Reply to reviewer comments

Our comments are written in blue and italics.

We thank both reviewers for their very constructive reviews that helped to enhance the manuscript.

Please see our detailed replies to each of their comments.

Reviewer 1: N. Ross

GENERAL COMMENTS:

This is an impressive, well written paper that undertakes analysis of the factors determining pingo development in Northern Asia. The methods are sound, and possible errors and uncertainties are carefully outlined and assessed. The novel approach of the paper is that it applies GIS techniques to evaluate the factors that determine pingo development. This has enabled a more quantitative regional analysis than has hitherto been possible. In many regards it is perhaps surprising that this has not been accomplished previously. The authors should be congratulated for undertaking the significant amount of work that has clearly gone into developing the database that underpins the paper.

Thank you.

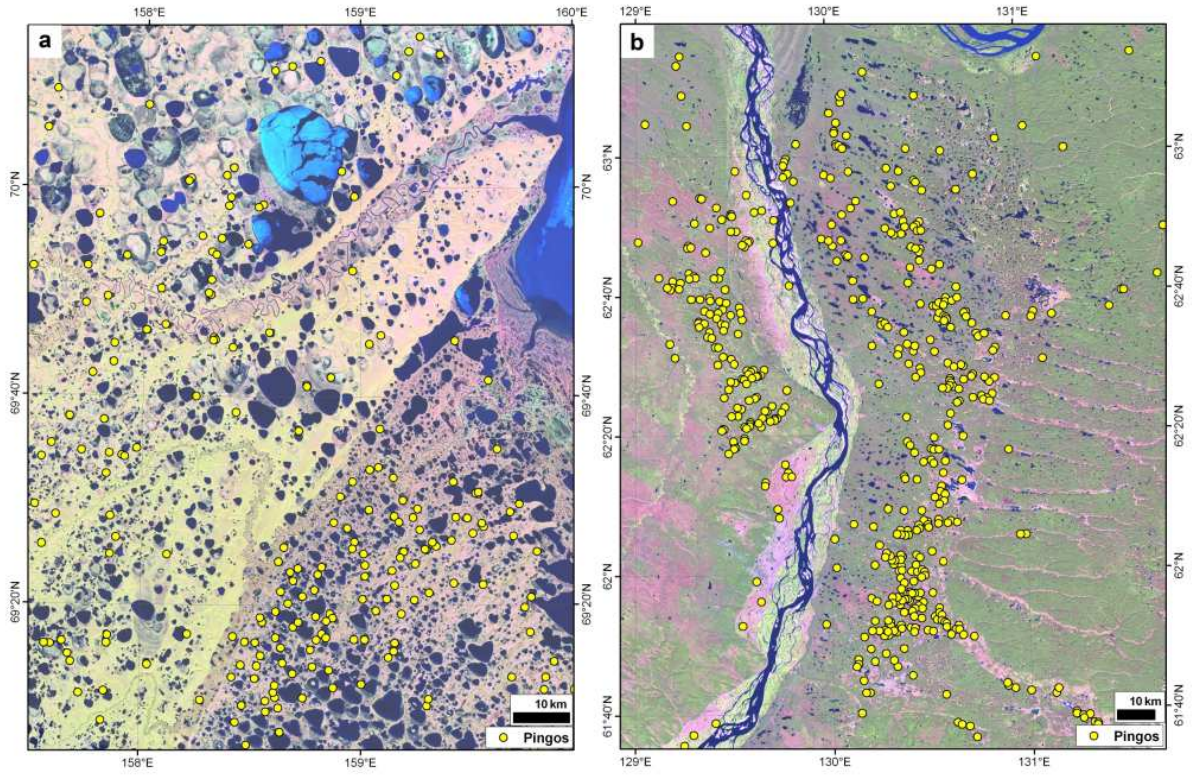
My only real misgiving about the paper is that the conclusions are not overly substantive. In the whole, the authors simply confirm previous findings by other authors (e.g. "In general, our findings are in good agreement with previous research on environmental conditions required for pingo presence." Conclusions: Page 1798 (lines 11-12)). I do therefore have concerns that the paper does not tell us a great deal about pingos that is new or novel. Nevertheless, the paper does provide a very useful regional overview of pingos in Northern Asia. It is also the first time that many of the relationships between pingos and the factors that influence their distribution have been quantified in a systematic way over a large spatial area and I believe that this alone probably warrants publication.

