Line numbers in referee comments (in blue) refer to the original manuscript, whereas line numbers in our responses (in black), refer to the revised clean manuscript.

RC1 Claire Treat: https://doi.org/10.5194/tc-2022-135-RC1

In this study, Könönen and colleagues build a dataset on peatland palsa and peat plateau occurrence, then extract environmental variables from gridded datasets to determine the climate space conducive to palsas. Then they use statistical modeling to predict the area of peatland palsas, and how this area will change in the future under changing climate. The question is interesting, if not particularly novel (see Halsey et al., 1995, Fewster et al. 2020, 2022). The main distinction here is that the authors expand on this from a regional analysis to a pan-Arctic analysis, which is a factor that dooms this manuscript in it's current form because of un-even spatial coverage in their dataset. The results that peat plateaus and palsas will disappear with climate change isn't especially new (see Halsey et al., 1995, Beilman et al., 2001, Tarnocai 2006, Camill & Clark 1995, Camill 2005), but the scope is interesting and alarming.
R1: We thank Dr. Treat for the highly valuable comments throughout the review. We are aware that some prior regional-scale studies affect the novelty of our study. This was one of the reasons why we aimed to conduct our study at the circumpolar scale, especially after the recent publications of Fewster et al. (2020, 2022). We believe that our predictions add value to the current knowledge of the distribution of suitable environments for palsas and peat plateaus, because there are very few studies from Central and Eastern Siberia. Thus, our predictions can give new insights into the landform distribution and guide future research in these insufficiently explored regions.

In addition to the more extensive research area, the fine spatial resolution (30 arc sec) used in this study is much finer than what previous studies have utilized and brings novelty to the results. Because of the fine resolution we can present more detailed picture of the potentially suitable environments for palsas and peat plateaus and find unsuitable regions within them, which is one aspect that previous coarser resolution studies have not considered. Moreover, the inclusion of soil and topographical variables (silt and soil organic carbon content, thickness of the soil layer, and topographical wetness index) distinguishes our study from climate envelope studies (e.g., Fronzek et al., 2006; Tam et al., 2014; Fewster et al., 2022). These points of novelty were recognized also by Paul J. Morris in his community comment to this manuscript. Consequently, we believe that our study makes a valuable contribution in the field of palsa and peat plateau research.

We modified the manuscript so that it is clear for the reader that our results for Central and Eastern Siberia are for the most part extrapolations from models fitted for North America, Northern Fennoscandia, and Western Siberia (see e.g., lines 78–81, p. 3; 203–204, p. 8; 403–404, p. 19; 487–488, p. 22). Discussion related to fine spatial resolution and inclusion of non-climatic variables can be found for example from lines 418–420 (p. 20) and 441–450 (p. 41).

I think in it's current form, the manuscript is unfocused as well as missing key information and methodology that prohibit the evaluation of the results and conclusions.
R2: In editing the manuscript, we focused on better readability throughout the text. Particularly, we described our methods more explicitly (e.g., lines 200–210, p. 6) and added reasoning so that the readers can evaluate the results and conclusions better. Please note that these issues are discussed later in this response letter in more detail.

The discussion is superficial and doesn't address key uncertainties and other factors that would affect the results.

R3: We added discussion about the uncertainties related to the model extrapolation (e.g., lines 403–413, pp. 19–20). Moreover, we will also include a new figure (fig.7 in the revised manuscript on p. 18) (here fig. R2; see reply no. R9). In this figure, we compare our predictions to the distribution and coverage of the peatlands, which will (allow us to) deepen the discussion of suitable environments for palsas and peat plateaus in the recent period 1950–2000 (lines 397–402, p. 19; 403–413, pp. 19–20). In addition, we incorporated better the discussion related to the role of the past climates to these landforms as suggested to lines 460–468 (p. 21).

For the focus, the majority of the methods and half of the conclusions are focused on present day conditions. Only one short section in the results section is and the discussion about this is superficial.

R4: Please note that the same modelling framework was used to produce the recent and future predictions so the methodological parts can be considered to describe both the recent period (1950–2000) and future scenarios. We elaborate the involved steps in the methods section (see below). By comparing our predictions for the recent period to different peatland datasets (see reply no R9) we were able to add and deepen our discussion related to the present-day distribution of the suitable environments.

We added a new paragraph about the future predictions to the methods (starting from line 205, p. 8)) as requested to make them easier to follow and balance the focus between present day and future parts.

The new paragraph in methods section:

"Future predictions were performed by using the BIOMOD_Projection -function in biomod2 (Thuiller et al., 2021; see Karjalainen et al., 2020). Here, the models calibrated for the recent period (1950–2000) were used to predict future suitable conditions by substituting the climate variables with future climatologies (Hijmans et al., 2005). Predictions were performed for each RCP-scenario (2.6, 4.5 and 8.5) and future period (2041–2060 and 2061–2080). Predictions were extracted to the current extent of the suitable environments because we did not consider it temporally plausible for new palsas and peat plateaus to develop in the region of continuous permafrost during the 21st century."

There is no section explaining how the forward projections were done and what data was used beyond the scenario names (and they are from AR5).

R5: Climatic variables which were for future scenarios are available in WorldClim v1.4 database (Hijmans et al., 2005), as mentioned in the manuscript (section 2.2, lines 133 and 138–140, p. 6). We decided to use RCP-scenarios available in WorldClim v1.4 as the recent period (1950–2000) for which the database provides 'baseline data' coincided well with the most of our landform observations (meaning years when landform observations were originally documented). An earlier climate period was also preferred as most palsas and peat plateaus were formed during colder climates than we are currently facing (Vorren, 2017; Fewster et al., 2020), and thus we expect that the period 1950–2000 represents better these climatic conditions than the more recent baseline periods. The new version of WorldClim (v2.1) using CMIP6 scenarios uses baseline period 1970–2000 and thus it was less suitable for our purposes. In addition, future scenarios in WorldClim v2.1 were not available at 30 arc sec resolution when we compiled the environmental data and thus, we were not able to utilize them.

This reasoning was added to the revised manuscript to the lines 135–136 (p. 6). We added also a new paragraph in the section ‘2.3 Statistical modelling’ about the future predictions as mentioned in the previous reply (starting from line 205, p. 8).

The most crucial information, the dataset about the palsas, is missing (cited as Appendix A). The information is not in the paper, is not already openly or provisionally available in an online repository (e.g. Zenodo or Pangaea or a Uni Helsinki repository), or in the supplementary materials.

R6: We would like to politely note that the Appendix A was placed at the end of the manuscript. However, it was unfortunate that the reviewer did not find the misplaced Appendix A. This may have caused some confusion in finding right references from the reference list. We wanted to provide this list of references of landform observations in the manuscript rather than in supplementary materials to acknowledge the authors for their contribution for our study.

We moved the Appendix A to its proper place (starting from line 524, pp. 24–32) and added the requested coordinates of the landform observations to the supplementary material after the revision.

This is problematic because from what I see, the model results for North America seem to be particularly biased towards where there are samples or not. I think the data coverage is exceptional for Fennoscandia but really limited for North America. The authors don’t explore the representativeness of the dataset that they’ve collected towards earlier described or known inventories of permafrost peatland areas or palsa areas or peatland areas. This could be normalized and some confidence assigned based on the number of samples per peatland area.

R7: We acknowledge this imbalance between regions in our dataset. We compiled as representative a dataset of landform observation across the permafrost region as possible. For Northern Europe there are many mapping studies and inventories available (Backe, 2014; Ottósson et al., 2016; Metsähallitus, 2019; Ruuhijärvi et al., 2022), which is not the case for North America to our knowledge. We are aware of the Wetland Data Base for the Western Boreal, Subarctic, and Arctic Regions of Canada (Zoltai et al. 2000) which was also utilized by Fewster et al. (2020). However, due to the low accuracy of the given coordinates in the database, it was not possible to locate all the landforms with high enough spatial accuracy to be used in this study, and we were not able to detect the landforms in satellite imagery in the data validation process. This reduced the number of observations in North America. Comparisons between palsa/peat plateau observations and (permafrost) peatland areas are problematic and do not directly give insights into the representativeness of our dataset (as permafrost peatland does not equal to palsas or peat plateaus). However, with the addition of a new figure 7 (line 372, p. 18) (see fig. R2 from reply no. R9) we can assess how representative the compiled observations are in relation to the known/estimated permafrost peatland/bog distribution.

I thought that the results look really biased towards where there are samples, and quite limited outside that as I would expect a lot more coverage in Northwestern Canada (Alberta). Other areas that don't look right to me, in particular a high chance for peat plateaus and palsas on the North Slope of Alaska and on the Seward Peninsula where the dataset is quite limited. To my knowledge, the peatland area is relatively limited on the North Slope and often limited to riverine systems and not so frequently peat occurence. Then further north, mostly polygonal tundra peatlands are found or no peatlands at all. As mentioned in the discussion, interior Alaska would make sense.

R8: The predictions likely underestimated suitable conditions in Alberta, but our models predicted suitable environments quite broadly in the Northwestern territories (fig. R1, see below). Fewster et al. (2020) predicted the high occurrence probabilities of the landforms broadly in the region, but this might be, at least partly, caused by the coarser resolution of their study. Higher resolution and soil variables used in this study, enables our models to recognize possibly unsuitable regions within the palsa region predicted by Fewster et al. (2020), which might cause the more limited distribution.

As for the predictions for Alaska, the results were surprising as discussed in the manuscript. Figure 2 shows relatively high occurrence probabilities for the occurrence of suitable environments on the North Slope and Seward Peninsula. However, when we classified these continuous predictions of suitable environments into binary maps used for the area calculations (provided in Table 1) this seems not to be so problematic. The binary classification is illustrated in the new figure 7 (here fig. R2 described in reply no. R9), and we added the simplified outlines of the binary classification to the revised figure 2 in order to decrease the subjectivity of the interpretation of our predictions (see reply no. R33). As one can see (fig. R2) for example the predicted suitable environments in North Slope are restricted to a much smaller area than the unrevised figure 2 suggested. For the Seward peninsula the difference is not so clear but still some improvements can be recognized when compared to unrevised figure 2. Notwithstanding, our models slightly over predicted the suitable environments when comparing to the distribution of peatlands in Alaska (fig. R2). To make this crystal clear, we added discussion related to issues above to the revised manuscript as well (see e.g., lines 365–371, p. 17; 414–424, p. 20).

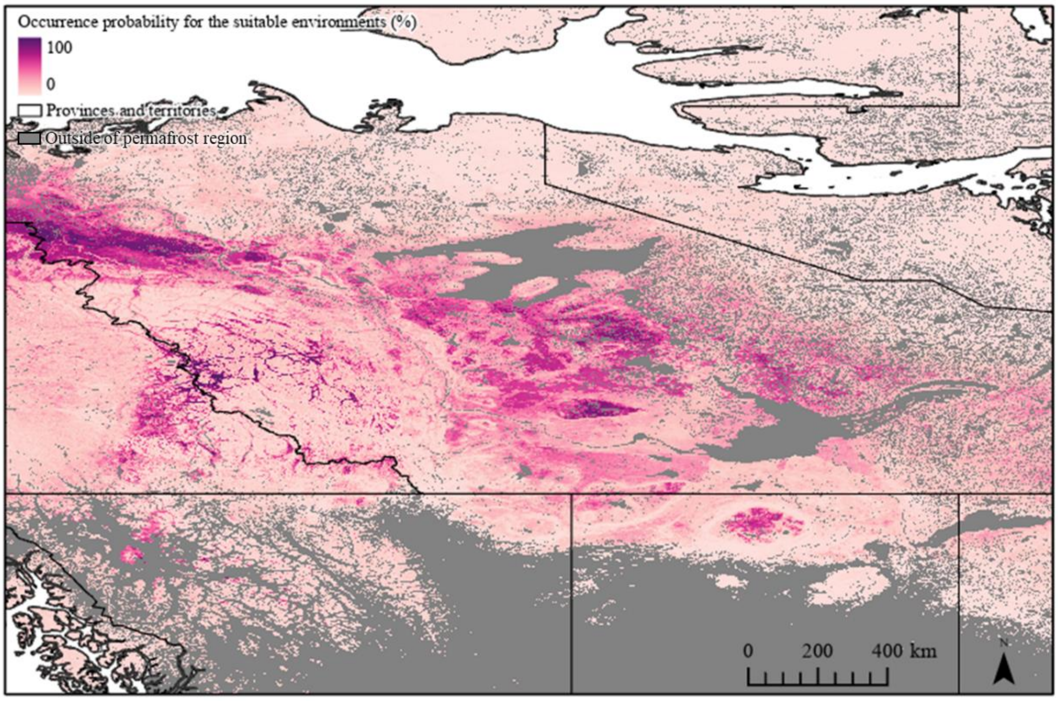


Figure R1: The occurrence probability for the suitable environments for palsas and peat plateaus is illustrated in pink-scale, borders of the Canadian provinces and territories with black outline, and regions without permafrost in grey. Predictions are extracted for the permafrost region (Ran et al., 2022).

I am also aware of some other large peatland datasets that could either be incorporated and referenced or used for validation (Treat et al., 2016, Table S1) as a presence/absence marker or a newer dataset from Olefeldt (BAWLD) that tackles this more directly (see “Permafrost Bog”). They show much more extensive permafrost bog coverage in northwestern Canada, for example.

