

Responses to the Reviewer's comments

Comments by the two referees were very enlightening and their suggestions useful; we are grateful for their input. His/her careful reading of the manuscript and his/her good knowledge of the subject-matter allowed providing relevant suggestions and additions to the manuscript. We treat each point raised in detail and with great interest.

Note that the line numbers given in this response refer to the revised version of the manuscript in track changes mode.

Referee #1

Major edits

Comment 1:

Referee #1: The Results section was confusing in terms of structure, order of the data, how the data were discussed, etc. Some examples of confusing groupings, structures, and statements:

Authors: We agree that the Results section needs improvements in terms of structure. First, we changed the names of the subsections so it matches the structure of the Methods section to facilitate reading and understanding. We also separated the 'lake sediments' and 'vertical structure of water column of lakes' into two distinct sections in the 'Results'. If the referee wants to offer more specific comments or guidance on how to improve this section, we would be more than happy to implement those recommendations.

(a) Radiocarbon dates and glacier retreat timing are discussed in the "Spatial distribution" section.

Authors: The purpose of the section is to show that lakes have formed in front of glaciers C-79 and C-93 as these glaciers retreated since the Little Ice Age. The radiocarbon date originates from a thrust plate forming part of the Neoglacial moraine of glacier C-79, indicating the timing of the last major glacier advance. We modified this paragraph to move the focus on the lakes rather than the retreat of these glaciers.

(b) In the "Morphology of lakes" the authors discuss deep vs. shallow, whether lake bottoms are smooth, etc., but the information is vague and doesn't seem to match the data in the figures. They say deeper lakes have smoother lake bottoms, but it doesn't look like they do from the figures. Is this statement based on statistical analyses?

Authors: Here, we refer to the microtopography of the lake floor. In shallow lakes, the irregular lake floors were inherited from the ice-wedge polygons which are now submerged and degrading. We added a few details to clarify this: "*The GPR profiles indicated that these deeper lakes usually have smoother microtopography at the lake bottoms, whereas lake L also exhibits an irregular lake floor micromorphology in the shallowest areas (Fig. S2), reflecting the pattern of submerged polygon-patterned ground and degraded ice wedge under frost crack troughs (Bouchard et al., 2020).*"

We also added this sentence for the shallow lakes: “*The lake floor is irregular at a small-scale (microtopography), which is attributed to submerged polygons (see the video supplement in Bouchard et al., 2020).*”

I think the addition of more data tables would help clarify the salient results, especially for the three lakes (G, K, L) that were analyzed in detail. I do not know how the written part of Results section can be made more organized and clear, but I ask that the authors rethink the structure of the Results section and try to reorganize if possible.

Authors: In the supplementary materials, there is a data table (S3) that summarizes the lake morphology for all lakes, including lakes G, K, L. We moved this table with the main figures and tables to address the reviewer’s suggestion.

Comment 2:

Referee #1: P15 L24-27 Here you discuss that the two sediment cores reveal two distinct basin types, but given that you only have two lake cores, this statement is a reach. If you took cores from four lakes (two shallow and two deep) you might end up with four distinct basin types or one of the deep lake cores might look similar to one of the shallow lake cores. I think the number of samples (n=2) prevents you from definitively stating that there are two distinct basin stratigraphies for the shallow vs. deep lakes. Sample duplication is needed to make that general statement.

Authors: We agree and added a sentence to clarify that more work is needed to make that general statement: “*However, more work is needed to establish a strong link between the origin of lakes and their sedimentation histories by collecting more sediment cores from different shallow and deep lakes in the Qarlikturvik Valley, but also in other glacierized arctic tundra settings.*”

Comment 3:

Referee #1: P22 Fig.1 - What data did you base the mapped “glacier positions” on? Need to support these glacier positions with field and/or remote-based data that definitively shows past glacier positions (moraines, ice-contact lake deposits, etc.).

