Discussion on the 1st Anonymous Referee review

Referee comment on "Particulate organic matter in the Lena River and its Delta: From the permafrost catchment to the Arctic Ocean" by Olga Ogneva et al., Biogeosciences Discuss., https://doi.org/10.5194/bg-2022-183-RC1, 2022

Comment types: Authors' Response: "AR", Referee Comment: "RC"

Comment colors: Authors Response: "blue", Referee Comment: "black"

Comment fonts: When it was possible, we highlighted changed text by the **bold font**, the text from the manuscript copied to this review was taped *cursive*

RC: Review of the manuscript "Particulate organic matter in the Lena River..." by Ogneva et al.

The paper addresses a fundamental question of riverine fluxes of particulate organic carbon in still poorly studied permafrost regions, and its potential impact on surrounding marine environments, and as such it fits the scope and potentially can make a good addition to the journal.

AR: Thank you for your review of our manuscript, we highly appreciate your time and work. We have answered all your comments below and revised the manuscript accordingly. As requested by Biogeosciences, the revised manuscript will be uploaded at a later stage after responding to all reviewer comments. There will be a track change version of the manuscript, as well as a clean version including all modifications following your and the 2 other reviewers' suggestions. All the line numbers refer to this clean revised version.

RC: Major critical comments are listed below.

The main conclusions of the authors – that estimation of river OM discharge to the coastal zone cannot be based solely on the data of the main stem far from the deltaic region – is certainly useful for modelers, although not novel and generally agrees with large body of evidences collected for example, by Shirshov's Institute of RAS in Arctic rivers and coastal zones (A.P. Lisitsyn's marginal filters concept suggested more than 30 years ago).

AR: Thank you for this suggestion. The publication mentioned by you (Lisitzin, 1994) will perfectly fit into the introduction, particularly into the sentences stating a high importance of the nearshore zones. Citing the work of Lisitzin will improve our introduction; however, we would like to stress that those published findings do not reduce the novelty of our work, since Lisitzin described the marginal zones of the ocean – the extensive coastal area up to several

hundred km from the delta, where riverine freshwater and saltwater are mixing and major sedimentation processes take place. In our paper, we focused on the Lena Delta itself which is right at the interface between land and sea and thus the "gateway" for riverine discharge supplying the marginal zone of the Laptev sea with organic matter.
L61-63 edited: *"The nearshore coastal zone of the Arctic Ocean (including deltas, estuaries, and coasts) is of great importance as major transformation processes of terrestrial material are expected to take place in these biogeochemically active areas (Tanski et al., 2019; Jong et al., 2020; Sanders et al., 2022)* ***as well as its sedimentation (Lisitzin, 1994)****."*

We also updated the reference list accordingly:
Lisitzin, A. P.: A marginal Filter of the Ocean. Okeanologiya, 34 (5), 735-747, 1994, (In Russian)

RC: The Introduction is well written but it is way too general. Former studies on the POC were not discussed (Semiletov, Kutscher, E. Karlsson). As a result, specific objectives and novelty of this work are unlear; and no new nypothesis is proposed to be tested (a degree of pOC lost in the deltaic zone or the age and origin of POC could be such hypotheses). In anyway, the authors should clearly position this work with respect to former studied of the Lena River to prove its real novelty.
AR: The importance of these (and other) previous studies investigating POC in the Lena River and its Delta is very much appreciated and respected by us. We were glad to refer multiple times to all studies mentioned (Semiletov et al., 2011;Kutscher et al., 2017; Karlsson et al., 2016) and to highlight them in this manuscript. They were included in the discussion part of the paper already, where they were discussed in great detail (Kutscher et al., 2017) and the data provided by these publications were included into our data plots as the referee points out (Kutscher et al., 2017 and Karlsson et al., 2016).
Nonetheless, we appreciate the suggestion of citing these references in an improved and more focused introduction, which we wrote for the revised manuscript.

