Responses to anonymous reviewer

Dear anonymous reviewer,

Thank you very much for your review of our manuscript entitled "Sediment and carbon accumulation in a glacial lake in Chukotka (Arctic Siberia) during the Late Pleistocene and Holocene: Combining hydroacoustic profiling and down-core analyses". We really appreciate your contribution to helping us to improve our manuscript with helpful suggestions and comments, especially during this difficult time of the ongoing global pandemic. We are happy that you found our diverse, multi-proxy approach interesting and we hope that it will form a useful basis for future studies. In the attached .pdf file, we provide our replies to each individual comment and provide our proposed alterations, changes, and adjustments to the manuscript that will be carried out and shown within the future revised manuscript version. As such your comments are highlighted in black and italicised and our replies are highlighted in blue. We sincerely hope that you are satisfied with our replies and our proposed changes.

Thank you once again for reviewing our manuscript,

On behalf of all the authors,

Stuart Andrew Vyse

Reviewer comments and author responses

- Line 67: Here and later, this unpublished study is cited very often, even in Fig.9. I understand that it is sometimes necessary to relate your own data to data collected in parallel by the working group that are not yet published elsewhere. However, these works are difficult to verify. In any case, these references should be removed, especially if there are other citations in the line. However, I leave the decision whether these references can be left in the article to the editor.

Thank you very much for your comment regarding the five citations of the paper of Jenrich et al. in review. We agree that it is difficult to verify papers that are currently going through the review process. We wanted to cite this upcoming paper due to the lack of comparable studies currently available on the topic of carbon storage within the Arctic Siberian landscape, particularly considering storage within lacustrine sediments. We can however confirm that the paper has since submission of this manuscript, been accepted for publication in Frontiers in Earth Science, and hence citations pertaining to Jenrich et al. will be updated to Jenrich et al. accepted. This also includes the complete reference in line 1045. It must be said, that some values pertaining to the calculated TOCpools and TOC-densities within the paper of Jenrich et al. accepted were slightly updated during the review process of their manuscript and will be updated in our manuscript text as follows:

Line 657:

Old: TOCpools(Bykovsky lagoons 5.6Mt)and TOC-densities (mean 14.24 kg m^{-3})

New: TOCpools(Bykovsky lagoons **5.72Mt**) and TOC-densities (mean 15.29 kg m^{-3})

Line 658:

Old: TOCpools(0.20Mt) and TOC-densities (10.45kg m^{-3}) of Polar Fox

New: TOCpools(**0.23Mt**) and TOC-densities (**12.54kg m^{-3}**) of Polar Fox

These values will also be updated within figure 9b.

We are aware that we also cited the paper of Andreev et al. accepted. This paper has also now been published, as such all occurrences of the reference to Andreev et al. accepted will be changed to Andreev et al., 2021 within the revised manuscript version.

Figure 1: The inlet map in 1a and labels are hard to read and could be a little larger

Thank you for pointing this out. We will make some changes to figure 1 following suggestions also from reviewer #2 to improve the readability of figure 1 in general. This will include removing the older simplified bathymetric map originally displayed in figure 1c and replacing this with an enlarged lake polygon with plotted hydroacoustic transects. We will also follow your additional suggestions and increase the font size of text within the inlet of figure 1a as well for the comparison sites to further improve the readability of the revised manuscript version.

Line 184: I think it would be helpful and interesting if the other elements could be presented in the supplement, especially because only a relatively small selection was made at the end for discussion.

Thank you for this suggestion. We wanted to limit our usage of excessive data within the manuscript due to the already large volume of included proxies that would otherwise lead to a reduction in the readability and interpretability of the presented manuscript as well as an extension to the current length of the manuscript. We agree however that this would be helpful and interesting to include within the supplement and hence we will subsequently include some stratigraphic plots of element data within the revised supplement version.

Line 189: I don't quite see the advantage of log transformation of the data, especially in terms of comparability with other studies. Please clarify.

You are correct that many studies do not use log transformation of the data and we take note of your suggestion that for comparability with the majority of other studies dealing with lake systems, it would be unnecessary and not advantageous to display log transformed data here. We hence decide to use the non-log transformed element ratios within the revised manuscript version. As such we will remove lines 188 to 190 from 3.2.3 i.e. "Ratios of element intensities were log transformed using the additive log ratio (ALR) transformation within the package “compositions” (version 1.40) in R (Aitchison, 1984; van den Boogaart et al., 2020; Weltje and Tjallingii, 2008)". We will display the non-log transformed data within the relevant figures and include them within statistical calculations in the revised manuscript version. The log-transformed and non-transformed data do not show significant differences between each other.

Figure 3: Please enlarge labels and legends

Thank you for this suggestion. We will enlarge the labels and legends to improve the readability of figure 3 as per your suggestion. We will also carry out some additional changes

to figure 3 as suggested by reviewer #2 which includes the adaptation of the scale so that intervals in each sub-figure are 1 m apart. Moreover, Artifacts that are currently marked in the colour white, will be changed to grey.

