Reviewer #2

The manuscript by Kim et al provides a detailed study of 3 sediment cores from Kongsfjorden, Svalbard, with the aim to improve our understanding of the relationship between organic carbon (OC) deposition in the fjord, its different sources and climatic/oceanographic changes. The authors combined sedimentological data, bulk parameters, biomarkers and a robust geochronology based on 210Pb to estimate the relative contributions of sedimentary OC sources to different coring sites in Kongsfjorden. The manuscript is very well written and very clear, and the described dataset represents an important addition to our knowledge of the organic carbon cycle in Svalbard. I have just a few general comments and suggestions, and some minor comments.

Reply: We sincerely appreciate Reviewer #2's thoughtful comments, which have greatly contributed to improving the quality of our manuscript. We will incorporate the suggestions into the final version wherever appropriate.

General comments:

It is unclear in the introduction which knowledge gaps you are trying to fill: is it the lack of observational data on AW inflow before the recent warming or during it? Or both? A few more words could be spent to underline and make clear the main aim of the work

Reply: As suggested, we will add a statement clarifying that our study aims to fill the gap in observational data on Atlantic Water (AW) inflow, both during the early phase of Atlantification (prior to recent warming) and in the context of more recent changes. This will be included in the revised manuscript.

Since the aim of the work is strongly related to the inflow of AW in the fjord, I think a section briefly explaining the mechanisms of AW intrusions in the fjord, mentioning also its effects, should be included. With it, a better representation of WSC-ESC dynamics could be included in Fig. 1 (for example, like in De Rovere et al 2022).

Reply: We appreciate this suggestion. In the revised manuscript, we will add a concise paragraph in the introduction that explains the mechanisms of Atlantic Water (AW) intrusion into Kongsfjorden, focusing on the roles of the West Spitsbergen Current (WSC) and the East Spitsbergen Current (ESC). Additionally, we will update Figure 1 to include a schematic illustrating the WSC–ESC dynamics and AW pathways, inspired by De Rovere et al. (2022), to provide a clearer representation of these processes.

The EM modeling for grain size seems an excellent tool to study grain size distribution with a more accurate approach, but I do not understand why EM3, as you presented it, can not be simply a combination of EM1 and EM2. Could you further explain how the procedure for establishing the different end members work?

Reply: In this study, endmember modelling of grain size data from sediment cores was conducted using the AnalySize program with a non-parametric approach, following the methodology of Ahn et al. (2024). This analysis resulted in the extraction of four endmembers (EMs). Based on the nature of their modal characteristics and principal mode values, two of the EMs were grouped as EM1a and EM1b, while the remaining two were defined as EM2 and EM3, respectively. EM1 (a + b) and EM2 were characterized by unimodal grain size distribution curves. EM1 had fine-grained mode values ranging from 8.2 to 9.3 µm, whereas EM2 was characterized by a relatively coarser mode at 29.3 µm. In this context, EM3, which exhibits a bimodal distribution, initially appears to result from a simple combination of EM1 and EM2. However, the coarse mode of EM3 reaches 81.2 µm, which is significantly larger than the principal mode of EM2. Therefore, EM3 cannot be regarded as a simple combination of EM1 and EM2.

S/V and C/V ratios, both in core and surface sediments, seem to point towards a quite strong contribution of gymnosperms, despite the major presence of angiosperm species in Svalbard archipelago (see for example https://npolar.no/en/themes/vegetation-svalbard/ and references therein). How does this compare to other lignin datasets from similar Arctic areas?

Reply: A previous study by Kim et al. (2023) analyzed lignin phenols in dominant plant species (Cassiope, Salix, and Dryas) from Svalbard and found a clear dominance of non-woody angiosperm-derived lignin signatures. However, the strong gymnosperm signal observed in the surface and core sediments, despite the prevalence of angiosperm species in the Svalbard archipelago today, suggests a significant contribution of OC from older sources, such as those stored in permafrost. This points to the potential input of OC from different time periods rather than solely from present-day vegetation.