RC: The Discussion is very much driven by postulated overwhelming role of phytoplankton in POC, d13C, D14C control in the main stem vs. delta. Without Chl a analysis, or any information on the phytoplankton, such a discussion is not substantiated and suggested explanations have low novelty and probably unwarranted. As a minimal research efforts, the authors could examine their TSM samples by SEM to show the presence of higher amount of diatoms in their deltaic samples vs main stem samples Examination of C/N ratio could aslo help a lot in distinguishing different sources of POM The discussion and data treatment (Fig 4) also ignore that part of POM may be represented by contemporary vegetation debris (i.e., lignin), especially from larch trees, dominating the Lena catchment

AR: Thank you for your comments and suggestions! As pointed out in the manuscript already, Chl-*a* was unfortunately not measured by us, since these kinds of analyses were not part of the work plan for our expedition. In our manuscript we discuss the potential phytoplankton contribution based on indirect indicators ($\delta^{13}C$ of POC and some supporting observation (chapter 4.2.1: weather conditions during the sampling period, nitrate gradient)) and previously published suggestions about the nature of POC depleted in $\delta^{13}C$ (Winterfeld et al., 2015; Kutscher et al., 2017; Bröder et al., 2020). The $\delta^{13}C$ values measured by us in the Lena Delta were significantly lower than in the river and very low in general. The range of values (between -33.32 and -31.01 ‰) which is lower than $\delta^{13}C$ from modern plants contribution (from -28.4 to -27.0 ‰) (Vonk et al., 2017) or for the terrestrial primary production (-27.7 ‰) such as organic and litter layers (Wild et al., 2019) and even lower than $\delta^{13}C$ reported in previous studies on phytoplankton contribution in the river waters. Such a low range of values was described for the POC during the algae bloom period (Finlay and Kendall, 2008) and for algae directly (Galimov et al., 2006). Thus, taking into account the above, the explanation of these low values in our opinion could be only a phytoplankton bloom.

As it was already mentioned, $\delta^{13}C$ for the contemporary vegetation debris is significantly higher than what we measured in POC. We would like to suggest that its input into the $\delta^{13}C$ composition of POC was lower than the one from phytoplankton, thus we cannot see its fingerprint in POC isotopic composition. Nevertheless, we consider that remains and particles of modern C3 plants vegetation are present in the riverine waters, thus we would like bring further clarifications into our manuscript:

L514-522: *"…weapons testing during the 1960s and 1970s; thus, values from organic litter from Russia, Scandinavia, and Alaska were included (Wild et al., 2019).*

Proposing phytoplankton as one of three main sources of POC does not exclude the input of contemporary vegetation into the riverine and deltaic OM. $\Delta^{14}C$ signals from modern vegetation and phytoplankton sources can be assumed to be identical, and similar to the atmosphere (Winterfeld et al., 2015, Wild et al. 2019), while their $d^{13}C$ values are likely different. Therefore, phytoplankton was proposed as a modern OM source based on evidence from $\delta^{13}C$ values of POC corresponding to algal input (see section 4.2.1) and suggesting sufficiently lower input of plant debits into POC. Modern plants likely contributed as well, but due to their rather constant $\delta^{13}C$ signature paired

with variable $\Delta^{14}C$ values (plant debris vs roots and litter) they cannot be distinguished from Holocene soils and must be regarded to be a contributor to this endmember."

We will take additional possible treatments and analyses, which you have kindly suggested in this review into consideration for our further work and future publications.

Specific comments:

RC: L117-120 This might be true; however, di not the former works of Semiletov, Kutscher etc address the transformation of C between Zhigansk/Yakutsk and the delta?

AR: We highly appreciate the study of Kutscher et al. and were glad to refer to this study multiple times in our publication. Nevertheless, the northernmost sampling point in the Kutscher et al. study is Dzhardzhan River (68.7°N, approximately 200 km north from Zhigansk and 600 km south from the Delta).

L118- 123 edited: *"… Zhigansk, located ~800 km upstream from the Lena Delta.* ***It is also known that a significant fraction of the suspended matter carried by the Lena River is deposited before the Lena reaches Kyusyur, along a narrow part of the Lena main stem called "Lena Pipe" (Semiletov et al., 2011 Fedorova et al., 2016).*** *As the ArcticGRO sampling location is far from the site where Lena runoff enters the Arctic Ocean and any biogeochemical processes* ***taking place downstream from Zhigansk and particularly in the delta*** *are not reflected in the ArcticGRO data, the properties of water and suspended materials sampled at Zhigansk may in fact not be entirely representative of the discharge to the ocean."*

RC: L176-177 Provide some numbers on the magnitude of Delta14C between "old" and "modern" for non-experienced reader

AR: Changed accordingly:

L186-188 edited: "*Since radiocarbon analysis is commonly used as a method for determining OM age, for discussion of the results, we refer to more $\Delta^{14}C$-depleted samples as "old"* ***or "ancient"*** *C from "old" OM sources* ***(less than -900 ‰ or ~18,500 ^{14}C years.)****, and to more $\Delta^{14}C$ enriched samples* ***(in the range above -50 or ~400 ^{14}C years.)****, as "young" or "modern" C."*

L265-L264 (edited):*" Radiocarbon levels of POC varied within a wide range between -243 and -88 ‰* ***(translating to approximately 2236 and 740 ^{14}C years mean age, respectively)"***

RC: L185-187 Neglecting the beginning of spring flood may underestimate sizable amount of riverine C, transported to the delta (which is not the case for the winter time). Justification ere is needed.

