<u>Reviewer responses</u>

Reviewer 1

General comments: The manuscript describes characteristics of palsa peatland permafrost in coastal Labrador, Canada, derived from electrical resistivity studies and local observations of ground temperature and climatic variables. These descriptions, from several sites in the area, are complemented with numerical transient modeling of the fate of permafrost under future warming for two studied boreholes in the study area. The results show that thin permafrost exist in isolated patches in palsa peatlands in the relatively warm coastal area of Labrador (-1.1°C to 1°C average annual air temperature) and that it is in equilibrium with present climate due to a combination of thin snow cover and large thermal offset caused by the peat cover. The simulations show that the permafrost would degrade in most or all of the study area for the range of tested climate warming scenarios.

The dynamics of permafrost in the discontinuous, sporadic and isolated patches permafrost zones is challenging to predict with today's simulation tools, which generally focus on coarse scales and vertical heat fluxes. This study adds valuable information on how and where permafrost appears in isolated patches, which is needed for understanding of how climatic changes can affect these areas. It further addresses the challenges associated with using numerical permafrost models, which do not represent lateral heat fluxes, for simulating this type of permafrost.

The manuscript is well-written and structured. The introduction is brief but relevant. The methods section could need some expansion and clarification on some details, in particular the simulation procedure should be better described (see detailed comments below). The results are presented straight-forwardly. The discussion puts the results in context of current knowledge and highlights the relevance and impact of the findings, but I lack a mention of the implications of the assumptions that the modeling is based on (see detailed comments below). The manuscript contains many figures which I think is of value for a study that presents this type of geophysical data for describing permafrost.

As the manuscript presents a significant contribution to our current understanding of palsa and peat plateau permafrost characteristics and dynamics, and is generally well written, I recommend that it is accepted after minor revisions.

[Authors' response] The authors' would like to thank reviewer 1 for taking the time to review this manuscript. We agree with reviewer 1's comments and have amended the manuscript accordingly.

Detailed comments:

P4, L1: Way and Lewkowicz full citation should be available when this is published.

[Authors' response] We agree. This contribution is now published online and we have amended the citation accordingly.

P4, L7: What is the water-jet method?

[Authors' response] Text added:

Five shallow boreholes (Table 2) were drilled using water jet drilling with a low horsepower pumping water from a nearby water body down a steel pipe used for penetrating the ground. Immediately post-drilling, holes were cased with 1-inch PVC pipe.

P4, L25: What is meant by "low sensitivity areas (<0.1)" and how does it reflect uncertainties?

[Authors' response] Amended to:

Modelled resistivities are presented as model blocks with less reliably measured blocks (sensitivity values < 0.1) faded to reflect that these sections are less certain in the modelled profile.

S1: In general, it would be good to state what the different parameter values are based on (local data, literature. . .?)

[Authors' response] Good suggestion. We added a column in the table S1 to indicate the sources and methods that each parameter was based on.

"Degree of decomposition" increases from 0.1 to 0.4 – is this linearly with depth?

[Authors' response] Yes. The degree of decomposition slightly increases with depth. Since the numbers are defined by the model and it is hard for readers to understand it, we revised it into descriptive words (texture of the peat).

"Organic matter content" – same as above

[Authors' response] Revised. For Cartwright site: 1.2-1.5 m: decreases from 100% to 5%, 1.5-3.2 m: 5%, then linearly decreases to 1% at 10 m. For Blanc Sablon: 1.75-2.0m: decrease from 100% to 5%, 2.0-3.2 m: 5%, then linearly decreases to 1% at 10 m.

"Degree of decomposition" again. . . Is this for mineral substrate?

[Authors' response] Yes. We revised it as "Texture of the organic matter in mineral soils". The numbers in the table were revised as descriptive words (from hemic to well decomposed at depth).

“Fraction of quartz” and “Thermal conductivity of rock” – how were these values chosen?

[Authors’ response] The references were added for them.

“Geothermal heat flux” – these were calibrated, right? This should be clearly stated in the table.

[Authors’ response] Revised as suggested.

“Water table reduces 10% when above ground surface” – This sentence is really difficult to understand. I have no idea what it means. 10 % of what? In what way does the model include water above the ground surface, and how is a lateral flux of water incorporated?

[Authors’ response] Although the model is one dimensional, we simply parameterized lateral water flows based on modelled water table. In our case, for example, when water table is above the land surface, 10% of the water table above the land surface will be reduced each day due to surface outflow. A detailed description of the method can be found in the following papers. We added these references in the foot notes of the table S1.

Zhang, Y., Li, C., Trettin, C.C., Li, H., and Sun, G., An integrated model of soil, hydrology and vegetation for carbon dynamics in wetland ecosystems. Global Biogeochemical Cycles, 16(4), 1061, 2002. doi: 10.1029/2001GB001838.