You present really interesting results on the change of OC sources in the latest decades, especially the increased marine OC accumulation rates in the middle fjord, but why do you think the same pattern is not present in the outermost core also? I think in general that this entire section of the discussion could be expanded, elaborating further the interpretation of the changes in sedimentary OC deposition, both in time and between coring sites.

Reply: Thank you for your valuable feedback. The observed increase in marine OC accumulation rates (ARs) at the middle fjord site (core HH22-1161MUC), but not at the outermost site (core HH22-1159MUC), likely reflects differences in hydrographic and sedimentary dynamics between these locations. The middle fjord site is strongly influenced by enhanced Atlantic Water (AW) inflow, regional warming, sea ice retreat, and glacier melt, particularly since the 1970s. This has resulted in increased marine productivity and nutrient delivery, especially from the Bayelva River, which supports higher OC burial. Furthermore, grain-size end-member modeling revealed a distinct EM3 signature at HH22-1161MUC, indicative of fluvial input of both fine and coarse sediments, which is absent in HH22-1159MUC. This suggests that the middle site is more influenced by fluvial processes, driving the temporal increase in marine OC accumulation. In contrast, the outermost site (HH22-1159MUC) is located in a more distal part of the fjord, where hydrodynamic conditions are stronger and sedimentation rates are lower. These conditions may limit the preservation of OC, making it more difficult to detect temporal trends in marine OC deposition. The outer site is also less influenced by riverine and subglacial discharge, further contributing to the observed difference in the patterns of OC accumulation between the two sites. We will expand on these interpretations in the revised manuscript to provide a clearer and more comprehensive understanding of the changes in sedimentary OC deposition both in time and across different coring sites.

Detailed comments:

Line 32-33: this sentence is a bit confusing; it reads as if the increased influence of AW underscores the potential future amplification of AW inflow itself. I think what you meant is that the increased influence of AW underscores the likely important effects of an even stronger AW inflow

Reply: Thank you for pointing this out. We agree that the original phrasing was unclear and could be misinterpreted. In the revised manuscript, we will reword the sentence to clarify that the increased influence of Atlantic Water (AW) observed in our study highlights the potentially significant effects of further strengthening AW inflow in the future.

Line 71-72: I am not sure what "long-term changes" are when referring to post 1990 effects, do you mean also changes that will happen in the future?

Reply: Thank you for this helpful comment. We agree that the term 'long-term changes' may be interpreted differently depending on the context. We will remove 'long-term' in this sentence in the revised version.

Line 88: I would add past changes to present and future changes

Reply: As suggested, we will revise the sentence in the revised version of the manuscript to clarify the intended meaning.

Line 93: refer to Fig. 1 in this instance

Reply: As suggested, we will revise the sentence in the revised version.

Line 102-104: change position of this sentence before the previous one, in line 99

Reply: As suggested, we will revise the sentence in the revised version.

Line 174: the procedure for sample preparation before 14C analysis of TOC is missing

Reply: Thank you for pointing this out. We will add a detailed description of the sample preparation procedure for radiocarbon (^{14}C) analysis of TOC in the revised manuscript. Briefly, sediment samples were pretreated with HCl to remove carbonates and with NaOH to eliminate humic acids, then dried at 60 °C. The alkali-insoluble fraction was combusted at 900 °C in sealed ampoules with CuO to generate CO_2, which was subsequently purified and converted to graphite following the method of Vogel et al. (1984). Radiocarbon ($^{14}C/^{13}C$) measurements were conducted using accelerator mass spectrometry (AMS).

Line 180: remove "the" before CuO oxidation

Reply: As suggested, we will remove "the" in the revised manuscript.

Line 190: change "precision" to "uncertainty"

Reply: As suggested, we will change the term in the revised manuscript.