We believe our main finished product is the geospatial pingo database for a very large continental scale region. In this respect, we learn something new and novel: That pingo numbers on Earth were vastly underestimated so far. We certainly encourage further work with this dataset to study the distribution and genesis of pingos, and their vulnerability to climate change on regional or local levels.

The paper should be condensed by shortening the introduction, removing some figures and removing unnecessary references (see specific comments below).

We removed Figures 6 to 11 (regional maps), Figure 13 (bioclimatic subzones), Figure 18 (mean annual precipitation) and Figure 20 (lake density vs. pingo density). We also removed some references from the introduction. Instead of the 6 regional subsets we added 1 figure (new Fig. 6) showing the Yakutsk region

and the Kolyma lowland region in more detail with Landsat data as background for easy interpretation of relations between basins, lakes, streams and pingos.



New Fig. 6: Local subsets of the pingo distribution in the Kolyma Lowland region (a) and the region north of Yakutsk, central Siberia (b). The distribution of pingos in both subregions seems clearly related to lithology, hydrology, and local permafrost conditions. In (a), pingo distribution is dense and possibly aligend with abandoned paleochannels of the Kolyma River in the Khalertchinskaya Tundra (lower right corner of image), whereas pingo distribution is loose and widespread in the region dominated by Yedoma and large drained lake basins (left and upper left corner). In (b), pingos are clearly aligned with fluvial terraces of the paleo-Lena River east and west of the modern Lena River. Also, there is a clustering of pingos at locations where elongated thermokarst (alas) valleys enter the paleo-Lena terraces from the east. For location of the subsets see Fig. 2. In both subsets the background image is a false color composite from Landsat-ETM+ with RGB bands 5-4-3 from the mid-summer season (data provided by USGS EROS Data Center).

The paper assumes that all landforms recorded in the database are pingos. At no point in the paper do the authors discuss the possibility that any of the landforms could be non-pingo frost mounds (e.g. lithalsas). As the majority of the landforms are <8 m high, it is possible that at least some of these landforms could be lithalsas (or some form of mineral-cored palsa) rather than pingos. I acknowledge

that without groundtruthing this is very difficult to establish, but do suggest that it probably warrants a short discussion.

We cannot exclude this possibility since the dataset is based on topographic maps, which ultimately are based on aerial image interpretation. We understand the reviewers concern that it is probably not always possible to distinguish between some lithalsas, palsas, and pingos in aerial images. Hence, there is a technical limitation in our database that only can be resolved with ground truth of all 6059 pingos. The topographic maps provide map labels for pingos (see Table 3), and about 1/6 (1126 mounds) of the frost mounds are not specified as pingos. As explained in the methods section, the majority of these also occurred in close proximity to frost mounds labeled as pingos (see also Fig. 3). With this dataset we certainly have to rely on the capabilities of the Russian cartographic service here. In the future, this point dataset could be used to analyze the specific local environmental settings at a site to better determine the likely genesis of a mapped frost mound. The ultimate confirmation can only come from detailed field studies, which would be very helpful to refine the database and greatly decrease the level of uncertainty. It would be exciting to include regional field data or even specific information about individual pingos in the database, as they are available.

We added a few sentences and reference on this in the section on database limitations.

Ideally I would like to have seen more Russian pingo literature included in the references, but I do understand that accessing this literature can be challenging.

We added three more Russian references:

Vasilchuk, Yu. K., and Budantseva, N. A.: Radiouglerodnoe opredelenye vosrasta bulgunnyakha na mestoroshdenii peszovoe v severnoi zhasti Sapadnoi Sibiri [Radiocarbon dating of the pingo in the Pestsovoye gas field in the North of West Siberia], Engineering Geology, July 2010, 14-21, 2010. In Russian.

Evseev, V. P.: Pingos of segregated ice in the northeast of the European part of the U.S.S.R in Western Siberia, Problemy Kriolitologii, 5, 95-159, 1976. In Russian.