R9: We thank the reviever for pointing out these datasets. We used them to discuss and evaluate our results. When we compiled the environmental dataset, we examined many peatland datasets including Hugelius et al. (2020) but our models yielded the highest evaluation scores with the soil organic carbon content (SOC) variable from the SoilGrids (Poggio et al., 2021) and thus it was utilized in the models. Many peatland datasets such as BAWLD (Olefeldt et al., 2021) are at coarser resolution than other variables and could not be used in this study. However, we recognized the value of suggested comparisons for validation of the results. We compared our predictions for the recent period (1950–2000) to four different peatland datasets (BAWLD, Hugelius et al. (2020), PEATMAP, and Treat et al. (2016a)). Based on these comparisons, our predictions (for 1950–2000) and the distribution and coverage of the peatlands coincide well especially in North America and Western Siberia (except in Alaska according to PEATMAP, Xu et al., 2018) (fig. R2). On the contrary, peatland datasets clearly underestimate the peatland coverage in Fennoscandia, probably due to their coarse resolution, as the datasets do not recognize permafrost peatlands there, although palsas and peat plateaus are relatively common in the region. We added two classifications of suitable climate spaces based on FDD and TDD values to the new figure (fig. R2); a liberal interpretation of our results and a stricter one (see fig. 3). According to these classifications some of the permafrost peatlands would not be climatically suitable for palsas and peat plateaus (i.e., in Northern Siberia, and according to the stricter interpretation in northwestern Canada as well).

New figure (fig. 7 in line 373, p. 18; here fig. R2) and results presenting these comparisons were added to the manuscript (lines 365–372, p. 17) to the section 3.4. This topic is also discussed in the revised discussion section (lines 339–402 and 405–413, pp. 19–20).

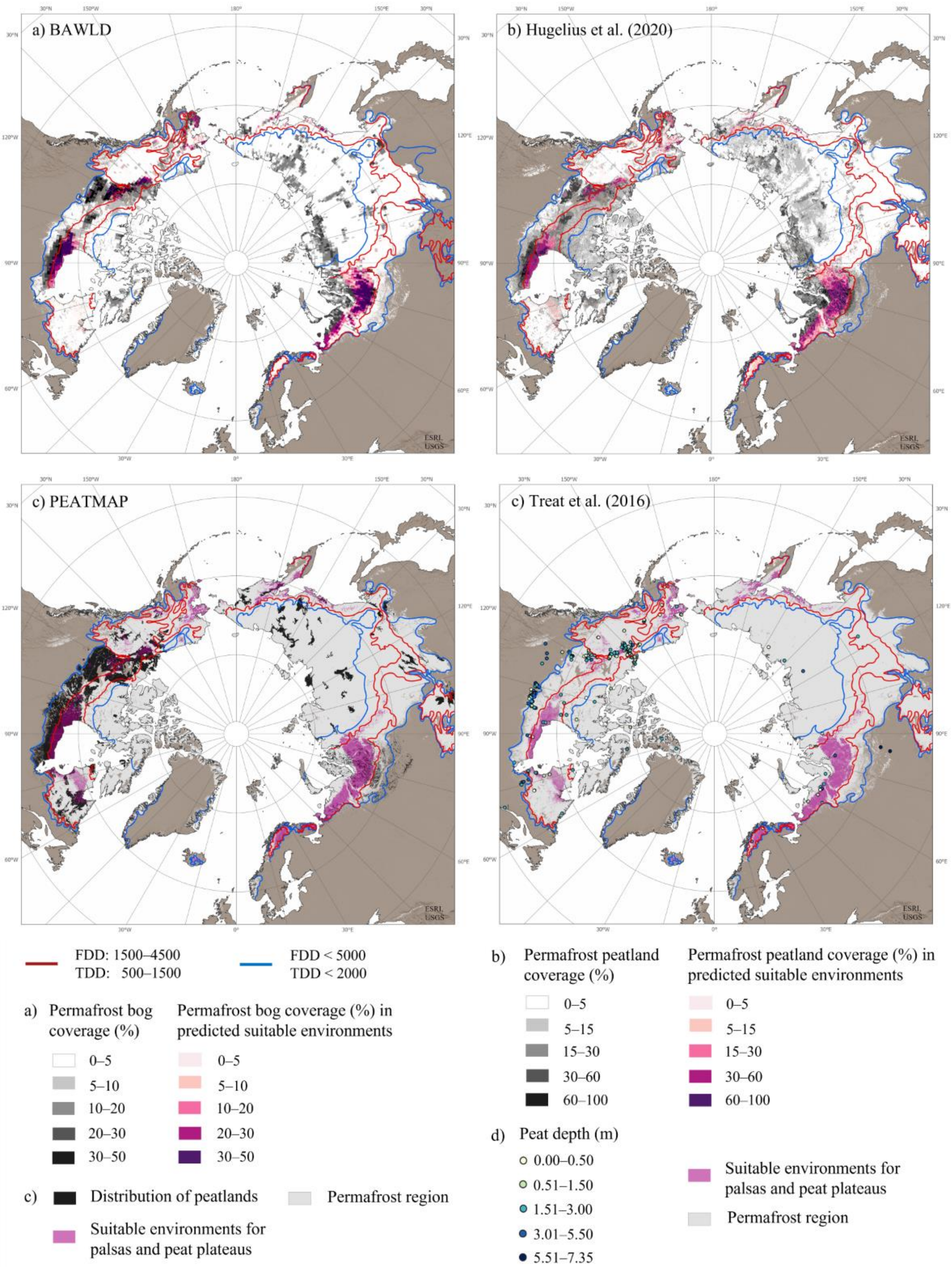


Figure R2: Comparison between the predicted suitable environmental spaces (for period 1950–2000), suitable climate spaces, and peatland datasets; (a) Permafrost bog coverage percent (0–50 %), in each grid cell according to the Boreal–Arctic Wetland and Lake Dataset (BAWLD; Olefeldt et al., 2021), (b) permafrost peatland coverage percent (0–100 %) (Hugelius et al., 2020), (c) distribution of peatlands according to PEATMAP (Xu et al., 2018), and (d) peat depth according to Treat et al. (2016b) in point symbols (yellow to blue scale). Permafrost regions are illustrated in light gray (Ran et al., 2022) and regions outside permafrost region with brown. The suitable environmental spaces are illustrated with pinkish colors, whereas areas outside our binary predictions are illustrated with grey scale. Two classification of suitable climate spaces are illustrated with red (a strict interpretation) and blue (a liberal interpretation) lines.

My other major concern in this study was the approach for validation. Not much space or effort was dedicated towards convincing me as a reviewer that this approach worked (and from my visual inspection of Figure 2 above, I'm not convinced) and what the results would actually represent. Is this potential permafrost palsa are or actual permafrost palsa area? The model validation isn't presented in the results section, or really at all. The closest we come is Table 1, giving the areas by region and the change over time.

R10: First, we would like to note that the good to excellent predictive performance of the modelling was demonstrated by the statistical evaluation metrics in figure 6. These evaluations included uncertainty measures (standard deviations) which were based on a 100-fold cross validation and evaluations against separate evaluation datasets. Standard deviations were also calculated to the True Skill Statistics (TSS) cut-off values, and a new figure comparing the extent of binary classifications (using average and ±1 s.d. cut-off values) was added to the supplementary material (fig. R3). We calculated the areal variance based on these classifications to the revised Table 1 (starting from line 279, p. 10).

Moreover, we compared the future predictions to the thermokarst data by Olefeldt et al. (2016) to assess the spatial match between their mapped thermokarst-prone areas and those of the currently suitable environments predicted to become unsuitable under the used future scenarios. The idea behind this was to link the loss of suitable environments with increased thermokarst activity. Reasoning for this comparison was added to lines 68–71 (p. 3) and 156–163 (p. 6).

We acknowledge that additional validations with the mentioned permafrost peatland datasets have the potential to more explicitly address the circumpolar distribution of suitable environments but also the unsuitability of certain permafrost peatlands (see fig. R4 from reply no. R18) into which our circumpolar analyses can shed novel insights. Thus, we added this comparison to our analysis as mentioned above (see reply no R9).

Throughout the manuscript we are using terms 'suitable environments' or 'suitable environmental spaces' instead of claiming that our results would present actual distribution of palsas and peat plateaus now and in the future. Discussion related to this topic was added to lines 451–459 (p. 21). We also modified the legend of figure 2 (line 248, p. 510) accordingly to follow this terminology (from 'Landform occurrence probability (%)' to 'Occurrence probability of suitable environments (%)'). See revised figure 2 from reply no R33.

Statistical modelling has successfully been used to model the distribution of landforms including palsas and other periglacial landforms (at regional to circumpolar scales) (e.g., Aalto et al., 2017; Fewster et al., 2020, 2022; Karjalainen et al., 2020). We added a new paragraph about the model evaluation and uncertainties to the discussion (lines 478–491, p. 22).

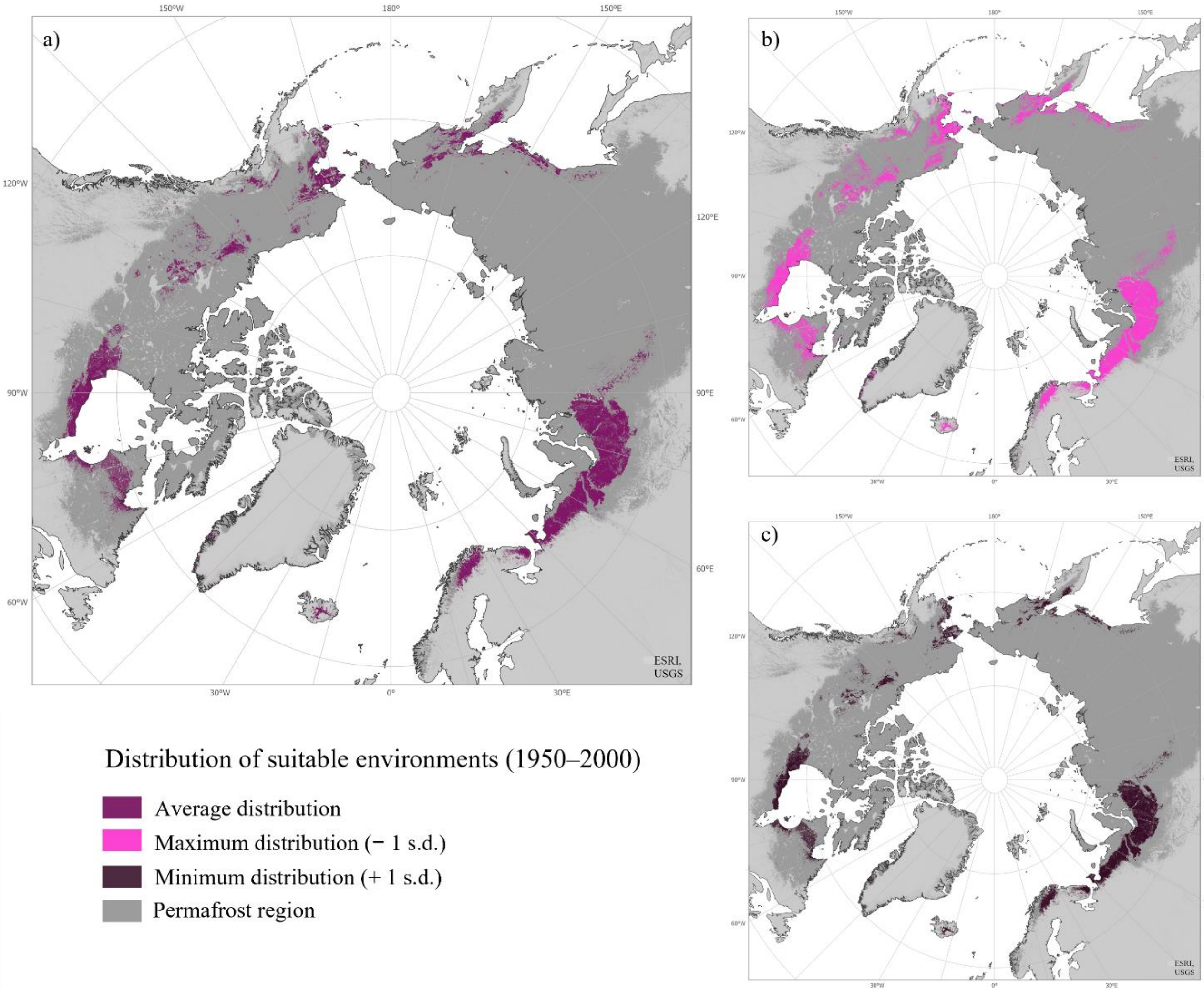


Figure R3: Comparison between binary classifications of the suitable environments (for period 1950–2000) for palsas and peat plateaus, based on different True Skill Statistic (TSS) cut-off values calculated from 100 model iterations: (a) average, (b) -1 standard deviation and (c) +1 standard deviation. On the background the permafrost region on dark grey (Ran et al., 2022).

Comparisons about the spatial distributions are made to Fewster, but the areas are not put into context of peatland areas, permafrost peatland areas, regional permafrost peatland areas, or other independent datasets so it is difficult to glean if these area estimates are even reasonable. I would expect to see a table comparing the areas predicted in this study to other estimates from Webster 2018, Hugelius et al. 2020, Olefeldt et al., and Fewster.

R11: We found the quantitative comparisons between the predicted distribution of suitable environments for palsas and peat plateaus and distribution of peatlands or permafrost peatlands difficult because they are not fully comparable, i.e., not all peatlands, even inside the permafrost area, have palsas or peat plateaus. Based on the response curves in Fig. 3 we can see that the probability of suitable conditions decreases sharply after around 4,000 FDD. This suggests that not all climate conditions inside the permafrost region are suitable for palsas and/or peat plateaus even though extensive peatlands are found in North Siberia, for example. The possible absence of palsas and peat plateaus in the continuous permafrost region could be caused by the environmental conditions favoring other periglacial landforms, such as pingos and polygon mires (French, 2017), and thinner peat coverages (Seppälä, 1988; Hugelius et al., 2020). This, in addition to the resolution difference between our study and peatland datasets (see above), poses a challenge for quantitative comparisons between our predictions and proposed permafrost peatland datasets.

Thus, we decided to present visual comparisons instead of a table. This new comparison including Olefeldt et al. (2021), Hugelius et al. (2020), PEATMAP (Xu et al., 2018), and Treat et al. (2016a) was presented above (fig. R2; fig. 7 in revised manuscript, line 372, p. 18).

Quantitative comparisons between our predictions and predictions of Fewster et al. (2020, 2022) would be useful in model evaluation. However, these comparisons were not possible as the predictions of Fewster et al. (2020, 2022) were not available as geospatial data.