Authors: We added more information in the ‘Materials and methods’ section to clarify how we mapped the glacier positions: “*We used remote-based data to map glacier frontal positions of glacier C-79 and C-93 to investigate the formation of new lakes in the valley at the termini of these glaciers over the past 60 years: 1) historical aerial photos (1961, 1982; National Air Photo Library) 2) GeoEye satellite imagery (2010, pixel = 0.5 m); 3) Sentinel-2 (2016, 2020, pixel = 10 m) and 4) field measurements using a real-time kinematic (RTK; July 2011; Trimble R8). The positions refer to the contact between the ice and moraine material.*”

Comment 4:

Referee #1: The article would be strengthened by the inclusion of a data table showing the lake morphology results for all of the lakes.

Authors: There is a data table in the ‘Supplementary information’ that summarizes the lake morphology for all lakes. We moved this table with the main figures and tables to address the reviewer’s suggestion.

Minor edits

Referee #1: P1 L20 – “remotely-sensed”

Authors: Modification made.

Referee #1: P1 L23 – Maybe change to “subsidence. They later”

Authors: Modification made.

Referee #1: P1 L27 – I do not understand what “if any” means here.

Authors: We added “if there is still some remaining” to clarify the sentence.

Referee #1: P2 L3-5 – “massive ice, they”

Authors: We modified the sentence to make it clearer: *“These ice-rich permafrost landscapes are experiencing thermokarst, through the thawing of near-surface ice-rich permafrost or the melting of massive ice, which may result in land subsidence and ponding.”*

Referee #1: P2 L6-8 – long sentence

Authors: We agree. The sentence was divided into two shorter sentences: *“In flat-lying terrains, thermokarst processes often result in the formation of numerous wetlands, ponds and lakes. This creates or modifies existing ‘limnoscapes’ (lake-rich landscapes) through thermal and mechanical erosional processes as well as thaw consolidation and subsidence beneath waterbodies.”*

Referee #1: P2 25-26 – This sentence is confusing.

Authors: We agree and changed it to: *“Some of these landscapes are now experiencing climate-driven renewed deglaciation leading to a second phase of post-glacial landscape evolution.”*

Referee #1: P2 L31 – em dash in “2–5”

Authors: Modification made.

Referee #1: P3 L7 – “amounts’

Authors: Modification made.

Referee #1: P4 L6 – em dash in “2–3”

Authors: Modification made.

Referee #1: P4 L15 – em dash in “1981–2020”

Authors: Modification made.

Referee #1: P4 L15 – should maybe be “189 mm/yr” or “189 mm yr⁻¹”

Authors: Modification made.

Referee #1: P4 L17 – em dash in “100–500”

Authors: Modification made.

Referee #1: P6 L23 – “lakes”

Authors: The sentence has been changed to address a previous comment (structure of the results section), so it should now be singular.

Referee #1: P7 L9-11 – This is a run-on sentence.

Authors: We divided this sentence into smaller sentences: “*We also profiled the same two lakes (G, K) as well as lake L in late winter under the ice cover (early June 2015) and during the ice-free period (July and August). The objective was to examine differences in water temperature and dissolved oxygen (DO) between lake types, and discuss the effects of water depth and vertical structure on GHG emissions and fish habitats.*”

Referee #1: P7 L11 – “discuss” seems like a strange verb here.

Authors: We replaced it by “address”.

Referee #1: P7 L21 – “Patterns of distribution emerge on this level” is confusing. On what level?

Authors: We replaced it by “Patterns of distribution emerge in the valley with higher densities, [...]”

Referee #1: P7 L24 – Which valley?

Authors: We added “Qarlikturvik”.

Referee #1: P7 L25 – “clustering in short distance” is vague.

Authors: The “ $r < 0.85$ km” in parenthesis specify the distance.

Referee #1: P7 L28-30 – Here you say “highest densities occur directly in front of contemporary glaciers and within the extent of local mountain glaciations,” but based on Fig. 6d it looks like there are high densities within the mapped extent of the LIS too. Please clarify.