Grave, N. A.: On the archaeological dating of hydrolaccoliths on the Chukotka Peninsula, Doklady Akademii Nauk, 106, 706-707, 1956. In Russian.

I would like to applaud the authors for their statement that they intend to make their database available (via the web) at some point in the future. I believe that making it available would strengthen the impact of this paper (ideally I think it would have been good to have published them simultaneously).

We started preparing the database for submission to NSIDC.

SPECIFIC COMMENTS:

1 Introduction

The introduction is very long and includes far too many references. I suggest that the authors look at condensing the introduction accordingly. In particular, I felt that the text between page 1784 (line 7) and page 1786 (line 7) could be condensed significantly without affecting the overall paper. This would also allow a significant reduction in the number of references that the paper cites (currently _90). The authors should retain the final paragraph of the introduction, however, as it introduces the paper nicely.

We reduced the number of references unrelated to pingo studies in the first paragraph of the introduction. We also removed the entire paragraph (p 1785, lines 20-26) referring to pingo-like features on shelves as well as on Mars, since it was only marginally relevant. We also did not change the last paragraph of the introduction.

I think that the introduction (and perhaps the paper in general) might benefit from the inclusion of a (slightly) more detailed description of the internal structure of pingos. I do appreciate that there are limited examples of exposure of pingo internal structures. However, internal structure (e.g. type of ground-ice, thickness of overburden) is important, as it will strongly influence the response of pingos to climate forcing via changes in active layer thickness.

We added the following sentence in the Introduction: “Limited examples of the internal structure of a pingo exist and are typically observed in rare cases of pingo collapse due to coastal, fluvial, or thermokarst erosion (Mackay, 1998), derived by mechanical drilling, or measured using geophysical techniques (Yoshikawa et al., 2006; Ross et al., 2005; Ross et al., 2007).“

We also expanded somewhat on this topic in the Discussion section 5: “Variation in the type of ground-ice and the thickness of the overburden will strongly influence the response of an individual pingo to climate forcing via changes in active layer thickness. Whereby, pingo collapse will occur most commonly in those pingos where massive bodies exist near the surface, and pingo persistence will most likely occur for those pingos that have an overburden that exceeds the projected depth of thaw for the region. Further, owing to the conical shape of a pingo, the possibility of differential thaw on south facing and north facing slopes exist, further complicating the response of pingos to climate change. “

Page 1784 (lines 26-28). If retained, three references appear to be spelt incorrectly or differ from spelling in reference list (Mueller 1959, Lagerbaeck and Kodhe 1985 / Lamborinchen 2000). Advise that authors check these references.

We corrected these references.

Page 1785 (lines 5-7). If retained, the sentence “Some studies describe. . ...conditions and processes” requires an example reference.

This sentence is actually an introduction referring to the studies cited in detail in the following sentences. However, we added two key references here.

2 Study Area

Page 1786 (lines 25-26) the reporting of latitude and longitude should be standardized (i.e. minutes as well as degrees should be reported).

We changed all reported geographic coordinates in the paper to decimal degrees.

4 Results

Page 1792 (line 2-13) – See comments referring to figures 6-11 below.

Instead of the 6 regional subsets we added 1 figure (new Fig. 6) showing the Yakutsk region and the Kolyma lowland region in more detail with Landsat data as background for easy interpretation of relations between basins, lakes, streams and pingos. Please see comment below on figures.

Page 1792 (line 2-13) – Authors should standardise the format of latitude and longitude throughout the paper. They are reported here as decimal degrees, but earlier in the paper (page 1786) as degrees/decimal minutes.

We changed all reported geographic coordinates in the paper to decimal degrees.

Page 1793 (lines 12-13) – “Only 236 pingos are higher than 8 m (8% of pingos with height data”. This is an important statement, as most descriptions of pingos concentrate on the very large-scale landforms (those over 30 m).

We completely agree. However, the heights are only represented by a proportion of the dataset (about 51% of the mapped pingos had height information; many more pingos might be missing from the maps), so this number should be treated with care.

Page 1793 (lines 19-23) – I suspect that if large pingos, with elevations greater than 50 m, were observed then they would have been mapped when the original 'base' maps were produced.