AR: The authors' team are fully aware of the crucial importance of the spring flood period for the entire annual C balance of the Lena River discharge. Nevertheless, the aim of this study was not to estimate the annual OM discharge, but to compare POC discharge and its sources in the Lena main stem and delta based on samples collected in summer 2019, during a time not affected by the spring flood conditions.

RC: L197-198 Former studies already shown this; why additional efforts are needed?

AR: Since stratification is one of the crucial parameters for estuaries in terms of their functioning (Geyer and Ralston, 2012) we found it essential to investigate if this parameter was reflected in the Lena Delta during sampling. Thus, we would like to keep mentioned information about our results (reference to the Fuchs et al., (2022), which is based on the same samples as this study) as a clarification of deltaic conditions. We further stress this here, as the lack of stratification is distinct from other Arctic rivers (e.g., Mackenzie, (Hilton et al., 2015)).

RC: L203-205 Unclear. If there is no difference in deltaic region (L197-198), why there should be any in the river main stem? More likely explanation is due to seasonal variations in C concentrations in the Arctic GRO dataset.

AR: We found this clarification essential, since potentially river water masses may be stratified as well, which is a reason for the ArcticGRO group to organize depth-integrated sampling. We added this explanation to the manuscript briefly:

L217-226: "*We did not collect samples from different water depths along the river transect from Yakutsk to Stolb but instead were only able to sample surface waters. In contrast to our surface water samples, ArcticGRO samples are depth-integrated,* ***since potentially river water masses may be stratified (e.g. Mackenzie: Hilton et al., 2015)****. This difference in sampling might explain some of the differences between our observations and those made by ArcticGRO (see sections 3.3.1 & 4.2.2****).****"*

Reference list updates:

Hilton, R., Galy, V., Gaillardet, J., Dellinger, M., Bryant, C., O'Regan, M., Gröcke, D.R., Coxall, H., Bouchez, J. & Calmels, D. Erosion of organic carbon in the Arctic as a geological carbon dioxide sink. Nature 524, 84–87, https://doi.org/10.1038/nature14653, 2015

RC: Fig. 2 is well presented. However, the data of former researchers, obtained at these transects (at least, the Yakutsk – Kusur one) should be also presented

AR: We appreciate this suggestion! We had considered including published data in Fig. 2 but finally decided against doing so. This is based on three reasons: 1) results from former studies are presented in Fig 3 and 4 already; 2) Fig 2 was dedicated to our results measured for this particular sampling campaign in summer 2019. We would like to keep the focus on our sampled sites; 3) Additional datasets would make the figure too crowded and would distract from our main findings.

RC: Section 4.1.1 can be strongly shortened; the novelty of these findings is low. Summarize in one paragraph. Some relevant information can be shifted to the caption of Fig. S1.

AR: Thank you, following your advice we shortened section 4.1.1 (L294-317):

"The Lena River is characterized by a nival hydrograph regime with a distinct flood event taking place in the beginning of summer during the snowmelt and ice breakup period (May-June) and a very low water flow in winter (Yang et al., 2002). Discharge has a strong effect on the amount of solids and OM released by a river (Magritsky et al., 2018). The peak of annual POC concentrations in the Lena River (>3.6 mg L^{-1}, McClelland et al., 2016) and TSM concentrations (>150 mg L^{-1}, ArcticGRO) occur right after the flooding following ice breakup in late May–early June.

The peak water yield in 2019 took place on 2 June and reached 83,000 m^3 s^{-1}, then it decreased and varied in the range of 49,200–45,999 m^3 s^{-1} during the time interval when the main stem transect was sampled. During the sampling in the Delta (2019/08/07–2019/08/09) the discharge was 19,600–19,000 m^3 s^{-1}, which was less than half the discharge during main stem sampling.

We analysed all ArcticGRO data on TSM and POC for the Lena River to demonstrate that TSM and POC concentrations were correlated with discharge (Figure S1). However, when considering a discharge ranging between 15,000 and 50,000 m^3 s^{-1}, (the typical range of discharge values in summer (including 2019) and in September), there is no significant relationship between discharge and TSM and POC concentrations (Figure S2). Thus, the strong relationship between discharge and TSM/POC appears to be driven by the large difference between maxima in all parameters (observed during the spring flood) and their minima (found during low flow in winter).