Authors: We agree. The purpose of figure 6d is to show that highest densities of lakes are typically found in association with the former positions of local glaciations, but also with the LIS. We forgot to mention it in the text, so we added “and the LIS” to the sentence.

Referee #1: P7 L30 – Need “yr” in “120 14C yr BP”

Authors: Modification made.

Referee #1: P8 L13 – “bottoms”

Authors: Modification made.

Referee #1: P8 L16 – “K and L are 5.5 and 5 m, respectively, below”

Authors: Modification made.

Referee #1: P8 L18 – please specify again what the “second group of lakes” are – the shallow lakes?

Authors: We added “shallow lakes” in parentheses.

Referee #1: P8 L22 – “platforms”

Authors: Modification made.

Referee #1: P8 L26 – “depths”

Authors: Modification made.

Referee #1: P9 L7 – Please specify which “unit” you are talking about here. “Did not reach the bottom of this unit” is confusing due to vagueness.

Authors: We added “the bottom of unit A” to clarify this sentence.

Referee #1: P9 L17 – Please specify how moisture content is measured/reported here. Is it gravimetric or volumetric?

Authors: We added “gravimetric water content” to clarify it was measured. (P8 L27)

Referee #1: P9 L28 – Do you mean “shifts” instead of “sifts”?

Authors: Yes, we made the correction. (P9 L31)

Referee #1: P9 L32 – what does “bottomed” mean? Do you mean “bottom”?

Authors: Yes, we made the correction.

Referee #1: P10 L13 – “kicked saturation level up again” is too informal. Maybe “increased saturations levels”

Authors: We changed it to “increased”.

Referee #1: P10 L13-14 – “(unpubl. data).” Why not just publish the data here? Is the plan to publish it in an upcoming paper – therefore it cannot be published here? Is the author of those data not an author on this paper?

Authors: These data will be published in an upcoming paper. The author of this data is Isabelle Laurion, and she is one of the coauthor of this paper.

Referee #1: P10 L15 – Maybe say “On its margin” rather than “On its side”

Authors: We agree and made the modification.

Referee #1: P11 L13 – is there a better way to say “broken horizon”? Disturbed? Faulted?

Authors: We agree and changed it to “disturbed horizons”

Referee #1: P11 L32 – I think there is an extra space between “content” and “measured”

Authors: We removed the extra space.

Referee #1: P11 L32 – Please specify which unit you are talking about here.

Authors: This sentence has been changed to address another comment.

Referee #1: P12 L12 – “which do not reflect”

Authors: Modification made.

Referee #1: P12 L13 – “similar to”

Authors: Modification made.

Referee #1: P11 L14 – delete “down” after the word “settle”

Authors: Modification made.

Referee #1: P12 L15 – should be a comma after “terrestrial runoff,”

Authors: Modification made.

Referee #1: P12 L15 – Maybe change to “aeolian activity, and/or 3)”

Authors: We agree and made the modification.

Referee #1: P13 L8 – Capitalize “Last Glacial Maximum”

Authors: Modification made.

Referee #1: P13 L9 – Maybe replace “in“ with “through” so it reads “channeled through major”

Authors: Modification made.

Referee #1: P13 L9 – “terminated”

Authors: Modification made.

Referee #1: P13 L13 – delete dash between “and” and “meltwater”

Authors: Modification made.

Referee #1: P14 L8-10 – Can you be more specific than “since the mid-Holocene” here in terms of timing?

Authors: We changed it to “~7-8 ka” to reflect the results presented in the references.

Referee #1: P14 L10-12 – This sentence “This situation applied ...” is confusing. Do not understand what you mean.

Authors: We changed it to: *“These warmer periods likely initiated or accelerated ice melt when (1) a thin layer of sediments covered the ice, or (2) topographic depressions allowed the accumulation of snow and water, hence overall warmer conditions, which further accelerated the melt.”*

Referee #1: P14 L18 – “preceded”

Authors: Modification made.

