, M. C., Lévy, M., Lindsay, K., Moore, J. K., & Nissen, C. (2019). Coccolithophore growth and calcification in an acidified ocean: Insights from community Earth system model simulations. Journal of Advances in Modeling Earth Systems, 11(5), 1418-1437.

***Author's response:** I considered Reviewer 2' comment, and included Krumhardt et al., 2019:*

Lines 39-42: "In the global ocean, coccolithophores form mesoscale blooms in high-latitude oceans (Brown and Yoder, 1994; Balch et al., 2005), which are associated with high rates of calcification (Poulton et al., 2007, 2014, Balch et al., 2011; Krumhardt et al., 2017, 2019)."

L43-44: Same, include more recent literature: Kwon et al. (2024)

Kwon, E. Y., Dunne, J. P., & Lee, K. (2024). Biological export production controls upper ocean calcium carbonate dissolution and CO2 buffer capacity. Science Advances, 10(13), eadl0779.

***Author's response:** More recent references have been added:*

Line 46-47: "...biological and ecological mechanisms such as zooplankton and procaryotes mediated dissolution (Sulpis et al., 2021, Kwon et al., 2024, Dean et al., 2024)"

L44-45: Refer to Dean et al. (2024)

Dean, C. L., Harvey, E. L., Johnson, M. D., & Subhas, A. V. (2024). Microzooplankton grazing on the coccolithophore Emiliania huxleyi and its role in the global calcium carbonate cycle. Science Advances, 10(45), eadr5453.

Author's response: *The paper of Dean et al. 2024, has been referenced here.*

Line 46-47: "...biological and ecological mechanisms such as zooplankton and procaryotes mediated dissolution (Sulpis et al., 2021, Kwon et al., 2024, Dean et al., 2024)"

L46: Consider adding a reference to Neukermans et al. (2023) here, too.

Author's response: *The reference has been added.*

Lines 47-48: "The sedimentation of calcifying organisms constitutes an export flux of $CaCO_3$ with estimated range of 0.4–1.8 Pg C y^{-1} (Berelson et al., 2007, Neukermans et al., 2023)."

L47-50: The idea that low latitudes have low export efficiency and high transfer efficiency is quite debatable since Henson et al. (2012), because satellite estimates have large uncertainties (Henson et al., 2019; Ryan-Keogh et al., 2023; Weber et al., 2016).

Henson, S., Le Moigne, F., & Giering, S. (2019). Drivers of carbon export efficiency in the global ocean. Global biogeochemical cycles, 33(7), 891-903.

Ryan-Keogh, T. J., Thomalla, S. J., Chang, N., & Moalusi, T. (2023). A new global oceanic multi-model net primary productivity data product. Earth System Science Data, 15(11), 4829-4848.

Weber, T., Cram, J. A., Leung, S. W., DeVries, T., & Deutsch, C. (2016). Deep ocean nutrients imply large latitudinal variation in particle transfer efficiency. Proceedings of the National Academy of Sciences, 113(31), 8606-8611.

Author's response: *The idea raised by Reviewer 2 mentioning that PE_{eff} in low latitude can be over/underestimated considering the uncertainties of satellite evaluation (together with the reference provided) have been implemented in the new version of the manuscript.*

Lines 52-53 "However, satellite estimation of net primary production at low latitude may have large uncertainties, which may result in a bias in the PE_{eff} estimation (Henson et al., 2019; Ryan-Keogh et al., 2023; Weber et al., 2016)."

L51: Please include more recent literature than Henson et al. (2012), Honjo (1976) and Pilskaln and Honjo (1987).

Author's response: *I added recent literature about the coccoliths transport to depth when incorporated into fecal pellets or marine snow aggregates:*

Guerreiro, C. V., Baumann, K. H., Brummer, G. J. A., Valente, A., Fischer, G., Ziveri, P., ... & Stuut, J. B. W. (2021). Carbonate fluxes by coccolithophore species between NW Africa and the Caribbean: Implications for the biological carbon pump. Limnology and Oceanography, 66(8), 3190-3208.