Average surface water TSM and POC concentrations in the Lena River in 2019 agree with reported average TSM and POC concentrations observed by ArcticGRO during periods with discharge within the mentioned range (TSM in this study: 21.29 mg L^{-1} as compared with 22.66 mg L^{-1} for ArcticGRO, and POC 0.77 mg L^{-1} and 0.79 mg L^{-1}, respectively). TSM and POC concentrations in the Lena Delta in summer 2019 were 2 and 1.5 times lower, respectively, than values reported by ArcticGRO for a comparable time of year and under similar discharge conditions (TSM: 9.3 ±5.2 mg L^{-1}, POC: 0.41 ±0.10 mg L^{-1}) (Figure 2a & b). On the other hand, our deltaic POC concentrations are similar to previously published POC data for the Lena Delta (Winterfeld et al., 2015) (Figure 3). This shows that the difference we observe between river and delta is a persistent feature that is not biased by sampling time or depth but is mostly caused by other factors such as, e.g., flow and velocity."

RC: L314-320 This is site description; re-arrange

AR: Rearranged accordingly, we also have edited this paragraph accordingly to the advise of the third reviewer.

L97-105: "*The Lena River watershed was subdivided into the Upper and the Lower Lena, which contribute differently to the TSM and water discharge into the Lena River and are characterised by distinct morphologies.* ***Here, we define the Upper and Lower Lena River by the area of subcatchments of the Lena River (https://www.hydrosheds.org/products/hydrobasins). The separation between the Upper and Lower Lena was made approximately 150 km downstream from Yakutsk (Figure 1a). The Upper Lena includes the southern limits of the river and the catchment upstream of the Aldan junction., Its watershed covers an extensive area between Lake Baikal and Yakutsk and includes dozens of tributaries including creeks and small rivers. The Lower Lena consists of the catchment area downstream of the Aldan junction excluding the catchments of Aldan and Vilyuy (Figure 1a). It flows from downstream of Yakutsk into the Laptev Sea and receives waters from catchments including the Verkchoyansk Range.***"

RC: L353 Present the numbers of velocities in thee regions

AR: Changed accordingly: L352-354: "... *to settle rapidly. Thus, decreasing velocity in the Lower Lena (**from 2.5 m s^{-1} to 0.8 m s^{-1} in May (Kääb et al., 2013)**) and the Lena Delta itself (**from 1.3 to 0.9 m s^{-1} in August (Nigamatzyanova et al., 2015**) allows further sedimentation of TSM and old C, resulting in a decrease of its concentration."*

Added to the Reference list: *Nigamatzyanova, G.R., Frolova, L.A., Chetverova, A.A., Fedorova, I.V.: Hydrobiological investigation of channels in the mouth region of the Lena River, Uchenye Zapiski Kazanskogo Universiteta. Seriya Estestvennye Nauki, vol. 157, no. 4, pp. 96–108, 2015, (In Russian)*

RC: L420 There should be some data for the man stem

AR: We agree with the reviewer that such data would be very valuable, but have so far not been able to find published $\delta^{13}C$ values of DIC in the Lena Delta. We would be most grateful if the reviewer would point us to references that we might have overlooked.

Nevertheless, we have changed the focus of this sentence from literature values to our results to avoid any possible misunderstanding. Thus, we state that measurement of $\delta^{13}C$ of DIC was not available, and not that it was never done before.

L420 edited: "*In the Lena Delta the $\delta^{13}C$ of DIC has not been **measured**, but the low $\delta^{13}C$ of POC…*"

RC: L439 d13C of POC?

AR: Thanks, we clarified this: L439 edited: "*$\delta^{13}C$ of **POC** from ArcticGRO was lower than the $\delta^{13}C$ of POC we measured in the main stem, which may indicate more phytoplankton…*"