Finally, the real trick in these discontinuous permafrost environments is to separate permafrost that shouldn't be there in today's climate envelope and is only there because it formed under colder climate conditions and non-permafrost, as would happen at the exact southern edge of the permafrost environment (e.g. when there are paired cores at a site, one with permafrost, one without and commonly found in palsa regions of Fennoscandia and Canada). My understanding in this is that these samples would be excluded because they are too close in location, which might limit the accuracy of this approach in the most sensitive regions. If this is only change in potential permafrost palsa area with no distinction between where there is permafrost and not, this really limits the utility of the whole analysis for future predictions.
R12: This is an important notion, and we are aware that modelling landforms commonly found in discontinuous and sporadic permafrost regions is tricky for the reason mentioned above. However, we did not consider it appropriate to exclude observations of the sensitive environments from the data, because like the reviewer points out, many palsas and peat plateaus in Fennoscandia and Canada are found in these sensitive regions. Thus, including these observations improves the spatial representativeness of the data. Permafrost can exist in palsas and peat plateaus in the sporadic and isolated permafrost regions. For this reason, we did not exclude landform observations even though their neighboring grid cells would not contain permafrost.

In addition, we could expect that including observations from the very limit of the permafrost occurrence would cause our models to predict suitable environments in warmer climates than where these landforms are actually found. However, our results show that the possible over-estimations are more likely to be found in the higher latitudes rather than regions too warm for the landforms.

Specific comments:
15-16: why -98.2 and 89.2 loss? Signs don't match?
R13:Revised to lines 15–17 (p. 1):
"Climate change was predicted to cause an almost complete loss (decrease of 98.2 %) of suitable environmental spaces under the high emissions scenario by 2061–2080, while under low and moderate emissions scenarios the predicted loss was 76.3 and 89.3 % respectively."

25: Wang 2022 is missing from refs or wrong reference.
R14: Wang (2022) can be found from the reference list. Another reference: Wang (2017) was used in the data compilation, and can be found from the Appendix A.

34: see additional refs above.
R15: We thank the referee for the useful suggestions for additional references. We cited to Halsey et al. (1995) and Treat et al. (2016a) in our revised manuscript on lines 37 (p. 2) and 461 (p. 21).

33: Hugelius has additional peatlands included in permafrost peatlands, not necessarily plateaus and palsas.

R16: Thank you for pointing this out. It is important to make a distinction between palsas and peat plateaus and permafrost peatlands (see above the reply no. R11). We reworded this to avoid misunderstandings.

Revised lines 35–36 (p. 2):
"According to Hugelius et al. (2020) nearly half of the peatlands of the Northern Hemisphere, including palsa mires and peat plateaus, contain permafrost."

49: see additional refs above

R17: We added citation to Zoltai et al. (2000) to the line 52 (p. 2).

51: yes, Siberia is a big unknown!

R18: We acknowledge this, as it was our biggest problem in the data compilation. As Paul J. Morris suggested in his community comment to this manuscript, modified our approach so that it is clear to the reader that the results for Central and Eastern Siberia are (for the most part) extrapolations of models fitted for North America, Northern Fennoscandia, and Western Siberia (see lines 78–81, p. 3; 203–204, p. 8; 403–404, p. 19; 487–488, p. 22).

As one can see from the new figure 7 (see fig. R2 from reply no. R9), the peatlands in Central and Eastern Siberia are concentrated at higher latitudes which might have too cold or continental environments for palsas and peat plateaus. This was one reason for us to include the annual air temperature range variable (Temp.range) in the analysis. The extent of peatlands (BAWLD, Hugelius et al., 2020, Treat et al., 2016, and PEATMAP) is quite limited within the suitable climate envelope that we estimated based on the modelled response shapes (Fig. 3). This indicates that there are not too many places where our models could underestimate suitable conditions. In the manuscript we presented the results for random forest (RF) models, but in the supplementary materials the maps present the distribution of the suitable environments according to all used modelling methods (see figs. S5 and S7). None of the used methods predicts much wider distribution for the suitable environments for Central and Eastern Siberia than the RF. The congruence between modelling methods provides additional support to our RF results.

Moreover, our preliminary results from regional analyses (results not shown) show that climatic conditions of palsas and peat plateaus do not substantially differ between relatively continental areas in Canada and Western Siberia. Thus, it is possible that palsas and peat plateaus in Central and Eastern Siberia occupy similar climatic envelopes than those elsewhere in relatively continental areas.

The suitable climatic space according to our preliminary results from regional analysis (results not shown) and literature review falls between the following ranges: strictly TDD: 500–1500 and FDD 1500–4500, or more liberally TDD < 2000 and FDD < 5000 (see lines 168–172 (p. 7) and fig. 7 (p.18 in revised manuscript). We illustrated these borders of the suitable climate space for palsas and peat plateaus of Central and Eastern Siberia below (fig. R4). Figure R4 shows that the suitable climate space for studied landforms is limited in the region, even when using the liberal classification (blue line in fig. R4). From Hugelius et al. (2020) data and our binary predictions in the background, one can see that few permafrost peatlands exist in these estimated suitable climate spaces, and our models found suitable environments from many of these peatlands. Hence the extrapolations of the suitable environments for Central and Western Siberia region might not actually be as far from the truth than one could expect from the low number of observations in the region.

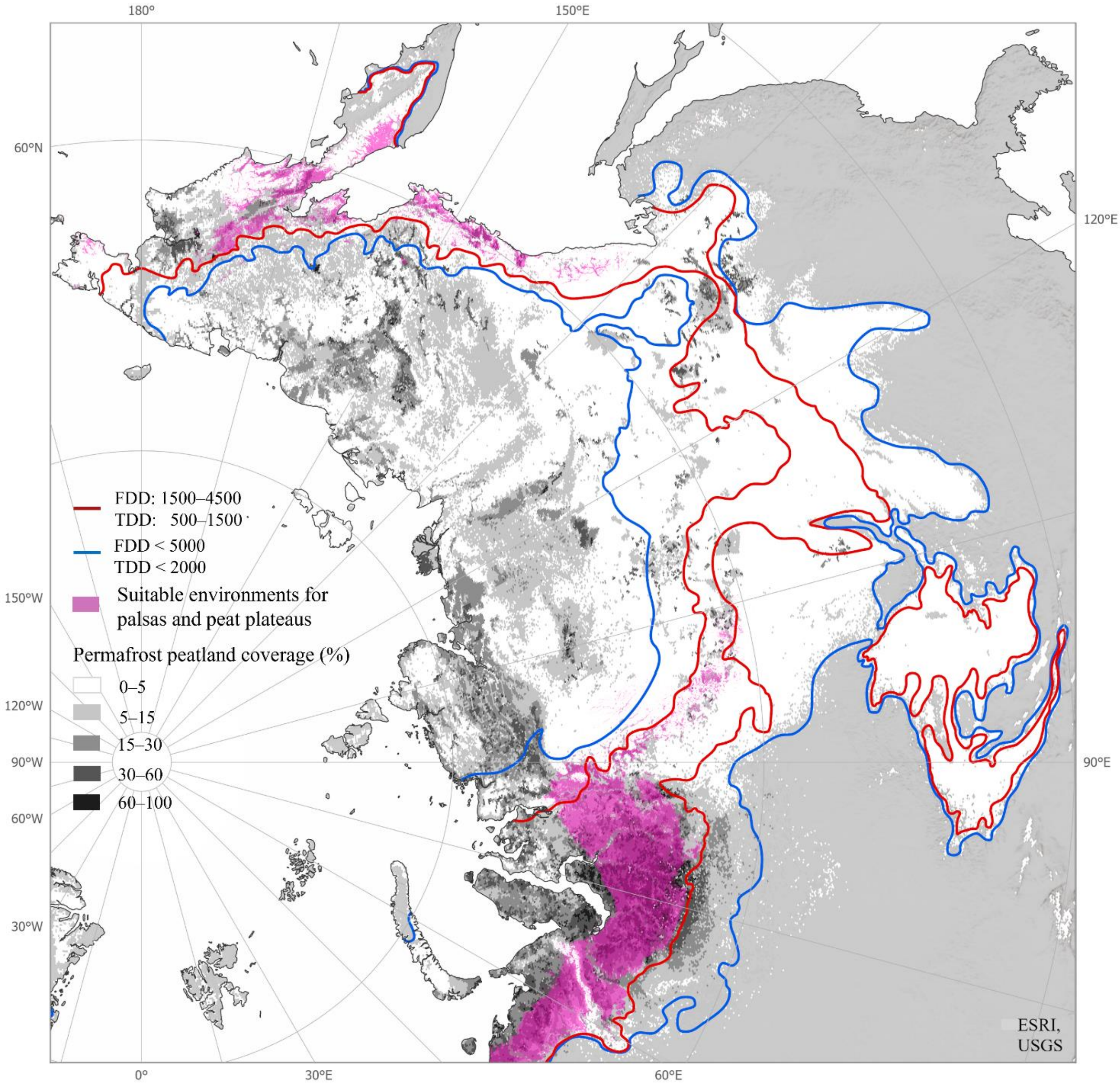


Figure R4: Suitable climate spaces (based on FDD and TDD) with two classifications are illustrated in red (strict interpretation) and blue (more liberal interpretation) lines. In the background suitable environmental spaces for palsas and peat plateaus (period 1950–2000) and permafrost peatland coverage (%) according to Hugelius et al. (2020). All datasets extracted for the permafrost region (Ran et al., 2022).

57: what about snow? Wind? Trees?

R19: As circumpolar datasets about the snow depth are not available in the used 30 arc sec resolution (at least to our knowledge), we used the Snowfall variable (precipitation sum for months with mean air temperature below 0 degrees Celsius) as an estimate of the snowpack. However, the most important reason to exclude snow, wind, and vegetation variables from our models was the exploration of climate change effects. These environmental factors can be assumed to change in the future, but we could not identify any suitable spatial projections to be used in the analyses. However, we acknowledge that wind and trees are important factors affecting the distribution of palsas and peat plateaus at local scale by controlling, for example, the snow depth.

We added a notion of these factors to the manuscript to the introduction (lines 59–60, p. 2) and discuss about their role in the discussion also (lines 493–497, p. 22).

65: why not some areas where palsa thaw is observed?

R20: We decided to compare our results to Olefeldt et al. (2016) dataset as it was available for the whole pan-Arctic area and because the distribution of thermokarst ponds can be used as a proxy for former distribution of permafrost landforms, including palsas (see e.g., Luoto and Seppälä, 2003). We acknowledge that thermokarst ponds are only an indicator for palsa degradation. Studies reporting degradation of palsas are usually conducted at local to regional scales, and the comparison between our 30 arc second resolution (ca. 1 km) predictions and studies reporting areal degradation for individual palsas, and peat plateaus (e.g., Borge et al., 2017; Mamet et al., 2017; Olvmo et al., 2020) would have been problematic. Olefeldt et al. (2016) dataset was the most suitable, consistently produced circumpolar data to compare our results with and use for the model evaluation.

84: appendix not found

R21: As mentioned earlier we apologize for the inconvenient placing of the Appendix A. Appendix A was moved to its proper place (after conclusions, starting from line 524, pp. 24–32).

90: Check Treat et al. 2016

R22: We thank for the useful reference, and we added citation to it to lines 37 (p. 2) and 461 (p. 21).

103: but this is the crucial distinction.

R23: Unfortunately, we could not identify the location for this comment because there seems to be no text in referred line 103 in the original manuscript.

Figure 1: coordinates for Kiruna leave me in a lake. Would be helpfult to see the traditional permafrost map from Brown also for reference.

R24: More accurate coordinates (68°28’36.0’’N, 20°55’06.0’’E) and IPA permafrost region by Brown et al. (1997) was added to the caption and figure (lines 118–121, p. 5; see below).

Revised figure 1:

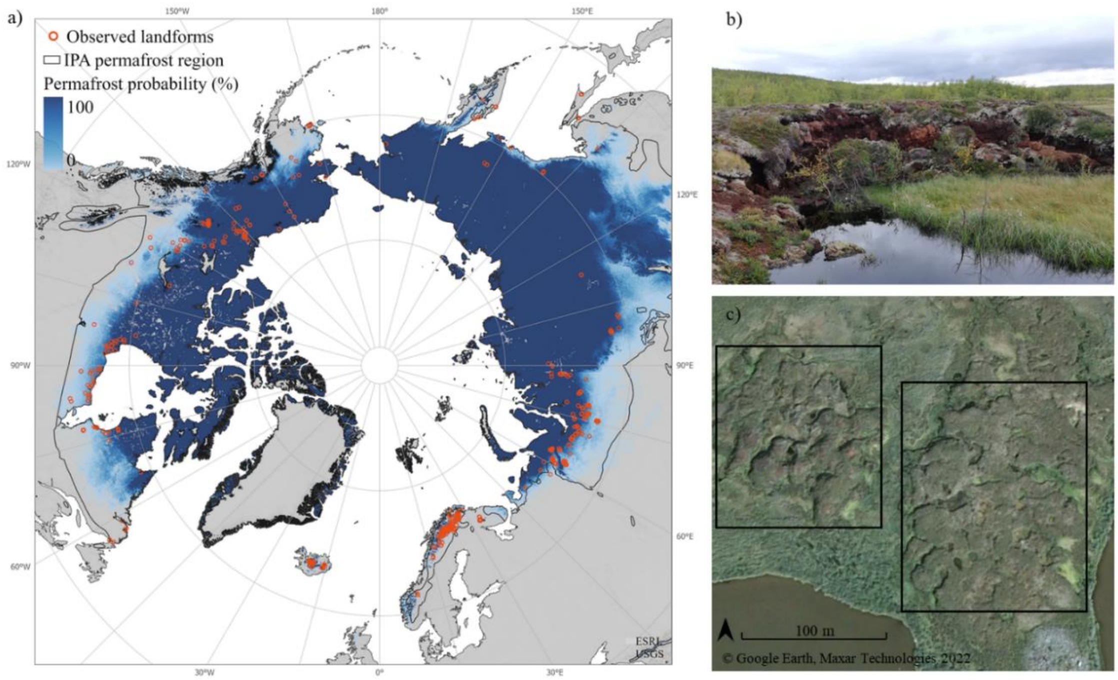


Figure 1: Distribution of the observed palsas and peat plateaus (N = 961) across the Northern Hemisphere,the probability of the permafrost occurrence (%, Ran et al., 2022) and International Permafrost Association (IPA) permafrost region (Brown et al., 1997) (a). A thawing palsa in Kilpisjärvi, Finland (b), and a satellite image of a palsa mire in Kiruna, Sweden (68°28’36.0’’N, 20°55’06.0’’E), groups of palsas have been framed with black lines (c).