Zhang, Y., Li, J., Wang, X., Chen, W., Sladen, W., Dyke, L., Dredge, L., Poitevin, J., McLennan, D., Stewart, H., Kowalchuk, S., Wu, W., Kershaw, G. P., Brook, R. K. and Burn, C. R. Modelling and mapping permafrost at high spatial resolution in Wapusk National Park, Hudson Bay Lowlands, Can. J. Earth Sci., 49(8), 925–937, 2012. doi: 10.1139/e2012-031.

The vegetation type is listed as shrub, but in your vegetation description you state that no shrubs are present on the palsas, only on the sides. How is this choice motivated?

[Authors’ response] This choice is based on the general description of the area. Although the surface of the palsas has no shrubs the general classification for this region would be a peat bog with small-to-medium shrubs scattered across the area. The model needs to select one of the five vegetation types: coniferous forest, broad leaf forest, mixed forest, shrubs, and sedge/grass/crops. We have expanded up on this in light of these comments.

P4, L33: Please clarify that all thermal properties and other necessary parameters and their motivations (literature, field observations) are listed in S1 and make sure that they are.

[Authors' response] Added a column as suggested.

P4, L30 – P5, L12: A presentation of the model discretization/mesh is lacking. It is also unclear how initial conditions were set up and how/if any spin-up procedures were performed. Was the model parameters calibrated after a spin-up from year 1900? If so, what were the initial conditions at year 1900? Was daily air temperature the only data needed for running the model for all time periods? If there is a snow wind-scouring factor, I would assume that the model also takes in snow/precipitation data.

[Authors' response] We added a sentence about the layer divisions for this one-dimensional model. The model was initialized by running the model iteratively using the climate data in 1900 until the modelled deep ground temperature are stable. We added a sentence about that as well. The input parameters were used and kept constant for the entire simulation years, including the spin-up years. The input climate data include daily minimum and maximum air temperatures, precipitation, vapour pressure, solar radiation and wind speed. We added a sentence about the model climate input requirement and a new section in the SI about the compilation and preparation of these data, including for future scenarios.

Please formulate this more clearly than "climatic inputs" (P4, L8).

[Authors' response] We added a sentence about the model requirement of the inputs climate data and a new section was added in SI about the compilation of the daily data.

P6, L10-12: I do not understand how the accuracy of the loggers and the inherent uncertainty in ERT is considered in estimating this very precise thickness value without an uncertainty range. Is this an estimate of maximum likely thickness?

[Authors' response] Yes and we have added more information and restated a portion of the phrase. Amended the text to read:

Considering the accuracy of the ground temperature loggers (± 0.2°C) and uncertainty inherent to the ERT, the permafrost thickness beneath P3 was estimated to be between 4 and 8 m with our best estimate being approximately 6 m.

P8, L30: TTOP?

[Authors' response] Amended to:

Annual ground temperatures measured at or close to the base of the annual freeze-thaw layer (e.g. TTOP; see Way and Lewkowicz, 2018) at…

P11, L4-15: So, the higher magnitude of the geothermal heat flux is used to compensate for the lack of horizontal heat fluxes in the model. How can you assume that the influence of the horizontal fluxes is stable over time, i.e. for keeping the calibrated geothermal heat flux values steady over the simulated warming periods? I understand that it is probably not possible to test this within this study, but the importance of this assumption should be noted in the text, especially as you argue for a higher geothermal heat flux in Cartwright due to smaller palsas in this location.

[Authors' response] We agree with the above comment and have added the following statement:

At both sites, the geothermal fluxes were also kept constant throughout the model simulations which is a limitation of the modelling approach employed. Three-dimensional modelling would be needed to resolve the nature of expected changes in these fluxes over time as feature morphology evolves with degradation.

P11, L9: Do you mean horizontal (instead of vertical)?

[Authors' response] Yes. Amended accordingly.

P12, L20: Another relevant reference about how snow influences palsa ground temperatures in Scandinavia is Sannel et al., 2016: Sannel, A.B.K., Hugelius, G., Jansson, P., Kuhry, P., 2016: Permafrost warming in a subarctic peatland – which meteorological controls are most important? Permafrost and Periglacial Processes, doi:10.1002/ppp.1862.

[Authors' response] Added and noted.

P12, L26-30: Why could it not be both? The simulation tool applied here does not take into account potential feedback processes that could speed up warming/thawing with time, such as increases in lateral heat transport as permafrost bodies decrease in size, and feedback from changing topography (with melt of ground ice) to decreased wind-scouring and subsequent warming/thawing.

[Authors' response] These feedbacks, although relevant for how permafrost may degrade in the future at these sites, are not considered to be directly attributable as being a cause of the large thermal offsets observed at these sites as referred to in these lines of text. We have added in discussion of these points elsewhere in the text however.

P13, L8: Why does these heat flows need to be advective? See for example Kurylyk et al., 2016: Kurylyk, B. L., M. Hayashi, W. L. Quinton, J. M. McKenzie, and C. I. Voss (2016), Influence of vertical and lateral heat transfer on permafrost thaw, peatland landscape transition, and groundwater flow, Water Resour. Res., 52, 1286–1305, doi:10.1002/2015WR018057.

[Authors' response] We have added the reference and removed advective. They could be both as noted by the reviewer.