Line 223: why were only 2 cores analyzed for geochronology? Besides, this would agree with fig. 3 where only the depth profiles of cores 1161MUC and 1159MUC are displayed, but the caption of the figure states that all 3 cores have depth profiles (line 891-892)

Reply: Thank you for pointing this out. In the revised manuscript, we will clarify in the Methods section that the inner fjord core (HH23-1058MUC) was excluded from ^{210}Pb dating, as previously mentioned. Additionally, we will correct the caption of Figure 3 to accurately reflect that only two sites (HH22-1161MUC and HH22-1159MUC) are shown.

Line 274-276: judging by the ranges and average values, it is dubious if the middle core or the outer core have different lignin phenols concentrations

Reply: Thank you for the observation. In the revised manuscript, we will remove the statement suggesting a difference in lignin phenol concentrations between the middle and outer cores, as the reported ranges and mean values do not support a statistically meaningful distinction.

Line 325: change "located closest" to "the closest one"
Reply: As suggested, we will change the term in the revised manuscript.

Line 331: why does the settling of fine particles contribute to the formation of EM2 near the glacier front? EM2 was described as an EM mainly constituted by coarser particles

Reply: Thank you for the insightful comment. We acknowledge that the original wording may have been unclear. To clarify, the presence of coarser-grained sediments associated with EM2 near the glacier front is interpreted as the result of energetic bottom currents generated by subglacial meltwater discharge. Specifically, the release of meltwater initiates buoyant upwelling plumes that enhance localized hydrodynamic activity in glacier-proximal environments. This circulation promotes strong bottom currents capable of winnowing finer particles and facilitating the preferential deposition of coarser material, which characterizes EM2. We will revise the manuscript accordingly to more clearly articulate this sedimentary mechanism and prevent potential misinterpretation.

Line 334-339: could it be that the mixed (fine + coarse) distribution that you observe in the middle of the fjord is generated by the combination of different (marine, fluvial and glacial) processes? This is one of the things which brings me to think that EM3 could be a combination of EM1 and EM2 (see also the 3rd general comment).

Reply: We thank the reviewer once again for this thoughtful comment. We agree that the mixed (fine + coarse) grain-size distribution observed in the middle of the fjord likely reflects the combined influence of glacial and fluvial processes. As noted in response to the general comment, EM1 primarily represents the settling of fine particles from suspension, largely driven by glacial meltwater, while EM2 reflects the deposition of coarser sediments likely resulting from bottom-current winnowing. EM3 displays a distinctly bimodal grain-size distribution, which may initially suggest a simple combination of EM1 and EM2. However, the coarse mode of EM3 is significantly coarser than the principal mode of EM2, indicating that EM3 is not a straightforward mixture of the two. We will clarify this point in the revised manuscript.

Line 349: remove the comma after 0.4

Reply: As suggested, we will remove the comma in the revised manuscript.

Line 362-364: please include in the text the range of values, or average values, for surface sediments, IRDs and coal to make it easier for the reader

Reply: As suggested, we will add the relevant range and/or average values for surface sediments, IRDs, and coal in the revised manuscript to facilitate comparison and improve clarity for the reader.

Line 369-370: as for the previous comment, please include the δ13C values for surface sediments, IRDs and coal in the discussion

Reply: As suggested, we will include the $\delta^{13}C$ values for surface sediments, IRDs, and coal in the revised manuscript to enhance the discussion and provide more clarity to the reader.

Line 390-392: this statement, which I fully agree with, also partly contrasts with the previous interpretation of EM3 in the middle fjord, where you stated that fluvial processes were the possible source of the bimodal distribution, while here it is stated that glacial processes were the key factor for the general lack of sorting of the sediments

Reply: We thank the reviewer for this thoughtful comment. To clarify, our interpretation of EM3 emphasized a fluvial origin for both the fine and coarse fractions. The fine particles were likely derived from suspended sediments transported by river input, while the coarse fraction was attributed to denser underflows originating from the same fluvial source. Therefore, rather than representing a mixture of glacial and fluvial inputs, EM3 was interpreted as the product of a distinct fluvial depositional regime capable of delivering a wide range of grain sizes. We will revise the manuscript to more clearly highlight the fluvial origin of EM3 and ensure consistency in our interpretation throughout the text.