110: this is all present day, good to acknowledge role of past climate and the limitations this presents.
R25: Dr. Treat brings up very important point here. We decided not to model the past suitable conditions because of multiple reasons, including difficulties in compilation of data describing the peat initiation for the entire pan-Arctic region at the resolution used. We made a compromise and decided to use climate variables describing the recent period (1950–2000) instead of present or past climate conditions from the period of landform initiation. We also wanted to avoid additional similarities with Fewster et al. (2020). More reasoning for our choice of climate data was provided earlier in this response letter (see reply no. R5).

We acknowledge the relict nature of many palsas and peat plateaus. More references related the role of past climate was added (to line 37, p. 2) to support this information as Dr. Treat suggested. We revised a paragraph in the section 2.2 to acknowledge this issue better and added relevant discussion also to the discussion section (lines 454–471) to address the limitation poses for our approach.

A revised paragraph in section 2.2. (lines 133–140, p. 6):
"All the environmental variables (hereafter variables) were computed separately for different time periods and RCP scenarios, using the WorldClim v1.4 data at 30 arc-second resolution (Hijmans et al., 2005). For these data, the baseline period is 1950–2000, which aligns well with the observations in our presence data. The use of recent climate period instead of the current one better acknowledges the possibility that the compiled landform observations are representing the conditions of past climate. For the climate change scenarios, we used the low emissions scenario RCP2.6, the moderate-emissions scenario RCP4.5 and the high-emissions scenario RCP8.5, and two future periods 2041–2060 and 2061–2080. Climate change projections included in the WorldClim v1.4 database (Hijmans et al., 2005) were derived from an ensemble of 18 global climate models (Taylor et al., 2012)."

136: why? what was the goal or motivation of this?
R26: The reasoning to the comparison with thermokarst data was added to lines 67–71 (p. 3) and 156–163 (p. 6). We revised the paragraph to clarify that we did not classify the thermokarst data as the classification was already done by Olefeldt et al. (2016).

Revised paragraph (lines 156–163, p. 6):
"We compared our predictions to a circumpolar thermokarst dataset by Olefeldt et al. (2016). Their prediction of thermokarst coverage is based on six environmental variables including the permafrost zonation, ground ice content, thickness of the sedimentary overburden, ecoregion, and ruggedness of the topography. These variables were not utilized in our study, and thus our analyses can be considered as independent. The dataset includes different types of thermokarst landscapes, and their areal coverages classified into five classes, ranging from none (0–1 %) to very high (60–100 %). We utilized wetland and lake thermokarst coverages as these types can be assumed to be present in degrading palsa mires (Luoto and Seppälä, 2003; Olefeldt et al., 2016). Regions predicted to become unsuitable for palsas and peat plateaus in future scenarios should have higher thermokarst coverage than persisting suitable environments."

Section 2.3: for all these paragraphs, WHY? What specifically was the purpose or goal of this analysis, what did you actually do? Where are the forward projections?
R27: Very important points. We added reasoning for each analysis step to clarify their purposes to the revised section 2.3. Also, a paragraph of the future predictions was included (lines 205–210, p. 8).

139: add citation for biomod2 package

R28: We added citations for biomod2 package (Thuiller et al., 2021) and R Core Team (lines 175–176, p. 7).

3.1 model evaluation of what? Why don't discuss suitable environments already? Where is the evaluation of the representativeness of the dataset? Or independent evalution? What about normalizing for areas? Also I've never heard of palsas in Iceland.

R29: The first sentence of the section 3.1 will be modified to make it clearer to the reader that we are referring here to the comparison of the used modelling methods.

Revised lines (237–238, p. 9):

"The presented results are based on the random forest (RF) models, which yielded the highest evaluation statistics among the used methods (see section 3.4 and supplementary material)."

The predictive performance of the models was evaluated against a semi-independent evaluation dataset of presence-absence observations that was randomly sampled from the full data before modelling. Moreover, we computed cross-validated evaluation statistics for the randomly sampled 30% of modelling data set aside for evaluation at each 100-modelling run. See additional comments on the model evaluation from the response concerning the section 3.4 below (reply no R32). As already mentioned, (please see reply no 9), added a figure 7 (line 372, p.18; here fig. R2) to provide an additional evaluation of the reliability of our predictions. The reasoning for the thermokarst comparison was also clarified (i.e., the thermokarst data were used to assess our future predictions) as mentioned earlier in reply no R10 (see lines 68–71, p. 3 and 156–163, p. 6).

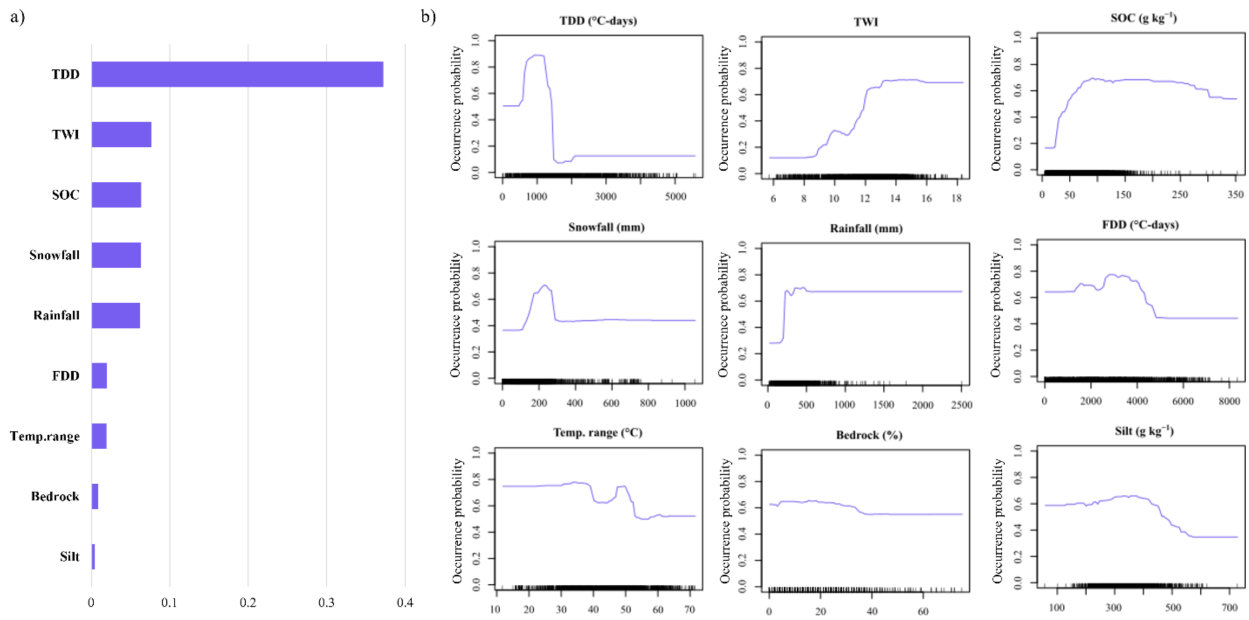
Palsas in Iceland have been documented by Saemundson et al. (2012), Ottósson et al. (2016), Emmert and Kneisel, (2021), for example.

Figure 2. The results looks really biased towards where there are samples.

R30: Please see the discussion above (reply no. R7 and R8).

Figure 3: y-axis labels

R31: y-axis labels were added to the figure 3 (see revised figure below).



Section 3.4 doesn't provide any real (independent) model evaluation, it only compares the different techniques used.

R32: The section 3.4 and figure 6 show that random forest (RF) had the highest evaluation scores and thus we focused on the results of RF models. However, the figure 6 also shows evaluation results for a separate evaluation dataset (solid whiskers), as discussed earlier in reply no. R10. Because we aimed to collect as presentative observational data as possible, it was not possible to utilize a fully independent datasets of landform occurrences for model evaluation. The spatial evaluation of the predictions was conducted by calculating the model agreement (see fig. S7 in supplementary materials): areas where multiple models predict suitable environments have higher possibility to be palsa and peat plateau environments. The lack of fully independent evaluation data was also compensated by adding the new comparison between our predictions and the peatland datasets (fig. R2; see above). These issues are discussed in a new paragraph (lines 478–491, p. 22).

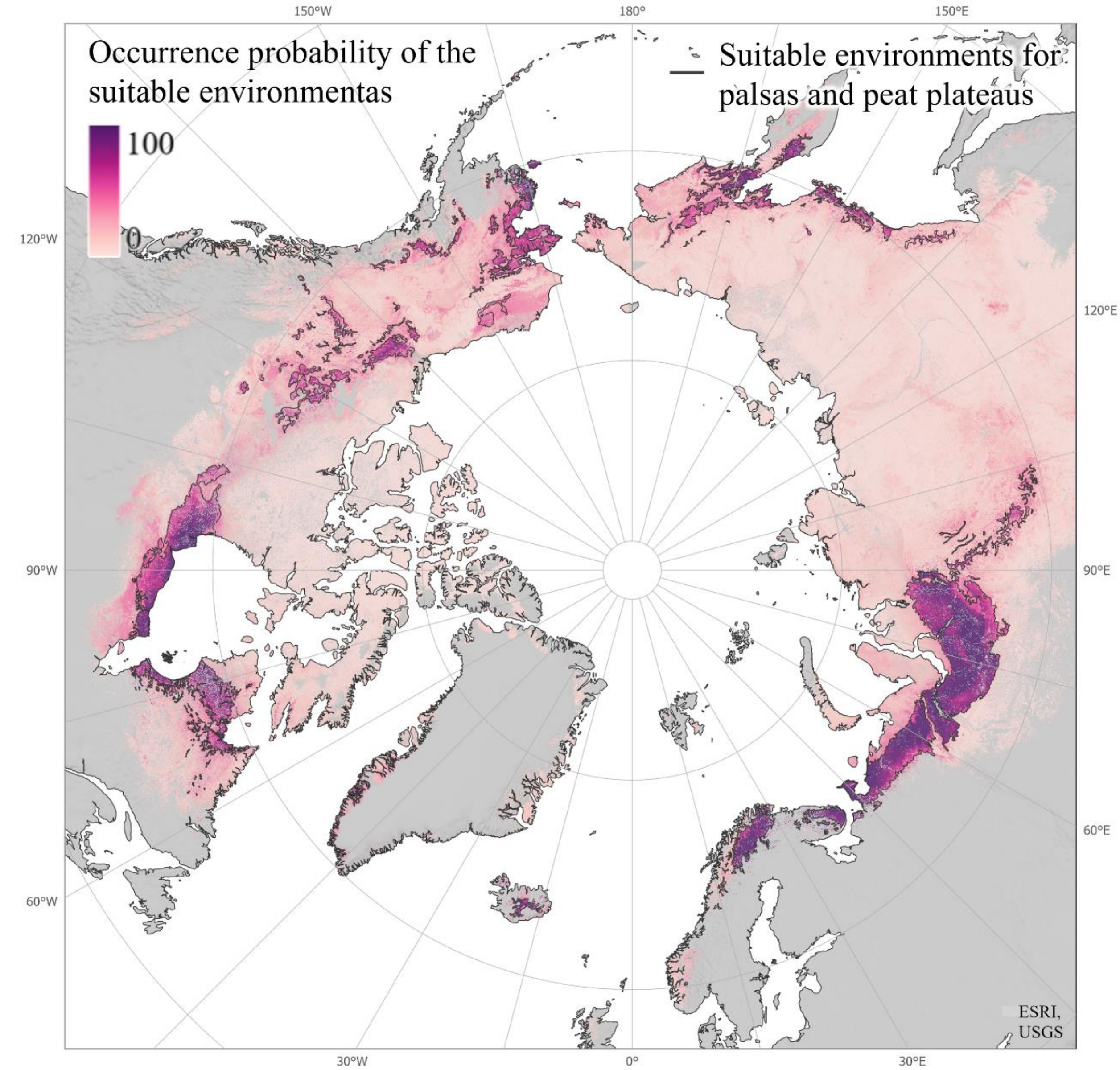
382: Yes, it is good that the model found palsas where the input data indicated there should be palsas. But it also found them where there is little evidence for palsa.

R33: Please see the discussion related to this issue above (e.g., reply no. R8).

As mentioned earlier, the landform occurrence probabilities shown in the Figure 2 might lead to subjective interpretations of the distribution of the suitable environments for palsas and peat plateaus. Thus, we classified the predictions to binary maps by using True Skill Statistic (TSS) cut-off values (provided in supplementary material Table S1). This binary classification of the suitable environments is illustrated in the new figure R2, and in figures 4 and 5. We added simplified outlines of the binary classification to the figure 2 (line 248, p. 10), to allow for an easier and more objective interpretation. The binary classification 'drops out' some of the controversial prediction areas (e.g., parts of the North Slope, Alaska). New figure (fig. R4) will be added to the supplementary materials to show the minimum, average, and maximum extents of the suitable environments based on the standard deviations of cut-off values from the 100 model iterations and the areal extents were added also to the revised table 1 (starting from line 279, p. 12)

Unfortunately, the observation data is limited in Central and Eastern Siberia because these regions are far less studied than other parts of the northern Hemisphere. Because of this lack of observations, we cannot provide more solid evidence for our predictions. However, our preliminary results from regional analyses (not shown here) do not indicate that palsas and peat plateaus in continental climates (such as those found in Siberia) would exist in remarkably different environmental conditions. Thus, our extrapolations can give useful insights to guide future's research in these regions. We modified our manuscript to acknowledge better that our predictions for this region are extrapolations to avoid misunderstandings of the presented results (as discussed earlier in reply no R1.)