Referee #1: P14 L23 – I don’t think it should be a semi-colon in “year; the rate” because the second clause is not a complete sentence.

Authors: We agree and we divided this sentence into two shorter sentences: *“Once a lake gets deeper than the maximum thickness of the winter ice cover (~2 m ± 20 cm in the valley as measured by Prėskienis et al., 2021), it will continue to grow laterally (thermo-mechanical erosion) and vertically (subsidence) by thermokarst processes each year. The rate of expansion depends on local climatic conditions, ground-ice content and lake bed temperature (Fig.7d).”*

Referee #1: P14 L28 – Put period after the citations.

Authors: Modification made.

Referee #1: P13 L31-33 – Can you provide a citation for the statement that kettle lakes should be very smooth and close to a perfect circle? There are kettles, like Walden Pond in Massachusetts, that are not circles and that do not have smooth shorelines. So, the statement needs a citation.

Authors: We agree that this statement needed a citation. In the literature, kettle holes and lakes are typically described as roughly circular, steep-walled or inversed-conical. However, to our knowledge, more precise descriptions of the morphology of these glacial features remains very rare. As a result, we conducted additional analyses to further investigate the morphology of glacial lakes formed in proglacial outwash deposits in front of glaciers C-79, C-93 and C-67, which is adjacent to C-79. A WorldView image (2010, pixel = 0.5 m) of the glacier termini served as the basis for mapping the glacial lakes (n=400) and investigate their morphology. We obtained an average shoreline development index of 1.1 ± 0.1 and average elongation index of 1.6 ± 0.1 , indicating that these recent glacial lakes are slightly oval rather than truly circular. The more oval and elongated lakes are aligned along the inter-morainal swales, which likely influence their shapes. These data will be published in the open-access Nordicana D data repository at Centre d'études nordiques (CEN – Centre for Northern Studies) (<http://www.cen.ulaval.ca/nordicanad/>) with the other datasets.

We added more details in the Methods, Results and Discussion sections to support the statement:

- *Methods: “For comparison, the morphological attributes of glacial lakes (i.e. kettle lakes) formed in proglacial outwash deposits in front of glaciers C-79, C-93 and C-67 were also calculated. Very few studies have studied kettle lake morphology, but these lakes are typically described as enclosed and steep-sided depressions, roughly circular and inverse-conical (Fay, 2002; Gorokhovich et al., 2009; Borsellino et al., 2017)”*
- *Results: “In addition, glacial lakes (n=490) located near the front of glaciers C-79, C-93 and C-67 have an average shoreline development index of 1.1 ± 0.1 and average elongation ratio of 1.6 ± 0.1 , indicating the shorelines are relatively regular and are mostly oval-shaped.”*
- *Discussion: “The shorelines of glacial lakes, such as kettle lakes, are expected to be very smooth and roughly circular or slightly oval-shaped, as shown by the morphological analysis of glacial lakes located at the termini of glaciers C-93, C-79 and C-67. However, most lakes studied here displayed slightly irregular shorelines (Fig. S3).”*

Referee #1: P15 L5 – “of evaporation and/or partial or complete”

Authors: Modification made.

Referee #1: P15 L11 – “It influences the mixing”

Authors: Modification made.

Referee #1: P15 L23 – Since all other verbs are past tense, change to “controlled”

Authors: Modification made.

**Referee #1: P15 L24 – Looks like there is a high dash between “L” and “The stronger.”
Please fix.**

Authors: Modification made.

Referee #1: P16 L1 – “the open-water period as compared”

Authors: Modification made.

Referee #1: P16 L17 – This part is confusing since you say “There are four key arguments” but then you only list three. Is the “Moreover, analysis of lake morphometry” section the fourth argument? If so, it needs to be numbered and indented.

Authors: We agree and changed it to “*There are three arguments [...]*”.