Line 392-396: I am not sure I agree with this interpretation. Of course, it is likely that the fjord experienced changes in the energy of the depositional environments, but the poor sorting in all cores could be simply due to the always present glacial activity, that even in stable conditions will provide poorly sorted sediments, just as you stated in the previous sentence citing Singh et al. 2019.

Reply: onsistently poor sorting observed across all cores can reasonably be attributed to the persistent influence of glacial activity, which delivers poorly sorted sediments even under stable environmental conditions. All core sites were primarily influenced by glacial processes, resulting in poor sorting. We also note that at the middle site, EM3 constituted only a small fraction of the overall grain size distribution, and therefore its sorting signal would be largely overprinted by EM1. Thus, even at the middle site, the overall grain size distribution reflected poor sorting. We acknowledge that our initial wording may have caused some confusion and will revise the manuscript accordingly to clarify this point.

Line 428: remove “The”

Reply: As suggested, we will remove the term in the revised manuscript.

Line 436-438: how do you explain a higher contribution of degraded OC in the middle and outer fjord, when supposedly the major source of old and reworked (and thus also degraded) OC in the fjord should be the Kongsbreen/Kronebreen (as it is also suggested by radiocarbon data)?

Reply: While radiocarbon data indicate that Kongsbreen/Kronebreen is a significant source of old and reworked OC, the higher 3,5-Bd/V and (Ad/Al)v ratios observed in the middle and outer fjord likely reflect additional degradation processes that occur during transport and post-depositional modification. As organic matter is transported seaward from glacial sources, it undergoes oxidation, microbial degradation, and hydrodynamic reworking, particularly in areas where sediment residence times are longer, such as in the middle and outer fjord, and where exposure to oxygen is more prolonged. Therefore, the observed increase in lignin degradation indicators offshore is not necessarily in conflict with the radiocarbon-based source attribution but instead reflects the combined effects of provenance and degradation processes along the transport pathway. We will clarify this aspect in the revised manuscript.

Line 481-485: while describing the results from Method 1, you used the range of % for each EM. Here instead you used the average values with SDs. Change one of the two descriptions for better uniformity

Reply: To ensure consistency and avoid redundancy in reporting, we will use the average values and standard deviations in this section, as they provide a clearer representation of the characteristic features of each end member. We will revise the manuscript accordingly.

Line 581: explain further what you mean with "two-step process", this point is not clear from the discussion

Reply: Our study highlights ongoing and significant shifts in carbon dynamics in the Svalbard region, driven by a combination of increased Atlantic Water (AW) inflow and glacier melting. Building on the findings of Tesi et al. (2022) and our results, we propose that the marked increase in AW inflow to Kongsfjorden during the 20th century likely occurred in two distinct phases, governed by complex and not yet fully understood mechanisms. To better constrain the timing, drivers, and consequences of AW variability, we emphasize the need for future research that integrates high-resolution climate modeling with sediment core records from Svalbard. This integrated approach will be essential for refining projections of climate and carbon cycle feedbacks in the rapidly warming Arctic. These aspects will be more thoroughly addressed and incorporated in the revised manuscript.

Fig. 11D: the axis label states "Distance from Blomstrandbreen front in 2006 (m)", but it is not clear from where this distance was measured. A figure in the Supplementary Materials showing the position of this glacier would also be useful for the readers

Reply: The distance shown in Fig. 11D was measured from the position of the Blomstrandbreen glacier front in 2006, based on data from Liestøl (1988), Landsat imagery, and aerial photographs. Glacier margin fluctuations have been well documented in Burton et al. (2016; see the figure below), with solid lines representing glacier margins determined with higher certainty. To further clarify the location of the glacier front for readers, we will include a supplementary figure illustrating the position of Blomstrandbreen.