Revised figure 2:



Data availability: The dataset should be provided with DOI not upon contact to author, especially since it is listed as Appendix A.

R34: Appendix A (a list of references used in the data compilation) was moved to its proper place and coordinates for our landform observations were included in the supplementary material, as mentioned earlier (in reply no R6).

References

Beilman, D. W., D. H. Vitt and L. A. Halsey (2001). "Localized permafrost Peatlands in Western Canada: Definition, distributions, and degradation." Arctic Antarctic and Alpine Research **33**(1): 70-77.

Camill, P. (2005). "Permafrost thaw accelerates in boreal peatlands during late-20th century climate warming." Climatic Change **68**(1-2): 135-152.

Camill, P. and J. S. Clark (1998). "Climate change disequilibrium of boreal permafrost peatlands caused by local processes." American Naturalist **151**(3): 207-222.

Fewster, R. E., Morris, P. J., Swindles, G. T., Gregoire, L. J., Ivanovic, R. F., Valdes, P. J., & Mullan, D. (2020). Drivers of Holocene palsa distribution in North America. *Quaternary Science Reviews*, *240*, 106337.

Fewster, R. E., Morris, P. J., Ivanovic, R. F., Swindles, G. T., Peregon, A. M., & Smith, C. J. (2022). Imminent loss of climate space for permafrost peatlands in Europe and Western Siberia. *Nature Climate Change*, *12*(4), 373-379.

Halsey, L. A., D. H. Vitt and S. C. Zoltai (1995). "Disequilibrium Response of Permafrost in Boreal Continental Western Canada to Climate-Change." Climatic Change **30**(1): 57-73.

Hugelius, G., J. Loisel, S. Chadburn, R. B. Jackson, M. Jones, G. MacDonald, M. Marushchak, D. Olefeldt, M. Packalen, M. B. Siewert, C. Treat, M. Turetsky, C. Voigt and Z. Yu (2020). "Large stocks of peatland carbon and nitrogen are vulnerable to permafrost thaw." Proceedings of the National Academy of Sciences **117**(34): 20438-20446.

Olefeldt, D., M. Hovemyr, M. A. Kuhn, D. Bastviken, T. J. Bohn, J. Connolly, P. Crill, E. S. Euskirchen, S. A. Finkelstein, H. Genet, G. Grosse, L. I. Harris, L. Heffernan, M. Helbig, G. Hugelius, R. Hutchins, S. Juutinen, M. J. Lara, A. Malhotra, K. Manies, A. D. McGuire, S. M. Natali, J. A. O'Donnell, F. J. W. Parmentier, A. Räsänen, C. Schädel, O. Sonnentag, M. Strack, S. E. Tank, C. Treat, R. K. Varner, T. Virtanen, R. K. Warren and J. D. Watts (2021). "The Boreal–Arctic Wetland and Lake Dataset (BAWLD)." Earth Syst. Sci. Data **13**(11): 5127-5149.

Tarnocai, C. (2006). "The effect of climate change on carbon in Canadian peatlands." Global and Planetary Change **53**(4): 222-232.

Tarnocai, C. and S. Zoltai (1988). Wetlands of Arctic Canada. Wetlands of Canada. N. W. W. Group. Ottawa, Sustainable Development Branch, Environment Canada**:** 28-53.

Treat, C. C., M. C. Jones, P. Camill, A. Gallego-Sala, M. Garneau, J. W. Harden, G. Hugelius, E. S. Klein, U. Kokfelt, P. Kuhry, J. Loisel, P. J. H. Mathijssen, J. A. O'Donnell, P. O. Oksanen, T. M. Ronkainen, A. B. K. Sannel, J. Talbot, C. Tarnocai and M. Väliranta (2016). "Effects of permafrost aggradation on peat properties as determined from a pan-Arctic synthesis of plant macrofossils." Journal of Geophysical Research: Biogeosciences **121**(1): 78-94.

Treat, Claire C; Jones, Miriam C; Camill, Philip; Gallego-Sala, Angela V; Garneau, Michelle; Harden, Jennifer W; Hugelius, Gustaf; Klein, Eric S; Kokfelt, Ulla; Kuhry, Peter; Loisel, Julie; Mathijssen, Paul J H; O'Donnell, Jonathan A; Oksanen, Pirita O; Ronkainen, Tiina M; Sannel, A

Britta K; Talbot, Julie; Tarnocai, Charles; Väliranta, Minna (2016): Synthesis dataset of physical and ecosystem properties from pan-arctic wetland sites using peat core analysis. PANGAEA, https://doi.org/10.1594/PANGAEA.863697,

Webster, K. L., J. S. Bhatti, D. K. Thompson, S. A. Nelson, C. H. Shaw, K. A. Bona, S. L. Hayne and W. A. Kurz (2018). "Spatially-integrated estimates of net ecosystem exchange and methane fluxes from Canadian peatlands." Carbon Balance and Management **13**(1): 16.

Zoltai, S. C., C. Tarnocai, G. F. Mills and H. Veldhuis (1988). Wetlands of Subarctic Canada. Wetlands of Canada. N. W. W. Group and C. C. o. E. L. Classification. Montreal, Polyscience Publication Inc.**:** 54-96.

Zoltai, S. C., R. M. Siltanen and J. D. Johnson (2000). A Wetland Data Base for the Western Boreal, Subarctic, and Arctic Regions of Canada. Edmonton, AB, Canada, Northern Forestry Centre, Canadian Forest Service**:** 30 pp.

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References cited in the response letter:

Aalto, J., Harrison, S., and Luoto, M.: Statistical modelling predicts almost complete loss of major periglacial processes in Northern Europe by 2100, Nat. Commun., 8, 1–8. https://doi.org/10.1038/s41467-017-00669-3, 2017.

Backe, S.: Kartering av Sveriges palsmyrar, Länsstyrelsen, Luleå, 72 pp., urn:nbn:se:naturvardsverket:diva-2318, 2014.

Borge, A. F., Westermann, S., Solheim, I., and Etzelmüller, B.: Strong degradation of palsas and peat plateaus in northern Norway during the last 60 years, The Cryosphere, 11, 1–16, https://doi.org/10.5194/tc-11-1-2017, 2017.

Brown, J., O. J. Ferrians, Jr., J. A. Heginbottom, and E. S. Melnikov, eds.: Circum-Arctic map of permafrost and ground-ice conditions. Washington, DC: U.S. Geological Survey in Cooperation with the Circum-Pacific Council for Energy and Mineral Resources. Circum-Pacific Map Series CP-45, scale 1:10,000,000, 1 sheet, 1997.

Emmert, A., and Kneisel, C.: Internal structure and palsa development at Orravatnsrústir palsa site (Central Iceland), investigated by means of integrated resistivily and ground-penetrating radar methods, Permafrost Periglac., 32, 503–519, https://doi.org/10.1002/ppp.2106, 2021.

Fewster, R. E., Morris, P. J., Swindles, G. T., Gregoire, L. J., Ivanovic, R. F., Valdes, P. J., and Mullan, D.: Drivers of Holocene palsa distribution in North America, Quaternary Sci. Rev., 240, 106337, https://doi.org/10.1016/j.quascirev.2020.106337, 2020.

Fewster, R. E., Morris, P. J., Ivanovic, R. F., Swindles, G. T., Peregon, A. M., and Smith, C. J.: Imminent loss of climate space for permafrost peatlands in Europe and Western Siberia, Nat. Clim. Change, 1–7. https://doi.org/10.1038/s41558-022-01296-7, 2022.

French, H. M.: The periglacial Environment, 4th edition, Wiley-Blackwell, Hoboken, 515 pp. LCCN 2017027903, 2017.

Fronzek, S., Luoto, M., and Carter, T.: Potential effect of climate change on the distribution of palsa mires in subarctic Fennoscandia, Clim. Res., 32, 1–12, https://doi.org/10.3354/cr032001, 2006.

Halsey, L. A., Vitt, D. H., and Zoltai, S. C.: Disequilibrium response of permafrost in boreal continental western Canada to climate-change, Clim. Change, 30, 57–73, https://doi.org/10.1007/BF01093225, 1995.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., and Jarvis, A.: Very high-resolution interpolated climate surfaces for global land areas, Int. J. Climatol., 25, 1965–1978, https://doi.org/10.1002/joc.1276, 2005.

Hugelius, G., Loisel, J., Chadburn, S., Jackson, R. B., Jones, M., MacDonald, G., Marushchak, M., Olefeldt, D., Packalen, M., Siewert, M. B., Treat, C., Turetsky, M., Voight, C. and Yu, Z.: Large stocks of peatland carbon and nitrogen are vulnerable to permafrost thaw, P. Natl. A. Sci. USA., 117, 20438–20446, https://doi.org/10.1073/pnas.1916387117, 2020.

Karjalainen, O., Luoto, M., Aalto, J., Etzelmüller, B., Grosse, G., Jones, B. M., Lilleøren, K., S. and Hjort, J.: High potential for loss of permafrost landforms in a changing climate, Environ. Res. Lett., 15, 104065. https://doi.org/10.1088/1748-9326/abafd5, 2020.

Luoto, M., and Seppälä, M.: Thermokarst ponds as indicators of the former distribution of palsas in Finnish Lapland, Permafrost Periglac., 14, 19–2, https://doi.org/10.1002/PPP.441, 2003.

Mamet, S. D., Chun, K. P., Kershaw, G. G. L., Loranty, M. M., and Peter Kershaw, G.: Recent Increases in Permafrost Thaw Rates and Areal Loss of Palsas in the Western Northwest Territories, Canada, Permafrost Periglac., 28, 619–633, https://doi.org/10.1002/ppp.1951, 2017.

Metsähallitus: Valtion suojelualueiden biotooppikuviot (Finnish dataset of biotopes), Metsähallitus, luontopalvelut, e3aa7b2a-e6e2-45dc-a29a-b64bcf2aba9f, 2019.

Olefeldt, D., Goswami, S., Grosse, G., Hayes, D., Hugelius, G., Kuhry, P., Mcguire, A. D., Romanovsky, V. E., Sannel, A. B. K., Schuur, E. A. G., and Turetsky, M. R.: Circumpolar distribution and carbon storage of thermokarst landscapes, Nat. Commun., 7, 1–11, https://doi.org/10.1038/ncomms13043, 2016.

Olefeldt, D., Hovemyr, M., McKenzie, A. K., Bastviken, D., Bohn, T. J., Connolly, J., Crill, P., Euskirchen, E. S., Finkelstein, S. A., Genet, H., Grosse, G., Harris, L. I., Heffernan, L., Helbig, M., Hugelius, G., Hutchins, R., Juutinen, S., Lara, M. J., Malhotra, A., Manies, K., McGuire., D. A., Natali, S. M., O'Donnell, J. A., Parmentier, F.-J. W., Räsänen, A., Schädel, C., Sonnentag, O., Strack, M., Tank, S. E, Treat, C., Varner, R. K., Virtanen, T., Warren, R. K., and Watts, J. D.: The Boreal-Arctic Wetland and Lake Dataset (BAWLD), Earth Syst. Sci. Data, 13, 5127–5149, https://doi.org/10.5194/essd-13-5127-2021, 2021.

Olvmo, M., Holmer, B., Thorsson, S., Reese, H., and Lindberg, F.: Sub-arctic palsa degradation and the role of climatic drivers in the largest coherent palsa mire complex in Sweden (Vissátvuopmi), 1955–2016, Sci. Rep.–UK., 10, 8937, https://doi.org/10.1038/s41598-020-65719-1, 2020.

Ottósson, J. G., Sveinsdóttir, A., and Harðardóttir, M.: Vistgerðirá Íslandi, Fjölrit Náttúrufræðistofnunar 54. Garðabær: Náttúrufræðistofnun Íslands (Habitat types in Iceland, Icelandic Institute of Natural History), ISBN 978-9979-9335-8-8, 2016.

Poggio, L., de Sousa, L. M., Batjes, N. H., Heuvelink, G. B. M., Kempen, B., Ribeiro, E., and Rossiter, D.: SoilGrids 2.0: Producing soil information for the globe with quantified spatial uncertainty, Soil, 7, 217–240, https://doi.org/10.5194/SOIL-7-217-2021, 2021.

R Core Team: R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/, 2022.

Ran, Y., Li, X., Cheng, G., Che, J., Aalto, J., Karjalainen, O., Hjort, J., Luoto, M., Jin, H., Obu, J., Hori, M., Yu, Q., and Chang, X.: New high-resolution estimates of the permafrost thermal state and hydrothermal conditions over the Northern Hemisphere, Earth Syst. Sci. Data, 14, 865–884, https://doi.org/10.5194/ESSD-14-865-2022, 2022.

Ruuhijärvi, R., Salminen, P., and Tuominen, S.: Distribution range, morphological types, and state of palsa mires in Finland in the 2010s, Suo, 73, 1–32, ISSN 0039-5471, 2022.

Saemundsson, T., Arnalds, O., Kneisel, C., Jonsson, H. P., and Decaulne, A.: The Orravatnsrustir palsa site in Central Iceland-Palsas in an aeolian sedimentation environment, Geomorphology, 167–168, 13–20, https://doi.org/10.1016/j.geomorph.2012.03.014, 2012.

Seppälä, M.: Palsas and Related Forms, in: Advances in periglacial geomorphology, edited by: Clark, M. J., John Wiley & Sons, Ltd, Chichester, 247–278, IBSN 0 471 90981 5, 1988.

