Point-by-point responses to Reviewer 1

Factors contributing to the concentrations and stable isotopic ratios of sea-ice particulate organic carbon and nitrogen in the Indian sector of the Southern Ocean

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Thank you very much for your time and peer review. The revised text is circled by quotation marks "" in this text.

Changes in the manuscript not mentioned by reviewers

In the estimation of POC_{Input}, we did not consider density of sea ice; the ice melt thickness in Table 2 was equivalent to the thickness "before" its melting (Komatsu et al. 2025). Therefore, the original sea-ice meltwater flux and estimation of POC_{Input} were slightly overestimated given that sea ice density is usually <950 kg m^{-3}. In the revised manuscript, we corrected the values by multiplying density of sea ice (ρ_i=900 kg m^{-3}) used in Komatsu et al. (2025). We added following equation in the text;

"The sea ice meltwater flux was multiplied by the POC_{VWM} concentration in sea ice to estimate the POC flux from sea ice to the water column per unit area (mg C m^{-2} $year^{-1}$).

$$POC_{Input} = H_i \times \rho_i \times POC_{VWM} \tag{6}$$

Here, H_i is ice melt thickness and ρ_i is the density of sea ice (0.90) used in Komatsu et al. (2025)."

We also noticed erroneous marks in Fig. 3f which indicated significant differences of $\delta^{13}C$ between the regions. We corrected the figure and checked these revisions did not change our discussion and conclusion.

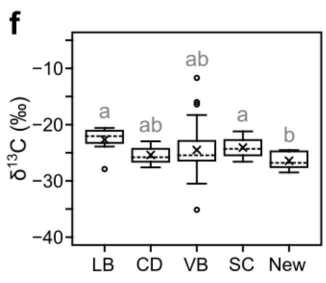

Figure 3f: Regional or ice-type (FYI/OI brash ice v.s. newly formed ice) differences in stable isotopes of POC (f).

Reviewer 1

This manuscript presents a valuable and comprehensive dataset on particulate organic matter bulk concentrations and stable isotope compositions from summer brash ice across a broad spatial extent of the Indian sector of the Southern Ocean. As current knowledge of sea-ice biogeochemistry is largely based on studies of spring fast ice, this investigation of degrading summer brash ice provides important insights into the composition, transformation, and potential export of organic matter during the seasonal melt period. The authors' estimation of the contribution of sea-ice-derived POC relative to regional primary production represents a particularly noteworthy contribution.

However, the manuscript has several key limitations, including a lack of alignment between the title and abstract and the broader context presented in the Introduction; an ecological interpretation that places considerable emphasis on zooplankton food-web dynamics without supporting evidence from direct zooplankton observations. Addressing these issues would substantially improve the coherence, scientific rigor, and overall impact of the manuscript.

Major Comments

1. The title can be made concise and eye-catching.
We changed the title to "Factors contributing to the concentrations and stable isotopic ratios of sea-ice particulate organic carbon and nitrogen in the Indian sector of the Southern Ocean".

2. The title and abstract explicitly position stable isotopes as a primary tool and the focus of this study. However, the current Introduction is heavily skewed toward lower-trophic-level synchronization, phytoplankton blooms, and physical sea ice retreat. There is almost no conceptual background establishing the biogeochemical framework of stable isotopes in polar environments. The authors should dedicate 1 paragraph in the Introduction to framing why isotopes are necessary here.
We created the following paragraph describing the significance to study the stable isotopes of POC/PN and their theoretical framework;

"The ranges of previously reported $\delta^{13}C$ and $\delta^{15}N$ values of sea-ice POM are extremely wide, yet the factors driving these variations are not fully understood. In aquatic systems, $\delta^{13}C$ and $\delta^{15}N$ change depending on isotopic fractionation by photosynthetic organisms, the types of assimilated nutrients (e.g., nitrate and ammonium), the isotopic composition of dissolved inorganic carbon in the environment, and differences in fractionation factors among taxonomic groups (Casciotti et al., 2003; 2009; Henley et al., 2012). Because the isotopic ratios of POM in the ocean often reflect the environmental conditions (e.g., dissolved CO_2 concentration), it is possible to reconstruct the past surface pCO_2 (Bentaleb et al., 1998; Lourey et al., 2004) or nitrate concentrations (Francois et al., 1992) by using the isotopic ratios in sediments. In sea ice, however, although the carbon isotope fractionation coefficient of ice algae is lower than that of open-ocean phytoplankton (Munro et al., 2010), $\delta^{13}C$ of POC is generally higher and wider due to a decrease in CO_2 concentration in the brine by active algal photosynthesis (Kennedy et al., 2002). Similarly, the $\delta^{15}N$ of PN in sea ice is higher than that in seawater (Rau et al., 1991), which is thought to be due to POM decomposition, the recycling of nitrogen nutrients, and the consumption of NH_4^+. Recently by using isotopic ratio of nitrogen, 70% of the consumed nitrogen was estimated to be from the regenerated nitrate in Antarctic sea ice (Fripiat et al., 2014). These studies indicate that the $\delta^{13}C$ and $\delta^{15}N$ of POM are closely related to ice-algal production, nutrient consumption, and recycling, suggesting that they can help us understand material cycling processes within sea ice which are difficult to observe directly."

We changed the last line of the abstract ”These results suggest that the carbon supply from sea ice is a crucial factor supporting ecosystems in the seasonal sea ice zone.” as follows;

"This result suggests that sea ice melt provides significant portion of organic matters potentially supporting Antarctic ecosystems in the seasonal sea ice zone, which could be traced by difference of sea-ice and seawater stable isotopic compositions."”