Line 56 "...fecal pellets or marine snow aggregates (Honjo, 1976; Pilskaln and Honjo, 1987, Guerreiro et al., 2021)."

L62-66: Try to link this paragraph with the ballast effect and check for more recent literature on the higher correlation of Teff with carbonate flux. See the comprehensive review in section 3.4 in Neukermans et al. (2023).

Author's response: *I added link with the ballast effect.*

Lines 66-72 "...The 'packaging factor' theory suggests that CaCO3-dominated ecosystems (subtropics and equatorial area) are associated with complex food web, and CaCO3 would be more tightly packaged in fast-sinking fecal pellets, associated with potential ballast effect on the POC (Laurenceau-Cornec et al., 2020). However, particle flux from seasonal, opal-dominated systems (Temperate and sub-Polar ecosystems) would be highly "degradable" formed aggregates, produced by the coagulation of senescent diatoms (Francois et al., 2002). This 'packaging factor' as well as the potential associated ballast effect hence should be a strong driver of Teff. Biominerals such as CaCO3 could be a major driver of POC flux (Lacour et al., 2023) or by physically protecting the more labile POC in aggregates from degradation during gravitational settling (Armstrong et al., 2001)."

Armstrong, R. A., Lee, C., Hedges, J. I., Honjo, S., & Wakeham, S. G. (2001). A new, mechanistic model for organic carbon fluxes in the ocean based on the quantitative association of POC with ballast minerals. Deep Sea Research Part II: Topical Studies in Oceanography, 49(1-3), 219-236.

Lacour, L., Llort, J., Briggs, N., Strutton, P. G., & Boyd, P. W. (2023). Seasonality of downward carbon export in the Pacific Southern Ocean revealed by multi-year robotic observations. Nature Communications, 14(1), 1278.

L79-80: Please add reference (Kwon et al., 2024) to the statement "heterotrophic respiration ... dissolve CaCO3 particles".

Author's response: *The paper of Kwon et al. (2024) has been added to support this statement.*

Lines 83-84: "Nowadays, heterotrophic respiration in sinking aggregates is considered creating a microenvironment supporting dissolution of CaCO3 in the upper ocean (Morse et al., 2006; Friis et al., 2006; Buitenhuis et al., 2019; Sulpis et al., 2021, Dean et al., 2024)."

L179: It looks like a half sentence. Can you double check there is no formatting issue here?

***Author's response**: My apologies for this mistake. Indeed, this sentence belongs to Fig. 1' legend.*

L202-203: And also along the Great Calcite Belt in the Southern Ocean and in the North Atlantic, but not in the Northern Indian Ocean.

***Author's response:** I implemented this statement regarding the results presented in the map (Fig. 2b).*

Lines 224-226: "In contrast to the NPP, the most PIC productive areas are located within subtropical gyres, in the Southern Ocean (along the "Great Calcite Belt"), in the North Atlantic, but not in the Northern Indian Ocean, and less productive within equatorial upwelling ecosystems (Fig. 2b)."

Figure 3: Not clear what the seasonal bias is and how it is calculated. Same for the residence time. Can you add some text to the methodology?

***Author's response:** The seasonal bias corresponds to the seasonal variation over the year. It is calculated by dividing the standard deviation between each month of the year, by the annual means. I modified the legend to be clearer.*

Fig. 2 legend: "...(c) NPP seasonal bias expressed as coefficient of variation (σ/μ) of monthly NPP climatology, (c) PIC production seasonal bias expressed as coefficient of variation (σ/μ) of monthly PIC production climatology"

The residence time corresponds to the division of the standing integrated stock (mg m^{-2}) by production (mg m^{-2} d^{-1}), the result is express in days that corresponds to the residence time (d). The trend can also be expressed as the turnover rate (d^{-1}) by dividing production (mg m^{-2} d^{-1}) by the standing integrated stock (mg m^{-2}).