Yes, such pingos would certainly have been identified in the original smaller scale maps based on aerial photography. However, there are other factors that are important to consider when analyzing these Russian topographic maps, including map scale and possibly even some inconsistencies in handling such features between different cartographers. Our analysis of the ASTER data showed that even very large pingos are sometimes not included in the maps in some regions (see figure 4). Our dataset does not show many very large pingos, although we cannot exclude the presence of more such large pingos. We also understand our dataset as a first attempt that needs to be developed and enhanced with more detailed data from higher-resolution maps, remote sensing imagery, and field data in the future.

Page 1794 (lines 21-23) (Figure 16) – I suggest that this statement be made less uncertain. I would place more emphasis on the fact that the area shown in figure 16 with a MAGT below -11 is negligible. Perhaps reword to: "There is a sharp decline in pingo numbers for MAGT above -3 _C and below -11 _C, most likely due to the limited area in the study region with ground temperatures below -11 _C (Figure 16).

We followed the advice of the reviewer and rewrote the sentence to: "There is a sharp decline in pingo numbers for MAGT above -3°C and below -11°C, most likely due to the limited area in the study region with MAGT below -11°C."

Page 1796 (line 17) – Authors should quantify the "..small number of pingos,". Was it <10%, <5% or <1%?

We quantified the number of potentially hydraulic pingos in these substrates in mountain regions and added this in the sentence.

Page 1796 (section 4.6: Distribution in relation to lakes and streams) - I do wonder if the authors could make more of their dataset. For section 4.6 I wonder if there are more sophisticated, yet accessible 'off the shelf' methods, for analysing, for example, the proximity of landforms to lakes and streams (e.g. ARCGIS 'proximity analysis') ?

We agree that a more detailed analysis of our pingo database with respect to lake and streams as well as to several other physical factors controlling pingo distribution would be interesting. We hope that through the publication of our dataset with NSIDC or another data center that it will make it possible for such interesting relations to be explored.

Related to this, I was wondering if there was a statistical way of ranking the importance of the factors that influence pingo development? For future publications it might be worth investigating the use of Principal Components Analysis (PCA). I have seen this applied to ecological datasets (e.g. which environmental factors determine diatom populations in lake systems). It might be totally inappropriate for application to the current topic, but I would suggest at least investigating whether it might be of any use.

We agree that this is an interesting statistical method and strongly hope that future work with this dataset will explore its use along this avenue.

Pages 1797-1798 (section 4.7): I really like the idea that pingos could be used as remote indicators of the future state of Arctic permafrost, but I do wonder whether the signal would be as clear as the authors suggest. The depth that ground-ice is found at in pingos means that they are not necessarily sensitive indicators of active layer change, due to insulation by overburden. As a result, changes in near surface ground and air temperatures may not lead to rapid pingo degradation, so pingos may not be as useful as future permafrost indicators in the way that other ground-ice mounds (palsas or lithalsas) might. This section could benefit from a more in-depth discussion of the internal structure and ground-ice composition of pingos derived from literature sources, to back up the authors' argument.

We agree that the use of pingos as indicator for a future state of permafrost will not be straightforward because of the issues the reviewer identified (and we also mention this in the paragraph; we now also added some more verbiage on the importance of internal pingo structure in the introduction and the discussion). We believe that on a case-by-case basis, pingos will behave very differently to different levels of warming and some might be more stable than others. However, if looking at the overall pingo population of a region that undergoes warming and permafrost degradation, we very likely will largely see the loss of some pingos because of a warming Arctic, continuing permafrost warming, and increase vulnerability to disturbances. It is important to note that today a much smaller number of pingos is present in regions with maximum active layer depths larger than 1 m than in regions with 0.5-1.0 m maximum active layer depth. Although active layer increase will hardly impact pingos directly by reaching the massive ice core due to thick overburden, active layer increases are a direct indicator of overall warming ground conditions. Projected active layer thickness will go way beyond 2 m in many regions with pingos today, and some of them might even be directly impacted.

In general, we added verbiage on how internal structure of pingos is influencing the vulnerability of pingos to climate warming, and emphasize that these relationships are quite complex to predict.

