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Comment on tc-2021-302

Steve Kokelj (Referee)

Referee comment on "Contrasted geomorphological and limnological properties of thermokarst lakes formed in buried glacier ice and ice-wedge polygon terrain" by Stéphanie Coulombe et al., The Cryosphere Discuss.,
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tc-2021-302

Review by SV Kokelj

Summary

In this manuscript, the authors have produced an interesting set of field observations from a well-studied proglacial permafrost environment in the eastern Canadian Arctic to examine the physical and limnological conditions of thermokarst lakes that have developed in ice-cored glaciated terrain. This study builds on a growing set of observations from other regions that have recognized the geomorphic sensitivity of permafrost preserved glaciated terrain. In this field study, thermokarst lakes that have formed in ice-cored moraine are contrasted with nearby lakes that have developed on a glaciofluvial plain due to the degradation of wedge ice. The differences in lake morphologies and limnological conditions occurring in proximal lakes, but between terrains with varying ground ice conditions provide a compelling study design. The Authors' data illustrate that terrain and ground ice context can drive significant spatial heterogeneity in the nature of thermokarst lakes. The results have the potential to yield a broadly relevant paper. The Authors summarize part of their study results in a conceptual model illustrating the development of thermokarst lakes in ice-cored moraine.

This paper has the potential to be a strong scientific contribution and well-cited as a broadly applicable case study showing how variation in landscape history plays a significant role in determining physical and limnological conditions of thermokarst lakes. This has significant implications concerning variation in the sensitivity of thermokarst lakes and the trajectories of future thaw-driven change. However, I think that several aspects of the paper could be improved so that it may reach its scientific potential and be accepted

for publication in The Cryosphere.

General comments on the Manuscript.

Overall the paper is fairly well-written, however, some sections require editorial clarifications. I think that improvements can be made in how the study is framed. The introduction focuses primarily on glaciated permafrost environments that host relict ice. There is a brief mention of thermokarst lake development in areas with wedges and segregated ice. While the authors emphasize that the paper is focused on lakes developing by delayed melting of buried glacier ice, a significant portion of the data presented in this manuscript seems to pertain to shallow thermokarst lakes that have developed due to the thawing of wedge ice. Even the conceptual model presented as a summary nicely illustrates two thermokarst lake types, but curiously, discusses the origins of only one. I think that the Authors have a great opportunity to cast the paper as a contrast between thermokarst lakes of varying origins, highlighting differences in their physical and limnological conditions and future sensitivity to change. This broadening of the focus would make a more compelling paper where issues like heterogeneity in lake type and physical and limnological conditions could be nicely linked to variation in the geological/permafrost/geomorphic history of the landscape. If the Authors chose not to frame the paper more broadly as suggested here, then they should remove the data and descriptions of lakes that have not developed in settings hosting relict ground ice because the material doesn't fit well with how the paper is currently scoped. This later adjustment would create a more focused paper consistent with its title and objectives.

Referencing past or related work could be slightly improved. Several of the concepts or ideas that the Authors have assessed with focused field investigations build on or relate to work from other regions, that may have been conducted at broader spatial scales, or pertain to concepts that have been integrated into ground ice modeling approaches. I think that making it clear that climate sensitivity of permafrost preserved glaciated is an established concept that this study builds on is important to clarify because it would better highlight that the paper findings are relevant to lake types and environments found across large parts of NW Canada, Alaska, and Siberia. I would note that there is also a fair bit of limnological and paleoenvironmental work on lakes developed in ice-rich glaciated terrain, so making better connections with some of that work from the western Canadian Arctic and Alaska could help draw interest from a broader Arctic change science community.

Returning to the issue of how the paper is framed, I would encourage the Authors to further develop the ideas that permafrost/ground ice/Quaternary history can lead to significant contrasts in the physical and limnological conditions of Arctic lakes and ponds. Framing results in this geographical/geomorphic context could help the Authors make more focused, yet broadly applicable statements about variability in Arctic aquatic environments based on what has been learned in this study. I think that this is a more interesting and useful avenue for discussion (the spatial variability in lake conditions is related to ground ice/geological history) than echoing generalities about the sensitivity of Arctic aquatic systems.