Fig. 2 legend: "...POC and PIC residence time is obtained by dividing the annual standing integrated stock (mg m^{-2}) by annual production (mg m^{-2} d^{-1}), results are expressed in days."

Figure 5: Can you comment more on the trends presented in this figure in the main text? Currently, there is no description and interpretation of how correlation fluctuates between the regions and why.

***Author's response:** I implemented some text to present Fig. 5.*

Lines 290-295: "At the global scale that the EZ PIC production is not correlated with PIC flux in the upper ocean. However, considering distinct oceanic bioregions (RECCAP2, Fig. 5), in the mesopelagic layer and deeper, significant correlations between EZ PIC production and deep PIC flux are observed in the North Atlantic (100-500m, 500-1000m, 1000-2000m, 2000-3000m, 3000-4000m and >4000m) and the Southern Ocean (100-500m and 1000-2000m). North Indian Ocean regions (subtropical areas) are also characterized by PIC production positively correlated with deep PIC flux (500-1000m, 1000-2000m, 2000-3000m and 3000-4000m, Fig. 5)."

Trends between bioregions is interpreted (mostly regarding the latitude) in the discussion.

L241: Define "SB".

Author's response: *The SB is the seasonal bias (expressed as CV, presented in Fig. 2). I modified the text.*

Line 302: "...both NPP and PIC production seasonal bias (Fig. 6a)."

I also gave details of the calculation:

Fig. 2 legend: "(c) NPP seasonal bias expressed as coefficient of variation (σ/μ) of monthly NPP climatology, (c) PIC production seasonal bias expressed as coefficient of variation (σ/μ) of monthly PIC production climatology,"

L242-246 and Figure 6: It is not clear why you are presenting the seasonal bias and the contributions to export from aggregates and faecal pellets. Can you add more explanations?

Author's response: *Reviewer 2 is right (this point has also been raised by Reviewer 1), details and used of Nowicki et al. 2022 model output were inappropriately reduced in the submitted version. My apologies for that. I added a mention of this dataset in the methods part (section 2.2.5. Supporting dataset). I also added more detail of the model output detail and use in the present manuscript:*

Lines 215-216, (section 2.2.5. Supporting dataset): "1° by 1° grid map of fecal pellet and aggregates contribution to the total particles export were obtained from model ensemble output from Nowicki et al., 2022 (FigShare database: https://doi.org/10.6084/m9.figshare.19074521)."

Lines 304-309: "The model output of Nowicki et al. (2022), estimated that the contribution to the gravitational carbon pump of zooplankton fecal pellets and sinking phytoplankton aggregates were respectively of 85% and 15%, (Nowicki et al., 2022).

Once mapped of 1° by 1° grid map, zooplankton fecal pellets and sinking phytoplankton aggregates contribution are characterized by a significant latitudinal pattern (Fig. 7 in Nowicki et al., 2022). The seasonality of NPP and PIC production can be overlapped with aggregates's contribution to the export (estimated by Nowicki et al., 2022), as shown in Fig. 6b."

L262-263: Can you relate more PIC transfer efficiency to POC transfer efficiency here? You present them both but make no link so the last sentence hangs without connection with what it said before.

Author's response: *I combined both Reviewer 1 & 2 comments on this paragraph. Please consider the new version (clearer and more complete):*

