AUTHOR RESPONSES TO REFEREE 2 COMMENTARY ON MANUSCRIPT 2022-38

Manuscript ID#: **2022-38**

Title: **Significant underestimation of peatland permafrost along the Labrador Sea coastline**

First Contact: **Yifeng Wang**

Second Contact: **Robert Way**

REFEREE 2

[Authors' Response]: We thank Referee 2 for taking the time to provide helpful comments on our manuscript and supplemental materials. We have responded to each comment below and have made corresponding changes to the revised manuscript and supplemental materials.

COMMENTS TO THE AUTHORS

Some consideration of the scale of existing maps of permafrost and peatland distribution compared to the scale of the authors' study is required in the analysis and formulation of the main conclusions regarding adjustment of existing maps for southern Labrador. The maps used for comparison are at a smaller scale (national and circumpolar) than the more local to sub-regional scale mapping presented in the MS. Many of the maps used (or the ones used to develop them) will have minimal mapping units so that the characteristics of smaller units will not be shown on the map. This would be the case for example, with the Heginbottom (1995) which is at a scale of 1:7 million, and to some extent O'Neill et al. (2019) which utilizes similar scale maps in its development. It is therefore not surprising that your results would be a bit different. At a national or circumpolar scale, the 15 km that the authors' suggest the southern permafrost boundary should be extended, is within the precision of these maps. One of the points that could be made is that the application of national and circumpolar scale maps is not really appropriate for addressing sub-regional to local scale issues including those related to plant and animal habitat or infrastructure scale integrity as has been done in a number of other studies. Although the authors do seem to hint at issues of scale, this aspect could be strengthened in the paper.

[Authors' Response]: We agree with the reviewer that the application of national and circumpolar scale maps is not appropriate when addressing sub-regional to local scale issues, but these smaller-scale maps are unfortunately often still used to inform local infrastructure and land use initiatives, or at least to characterize and provide context to a study area, especially in the absence of more appropriate or relevant datasets. However, it is arguably more important to recognize that the Permafrost Map of Canada and the International Permafrost Association's Circumarctic Map of Permafrost and Ground Ice Conditions was not derived from an actual areal calculation of permafrost but is rather based on a holistic assessment of existing permafrost information in conjunction with physiographic data (Heginbottom et al., 1997; Heginbottom, 2002; Zhang et al., 2008). We believe that the primary reason that the sporadic discontinuous zone was not extended farther south along the coast of Labrador was because the very few studies from Labrador that might have informed the development of this map (the Ecological Land Classification (Environment Canada, 1999) and Roger Brown's investigations (1975; 1979)) did not cover the areas that we are currently describing as having a high density of peatland permafrost complexes. Issues of scale certainly do apply to maps derived using explicit areal calculations and modelling,

but for a holistic mapping effort like the IPA map, we believe the comparison is fair. We have elaborated on these issues in the supplemental material (Supplement Sect. S5).

The inventory would appear to consist of point observation of frozen peatlands. It is not clear if the area of these features has also been determined. This would be useful for the comparison to existing permafrost and peatland maps which show distribution in terms of areal coverage rather than location of specific occurrence of features. Although the density of peatland complexes likely containing permafrost (number) per 400 km^2 is shown in figure 3b this is not the same as % areal coverage as shown on other existing maps. This makes it difficult to determine whether the results indicate greater occurrence of frozen peatlands than the maps that are used for comparison in the MS (i.e. comparing apples to oranges). Many of the likely or possible occurrences of peatland permafrost complexes are for example within the sporadic or isolated patches zones shown on the Heginbottom et al. (1995) map which means permafrost is more likely than not to be absent and limited to organic terrain in the case of isolated patches. It is difficult to determine from the results presented whether the map presented in the MS indicates a permafrost distribution that is different from the Heginbottom et al. map. Some further discussion is probably required regarding area of the features identified in the inventory.

[Authors' Response]: We appreciate this comment and have clarified in the Abstract, the Introduction, and the Methods that the inventory is a point inventory. We agree with the reviewer that the occurrence of likely or possible peatland permafrost complexes within the sporadic or isolated patches of permafrost zones suggest that permafrost is likely limited to organic terrain. However, we note that one's interpretation of the isolated patches of permafrost zone, as a zone within which less than 10% of the area is underlain by permafrost, can complicate areal estimates and one's general understanding of permafrost coverage given this distribution zone's lack of a lower threshold. Rather than provide an estimate of the areal coverage of peatland permafrost landforms within each WOI, we have conducted and included an additional analysis, in which we have classified each likely and possible peatland permafrost complex type as palsa, peat plateau, or mixed (palsa and peat plateau). This information has been included in the main manuscript (Figure 6) and will provide us with a solid platform for future area-based analyses, especially given the more extensive permafrost coverage by peat plateaus compared to palsas. We have also included a description of the size range for the WOIs in Section 3.2.1 (Identifying wetlands of interest (WOIs), and we have addressed some of the limitations of the point-based nature of the inventory in Section 5.3 (Challenges and limitations of a point-based inventory of peatland permafrost complexes in coastal Labrador), compared to a grid-based or similar area-based inventory.