5 Discussion

Page 1799 (lines 2-15) – I am a little unclear how the authors can use their data to "assess the temporal dynamics of thermokarst lakes and basins over longer Holocene time-scales". Dating pingos is fraught

with difficulties and I can only see that this goal could be achieved by accessing the internal structure of numerous pingos and recovering samples for radiocarbon or luminescence dating.

We reformulated our statement to make clear that the pingo dataset might prove useful to access long-term and broad-scale trends of thermokarst lake drainage in lowland regions in future studies. Hydrostatic pingos for which absolute dates exist or for which growth rate estimates allow calculation of an approximate age were found by many authors to be largely on the order of hundreds to few thousand of years old. The combination of a spatial dataset of pingo distribution and an approximate knowledge of when they formed due to rapid lake drainage could be very useful information for understanding long-term lake drainage dynamics in Arctic lowlands.

I suspect that stating "..a detailed pingo dataset could help to refine long-term carbon budgets in permafrost regions" might be overstating the usefulness of the dataset a little. The authors should remove this statement or back it up.

We agree that this statement was a little ambitious and have removed it per the suggestion of the reviewer.

Page 1799 (line 10) 'absolutely' is spelt incorrectly.

We corrected this error.

Page 1799 (line 23) should read ". . .large regions with pingos present. . ." rather than "presence of pingos"

We followed the advice and corrected the sentence accordingly.

Page 1800 – The authors have provided an excellent section that realistically discusses the limitations of the database.

Thank you.

Page 1802 (line 2) – should read ". . .can safely assume. . ."

We followed the advice and corrected the sentence accordingly.

Page 1802 (lines 14-18) – authors should be specific about the number of examples where multiple pingos were combined into a single pingo location.

There was at least on occasion where a pingo field was pointed out on the map. This was labeled in the topographic maps as "bulgunnyakhi" (plural), while only one pingo symbol was shown. We mapped this pingo field as one pingo in our dataset. We added this information in the sentence.