Lines 320-332: "The fraction of phytoplankton exported production that is remineralized, is mainly influenced by ecosystem structure, which is related to the seasonal amplitude in NPP. Bloom of diatoms and coccolithophores (e.g. Gephyrocapsa (Emiliania) huxleyi), which are expected to cause intense particle sedimentation, take place mostly in in areas associated with high annual mean and amplitude of NPP, while nanoplankton/picoplankton global production are dominant in oligotrophic areas associated with low annual amplitude of NPP (Lima et al., 2014). The 'ballast effect hypothesis' induced by the inclusion of biominerals (calcite and biogenic silica) has been considered for a long time to boost the particle export efficiency ($PE_{ef}f$), which corresponds to the proportion of primary production that is exported from the surface ocean. In the present study, the PIC E_{eff} (which corresponds to the proportion of PIC production that is exported from the surface ocean) is commonly higher above 40°N and below 40°S (temperate and subpolar oceanic regions), while the PIC Teff (which corresponding to the proportion of exported PIC that reaches the deep ocean), is higher between 40°N and 40°S (subtropics), and follow the pattern than zooplankton fecal pellet contribution to the gravitational pump (Fig. 6). Considering, particles type contribution to the gravitational pump (estimated by Nowicki et al., 2022), phytoplankton aggregates could enhance the PIC Eeff while zooplankton fecal pellet could enhance the PIC T_{eff}. The rest of the discussion aims to identify which processes may be involved."

L268-269 (Section 4.1): I struggle here with the statement that the ballast effect is not related to ecosystem structure. On the contrary, I would argue that the ballast effect results from ecosystem structure as it depends on the synergy of biological processes, such as PIC production by pelagic calcifiers, surface dissolution due to respiration and packaging of CaCO3 with organic matter either due to grazing and fecal pellets or aggregation.

Author's response: *My statement was not that the ballast effect is not related to ecosystem structure. This paragraph seems to be confusing on this point. I am also convinced that ballast effect results from ecosystem structure and the phenological dynamic. I wanted to highlight that ecosystem structure and phenological dynamic are more important than only PIC production in the surface. I implemented elements to argue in that direction:*

Lines 337-339: "Indeed, Henson et al. (2012) concluded that ecosystem structure is the key factor controlling the efficiency of the biological carbon pump, rather than the ballast effect induced by $CaCO_3$."

Lines 333-334: "which argue in favor of ecosystem structure and phytoplankton phenology."

Lines 350-351: "This evaluation demonstrates that at the global scale, ecosystem structure and phytoplankton phenology should be more of a determining factor for the PIC E_{eff} and PIC T_{eff} than the ballast effect"

Lines 336-337: "The hypothetic processes behind theses variability are discussed in the following part of this section, regarding the planktonic functional composition and the phenological dynamic. »

L270: "high CaCO3 productive systems (Subtropics)" is misleading. Francois et al. (2002) refer to the subtropics as CaCO3-dominated systems in the context of opal versus calcium carbonate ballast regimes. This is a subtle difference but key one as again and also underdeveloped the view that coccolithophores current understanding presents them to be higher in the subpolar regions. Also, here, the point made about Le Moigne et al. (2014) is not consistent with Francois et al. (2002), highlighting that subtropics export flux is not associated with mineral ballast. Can you address these points?

Author's response: *Indeed, this is also why I removed Fig. 1 in the new version (opal vs $CaCO_3$ productive regions). Fig. 1 was a big source of confusion and to a lesser extent contradictory statements suggested in the discussion and Fig. 3b.*

Please consider my rephrasing:

Lines 339-344: "François et al. (2002) hypothesized the 'packaging factor' theory, explaining that high $CaCO_3$ productive systems (relative to opal) also contain organisms that produce sinking fecal pellets capable of efficiently delivering organic carbon to deep waters (e.g model from Nowicki et al. 2022). In Subtropics and equatorial upwelling regions, the export flux is not associated with mineral ballasts (Le Moigne et al., 2014), while François et al.' packaging factor would suggest the opposite. These statements *highlight the great spatial variability of biomineral inclusion into sinking particles, which argue in favour of ecosystem structure and phytoplankton phenology.»*

L277-280: These look like important results of your study that aren't detailed in the results section. Can you expand on these in the results section? This also relates to my comments on Figure 5.