There are one or two sections in the methods and results where the purpose of the analyses needs to be clarified. Specifically, it was not obvious to me how some of the spatial analyses were linked to specific research objectives. I think that minor editorial modifications could address this concern. Also, if lake types were dichotomized by origin or type then summarizing their morphological characteristics could be of interest. In this regard, providing a more-clear rationale for presenting data on different lake types would be useful. Finally, the organization of the paper requires some improvement. Specifically, in the version of the Manuscript that I have reviewed many of the figures are cited in the wrong order. The Authors include figures, an appendix, and supplementary materials. I would suggest including the figures in the appendix in the main body of the manuscript or the supplement.

With all of this said, I think that the field design, the data presented in the paper, and interpretations are good. I believe that with some editorial effort, a revised version of the manuscript has the potential to make an excellent scientific contribution suitable for publication in The Cryosphere.

I view the suggested revisions as “moderate”.

I have provided several specific comments that I hope the authors will find useful in revising their manuscript.

Specific Comments.

The title of the manuscript matches the abstract, but after reading the paper it seems to only describe a portion of the data presented. While the information on the lakes developing in buried ice is interesting, the data presented on the contrasting cases are also instructive and should be more fully addressed.

P1

Abstract – Overall the abstract is well-written, but seems to omit aspects of the paper on thermokarst lakes in polygonal terrain on glaciofluvial plain. A significant portion of the data and figures in the paper contains information on the latter type of lake. So, strictly speaking, given the content of the paper, the abstract seems incomplete.

L16-17. Minor modification to better contextualize the statement is required here. Are all relict bodies of ice going to melt, over what time scale, and with what projected warming?

P2

L20. It would be good to attribute the broad-scale linkage between “permafrost preserved-preserved glacial landscapes and thermokarst vulnerability” in this sentence to the research that produced this conclusion.

P3

L5-12. Overall, I find the introduction to be well-written. As indicated in my summary, after reading the manuscript I feel that the background, and specifically the objectives seem to frame only a portion of the data that is presented in the paper.

L19. It would be helpful to show the Eclipse moraine on the maps in Figure 1.

After reading the manuscript, I wonder if the Eclipse moraine is that shown in Figure 6d. It would be useful to reference the figure at this point in the manuscript. Also, confirm on the figure the direction of ice flow of the LIS vs the alpine glaciers.

L24. Spelling correction – change “through” to “trough”.

L25. The Authors could add that more generally, the valley has a diversity of depositional environments, including glacial/ice-cored deposits of varying age, making it an excellent place to study ice types and thermokarst lake development under varying ground ice and terrain conditions.

P4.

L1. If the net pattern on Figure 1 represents polygonal patterned ground this should be added to either the legend or the caption. The Authors should also indicate in the legend that the dotted green lines indicate “former glacier positions”.

L 2. Remove the word “an”.

L13-14. The Authors cite measurements from Somerset and Devon Islands for permafrost

thickness as a range from 100 to 500 m. Given the climate and geological history, where does the study area fit in this range?

3 Materials and Methods

Here it would be useful to mention that various spatial scales were used to investigate the contrasting roles of buried and wedge ice in the formation and evolution of thermokarst lakes.

P5.

3.2.

By examining the nature of lakes concerning different glacial limits is there a time factor that is sampled across that the Authors should/could consider in their analysis?

Regarding the clustering analyses to investigate lake distribution: it would be useful to better link the method and results to a specific research question. Also, it is stated that the analyses assume that objects, which I gather are lake centroids, can be distributed anywhere in the region of interest. Is this assumption valid if the input data is lake centroid, but the lake is some area greater than the lake centroid? The centroid of an adjacent lake could not be located within another lake, and therefore could not be distributed anywhere on the spatial surface.