I am somewhat curious as to how the maps for comparison in the main paper (figure 5) were chosen especially the circumpolar maps (Hugleius et al. 2020; Olefeldt et al. 2021) rather than some of those included in the supplementary information. Would the larger scale map of Tarnocai et al. (2011) for example (which I believe also includes information on whether peatlands are frozen), be more suitable for comparison in the main paper.

[Authors' Response]: The three peatland permafrost distribution products that were included in the main paper are the most recently published estimates for peatland permafrost distribution. Unfortunately, the Tarnocai et al. (2011) dataset suggests that there are no perennially frozen peatlands in any part of Labrador. We have presented a comparison between the inventoried peatland permafrost complexes and the Tarnocai et al. (2011) product in the supplemental material (Supplement Sect. S4).

Some clarification on the study area is required. It would seem that the focus is on Labrador (coastal Labrador?) but the authors should clarify if the imagery analysis was done for all of Labrador or only specific areas. Also there appear to be observations outside of Labrador and it is unclear which areas outside of Labrador were included in the imagery analysis. A map clearly showing the area for which imagery analysis was done would therefore be useful. For field-based observations, some information on how sites were chosen beyond accessibility is probably required for the reader to understand whether there is any bias in the site selection and validation.

[Authors' Response]: Prior research in the region, including early works by Roger Brown (1975; 1979), and more recently by Way and Lewkowicz (2016; 2018) and Way et al. (2018), suggest a relative absence of peatland permafrost in the interior. For the purposes of streamlining and making a clearer study design, we have modified Figure 1 to include an outline for the main study area, corresponding to the area within 100 km of the Labrador Sea coastline. We have also included a Section 2.4 entitled "Inventory extent" which describes the extent of the inventory and the justification for our focus on the coast. We have also provided additional information in Section 3.3 (Validation of subset of WOI database) on the access to WOIs for field validation.

L2 – Title – would it be better to refer to the "Labrador coast"?

[Authors' Response]: We have added "in northern Canada" to the end of the title, based on a suggestion by Referee #1.

L30-31 – insert "in temperature" between "offset" and "between" (i.e. be clear that the offset is referring to a difference in temperature). You could also add that it is the difference between the frozen and unfrozen thermal properties that is an important factor.

[Authors' Response]: We agree and have clarified that it is "a large temperature offset".

L34 – "assessment of thermokarst…." Is probably better and more inclusive.

[Authors' Response]: We agree and have changed "predicting thermokarst potential" to "assessing thermokarst potential".

L50 – O'Neill et al is a national scale map and is based on integration of a national scale surficial map which will not show local scale distribution of peatlands or other organic terrain.

[Authors' Response]: We have clarified that the ongoing underestimation of peatland permafrost in the region can influence ground ice estimates. We recognize that the O'Neill et al. (2019) product integrates information on surficial materials, paleovegetation, deglaciation, and contemporary permafrost distribution, but we think that ground ice content, thermokarst potential, and carbon content are important to mention in relation to the distribution and sensitivity of peatland permafrost.

L60 – There is the peatland map and database which I believe is at least partly based on air photo interpretation of Tarnocai at al. (cited in Supplemental Information).

[Authors' Response]: Unfortunately, the Tarnocai et al. (2011) dataset suggests that there are no perennially frozen peatlands in any part of Labrador. We have presented a comparison between the inventoried peatland permafrost complexes and the Tarnocai et al. (2011) product in the supplemental material (Supplement Sect. S4).

L275-277 – Way and Lewkowicz (2018) includes ground temperature measurements in Labrador and the thermal offsets for various terrain types. Could you be more quantitative and use these

results to strengthen the point you are trying to make regarding importance of thermal offset. James et al. 2013 ERL also discusses the importance of thermal offset in persistence of permafrost in organic terrain.

[Authors' Response]: We appreciate the suggestion and have included the approximate thermal offset at peatland permafrost locations from Way and Lewkowicz (2018) to this section of the Discussion to strengthen our argument against the utility of MAAT-based thresholds for predicting peatland permafrost distribution.