Author's response: *I implemented some text to present Fig. 5.*

Lines 290-295: "At the global scale that the EZ PIC production is not correlated with PIC flux in the upper ocean. However, considering distinct oceanic bioregions (RECCAP2, Fig. 5), in the mesopelagic layer and deeper, significant correlations between EZ PIC production and deep PIC flux are observed in the North Atlantic (100-500m, 500-1000m, 1000-2000m, 2000-3000m, 3000-4000m and >4000m) and the Southern Ocean (100-500m and 1000-2000m). North Indian Ocean regions (subtropical areas) are also characterized by PIC production positively correlated with deep PIC flux (500-1000m, 1000-2000m, 2000-3000m and 3000-4000m, Fig. 5)."

Sections 4.2, 4.3, 4.4.1, 4.4.2, 4.4.3.1 (L362-380), 4.4.3.2 do not even mention the results, so it is hard to relate to it. Can you spell the links more clearly?

Author's response: *I completely understand Reviewer 2's points (also raised by Reviewer 1).*

Section 4.2: *This section seems to be important to consider carbonate chemistry and dissolution pattern in the water column. I added a supplementary figure showing the saturation depth of calcite and aragonite (according to Feely et al., 2002), together with some explanation regarding the dissolution pattern:*

Lines 365-371: "In most of bioregions, saturation horizon for calcite and aragonite reach respectively 1000 and 800m depth (Fig. S1). North Subtropics Pacific (NSTP) is characterized by a shallow saturation horizon for both calcite and aragonite (respectively 500m and 400m, Fig. S1), despite the positive correlation between PIC production and flux is observed between 1000 and 2000m (Fig. 5). This observation means two hypotheses: In one hand the $CaCO_3$ is well protected from dissolution inside packaged vehicles such as low porous aggregates and fecal pellet (protected by the peritrophic membrane). On the other hand, because packaged $CaCO_3$ sink fast (≈ 100m d-1), the dissolution rate of $CaCO_3$ can be too slow to significantly decrease deep PIC flux."

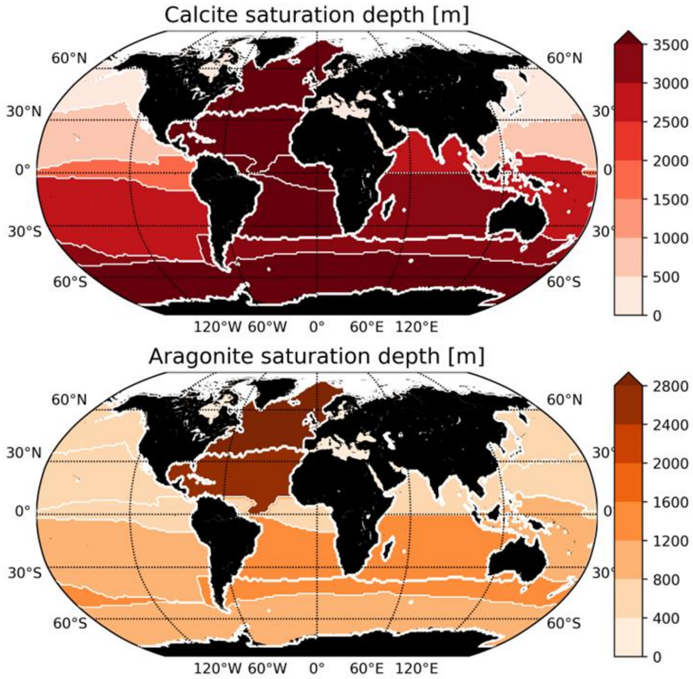

Figure S1: a) Map Calcite saturation depth (m) according to the RECCAP2 regions. b) Map of aragonite saturation depth (m) according to the RECCAP2 regions. Data are extracted from Feely et al., 2002

If Reviewer 1 is not at all convinced by keeping this section in the current manuscript, it can be permanently removed from the manuscript as requested.