Regardless, a bit more detail on the analyses, and later on an explanation of the results would be helpful.

Section 3.3

On what basis were the 21 lakes selected? It seems that a portion of the lakes was not associated with moraine deposits. How does this sampling design fit with the broader study objectives?

P6.

L8 Section numbering is incorrect. This should be 3.4 Lake sediments

L 9. The Authors identify 3 lakes (G, K, and L). Why were these particular lakes selected for study? Given the topic of the paper, I had assumed that these were lakes that had developed due to the degradation of relict glacier ice, but they seem to have been selected to contrast conditions in different lake types. It would be helpful if they were labeled more intuitively, perhaps by the type of physiographic environment that they occur in. Further to earlier points in this review, if the paper is only focused on "Thermokarst lakes formed in buried ice" it is odd to include lake G which I believe has a contrasting origin.

To better clarify the nature of data collection I suggest adding "the stratigraphic profiles of lake bottom sediments, and water column profiles of temperature and dissolved oxygen."

L 11. Remove the word "lake" to read "...lakes K and L are the deepest in the valley"

L12-14. Slight editorial adjustment is suggested to reduce redundancy. "..... degraded ice-wedge troughs confirmed that the shallower lake (G) is evolving through the"

L30 This section of the methods was surprising because it was not clear in the introduction that contrasting limnological conditions between lake types were a study objective. As the paper is currently scoped, these methods do not seem relevant to the study.

P7. The figures appear to be out of order, as Fig. 6c and d are referred to before Figure 6a and b, or Figure 5, and so forth.

The analyses of lake and pond conditions would benefit from showing a frequency distribution of waterbody occurrence by size. Consider presenting these results for the entire population and then for the respective clusters identified in the analysis. Given the small size of many of the water bodies, how does this affect the clustering? Is the size of the lake associated with lake origin?

L15. The purpose of this analysis and the meaning of these results is unclear. I am not sure what research question this analysis is investigating. Some additional narrative in the methods or here would help to clarify this point.

L20-23. Can the Authors provide a bit more explanation of the TC figure 6b? For example, why is the active burial of glacier ice indicated by the red colors? What do the other

red/orange areas in the floodplain of the braided stream valley indicate? Do the TC analyses indicate any evidence of pond development or expansion of water bodies as per Fraser et al., (2014)?

Section 4.4

It would be useful to lead off this section with a brief explanation as to why cores from these two particular lakes are presented.

Section 5.1

This summary section identifies contrasts in characteristics of different lake types. There seems to be a great opportunity to elaborate this slightly to highlight the spatial heterogeneity in ground ice associated with ice-marginal environments leading to significant small-scale differences in lake types, their limnological conditions, and potential for thaw-driven change.

P11 L23-25. Reference to Russian literature here is good, however, there are also examples from western Arctic Canada, where melt out of massive ice has yielded lakes with deep holes that are also prone to thaw slumping.

P12

Given the data presented in the paper and the two lake types shown in the schematic, it would seem logical to frame the conceptual diagram here as a contrast of two types of thermokarst lake formation common in the study region (and in other ice-marginal permafrost preserved environments).

Stage 1. I presume glaciofluvial processes could also have eradicated buried ice as well. Is its preservation also possible in the glaciofluvial outwash plain sediments in the study region?

Consider adding some vertical scale or a stable reference marker to better visualize terrain evolution.

Stage 2-3. Do the ice wedges also get wider over time?

P15 L7-9. I think based on the strong links between lake characteristics and their geomorphic/ground ice environments that are shown in this study there is an opportunity for the Authors to develop more geographically focused comments on how results in this research contribute towards understanding variability in the thermokarst sensitivity of Arctic lakes.

Conclusions

P15 L15-18. The authors state that their data shows a strong contrast between two lake types and then summarize conditions in one lake type. It would seem logical to summarize information on both lakes types since the data are presented in the paper.