L278-285 (also figure 4) – With respect to associations with elevation, it might be more important to consider whether the area is above or below the marine limit rather than the elevation itself. Given the marine limit varies with latitude, as described in section 2.2, it would make sense to consider the location with respect to the marine limit. For sites below the marine limit, wouldn't the time since emergence be a factor as it would influence age of peatland and also length of time over which ground freezing occurs.

[Authors' Response]: We agree with the reviewer that providing information about the distribution of peatland permafrost complexes relative to the marine limit would be extremely relevant and useful for this study and for understanding overall permafrost distribution in Labrador. Unfortunately, there is no existing marine limit or marine sediment dataset for the entire coast of Labrador, so it is difficult to provide an estimate of the elevation of each of the peatland permafrost complexes relative to the local marine limit. We have estimated the local marine limits for as much of our study area as possible using inverse distance weighted interpolation from a series of observations that were compiled in Dyke et al. (2005) and have presented this information in the supplemental (Supplement Sect. S3), but we have not presented it as part of the main manuscript given that the interpolation does not cover our entire study area. We have also included additional information in Section 5.2 (Implications for peatland permafrost and permafrost distribution in northeastern Canada) describing the lack of available data on marine limits or marine sediments, and we have included information in Section 5.1 (Distribution of peatland permafrost in Labrador) on the potential role of peat age and peat thickness in peatland permafrost development and persistence through the thermal offset.

L287-299 – Reference is made to model predictions. It might be better to refer to simulations which would be more inclusive as the various studies mentioned use various approaches including compilation/synthesis of existing information.

[Authors' Response]: We agree and have changed "models" to "simulations".

L298 – The surficial deposits are a key factor influencing drainage and accumulation of organic matter as well as formation of segregated ice. You might consider association of peatland permafrost with surficial deposits as has been done for other parameters in figure 4.

[Authors' Response]: We agree with the reviewer that surficial deposits are very important for understanding peatland permafrost distribution. Surficial materials information for the entirety of Labrador is currently only available at the 1:1,000,000 scale, with some information at the 1:50,000 scale in scattered locations. Our ability to make these kinds of comparisons is unfortunately limited by the availability of surficial materials products at an appropriate scale and will not be possible until significant advances are made in this area by partner institutions or governments. We have included additional information in Section 5.1 (Distribution of peatland

permafrost in Labrador) describing the lack of available surficial materials data at a suitable scale for all of Labrador.

L309-310 - Obu et al. (2019) map represents equilibrium conditions so it doesn't adequately consider past climate history which is important as you have mentioned in the discussion. Permafrost occurrence will be underestimated, especially in the southern portion of the permafrost zone.

[Authors' Response]: We do not believe that the disagreement with Obu et al. (2019) in our region is due to equilibrium modelling but rather reflects performance issues with their implementation of the TTOP model. Unpublished work by Way and Lewkowicz presented at the Eastern Snow Conference in 2017 showed that discrepancies between TTOP spatial models (e.g., Way and Lewkowicz, 2016) and observations of peatland permafrost along the southern coast of Labrador could largely be reconciled with an improved snow redistribution algorithm and more precise land cover maps. While equilibrium modelling could potentially explain a lack of peatland permafrost in some areas, it is not the primary source of disagreement. We have elaborated on potential issues in the interpretation of TTOP model results in the supplemental material (Supplement Sect. S5).

L319 – You need to consider the scale of the maps to which you are comparing your results. Heginbottom et al. is a national scale map and is much at a much smaller scale than your study – 15 km on the national scale mapping is likely within the precision of the map.

[Authors' Response]: We have briefly mentioned the differences in scale between our inventory and the products used for comparison in Section 5.2 (Implications for peatland permafrost and permafrost distribution in northeastern Canada) and have elaborated on issues of scale in the supplemental material (Supplement Sect. S5). However, we also note that the Permafrost Map of Canada and the International Permafrost Association's Circumarctic Map of Permafrost and Ground Ice Conditions were derived from a holistic assessment of existing permafrost information in conjunction with physiographic data (Heginbottom et al., 1997; Heginbottom, 2002; Zhang et al., 2008). We believe that the primary reason that the sporadic discontinuous zone was not previously extended farther south along the coast of Labrador was because the very few studies from Labrador that might have informed the development of this map (the Ecological Land Classification (Environment Canada, 1999) and Roger Brown's investigations (1975; 1979)) did not cover the areas that we are currently describing as having a high density of peatland permafrost complexes. Issues of scale certainly do apply to maps derived using explicit areal calculations and modelling, but for a holistic mapping effort like the IPA map, we believe the comparison is fair.