Section 4.3: *Considering Reviewer 1's concerns the implication of the other pelagic calcifiers (Pteropods and foraminifers cannot be ignored), I included section 3.2. Taxa contribution to global PIC stock in the results (together with Fig. 3, foraminifers and pteropods annual standing stock and seasonal variation along the year) in the new version (see previous author's response). Section 4.3 in the discussion is now more relevant to being there*

Section 4.4.1 *&* ***Section 4.4.2:*** *These sections are indeed speculative and do not come directly from my analysis. However, the references listed support the hypotheses raised in the manuscript concerning the potential PIC dissolution inside aggregates and PIC "dissolution escaping" inside the fecal pellets. Where most of study about carbonate pumps assume that PIC dissolution is associated with biological and ecological mechanisms, without explaining hypothetic mechanism:*

Line 43-47: A large proportion of these $CaCO_3$ produced in the euphotic zone is dissolved within the first 300m of the ocean (Sulpis et al., 2021, Feely et al., 2002; Milliman et al., 1999), thereby increasing ocean alkalinity and CO2 uptake (Sarmiento, 2013). This shallow dissolution is not yet clearly explained but considered to be associated to biological and ecological mechanisms such as zooplankton and *procaryotes mediated dissolution (Sulpis et al., 2021, Kwon et al., 2024, Dean et al., 2024).”*

In these 2 sub-sections, I propose potential processes, supported by references.

I modulated the title (“Hypothetic processes…”).

I also implemented some links to the results presented in the present study:

Lines 421-425: “However, PIC E_{eff} is higher at high latitude where fecal pellet contribution to gravitational pump is lower (Fig. 6b). This result suggests more complex mechanism and implication of plankton community phenology into the PIC E_{eff} control (see sections 4.4.3. and Fig. 7). In addition, PIC E_{eff} is higher at high latitude where phytoplankton aggregates contribution to gravitational pump is also higher (Fig. 6b), which suggest implication seasonal phytoplankton phenology.”

Lines 436-439: “This latitudinal variation of microzooplankton grazing pressure could partially explain the PIC E_{eff} and PIC T_{eff} observed (Fig. 6). Annual higher grazing rates by microzooplankton are also expected in subtropical regions due to a low seasonal bias (Fig. 6a), leading to continuous grazing pressure from microzooplankton. This idea is also supported by the contribution of fecal pellet to the gravitational particles flux (Fig. 6b).”

Also, if Reviewer 2 is not at all convinced by keeping this section in the current manuscript, it can be permanently removed from the manuscript as requested.

L314-315: Again, this seems like an important result “PIC export flux and deeper flux … are globally lower in these regions (despite higher PIC production)”. Can you expand on this in your results section, especially in contrasting PIC Teff with PIC production?

Author's response: *I expanded this finding on the results part and added support Fig. 6 into the discussion.*

Line 301-304: “Regions above 40°, are characterized by higher PIC E_{eff} and lower PIC T_{eff} compared to subtropics and equatorial areas (Fig. 6a). The higher PIC production seasonal bias in the euphotic layer coincides with higher normalized PIC E_{eff}, but lower PIC T_{eff} (Fig. 6a).”

Lines 345-349: “The results presented in this study demonstrates at the global scale that the EZ PIC production is not correlated with PIC flux in the upper ocean. However, considering distinct oceanic bioregions (RECCAP2), in the mesopelagic layer and deeper, significant correlations between EZ PIC production and deep PIC flux are observed in the North Atlantic and the Southern Ocean. These correlations are observed on every layer of depth and present the best R^2 coefficient (Table S2). North Indian Ocean regions (subtropical areas) are also characterized by PIC production positively correlated with deep PIC flux (Fig. 5).”