Referee #1: P16 L31 – Replace “It suggests” with “This suggests”

Authors: Modification made.

Referee #1: P17 L4 – “and that slumping and thaw subsidence”

Authors: This addition will change the sense of the sentence.

Referee #1: P17 L6 – “hydrological and ecological”

Authors: Modification made.

Referee #1: P24 Fig. 1 – In the left part of the figure the study area seems to be shaded in (light yellow). Please mention this in the caption or delete the shading. As is, it is confusing

Authors: We agree and added this sentence in the caption: “*The yellow shaded area shows the southwestern plain of Bylot Island*”.

Referee #1: P28 L3 (Caption Fig. 4) – “slump found as buried glacier ice” is confusing.

Authors: We removed “found” and added commas to make it clearer: “*We interpreted the massive ground-ice, exposed at the headwall of thaw slump, as buried glacier ice on the basis of cryostratigraphic, crystallographic and geochemical analyses*”

Referee #1: P28 Fig.4 – On both Lakes (K and G) the second panel in black does not have a label. Please label.

Authors: We added labels to all panels.

Referee #1: P30 Fig.6 – Since early June is actually spring, I think this should be labeled as “late spring” and not late winter.

Authors: We suggest replacing ‘late winter’ and ‘summer’ by the months during which the measurements were taken. Initially, we used ‘late winter’ to better reflect the field conditions when snow and lake ice has not started to melt or has just started. We also replaced ‘late winter’ by early June in the “Results” section and the caption.

Referee #1: P25 Fig.2b – Please provide a color scale and key for this figure. Even though the caption states that red denotes sediment accumulation, the other colors are not explained and the scale of the colors is not explained.

Authors: We added more details in the caption: *“Sediment accumulation at the glacier front, which are drier and un-vegetated areas, are represented by red colours on the images. Wetter areas are shown in blue, and vegetated areas are distinguished by teal and yellow colours.”*

Referee #1: P25 L2 – “120 yr BP to present” or “~1900 to 2020”

Authors: We changed it to “120 yr to present”.

Referee #1: P25 L7 – “unvegetated”

Authors: Modification made.

Referee #1: P33 A2 – In caption, please explain the open circles and the error bars. Are the error bars based on a 2-sigma or 95%? What are the open circles denoting – are these outliers? Total ranges?

Authors: We added details in the caption: *“The thick line marks the median value. The bottom and the top of the box correspond to the first and third quartiles, respectively. The whiskers show the range of observed values that are not within the first and third quartile but not further away than 1.5 times the interquartile range (IQR) from the hinges, and open circles represent outliers.”*

Referee #1: P31 Table A4 – Why are the thaw settlement values red and bold?

Authors: We removed this table (see next comment).

Referee #1: P31 Table A4 – Please provide a citation for footnote 3 “Values typically found in these materials.”

Authors: We agree that a citation is required to support this table. However, we decided not to provide thaw settlement values due to a lack of data available., laboratory measurements of the soil porosity and volumetric or volumetric ice content is required to accurately estimate the potential thaw settlement of the two uppermost units (peat and silt, glaciofluvial sands). As a result, we removed this sentence: *“The highest estimates for potential thaw settlement varied from 1.2 m in gravel and sandy soils to 2.4 m in very ice-rich silty and peaty soils”*, and we replaced it by:

“The cryostratigraphic context of the Qarlikturvik valley is not conducive to the formation of deep depressions. The uppermost unit consists of interstratified peat and silt (thickness ~ 2–4 m) with high volumetric ice content ($74.6 \pm 10.6\%$; Veillette et al., unpublished data), while the underlying unit is glaciofluvial sand and gravel, which typically have low ice contents and minimal expected settlement. Given the thickness of the silt and peat sequence and low ice content in the glaciofluvial sands, the amount of intrasedimental ice is not sufficient to create lakes with depths reaching up to 12 m, even if all the intrasedimental ice melted and drained out of the soil porosity.”