Line 305 – 310: It is really impressive to see such a good age model, which is only made up of bulk ages and depends on low levels of organic matter in the sediment, but reflects an almost continuous and seamless stratigraphy for the last 30,000 years. The authors are discussing sediment mixing or re-deposition of organic material from the catchment area here already, but only for two inverse ages. How can you rule out mixing and rearrangement of older (and/or younger) organic matter from the catchment area for the rest of the stratigraphy? Can we always assume the actual sedimentation age here? I think a little more explanation on this in the discussion chapter would be useful.

Thank you for your positive comments regarding our age model. We agree with you that dating of Arctic glacial lakes is often very challenging, especially when dealing with sediments of low organic matter content, such as at Lake Rauchuagytgyn.

In practice, it is very difficult to completely rule out mixing and rearrangement of older and/or younger organic matter for other intervals within the stratigraphy.

In addition to the two inverse ages present within LU-I, we could also expect some reworking of catchment organic material within LU-III and the lowermost LU-II units due to the larger scatter observed amongst the ages of dating samples. This may be related to processes associated with the presence of a catchment glacier that could provide a mechanism to rework palaeo-soils and organic-containing catchment sediments. We have partially alluded to this in lines 459 to 461 of section 5.1.1 of the discussion and we will add additional information and references to read as follows: "It must be however noted that the radiocarbon age scatter in LU-III contributes uncertainty to the SRs and MARs derived for this interval as marked by the wider uncertainty band within the presented age model (Fig. 4b). **Age scatter within this unit may be at least in part associated with catchment glacial activity that may lead to the reworking of older catchment organic material with subsequent deposition within the glacio-lacustrine environment (Lunkka et al., 2001)**".

We will also add an extra sentence to dating uncertainty within section 5.2.3 Regional and local controls on carbon accumulation and methodological limitations in lines 716 to 720 to read as follows: "from empirical equations of DBD and carbon content where discrete, volumetric measurements do not exist (Avnimelech et al., 2001; Kastowski et al., 2011) **as well as** varied approaches used for the measurement of sample carbon contents (Elemental analyser vs LOI) (Munroe and Brencher, 2019). **Limitations associated with radiocarbon dating of Arctic glacial lakes due to the absence of appreciable amounts of datable organic material as well as the influence of reworking processes associated with permafrost and glacial processes can also lead to uncertainty with regards to actual sediment ages and hence reconstructed accumulation rates (Abbott & Stafford, 1996; Björck & Wohlfarth 2002).**"

It must however be said, that apart from the two excluded dates within LU-I and scatter within LU-III, much of the rest of the sequence showed a lack of age inversions which may support the reduced influence of re-deposition of organic material from the catchment for most of the sedimentary succession. Moreover, we attempted to account for age uncertainty within this study by including the uncertainty bands for sedimentation rates, mass accumulation rates, and organic carbon accumulation rates to give an estimation of the possible error that might

be induced through age-model uncertainty, that is an advancement upon many studies within this field.

Later the authors discuss wind-driven shoreline erosion and sediment redistribution during the Holocene as well as heightened availability of catchment sediments by increasing active layer thickness. They also explain the complex morphology of the lake basin, in particular the primary inflow in the south and the associated presence of a large alluvial fan. I don't want to doubt all of that, but I would like to see a little more critical examination of the dating results and the sedimentation history of the lake.

Thank you for this comment and the suggestion to more critically examine the dating results and sedimentation history. We have responded to the dating results and also considered the implications for accumulation rate estimations in response to the previous comment and added extra information within sections 5.1.1 and 5.2.3 to account for this within the discussion.

With regards to the sedimentation history, we anticipate a complex Holocene sedimentation dynamic that likely reflects a mixture of processes that we believe has been aptly discussed within the current manuscript version. Delving further would be beyond the current scope of this paper, particularly due to the current length and the hybrid aims of this manuscript. Multiple sedimentological studies from lake El´gygytgyn (ca. 150 km away), have suggested a similarly complex intertwinement of processes that we consider here in our discussion in relation to our record. These processes were interpreted to have lead to higher sedimentation rates and coarser grain sizes during interglacial phases when compared with glacial phases. Asikainen et al. 2007 and Francke et al. 2013 suggested that the increased duration of summer ice-free conditions during the Holocene and other interglacials at lake El´gygytgyn played a crucial role in controlling detrital input to the lake basin by regulating wind-driven sediment redistribution by summer storms and aeolian input. During these warmer phases, increased moisture has been implied to have increased fluvial sediment delivery and warmer temperatures to a thickening of the catchment active layer which enhanced the sediment availability at lake El´gygytgyn.