Seppälä, M.: Synthesis of studies of palsa formation underlining the importance of local environmental and physical characteristics, Quaternary Res., 75, 366–370, https://doi.org/10.1016/j.yqres.2010.09.007, 2011.
Tam, A., Gough, W. A., Kowal, S., and Xie, C. (2014). The Fate of Hudson Bay Lowlands Palsas in a Changing Climate, Arct., Antarct. Alp. Res., 46, 114–120, https://doi.org/10.1657/1938-4246-46.1.114, 2014.
Thuiller, W., Georges, D., Gueguen,M., Engler, R., Breiner, F.: Biomod2: Ensemble Platform for Species Distribution Modelling. CRAN, https://cran.r-project.org/web/packages/biomod2/biomod2.pdf, 2021.
Treat, C. C., Jones, M. C, Camill, P., Gallego-Sala, A. V, Garneau, M., Harden, J. W., Hugelius, G., Klein, E. S., Kokfelt, U., Kuhry, P., Loisel, J., Mathijssen, P. J. H., O'Donnell, J. A., Oksanen, P. O., Ronkainen, T. M., Sannel, A. B. K., Talbot, J., Tarnocai, C., Väliranta, M.: Synthesis dataset of physical and ecosystem properties from pan-arctic wetland sites using peat core analysis. PANGAEA, https://doi.org/10.1594/PANGAEA.863697, 2016a.
Treat, C. C., Jones, M. C., Camill, A., Gallego-Sala, A., Garneau, M., Harden, J. W., Hugelius, G., Klein, E. S., Kokfelt, U., Kuhry, P., Loisel, J., Mathijissen, P. J. H., O’Donnell, J. A., Oksanen, P. O., Ronkainen, T. M., Sannel, A. B. K., Talbot, J., Tarnocai, C., and Väliranta, M.: Effects of permafrost aggradation on peat properties as determined from a pan.Arctic synthesis of plant macrofossils, J. Geophys. Res. Biogeo.sci 121, 78–94, https://doi.org/10.1002/2015JG003061, 2016b.
Vorren, K.-D.: The first permafrost cycle in Faerdesmyra, Norsk. Geogr. Tidsskr, 71, 114–121, https://doi.org/10.1080/00291951.2017.1316309, 2017.
Xu, J., Morris, P. J., Liu, J., and Holden, J.: PEATMAP: Refining estimates of global peatland distribution based on meta-analysis, CATENA, 160,134–140, https://doi.org/10.1016/j.catena.2017.09.010, 2018.
Zoltai, S. C., R. M. Siltanen & J. D. Johnson: A wetland environmental data base, NOR-X Report, Northern Forestry Centre, Canadian Forest Service, Edmonton, Alberta, Canda, ISSN 0704-7673, 2000.

List of relevant changes:

- Manuscript modified so that it is clear for the reader that our predictions for Central and Eastern Siberia are extrapolations of models fitted elsewhere. Discussion added. (e.g., lines 78–81, p. 3; 203–204, p. 8; 403–404, p. 19; 487–488, p. 22).
- New figure (fig. 7, p. 18) and comparison with four peatland datasets were added to the revised manuscript. Results and discussion related to the topic was added (lines 365–371, p. 17; 400–414, pp. 19–20).
- More reasoning for our methodological choices was added to the section 2.3.
- We calculated standard deviations for the areal extent of the suitable environmental spaces for palsas and peat plateaus. These are presented in revised table 1 (starting from line 279, p. 12) and visually on maps in the revised supplementary material (fig. S8).
- New paragraph of the future predictions was added (lines 205–210, p. 8).
- New discussion paragraph of the uncertainties and evaluation methods was added (lines 479–492, p. 22).
- We added discussion related to the role of past climate (lines 461–469, p. 21)
- More reasoning for the comparison with thermokarst data (Olefeldt et al., 2016) was added (lines 67–71, p. 3;156–163 (p. 6).
- Appendix A was moved to its proper place (pp. 24–32).
- Coordinates of our landform observations were added to the supplementary materials.

Line numbers in referee comments (in blue) refer to the original manuscript, whereas line numbers in our responses (in black), refer to the revised clean manuscript.

RC2, Anonymous referee: https://tc.copernicus.org/preprints/tc-2022-135#RC2

The manuscript "Environmental spaces for palsas and peat plateaus are disappearing at a circumpolar scale" by Könönen et al. presents statistical modeling of the future distribution of the palsa/peat plateau landform, with the key result that the largest part of todays palsas/peat plateaus will move outside the suitable climate space for some of the future scenarios considered. The study is well-designed and well-written, so I recommend it for publication after revisions.
R1: We thank the reviewer for these positive and encouraging comments. Below we address the raised concerns in detail.

-Introduction: the authors should make an attempt to clarify the terms "peat plateau" and "palsa", or state that they made no clear distinction between the two (since there are many transitional types, for example). In some parts of the text, it appears that the authors do distinguish between them. They for example only refer to palsas in Scandinavia (l.48, and actually continue only using palsa to l. 65), but there are many plateau-like structures in Scandinavia, which published studies have referred to as peat plateaus. They also cite studies claiming that "peat plateaus are only 1m high" (l. 30), but there are much higher plateau-like features in many peatlands with permafrost.
R2: Thank you for these important points. We will add two new sentences to clarify that these two landforms are not clearly distinguishable from each other (lines 32–34, p. 2):
"Palsas and peat plateaus are not clearly distinguishable from each other and many transitional types between these landforms are found. Peat plateaus can be considered as a morphological class of palsas, so-called palsa plateaus (e.g., Åhman, 1977; Seppälä, 1988).".

We will modify referred lines and the whole manuscript so that both landforms are discussed at the same time without the distinction. We will also add word 'usually' when describing the height of peat plateaus (line 31, p. 2) to acknowledge that higher peat plateaus exist.

-L. 84: same here, how do the authors distinguish a "true" palsa?
R3: The term "true palsa" here refers to a peat hummock with a frozen core. Studies and observations of lithalsas (so-called mineral palsas) were excluded from the data as they don't have the necessary peat cover on them, or the peat cover is very thin. The distinction was based on the description of the studied landforms in the utilized literature. For example, if palsas were referred to as lithalsas or mineral palsas they were not included. We modified the lines 95–98 (p. 4) to make this distinction clearer for the reader.

-L. 87: were high enough resolution images available on Google Earth for all of the sites?
R4: We used both Google Earth and satellite images in ESRI's ArcGIS Pro to verify the landform observations as stated in the manuscript (as mentioned on lines 100–102, p. 4). For some sites better resolution images were available in ArcGIS Pro and vice versa. The resolution of the images between regions varied substantially and some observations had to be left out because of inadequate image resolution.

-L. 123: These data sets can have a poor quality, especially at the resolution needed for the study setup. Please comment on this already in the Methods.
R5: We revised the text related to the quality issues as proposed.

The revised paragraph (starting on line 141, p. 6):
"Variables to describe the surficial soil conditions (≤ 2 m depth) were obtained from SoilGrids250m 2.0 database (Poggio et al., 2021). Noteworthy, the SoilGrids data layers have been produced using a relatively small amount of data from some permafrost regions, especially Central Siberia and High-Arctic Canada, which may affect the accuracy of data in these regions, especially at finer resolution. SoilGrids were used as alternative soil data were not available in the used (30 arc sec) resolution, and we considered it necessary to account for soil properties, especially soil organic carbon (SOC), which are essential to palsa and peat plateau formation. Here, the SoilGrid variables at the spatial resolution of 7.5 arc-second (~250 meters) were aggregated to the 30 arc-second resolution using bilinear interpolation in ArcGIS Pro. Owing to the lack of high-resolution peat thickness data we used SOC, (g kg-1) as a proxy for the of peat layer. In addition to SOC, we used silt content (Silt, g kg-1) and probability of bedrock within two meters from the ground surface (Bedrock, %, Shangguan et al., 2017) to describe the texture and thickness of the soil layer. Topographic Wetness Index (TWI) (Böhner and Selige, 2006) was calculated using the Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010) (Danielson and Gesch, 2011) to characterize the accumulation potential of ground moisture. The grid cell-wise values from each variable were extracted for the presence/absence observations. In case no value from an environmental variable was available at presence or absence location (109 cases), the value was extracted from the neighboring grid cell. If none of the neighboring grid cells had the missing value, the observation was removed from the dataset."

-Eq. 1: shuffled
R6: Corrected (line 223, p. 8).

-L. 188: it is easier to read if the authors spell out Random Forest (RF) once more at the beginning of the Results section.
R7: We spelled out Random Forest once more as requested to line 236 (p. 9).

-Fig. 3: spell out the abbreviations in the figure caption.
R8: Abbreviations was spelled out in the figure caption (lines 267–270, p. 11).

-L. 237: MAJOR COMMENT: Maybe I have overlooked it, but the authors should clarify if they only consider areas that are in the suitable palsa space now AND in the future as "remaining areas", or if they also count areas that are not suitable now (e.g. too cold in summer), but will become suitable in the future. As shown e.g. in the works of Seppälä, one needs permafrost-free conditions in the vicinity of emerging palsas for this process to work. So areas which today are too cold for palsas to exist may not develop palsa landforms for a long time (or never), even if they move to the suitable space (for example continuous permafrost first needs to thaw, etc.) On the other hand, areas with palsas today will be preserved if they still fall in the suitable space in the future. I think it is worth to make this distinction and possibly present the numbers for both cases. The wording in this section is incoherent, the authors use "remain" and "persist" in some cases, and "could be found" in others.
R9: We thank the reviewer for this important remark. In the caption of figure 4 it was mentioned that our future predictions were extracted for the extent of the suitable environments for the period 1950–2000. So, we did not present any 'new' palsa and peat plateau environments that might develop as there are several uncertainties, as the reviewer points out. As mentioned by the reviewer the development of palsas (and peat plateaus) might require permafrost-free conditions nearby the emerging palsas before the landforms can start to develop. In addition to this, sufficient peat layer is also needed for palsas and peat plateaus to form. Peat accumulation is a slow process and affected also by the climate change. For these reasons we did not consider it plausible that many new suitable environments could form, at least during the 21st century.

To clarify our decision to the reader we added a new sentence to lines 208–210 (p. 8):
"Predictions were extracted to the current extent of the suitable environments because we did not consider it temporally plausible for new palsas and peat plateaus to develop in the region of continuous permafrost during the 21st century."

We modified our wording to be more coherent by using only the word 'persist' as suggested.

-Sect. 3.3 The comparison with the thermokarst map is the weakest part of the study, e.g. it is unclear to what extent some of the data sets used by Olefeld et al. may have been similar to the data sets used for this palsa mapping. Furthermore, it is unclear if one should expect a close match or not, given the methods used by Olefeld (i.e. were the specific thermokarst conditions of palsas/peat plateaus accounted for in this work?). I leave it to the authors to decide, but I am not learning anything from this comparison, it more dilutes the very nice results from the previous section with a poorly motivated add-on.
R10: The purpose of the comparison was to assess the consistency of our future predictions. Palsas and peat plateaus form thermokarst ponds when ice-rich permafrost thaws (e.g., Seppälä, 2011). Consequently, regions with high thermokarst coverage can be assumed to indicate degradation of palsas and peat plateaus. Regions predicted to become unsuitable for palsas and peat plateaus in future scenarios should have higher thermokarst coverage than persisting suitable environments.

We decided to include the comparison in our study, but we clarified our motivation for it in the revised manuscript (lines 67–70, p. 3).

-L. 308: Extrapolate instead of present?
R11: We will use the suggested wording. The whole manuscript will be modified so that it is clearer for the reader that our results (especially for Central and Eastern Siberia) are extrapolations of models calibrated for Northern Europe, Western Siberia, and North America.

-L. 360: MAJOR COMMENT: this is an extremely important point that needs to be discussed in much more detail. Some of the studies cited, e.g Borge, provide indications that peat plateaus were already degrading more than 50 years ago, so they may have left the suitable climate space already after the end of the Little Ice Age (or in the 1990s, when exactly is unclear and certainly depends on the exact location), but the degradation is slow so that it takes decades or even centuries to complete. However, these areas were still used by the authors for training their model. With the simple analysis and no means of telling which palsa areas are stable and which are degrading already now, I don't think that this can be taken into account, but it is a limitation that should be stated clearly.
R12: We thank the reviewer for this important comment. We agree that there is a need to address this point in the revised manuscript. As the reviewer mentioned there are no simple ways to take this point of view into account in our analysis. For example, we did not have comprehensive information on the 'stage' of palsas (stable/degrading) and had no basis to remove just certain observations. The best that we were able to do here was to use 'a recent' climate period (1950–2000) instead of a current one (e.g., 1991–2020). The recent period presents colder climate than our current climatic conditions and thus resembles better the conditions of the period of palsa/peat plateau formation. We added notions and discussion related to this topic to lines 134–137 (p. 6) and 466–468 (p. 21).

Furthermore, given this complexity, I strongly disagree with the statement "support the rapid degradation of the landforms." First, with rates of 1% per year, it will take longer than the 2080 timeframe considered by the authors for the palsas/peat plateaus to actually disappear, in any case several decades. Second, it is very likely that palsas degrading rapidly already now, e.g. in the ones in Scandinavia, will indeed disappear until 2080, but palsas in areas that are still largely stable today might only be pushed just outside the suitable climate envelope and only then start to degrade slowly (similar to the ones in Scandinavia after the LIA). So we might expect palsas and peat plateaus to exist there much longer than 2080, although they are outside the suitable climate envelope.
R13: This is an important point. We revised the paragraph and added discussion related to this issue as mentioned above (in reply no. R12).

I very much like that the authors use the wording "inside/outside the suitable climate envelope/environmental space" throughout the manuscript and do not refer to their study as a model for palsa degradation. But it is important to clarify and discuss this relationship in much more detail, so this section of the discussion should be extended. In particular, the authors should point out that not all palsas inside the suitable climate envelope are equal, but palsas on the "warm side" of the envelope likely degrade earlier and more rapidly, while the ones on the "cold side" might persist for many more decades
R14: We are glad to hear that the reviewer shared our vision of the best terminology for our predictions. To make this distinction clearer for the readers also, added a short discussion about the differences between degradation of palsa and peat plateaus and the changes in suitable environments (lines 454–457, p. 21).

As the reviewer pointed out, all palsas and peat plateaus will not degrade at the same pace. More likely palsas in equilibrium with the current climate will persist longer (see Tam et al., 2014) than those in imbalance with it (e.g., Olvmo et al., 2020). We incorporated this discussion related to these "warm" and "cold" palsas and peat plateaus to the discussion mentioned above (lines 454–457, p. 21).