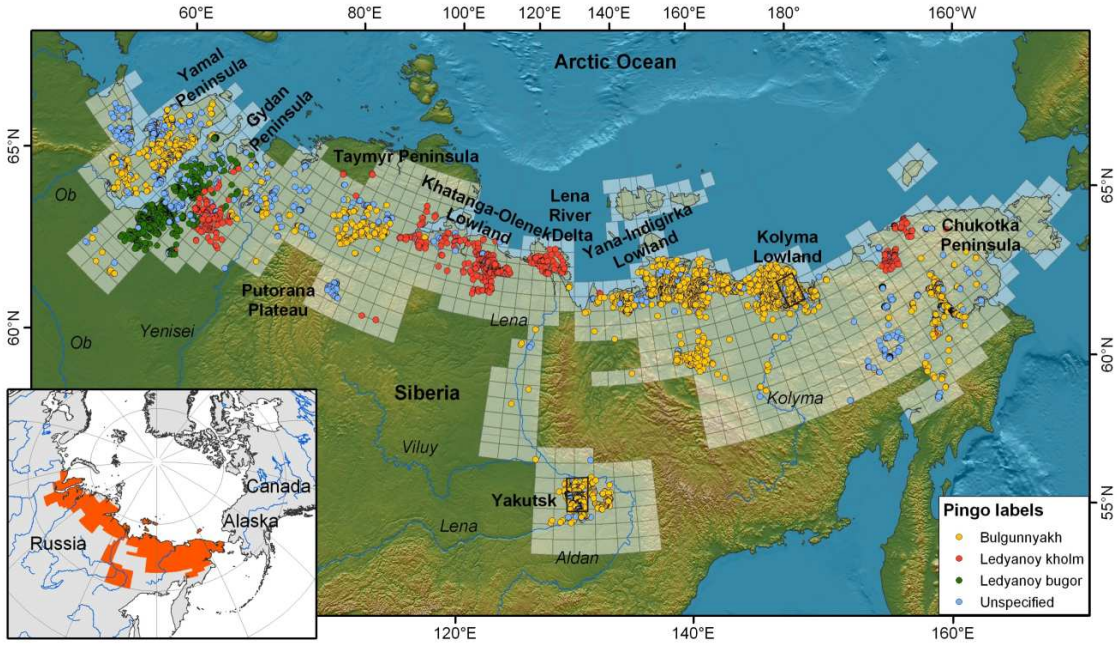
Figures

Are figures 6-11 really necessary? They are not discussed in the text in any great detail (only on page 1792 lines 2-13, and a brief mention on page 1797, line 3). As the paper concentrates on the macro- rather than meso-scale I do wonder whether these figures can be removed entirely. A compromise might be to only have one or two sub-region 'case studies' and analyse them in depth (i.e. pick the ones that show something novel, unusual (e.g. the "dense pingo occurrence of the Central Yakutian region"), or contributes to the findings of the paper considerably. Another possibility would be to include figures 6-11 as supplementary info if this is possible?

We deleted figures 6-11. Instead of the 6 regional subsets we added 1 figure (new Fig. 6) showing the Yakutsk region and the Kolyma lowland region in more detail with Landsat data as background for easy interpretation of relations between basins, lakes, streams and pingos.

If the authors do choose to retain figures 6-11 then I suggest that they show the boundaries of the subregions on one of the regional figures (e.g. figure 2), so that readers can easily identify where they are located.

We added the boundary of the 2 subregions (Yakutsk and Kolyma Lowland region) shown in new Fig. 6 in the new figure to Fig. 2.



New Fig. 2

If 6-11 are retained, then the 'Lakes' label in the legend should be renamed 'Lakes and rivers'. It might also help figures 6-11 if the geology layer were transparently draped over the topography.

These figures were deleted from the revised manuscript.

Figure 12 – It is interesting that there are two very distinct populations in the bar chart associated with figure 12. This may warrant more discussion in the text of the paper?

We added the following sentence in section 4.1 on geographic distribution, in the description of pingo distribution by elevation: "Pingos in these mountainous areas are likely hydraulic pingos located in river valleys."

We also added the following sentence in the section 5.1 Limitation of the pingo database: "For example, the elevation of the pingos derived with a 1 km DEM can only be used for a first order regional study, but is likely to contain errors on the local level because hydrostatic pingos occur in lowland landscapes with relief undulations below the DEM resolution, and hydraulic pingos often occur in valleys in mountainous regions for which the DEM resolution also does not apply very well."

Figure 20 – In the hard-copy I made of the paper, the hatched area of high pingo density was very hard to make out in this figure. Suggest that the authors might want to edit this figure to address this problem.

We deleted this figure for space reasons.

Anonymous Referee #2

GENERAL COMMENTS:

This is a very extensive paper and clearly represents a huge amount of mapping. It has the potential to form a major contribution to our knowledge of the spatial distribution of pingos in the northern hemisphere. The methodology appears to be sound and the research has been conducted in an assiduous fashion. The maps and figures which accompany the paper, are generally excellent, although I doubt that all of maps reproduced are strictly necessary. I would favour a few large scale maps which really show the spatial distribution of the features in a small area.

Thank you.

We removed the Figures 6 to 11 (regional maps), Figure 13 (bioclimatic subzones), Figure 18 (mean annual precipitation) and Figure 20 (lake density vs. pingo density). We also removed some references from the introduction. Instead of the 6 regional subsets we added 1 figure (new Fig. 6) showing the Yakutsk region and the Kolyma lowland region in more detail with Landsat data as background for easy interpretation of relations between basins, lakes, streams and pingos.

Overall, I support the publication of this paper, but suggest a small number of minor revisions.

SPECIFIC COMMENTS:

I would have liked to have seen greater reference to the pingo literature and importantly reference to the work of Mackay (1979) which clearly sets out the reasons for using the terms 'hydrostatic' and 'hydraulic' instead of closed system and open system. The use of these outdated and misleading terms persists because they are continually promulgated in the new publications. We need to ensure that this stops in order to avoid further confusion in the future.

We now reference to Mackay (1979) and exchanged the terms "closed system pingo" and "open system pingo" with "hydrostatic pingo" and "hydraulic pingo", respectively, throughout the text. We also added 3 more Russian references on pingos:

Vasilchuk, Yu. K., and Budantseva, N. A.: Radiouglerodnoe opredelenye vosrasta bulgunnyakha na mestoroshdenii peszovoe v severnoi zhasti Sapadnoi Sibiri [Radiocarbon dating of the pingo in the Pestsovoye gas field in the North of West Siberia], Engineering Geology, July 2010, 14-21, 2010. In Russian.