Due to the proximity of both lake systems and a similar proxy response, a similarly complex interaction may be interpreted for lake Rauchuagytgyn during the Holocene during which time, the lakes were likely exposed to similar climate conditions.

Section 5.2.1 and Line 616: I think in this context that the authors should also briefly discuss the completely different environmental and catchment area conditions of boreal, thermokarst, and glacial lakes.

Thank you for this suggestion. We do consider these factors in more detail within the section 5.2.3 "Regional and local controls on carbon accumulation and methodological limitations" but we agree with your suggestion and will consider the major environmental and catchment area differences between these lake systems within section 5.2.1. We will thus add additional sentences to line 616 as follows: "As such, limited comparable studies exist and are restricted to studies of Siberian thermokarst lake systems that are generally younger and smaller (Anthony et al., 2014). Comparisons must therefore be **additionally** drawn to Boreal lakes from North America and northern Europe, **as well as to proglacial and bedrock-catchment lakes from Greenland. Significant differences however exist between these lake systems relating to contrasting environmental conditions prevailing at different**

latitudes as well as high variability with regards to lake and catchment spatial extent and lake water depth and catchment environmental and vegetation properties."

We will also add some more simple information regarding the size and water depth of lake systems discussed by the comparison studies within section 5.2.1 in Lines 623 to 637: "The range of Holocene rates is on average lower but generally overlaps with Holocene organic carbon accumulation rates of **small (0.033- 0.73 km2)** Greenlandic lakes (mean 6 g OC m−2 a−1625) (Anderson et al., 2009), and to **small (0.022- 0.145 km2)** Uinta glacial lakes, USA (mean 5.4 g OC m−2 a−1) (Munroe & Brencher, 2019). A strong resemblance is also observed when comparing to rates of accumulation calculated for Finnish Boreal lakes that became Ice-free at the Holocene start (Fig. 8, 9a, 9b) (Pajunen, 2000; Kortelainen et al. 2004). The average Holocene and whole core Rauchuagytgyn rates plot well within the range of Finnish lakes and close to the mean of **shallow** Quebec boreal lakes when considering sediment volumes derived from sub-bottom profiling approaches or estimated from core length and lake surface area (Uinta lakes) (Fig. 9a). Recent syntheses of average carbon accumulation rates within European lakes also suggest similar mean accumulation rates ca. 5.6 g OC m−2 a−1 (Kastowski et al., 2011). Pronounced differences exist when compared with **larger** lake systems reported from Alberta, Canada (mean 15 g OC m-2 a-1) (Campbell et al., 2000) and global lakes, reservoirs and peatlands (Dean & Gorham, 1998; Mendonça et al., 2017). Furthermore, average Holocene rates calculated for thermokarst lakes from the 635 Cherskii -Kolyma Tundra, far east Siberia are markedly higher (mean 47 g OC m-2 a-1) than Rauchuagytgyn rates (Anthony et al., 2014)(Fig. 8)."

Figure 8: Please enlarge the inlet labels. Also, what is the meaning of the red bar for Alberta?

Thank you for commenting on the small font size of the inlet labels. We will increase the font size of the labels within figure 8 in the revised manuscript version to improve readability. The red bar refers to the average carbon accumulation rate (15 g C m–2 a–1) that was estimated for Alberta lakes by Campbell et al. 2000. Unfortunately only this value was available from the literature for plotting and comparison as the individual values per lake have not been reported in literature sources. This was plotted in a similar fashion within the paper of Munroe and Brencher, 2019 regarding Uintas lakes.

Line 642: What is the meaning of this sentence. Isn't that just the other way around? What is meant here by inorganic detritus?

Thank you for your question here. As currently written we agree that this phrasing may be unclear. We meant to convey that the sediment is predominantly organic poor as represented by the very low TOC values and is hence dominated by inorganic sediment. We will now restructure and rephrase line 642 to read as follows: "**The sediment at lake Rauchuagytgyn is predominantly inorganic as represented clearly by the very low total organic carbon content of sediments**".

Line 685: Please change to "aeolian pathways"

Sorry for this bad capitalization. We will now alter line 685 to read as follows: "dissolved organic carbon (DOC) via fluvial and/or **aeolian pathways**".

Supplement:

I cannot find Figure S5 and Figure S6 referenced in the text.

We apologize for this lack of clarity. We did reference both figures S5 and S6 within line 595 of the original manuscript version that reads as follows: "This is further supported by coarse, sand-dominated surface sediments close to the alluvial fan front (site EN18220) (Fig. 1 & ***Figs S5, S6****)."*

Additional references cited in the authors responses

Lunkka, J.P., Saarnisto, M., Gey, V., Demidov, I., Kiselova, V.: Extent and age of the Last Glacial Maximum in the southeastern sector of the Scandinavian Ice Sheet, Glob. Planet. Change, 31, 407-425, https://doi.org/10.1016/S0921-8181(01)00132-1, 2001.