RC: L558-563 The novelty of the present study seems to be low

AR: We disagree respectfully with this statement. With our research we provided a direct and detailed comparison of POC in the Lena River (measured along the transect from Yakutsk to the Lena Delta) and in the Lena Delta (along the entire Sardakhskaya branch). Our findings are based on C isotopic composition analyses of POC which require some state of the art facilities which were unfortunately not available for the excellent, deep and extensive studies on the region from the past (30 years ago and earlier). Modern studies, where C isotopic composition was analysed usually focus on the wide coastal zone of Laptev sea (for example as L558 Karlsson et al 2016 and Semiletov et al., 2011) or the river borne OM (Wild et al., 2019, etc, Semiletov et al., 2011). In both cases, the studies do not consider the Lena Delta and its role in the balance and composition of OM discharge. With this manuscript, we would like to fill in this gap and to highlight the high importance of the Delta in terms of the Lena River OM discharge to the ocean. Thus, with our study we built a bridge between two major approaches of investigations in this area: study of the riverine OM or Laptev Sea shelf investigations. Finally, we see this manuscript as a crucial piece into the puzzle of understanding of the Lena River – Laptev Sea interaction. Especially in the context of ongoing climate change and permafrost degradation as it was demonstrated in L558-563, where we showed the evidence of an additional contribution of Yedoma to OM discharged by the Lena River to the Laptev Sea, which takes place particularly in the Delta. This finding was not demonstrated and published before.

To make this clearer we edited L79-80: "*In this study, we aim* ***to bridge this gap and to*** *characterise…"*

The team of authors would like to thank AR for the work, time, editing and contribution to our manuscript and wish all the best!

References used in this response:

Bröder, L., Davydova, A., Davydov, S., Zimov, N., and Haghipour, N.: Particulate Organic Matter Dynamics in a Permafrost Headwater Stream and the Kolyma River Mainstem Journal of Geophysical Research : Biogeosciences. 1–16, https://doi.org/10.1029/2019JG005511, 2020

Geyer, W. R., and D. K. Ralston. 2012. The Dynamics of Strongly Stratified Estuaries. Treatise on Estuarine and Coastal Science. Vol. 2. Elsevier Inc. https://doi.org/10.1016/B978-0-12-374711-2.00206-0

Finlay, J. C., and Kendall, C.: Stable Isotope Tracing of Temporal and Spatial Variability in Organic Matter Sources to Freshwater Ecosystems. In Stable Isotopes in Ecology and Environmental Science: Second Edition (pp. 283-333). Blackwell Publishing, https://doi.org/10.1002/9780470691854.ch10, 2008

Fuchs, Matthias, Juri Palmtag, Bennet Juhls, Paul Overduin, Guido Grosse, Ahmed Abdelwahab, Michael Bedington, et al. 2022. "High-Resolution Bathymetry Models for the Lena Delta and Kolyma Gulf Coastal Zones." Earth System Science Data Discussions, 1–30.

Hilton, R., Galy, V., Gaillardet, J. et al. Erosion of organic carbon in the Arctic as a geological carbon dioxide sink. Nature 524, 84–87. https://doi.org/10.1038/nature14653, 2015

Karlsson, E., Gelting, J., Tesi, T., van Dongen, B., Andersson, A., Semiletov, I., Charkin, A., Dudarev, O., and Gustafsson, Ö.: Different sources and degradation state of dissolved, particulate, and sedimentary organic matter along the Eurasian Arctic coastal margin, Global Biogeochem. Cycles, 30, 898– 919, https://doi:10.1002/2015GB005307, 2016

Kutscher, L., Mörth, C.-M., Porcelli, D., Hirst, C., Maximov, T. C., Petrov, R. E., and Andersson, P. S.: Spatial variation in concentration and sources of organic carbon in the Lena River, Siberia, J. Geophys. Res. Biogeosci., 122, 1999– 2016, https://doi:10.1002/2017JG003858, 2017

Lisitzin, A. P.: A mariginal Filter of the Ocean. Okeanologiya, 34 (5), 735-747, 1994, (In Russian)

Nigamatzyanova, G.R., Frolova, L.A., Chetverova, A.A., Fedorova, I.V.: Hydrobiological investigation of channels in the mouth region of the Lena River, Uchenye Zapiski Kazanskogo Universiteta. Seriya Estestvennye Nauki, vol. 157, no. 4, pp. 96–108, 2015, (In Russian)

Vonk, J. E., Tesi, T., Bröder, L., Holmstrand, H., Hugelius, G., Andersson, A., Dudarev, O., Semiletov, I., and Gustafsson, Ö.: Distinguishing between old and modern permafrost sources in the northeast Siberian land–shelf system with compound-specific δ2H analysis, The Cryosphere, 11, 1879–1895, https://doi.org/10.5194/tc-11-1879-2017, 2017

Winterfeld, M., Laepple, T., and Mollenhauer, G.: Characterization of particulate organic matter in the Lena River delta and adjacent nearshore zone, NE Siberia – Part I: Radiocarbon inventories, Biogeosciences, 12, 3769–3788, https://doi.org/10.5194/bg-12-3769-2015, 2015