Evseev, V. P.: Pingos of segregated ice in the northeast of the European part of the U.S.S.R in Western Siberia, Problemy Kriolitologii, 5, 95-159, 1976. In Russian.

Grave, N. A.: On the archaeological dating of hydrolaccoliths on the Chukotka Peninsula, Doklady Akademii Nauk, 106, 706-707, 1956. In Russian.

I would question whether some of the features mapped are perennial cryogenic mounds of a non-pingo origin, such as lithalsas or mineral permafrost mounds. There is little discussion of this possibility.

We cannot exclude this possibility since the dataset is based on topographic maps, which ultimately are based on aerial image interpretation. We understand the reviewers concern that it is probably not always possible to distinguish between some lithalsas, palsas, and pingos in aerial images. Hence, there is a technical limitation in our database that only can be resolved with ground truth of all 6059 pingos. The topographic maps provide map labels for pingos (see Table 3), and about 1/6 (1126 mounds) of the frost mounds are not specified as pingos. As explained in the methods section, the majority of these also occurred in close proximity to frost mounds labeled as pingos (see also Fig. 3). With this dataset we certainly have to rely on the capabilities of the Russian cartographic service here. In the future, this point dataset could be used to analyze the specific local environmental settings at a site to better determine the likely genesis of a mapped frost mound. The ultimate confirmation can only come from detailed field studies, which would be very helpful to refine the database and greatly decrease the level of uncertainty. It would be exciting to include regional field data or even specific information about individual pingos in the database, as they are available.

We added a few sentences and reference on this in the section on database limitations.

It is interesting to note that there are no features in excess of 40 m high (the highest pingo globally is of the order of 55 m). Although the authors make the comment that there may be some features that have been missed. Surely the largest pingos would be more likely to have been included in the original mapping which was acquired for this work?

Yes, such pingos would certainly have been identified in the original smaller scale maps based on aerial photography. However, there are other factors that are important to consider when analyzing these Russian topographic maps, including map scale and possibly even some inconsistencies in handling such features between different cartographers. Our analysis of the ASTER data showed that even very large pingos are sometimes not included in the maps in some regions (see figure 4). Our dataset does not show many very large pingos, although we cannot exclude the presence of more such large pingos. We also understand our dataset as a first attempt that needs to be developed and enhanced with more detailed data from higher-resolution maps, remote sensing imagery, and field data in the future.

It is possible that within these data on pingo distribution (e.g. in the Anadyr river valley displayed in Figure 11) there might be some clues concerning, or at least further examples, of what have been described as ‘aligned pingos’ by other workers (e.g. Gurney and Worsley, 1997). There are some

references made to hydrogeological controls in the discussion and these could be extended if examples of 'alignment' were discovered.

We have decided to remove this figure as well as figures 6-10, that showed detailed pingo districts in northern Asia. Instead of the 6 regional subsets we added 1 figure (new Fig. 6) showing the Yakutsk region and the Kolyma lowland region in more detail with Landsat data as background for easy interpretation of relations between basins, lakes, streams and pingos. While the topic of aligned pingos is very interesting we felt that it was best to stick to the presentation of pingo distributions at large regional scales.

The analysis of hydrogeologic controls would be an interesting topic that one can pursue further by using our dataset in the future.

On the issue of pingo densities, it is stated that 8 pingos per square kilometre is the maximum recorded in the literature. This is incorrect. Worsley and Gurney (1996) report a group of hydraulic pingos on Traill Ø (Traill Island), east Greenland which number 11 (named the 'Zurich group') and which exist in less than one square kilometre. Not all of the features are active as some have decayed and have been eroded by fluvial processes, nevertheless, this is the highest ever pingo density reported. This paper is cited elsewhere in the manuscript (in Table 5) and is listed in the references.

We thank the reviewer for pointing at this example, which we added in the text and table 4.

TECHNICAL CORRECTIONS:

Page 1, Line 18 (P1, L11): a comma is needed in 6000 to read 6,000.