L400-401 – Is this a conference presentation with abstract? Provide the conference details and abstract if that is the case

[Authors' Response]: Thank you, we have reformatted the reference.

L404-405 – Incomplete citation. Is this an unpublished report?

[Authors' Response]: Thank you, we have reformatted the reference.

L406 – Unpublished report, conference presentation? Provide details.

[Authors' Response]: Thank you, we have reformatted the reference.

L413-414 – This is NRC Internal Report No. 82 with 1956 publication date.

[Authors' Response]: Thank you, we have reformatted the reference.

L415-416 – Incomplete. This is NRC Technical Paper 449

[Authors' Response]: Thank you, we have reformatted the reference.

L432 – Is this correct. Seems like an odd reference for a land survey

[Authors' Response]: We agree that it is an odd reference, but it seems to be the only available resource describing the survey. The audio tape transcript is available for download from Natural Resources Canada. We have included the download link for the transcript document to the reference.

L434 – van Everdingen is the editor. Also, you should indicate this is an International Permafrost Association publication of the Terminology Working Group

[Authors' Response]: Thank you, we have reformatted the reference.

L441 – Is this from the Quaternary Geology of Canada and Greenland. Add missing citation info.

[Authors' Response]: Thank you, we have reformatted the reference.

L442 – This is Map 1880A and it should have a doi number (check GEOSCAN https://geoscan.nrcan.gc.ca/)

[Authors' Response]: Thank you, we have reformatted the reference.

L453 Missing information. This is from the National Atlas (5th Edition) Geomatics Canada series number MCR 4177. It also has a doi number (check GEOSCAN https://geoscan.nrcan.gc.ca/)

[Authors' Response]: Thank you, we have reformatted the reference.

L535 – Is this the database for the inventory (at Nordicana D?) – There should be additional information including doi number.

[Authors' Response]: Thank you, we have reformatted the reference.

L538-539 – Is this a conference presentation/abstract, unpublished report? Provide additional information.

[Authors' Response]: Thank you, we have reformatted the reference.

Figure S3 – Why only show where permafrost is not present based on 2013-17 study? It would be more useful to also include where permafrost was present during the 2013-17 study.

[Authors' Response]: We have removed this figure from the supplemental material.

Figure S5 – I believe Tarnocai et al. (2011) also indicates whether peatland is frozen or unfrozen. Wouldn't it be useful to show this on the map?

[Authors' Response]: We have presented a comparison between the inventoried peatland permafrost complexes and the Tarnocai et al. (2011) perennially frozen peatlands product in the supplemental material (Supplement Sect. S4). Unfortunately, this dataset suggests that there are no perennially frozen peatlands in any part of Labrador.

Figure S8 – How useful is this comparison given Obu et al. map is based on an equilibrium permafrost distribution and past climate conditions are not considered? Since permafrost

aggradation in this region likely occurred under a colder climate than present, the Obu et al. map will underestimate the permafrost occurrence.

[Authors' Response]: We believe that the disagreement with Obu et al. (2019) in our region reflects performance issues with their implementation of the TTOP model rather than the utility of the TTOP model itself. Unpublished work by Way and Lewkowicz presented at the Eastern Snow Conference in 2017 showed that discrepancies between TTOP spatial models (e.g., Way and Lewkowicz, 2016) and observations of peatland permafrost along the southern coast of Labrador could largely be reconciled with an improved snow redistribution algorithm and more precise land cover maps. Further, while we agree that much of the literature suggests that peatland permafrost, especially if found near its southern limit, tends to be relict permafrost that may be in disequilibrium with the current climate, we note that one-dimensional thermal modelling for two palsas in southeastern Labrador by Way et al. (2018) found that these landforms were largely in equilibrium with current climate conditions. We have elaborated on these issues, including potential issues in the interpretation of TTOP model results, in the supplemental material (Supplement Sect. S4).

L71-72 – Heginbottom et al. – see earlier comment

[Authors' Response]: Thank you, we have reformatted the reference.

L86-88 – More information about these publications should be provided. Is the NRCan Land cover map the one described below (it might also be from National Atlas 6th Edition reference outline series 6409).

Canada's land cover; Latifovic, R. Natural Resources Canada, General Information Product 119e, (ed. version 2015), 2019, 1 sheet, https://doi.org/10.4095/315659

[Authors' Response]: Thank you, we have reformatted the reference.

L100-101 – Missing info for Tarnocai et al. This is Geological Survey of Canada Open File 6561 and has a doi number – check GEOSCAN

[Authors' Response]: Thank you, we have reformatted the reference.