Line 304-309: "The model output of Nowicki et al. (2022), estimated that the contribution to the gravitational carbon pump of zooplankton fecal pellets and sinking phytoplankton aggregates were respectively of 85% and 15%, (Nowicki et al., 2022). Once mapped of 1° by 1° grid map, zooplankton fecal pellets and sinking phytoplankton aggregates contribution are characterized by a significant latitudinal pattern (Fig. 7 in Nowicki et al., 2022). The seasonality of NPP and PIC production can be overlapped with aggregates's contribution to the gravitational pump (estimated by Nowicki et al., 2022), as shown in Fig. 6b."

Lines 391-392: "However, PIC export flux and deeper flux in our dataset are globally lower in these regions (despite higher PIC production, see Fig. 6), which is the opposite of the idea that packaged CaCO3 into the fecal pellet is protected from dissolution"

L320-328: Please introduce here what you are trying to show: an explanation for the decoupling between PIC Teff and PIC production. Not easy to guess.

Author's response: *Yes, I am suggesting that the decoupling between PIC P_{eff} and/or PIC T_{eff} and PIC production is caused by biologically mediated PIC dissolution. I rewrote the paragraph to improve the readability and the concept.*

Lines 397- 406: "PIC production in the euphotic layer is decoupled from PIC E_{eff}. As well as PIC T_{eff} through the mesopelagic layer. PIC loss in the upper ocean is generally attributed to biologically mediated dissolution (Morse et al., 2006; Friis et al., 2006; Buitenhuis et al., 2019; Sulpis et al., 2021, Dean et al., 2024). Zooplankton and bacterial activities decrease with depth (Hernández-León et al., 2020), hence, intense zooplankton grazing and potential mediated PIC dissolution should occur in the epipelagic and mesopelagic layer. However, once the CaCO3 is packaged into aggregates or fecal pellets, it should be protected from surrounding seawater and associated dissolution process, regardless of the respective depths of calcite and aragonite saturation. In that way, packaged CaCO3 into aggregates of fecal pellets that settle below the saturation depth should be protected from surrounding seawater. However, zooplankton grazing could also induce aggregate fragmentation in the epipelagic and mesopelagic layers, which could be responsible for the loss of PIC in shallow waters (Toullec et al., 2019 and references in there)."

L400: Not clear what "This study" refers to.

Author's response: *I referred to the present study. I modified the text.*

Line 484: "The present study..."

Figure 7 shows an interesting pattern, but needs to be much better integrated with the results of the study.

Author's response: *I considered the lack of integration of the concepts raised by Fig. 7 (which are fundamental to the discussion). I implemented several sentences in the text to highlight the impact of Fig. 7.*

Line 482: "...The concepts behind this aspect are highlighted in Fig. 7."

Lines 421-425: "However, PIC E_{eff} is higher at high latitude where fecal pellet contribution to gravitational pump is lower (Fig. 6b). This result suggests more complex mechanism and implication of plankton community phenology into the PIC E_{eff} control (see sections 4.4.3. and Fig. 7). In addition, PIC E_{eff} is higher at high latitude where phytoplankton aggregates contribution to gravitational pump is also higher (Fig. 6b), which suggest implication seasonal phytoplankton phenology."

Lines 484-485: "The present study hypothesizes that zooplankton functional groups could control the PIC export efficiency and transfer efficiency, probably mediated by guts and vacuoles dissolution of $CaCO_3$. A summary of the hypothetic mechanism is displayed in Fig. 7."

Lines 488-489: "...this trophic cascade is expected to be season dependent (blooming event, Fig 7)."

Line 483-499: "On the other hand, in subtropical areas, which is less seasonal, planktonic ecosystems is more complex (Chaffron et al., 2021). In subtropical areas, grazing rate are higher during daylight (annually) while they are diffuse in temperate productive areas. Subtropical areas were more efficient at recycling and using nutrients through phytoplankton, while the energy transfer efficiency from nutrients to mesozooplankton appeared more efficient in temperate productive waters (Armengol et al., 2019). Shorter food web may be more efficient in energy transfer towards upper food web levels in temperate productive regions and could be the potential driver of PIC export efficiency (Fig. 7)."