References used in the response letter

Åhman, R.: Palsar i Nordnorge: En studie av palsars morfologi, utbredning och klimatiska förutsättningar i Finnmarks och Troms fylke, Royal University of Lund, Department of Geography, 165 pp, 1977.
Luoto, M., and Seppälä, M.: Thermokarst ponds as indicators of the former distribution of palsas in Finnish Lapland, Permafrost Periglac., 14, 19–2, https://doi.org/10.1002/PPP.441, 2003.
Olefeldt, D., Goswami, S., Grosse, G., Hayes, D., Hugelius, G., Kuhry, P., Mcguire, A. D., Romanovsky, V. E., Sannel, A. B. K., Schuur, E. A. G., and Turetsky, M. R.: Circumpolar distribution and carbon storage of thermokarst landscapes, Nat. Commun., 7, 1–11, https://doi.org/10.1038/ncomms13043, 2016.
Olvmo, M., Holmer, B., Thorsson, S., Reese, H., and Lindberg, F.: Sub-arctic palsa degradation and the role of climatic drivers in the largest coherent palsa mire complex in Sweden (Vissátvuopmi), 1955–2016, Sci. Rep.–UK., 10, 8937, https://doi.org/10.1038/s41598-020-65719-1, 2020.
Seppälä, M.: Palsas and Related Forms, in: Advances in periglacial geomorphology, edited by: Clark, M. J., John Wiley & Sons, Ltd, Chichester, 247–278, IBSN 0 471 90981 5, 1988.

Seppälä, M.: Synthesis of studies of palsa formation underlining the importance of local environmental and physical characteristics, Quaternary Res., 75, 366–370, https://doi.org/10.1016/j.yqres.2010.09.007, 2011.
Tam, A., Gough, W. A., Kowal, S., and Xie, C. (2014). The Fate of Hudson Bay Lowlands Palsas in a Changing Climate, Arct., Antarct. Alp. Res., 46, 114–120, https://doi.org/10.1657/1938-4246-46.1.114, 2014.

List of relevant changes:

- We clarified that we are not making distinction between palsas and peat plateaus (line 32–34, p. 2).
- Meaning of ‘true palsa’ was clarified (p. 95–98, p. 4).
- Notion of the quality issues in the soil data was added (142–144, p. 6)
- We clarified our decision not to model ‘new’ suitable environments for palsas and peat plateaus (lines 208–209, p. 8).
- More reasoning for the comparison with thermokarst data (Olefeldt et al., 2016) was added (lines 67–71, p. 3; 156–163, p. 6).
- We added discussion related to the role of past climate (lines 452–469, p. 21), including the notion that not all palsas and peat plateaus are degrading at the same pace.

Line numbers in referee comments (in blue) refer to the original manuscript, whereas line numbers in our responses (in black), refer to the revised clean manuscript.

CC1, Paul J. Morris: https://doi.org/10.5194/tc-2022-135-CC1

General remarks

I enjoyed reading this interesting manuscript by Könönen et al., which seeks to fit bioclimatic models to permafrost peatland landforms, and then project those models into the future under two of the four RCP scenarios to examine shrinking climate spaces. The findings agree with other recent studies that strong climate migiation may retain some areas that are climatically suitable for permafrost peatlands by the end of the century, while the failure of climate change mitigation will lead to an almost-complete loss of suitable climate space.
R1: We are pleased to hear that Dr. Morris enjoyed reading our manuscript. Please note that we address all his comments below.

The study is strikingly similar to a paper that my group published earlier this year in Nature Climate Change (Fewster et al., 2022), to the point that much of the method and some of the conclusions are all but identical. Given the timing of the two articles, it appears that the two groups have been working on similar studies simultaneously. The timing is of course inconvenient for the group that publishes second, who find the novelty of their study reduced. Comparisons between the two studies are inevitable.
R2: Yes, it was very unfortunate that two research groups were studying the same theme with comparable methods, without knowing about each other's work. A great chance for collaboration was missed. Even though there are similarities between our data collection and methodology used, there are also differences beyond those mentioned in Morris' comment below. Fewster et al. (2022) used one-versus-all binary logistic regression, whereas we used four different modelling methods generalized linear model (GLM), generalized additive model (GAM), generalized boosting model (GBM) and random forest (RF) and their ensemble to examine potentially complex non-linear relationships between palsa/peat plateau occurrence and environmental variables, and interactions among these variables. Our results are based on 100 iterations which enables prediction uncertainty estimation, and we evaluated our models not only with the cross-validation but also with a separate evaluation data, which was set aside before the model calibration. But like Dr. Morris comments the comparisons between our studies are inevitable, which is why we reflect our results to those of Fewster et al. (2020, 2022).

I am sympethetic to this potentially awkward situation, and I believe there is certainly room in the literature for this new study.In their favour, Könönen et al. have a larger spatial domain than ours, a much finer grid resultion, and a more detailed representation of soil organic carbon as a continuous variable rather than our simple binary peat presence/absence. All of these things add value and novelty to the current study. On the other hand, Könönen et al. omitted RCP2.6, and therefore don't provide an optimistic, "best case" future scenario; and the large increase in spatial domain comprises extremely data-poor regions, leading me to question the validity of the findings there.
R3: We appreciate Dr. Morris' sympathy and encouragement for our study. We were aware of this awkwardness of our timing. However, we considered that including the entire circumpolar permafrost region to the analyses gives important new insights to the field of study, even though the approach has own challenges. Morris made good suggestions in his community comment and our responses (i.e., incorporation of RCP2.6 scenario) appear later in this response letter.

Substantive issues

My main concern is how far the authors have had to extrapolate from extremely sparse observataional data in central and eastern Siberia. This is particularly evident in Fig. 1a, which shows that there are about 20 observations across the whole of this huge area, despite the widespread distribution of modern permafrost, and plenty of peat there too. It is difficult to believe that tehre are so few palsas and plateaus there, and the authors acknowledge later on that more observational work is needed in these areas. However, the consequence for the current study is that the vast majority of observations are in western Siberia, Europe, and North America, meaning that the statistical modelling is in effect a hemispheric extrapolation of a model fitted to specific locations. The paucity of observations in central and eastern Siberia is the main reason we omitted these regions from our own study. It is quite possible that palsas/plateaus in C/E Siberia occupy different climatic envelopes than those elsewhere, but without observational data we can't tell. As stated above, I am sympathetic to the fact that our two groups appear to have been working on similar studies at the same time, and without central and eastern Siberia, the current study loses much of its novelty. Therefore, I recommend that the current authors make it clear early on (in their aims and/or methodological summary) that the modelling in central and eastern Siberia is an extrapolation from models fitted to N America, Europe, and W Siberia; and qualify their findings throughout accordingly
R4: We appreciate the helpful suggestion. The extrapolation of the models was a concern for us also. We did the suggested and much needed modifications throughout the manuscript to clarify that our results for Central and Eastern Siberia are extrapolations from models fitted to other parts of our research area (see e.g., lines 78–81, p. 3; 203–204, p. 8; 403–404, p. 19; 487–488, p. 22).

Moreover, we would like to make a note on the comment: ‘It is quite possible that palsas/plateaus in C/E Siberia occupy different climatic envelopes than those elsewhere, but without observational data we can't tell.’ We agree on this because there are not enough data to test this hypothesis. On the other hand, preliminary results from regional analyses (results not shown) show that climatic conditions of palsas and peat plateaus do not substantially differ between relatively continental areas in Canada and Western Siberia. Obviously, colder climates are found in Siberia, but no palsa or peat plateau observations are available from these regions. The possible absence of palsas and peat plateaus therein could be due to the continuous extent of permafrost that favors the development of other periglacial landforms, such as ice-wedge polygons and pingos (French, 2017), or thinner peat cover (Seppälä, 1988, 2011; Hugelius et al., 2020).

We added a new figure to the manuscript (fig. 7 on line 372, p.18; here fig. R1) comparing our binary predictions for the period 1950–2000 with different peatland datasets. According to these comparisons and the used peatland datasets, there are not many suitable peatlands in Central and Eastern Siberia. The lack of peatlands within the suitable climate space (fig. R2) indicates that our sparse observational data might not actually underestimate the occurrence of palsas and peat plateaus in the region as much as one could expect. Along the new figure, discussion related to this issue will be added to the manuscript to the result and discussion sections (see lines 365–371, p. 17; 399–413, pp. 19–20).

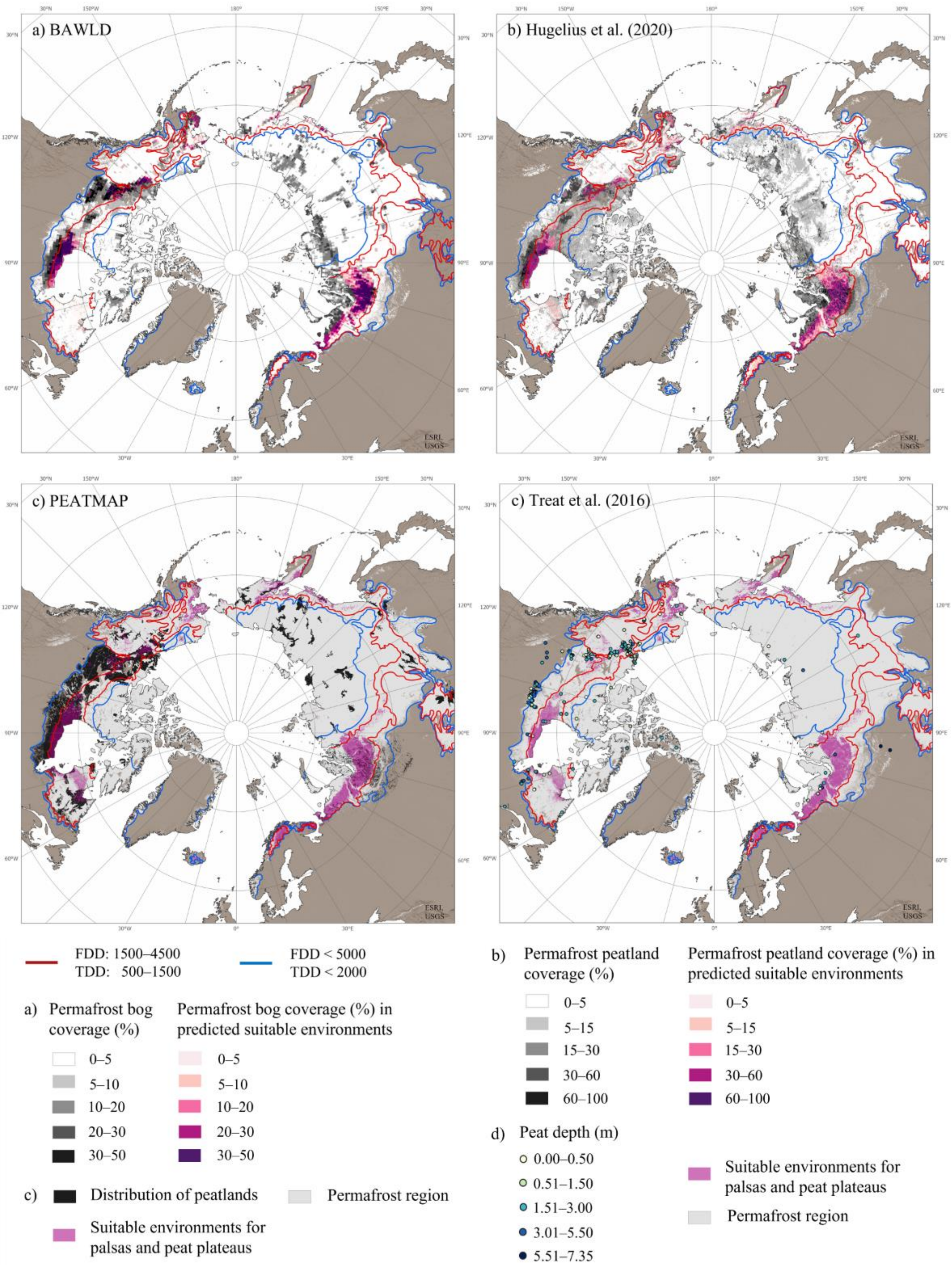

Figure R1: Comparison between the predicted suitable environmental spaces (for period 1950–2000), suitable climate spaces, and peatland datasets; (a) Permafrost bog coverage percent (0–50 %), in each grid cell according to the Boreal–Arctic Wetland and Lake Dataset (BAWLD; Olefeldt et al., 2021), (b) permafrost peatland coverage percent (0–100 %) (Hugelius et al., 2020), (c) distribution of peatlands according to PEATMAP (Xu et al., 2018), and (d) peat depth according to Treat et al. (2016b) in point symbols (yellow to blue scale). Permafrost regions are illustrated in light gray (Ran et al., 2022) and regions outside permafrost region with brown. The suitable environmental spaces are illustrated with pinkish colors, whereas areas outside our binary predictions are illustrated with grey scale. Two classification of suitable climate spaces are illustrated with red (a strict interpretation) and blue (a liberal interpretation) lines.