3. The sea-ice dataset is impressive, capturing 102 samples across 24 stations over a four-year period (2016–2020) across a massive geographical range. In contrast, the comparative seawater POM dataset is highly restricted, sampled only twice daily during a single cruise in a single month (January 2019, UM18-08 cruise). The authors must explicitly discuss this limitation in the Discussion and exercise caution when making direct statistical or variance comparisons between the two distinct sample matrices.
We revised text to explicitly state that our data is not representative of all regions/seasons by stating the spatio-temporal limitation of our POM data in surface water, in particular when comparing with sea-ice POM.

In Section 4.2. we compared our $\delta^{13}C$ and $\delta^{15}N$ values and stated it’s restricted in January;

"Although spatiotemporally limited, our $\delta^{13}C$ and $\delta^{15}N$ of surface seawater obtained in January was lower than those of sea ice (−29±1.0‰ for $\delta^{13}C$ and −0.5±1.3‰ for $\delta^{15}N$). The small variability in isotopic ratios in seawater is likely owing to the narrower ranges of sampling region (50–64°S) and periods (January) compared to the previous data sets conducted in 37–70°S during June and May over several years (Espinasse et al., 2019)."

In Section 4.4. we noted seasonal variations of POC:PN in seawater;

"It should be noted, however, that surface seawater POC:PN ratios in this study are conservative values for they were determined in the most productive season (Janurary), when POC:PN usually reaches minimum during spring and autumn (Smith et al., 2000)."

4. The Introduction builds an extensive narrative around filter-feeding zooplankton communities, copepod/krill life cycles, and trophic structures. Because the manuscript does not measure actual zooplankton tissue isotopes or grazing rates, the ecological conclusions are entirely speculative based on estimated flux. To avoid over-promising, the text in the Introduction and Discussion should be re-scoped to focus tightly on characterizing the supply and quality of the organic matter source itself, rather than framing the manuscript as a direct investigation into zooplankton feeding ecology.
We merged the 2nd and 3rd paragraphs of introduction and substantially shortend the paragraphs with more focus on the quality and quantity of sea-ice POM;

"In the Southern Ocean, the vast seasonal sea ice zone (SIZ) plays a crucial role in controlling the primary production and carbon export to the depth (Ardyna et al., 2017; Zúñiga et al., 2021). Ice-edge phytoplankton blooms can occur during sea ice melting

(Wilson et al., 1987), which accounts for more than 10% of primary production south of 50°S (Arrigo et al., 2008). Primary consumers (such as copepods and salps), the drivers of the biological pumps and sequestering organic carbon into the deep ocean, have life cycles that rely on carbon dynamics following ice melting (Makabe et al., 2017; Tachibana et al., 2023; Sugioka et al., 2021). However, ice-edge blooms occur in only approximately 20% of the area (Fitch and Moore, 2007) because of large variations in iron supply (Sedwick and DiTullio, 1997), water-column stratification (Wilson et al., 1986), and the released ice algae, which serve as a seeding population (Garrison et al., 1987; van Leeuwe et al., 2022). Despite the significant heterogeneity in phytoplankton biomass (chlorophyll *a* [Chl *a*] concentration), zooplankton distribute more ubiquitously (Takahashi et al., 2011). Reviews by Dalman et al. (2025) summarized high particulate organic carbon (POC) concentrations (>1,000 µg L^{-1}) and POC:Chl *a* ratios (>1,000) in the upper summer sea-ice cores. Hence, particulate organic matter (POM) from sea ice is hypothesized to sustain these primary consumers and the knowledge on its quantity and quality could contributes to our understanding of the carbon cycle in the Southern Ocean."

The final paragraph in Section 4.4., which was the only discussion part about the influence of sea-ice POM on zooplankton, was shortened and any speculative notion was deleted;

"Finally, we discuss the impact of POC supply from sea ice on the carbon content in the water column from the perspective of primary consumers. Antarctic filter-feeding euphausiids have been reported to consume ice algae which constitute 5–36% (11% on average) of the carbon in their diet in the summer MIZ (Kohlbach et al., 2019). Although it remains unknown if all sea-ice derived POM are consumed or settle to the depth or remineralized in the water column, our estimate (>14% of MIZ production), which was temporally integrated, fell within this range. In this study, the POC:PN ratio was >10 on average, indicating lower food quality than phytoplankton (surface seawater POM, 5.2±0.5 POC:PN ratio in this study). It should be noted, however, that surface seawater POC:PN ratios in this study are conservative values for they were determined in the most productive season (Janurary), when POC:PN usually reaches minimum during spring–autumn (Smith et al., 2000). Daase et al. (2011) found the growth time and body size during the nauplius stage were equivalent to those when fed high-quality (low POC:PN ratio) food (Daase et al., 2011). Therefore, POM from sea ice during the summer have a potential to support the growth of zooplankton larvae (such as copepod nauplii) and needs to be tested by grazer's isotopic signatures."

5. Line no. 229 "Sea-ice POM δ13C and δ15N ranged from −35.1‰ to −3.1‰" are correct values, but they do not match with Table 1 and Figure 2.
We revised the original text. The correct values are −35.1‰ to −11.7‰ for $\delta^{13}C$ and −3.8‰ to +11.1‰ for $\delta^{15}N$. The range (y-axis) of $\delta^{15}N$ plot (Fig. 2b) is smaller than the sample range because the sample with the highest $\delta^{15}N$ (+11.1‰) did not have $\delta^{13}C$ value due to the lack of quality for this sample.

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