We corrected this accordingly here and in all other instances throughout the paper.

Page 1, Line 18 (P1, L18): Do not use the term 'closed system'; instead use the term 'hydrostatic' (see comments above).

We now use "hydrostatic pingo" and "hydraulic pingo" throughout the text.

P2, L24: It is possible to write ground water as one word 'groundwater'.

We corrected this accordingly.

P3, L2: The highest pingo ever recorded had a height in excess of 50 m, see paper by Mackay in 1998.

Thank you, we added this detail information in a separate sentence. According to Mackay 1998, the highest pingo is found in Alaska, SE of Prudhoe Bay, with a height of 54 m above the surrounding lake plain.

P3, L23: Mueller should be Müller. It is correct in the reference list.

We corrected this accordingly.

P3, L24: The reference should be Lomborinchen, 2000. It is correctly listed in the references.

We corrected this accordingly.

P4, L10: Again ground water can be written as one word.

We corrected this accordingly.

P4, L11: Citation of Worsley and Gurney (1996) would be useful here as it is a paper on pingos which specifically discusses their hydrogeological significance.

We agree and added this reference in this sentence. We also moved the sentence more to the front of the Introduction (now at end of second paragraph).

P 7, L12: Comma need in 3600 to read 3,600.

We corrected this accordingly.

P9, L6: Comma needed in 6059 to read 6,059.

We corrected this accordingly.

P9, L19: Comma needed in 2990 to read 2,990.

We corrected this accordingly.

P9, L22: Comma needed in 1620 to read 1,620.

We corrected this accordingly.

P9, L28: Spaces and long hyphen for the reference here which is not consistent with the format used elsewhere on this page (no space & short hyphen).

We corrected this accordingly.

P10, L10: Comma needed in 4166 to read 4,166.

We corrected this accordingly.

P10, L23: Comma needed in 3109 to read 3,109.

We corrected this accordingly.

P10, L10: Comma needed in 2873 to read 2,873.

We corrected this accordingly.

P13, L1: Comma needed in 2525 to read 2,525.

We corrected this accordingly.

P13, L13: Comma needed in 1558 to read 1,558.

We corrected this accordingly.

P14, L21: Comma needed in 2073 to read 2,073.

We corrected this accordingly.

P16, L19: Should this not read “Limitation of the pingo database”?

We followed the suggestions and added "the" to the title.

P16, L21: Comma needed in 6000 to read 6,000.

We corrected this accordingly.

P18, L6: This is not the case as discussed above. The paper by Worsley and Gurney (1996) on pingos in east Greenland should be checked and the text changed to reflect the new information.

We followed the reviewer's suggestion and added this reference for a dense patch of hydraulic pingos in addition to the reference by Stager on hydrostatic pingos.

P23, L15: The reference should be Lagerbäck R and Rodhe L (hence both authors names are incorrect here).

We corrected this accordingly.

Figure 2 caption: Comma needed, 6059 should read 6,059.

We changed this according to the reviewer's suggestion.

Figure 9: A much more useful map would show an enlargement of the area north and east of Yakutsk (i.e. just the central section of this map).

We no provide a figure enlarging the area north of Yakutsk with a Landsat image as back ground (new Fig. 6).

Figure 11 caption: Please use the term 'hydraulic' NOT 'open system' in this caption.

We changed this according to the reviewer's suggestion.

Figure 12 caption: A space is needed between the value and unit (50m becomes 50 m) and a comma in 1000 to become 1,000.

We made these changes according to the reviewer's suggestion.

Figure 14 caption: A comma is required, 3109 should read 3,109.

We made this change according to the reviewer's suggestion.

Figure 20: Highlighting the area with highest pingo density is a good idea, but it is not all clear, in practice on a map of this scale.

We deleted Figure 20 for space and clarity reasons. We now provide a figure (new Fig. 6) with 2 panels showing pingo distribution in subregions of the study area with Landsat satellite data as background. The satellite data provides easy visualization of important factors for pingo distribution, such as lakes and drained basins, as well as fluvial networks.

Figure 21 caption: Space needed between value and unit (2m becomes 2 m).

We added a space between value and unit. This is now figure 13.