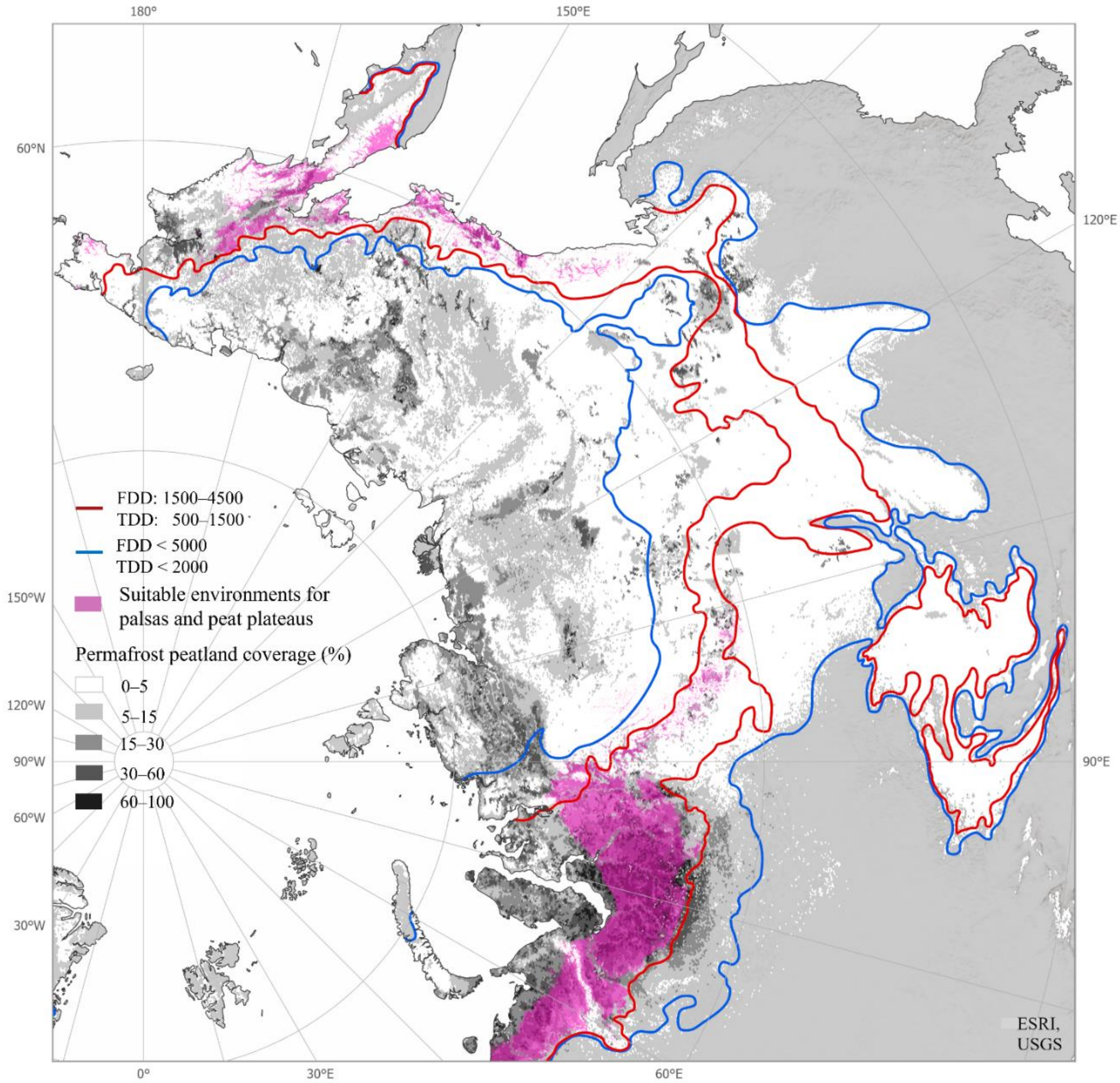

Figure R2: Suitable climate spaces (based on FDD and TDD) with two classifications illustrated are in red and blue lines. In the background suitable environmental spaces for palsas and peat plateaus (period 1950–2000) and permafrost peatland coverage (%) according to Hugelius et al. (2020). All datasets extracted for the permafrost region (Ran et al., 2022).

The authors have used only two of the four RCP scenarios - the pessimistic, worst-case RCP8.5, and the moderately-optimistc RCP4.5. However, it would be valuable to see the other two scenarios, RCP2.6 and 6.0. too. In particular, there may be a big difference from RCP2.6 to RCP4.5. Even in RCP4.5, we can see that the large majority of of the 20th century climate space has gone. We recently showed (Fewster et al., 2022) that the lowest emissions scenario (SSP1 in our case) predicts the preservation of much of the original climate space in western Siberia. A similar finding across the larger study area here would be valuable to know. I recommend that the authors add at least RCP2.6 to their analysis, if not RCP6.0.

R5: This was a great idea on how to improve this study. Originally, we left the RCP2.6 scenario out from the manuscript as we considered it unlikely for this optimistic scenario to be realized, taking into account the fast current pace of the climate change. However, after reconsideration and Morris' recommendation we decided to include this lowest emissions scenario to the study.

We added RCP2.6 scenario to our analysis but left the RCP6.0 out because we thought that it would not have similar added value.

Other than these things, I found the paper to be mainly logical and well-written, clearly and attractively illustrated, and with sound and reproducible methods. The comparison of predictions of shrinking palsas to remotely-sensed images of thermokarst ponds is a clever way to provide some validation.
R6: We thank Dr. Morris for the overall positive comments and important suggestions to improve our manuscript.

Minor and typographical issues

Throughout - overuse of the word "the". I have been through the PDF manuscript and added strikethrough annotation to examples that could be deleted for improved English. Please see attached.
R7: We highly appreciate Dr. Morris' efforts to improve the English of the manuscript. We have checked the attached supplement and removed unnecessary "the" words from the manuscript.

27 - primarily in regions
R8: Corrected: from → in

28 - ...differ mainly in their extent and height...
R9: Corrected: by → in

39 - important to global carbon budgets, palsas and peat plateaus
R10: Sentence was modified accordingly.

46 - classified palsas as critically endangered
R11: The word 'as' was added

60 - not found in the Southern Hemisphere
R12: Corrected: from → in

79-85 - the method description here is almost identical to that by Fewster et al. (2022), which you cite elsewhere. Even to the point of identifying the search terms for nations and Canadian provinces. It would seem appropriate to acknowledge that this is all but the same method.
R13: Citation "(see Fewster et al., 2022)" was added to line 91 (p. 3).

100-101 - in the evaluation set were selected so that they were located at least
R14: We added another 'were'

101 - crietrion (not criteria; singular, not plural)
R15: Corrected to singular

102 - as they were located too close
R16: The word 'were' was added

117 - were computed separately
R17: Word order was corrected.

142-3 - jumbled sentence, please reword. I can't follow the intended meaning of this sentence, so can't suggest an edit myself.
R18: The sentence was removed, and the content was reworded in the first paragraph of the section 2.3.
Revised paragraph (lines 175–186, p. 7):
"Statistical modelling was conducted using the biomod2 (version 3.5.1; Thuiller et al., 2021) package in R (version 4.1.3; R Core Team, 2022). We used four methods which have been previously used in distribution modelling of periglacial landforms and processes (e.g., Aalto et al., 2014, 2017; Rudy et al., 2016; Karjalainen et al., 2020) and other permafrost characteristics, such as soil organic carbon content (Siewert, 2018; Mishra et al., 2021). The used methods were generalized linear model (GLM, Nelder and Wedderburn, 1972), generalized additive model (GAM, Hastie and Tibshirani, 1986), generalized boosted model (GBM, Elith et al., 2008) and random forest (RF, Elith et al., 2005). Multiple modelling techniques were utilized in order to acknowledge the uncertainties associated with individual modelling methods (see Thuiller et al., 2009) and to select the one with the highest model performance. In addition, we built an ensemble based on the former methods to find out whether it outperforms the individual modelling techniques in the distribution modelling of suitable environments for palsas and peat plateaus. Ensemble approach has been utilized previously for example to predict ground temperature (Aalto et al., 2018), soil hydrology (Cisty et al., 2014), distribution of plants species (Rissanen et al., 2021) and other periglacial landforms (Karjalainen et al., 2020)."

153-4 - some justification would be in order here. Why not consider interaction terms? Particularly given that they are included in the random forest model.
R19: We appreciate Dr. Morris' attention to details here. We retained from including interaction terms in GLM and GAM for a couple of reasons. We aimed to keep the models as simple, and hence, as generalizable as possible in belief that this would suite the current task which involved model extrapolation to some regions sparsely represented in the modelling data. That is, we anticipated that fitting potentially complex interactions would have weaker transferability. GBM and RF inherently consider interactions owing to the tree-based model fitting approach where the model fit can be closely controlled with a set of model parameters (such as learning rate, and the number and depth (complexity) of the fitted trees). As such, they are transferable across the study region without a risk of overfitting to the data used in model calibration.

The above-mentioned characteristics of GBM and RF turned out advantageous in the case of circumpolar palsa and peat plateau modelling, but prior to achieving these results we considered it possible that the implementation of regression based GLM and GAM without interaction terms could indeed prove valuable with the task at hand. Whatsoever, the evaluation (Fig. 6, line 360, p. 17) demonstrated them having lower predictive performance compared to GBM and RF. Yet, with the separate evaluation dataset TSS values were only slightly lower and with remarkably low standard deviation which speaks for their generalization ability with the spatially semi-independent evaluation dataset.

192 - remove superfluous comma after "Other".
R20: The comma was removed.

192 - were found in the Northwest Territories...
R21: Corrected: from → in

350 - also affect
R22: Word order was corrected.

References used in the response letter:

Fewster, R. E., Morris, P. J., Swindles, G. T., Gregoire, L. J., Ivanovic, R. F., Valdes, P. J., and Mullan, D.: Drivers of Holocene palsa distribution in North America, Quaternary Sci. Rev., 240, 106337, https://doi.org/10.1016/j.quascirev.2020.106337, 2020.

Fewster, R. E., Morris, P. J., Ivanovic, R. F., Swindles, G. T., Peregon, A. M., and Smith, C. J.: Imminent loss of climate space for permafrost peatlands in Europe and Western Siberia, Nat. Clim. Change, 1–7. https://doi.org/10.1038/s41558-022-01296-7, 2022.

French, H. M.: The periglacial Environment, 4th edition, Wiley-Blackwell, Hoboken, 515 pp. LCCN 2017027903, 2017.

Hugelius, G., Loisel, J., Chadburn, S., Jackson, R. B., Jones, M., MacDonald, G., Marushchak, M., Olefeldt, D., Packalen, M., Siewert, M. B., Treat, C., Turetsky, M., Voight, C. and Yu, Z.: Large stocks of peatland carbon and nitrogen are vulnerable to permafrost thaw, P. Natl. A. Sci. USA., 117, 20438–20446, https://doi.org/10.1073/pnas.1916387117, 2020.

Karjalainen, O., Luoto, M., Aalto, J., Etzelmüller, B., Grosse, G., Jones, B. M., Lilleøren, K., S. and Hjort, J.: High potential for loss of permafrost landforms in a changing climate, Environ. Res. Lett., 15, 104065. https://doi.org/10.1088/1748-9326/abafd5, 2020.

Olefeldt, D., Goswami, S., Grosse, G., Hayes, D., Hugelius, G., Kuhry, P., Mcguire, A. D., Romanovsky, V. E., Sannel, A. B. K., Schuur, E. A. G., and Turetsky, M. R.: Circumpolar distribution and carbon storage of thermokarst landscapes, Nat. Commun., 7, 1–11, https://doi.org/10.1038/ncomms13043, 2016.

Olefeldt, D., Hovemyr, M., McKenzie, A. K., Bastviken, D., Bohn, T. J., Connolly, J., Crill, P., Euskirchen,E. S., Finkelstein, S. A., Genet, H., Grosse, G., Harris, L. I., Heffernan, L., Helbig, M., Hugelius, G., Hutchins, R., Juutinen, S., Lara, M. J., Malhotra, A., Manies, K., McGuire., D. A., Natali, S. M., O'Donnell, J. A., Parmentier, F.-J. W., Räsänen, A., Schädel, C., Sonnentag, O., Strack, M., Tank, S. E, Treat, C., Varner, R. K., Virtanen, T., Warren, R. K., and Watts, J. D.: The Boreal-Arctic Wetland and Lake Dataset (BAWLD), Earth Syst. Sci. Data, 13, 5127–5149, https://doi.org/10.5194/essd-13-5127-2021, 2021.

Ran, Y., Li, X., Cheng, G., Che, J., Aalto, J., Karjalainen, O., Hjort, J., Luoto, M., Jin, H., Obu, J., Hori, M., Yu, Q., and Chang, X.: New high-resolution estimates of the permafrost thermal state and hydrothermal conditions over the Northern Hemisphere, Earth Syst. Sci. Data, 14, 865–884, https://doi.org/10.5194/ESSD-14-865-2022, 2022.

Seppälä, M.: Palsas and Related Forms, in: Advances in periglacial geomorphology, edited by: Clark, M. J., John Wiley & Sons, Ltd, Chichester, 247–278, IBSN 0 471 90981 5, 1988.

Seppälä, M.: Synthesis of studies of palsa formation underlining the importance of local environmental and physical characteristics, Quaternary Res., 75, 366–370, https://doi.org/10.1016/j.yqres.2010.09.007, 2011.

Treat, C. C., Jones, M. C, Camill, P., Gallego-Sala, A. V, Garneau, M., Harden, J. W., Hugelius, G., Klein, E. S., Kokfelt, U., Kuhry, P., Loisel, J., Mathijssen, P. J. H., O'Donnell, J. A., Oksanen, P. O., Ronkainen, T. M., Sannel, A. B. K., Talbot, J., Tarnocai, C., Väliranta, M.: Synthesis dataset of physical and ecosystem properties from pan-arctic wetland sites using peat core analysis. PANGAEA, https://doi.org/10.1594/PANGAEA.863697, 2016a.

Xu, J., Morris, P. J., Liu, J., and Holden, J.: PEATMAP: Refining estimates of global peatland distribution based on meta-analysis, CATENA, 160, 134–140, https://doi.org/10.1016/j.catena.2017.09.010, 2018.

List of relevant changes:

- Manuscript modified so that it is clear for the reader that our predictions for Central and Eastern Siberia are extrapolations of models fitted elsewhere. Discussion added. (e.g., lines 78–81, p. 3; 203–204, p. 8; 403–404, p. 19; 487–488, p. 22).
- We added the low emissions scenario (RCP2.6) to our analyses.
- New figure (fig. 7, p. 18) and comparison with four peatland datasets were added to the revised manuscript. Results and discussion related to the topic was added (lines 365–371, p. 17; 400–414, pp. 19–20).