

Interactive comment on “Numerical modelling of permafrost spring discharge and open-system pingo formation induced by basal permafrost aggradation” by Mikkel T. Hornum et al.

Anonymous Referee #2

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In this paper, the authors investigate the question: “Why are there pingos in Adventdalen when there seem to be no groundwater recharge? They do this with a conceptual model, and find that the observed pingos are sustained by groundwater supply with residence times exceeding the duration of Holocene. In addition to the modeling, the work relies on a wide range of field observations.

The work presented in this paper is impressive. A new model is developed and data from many different sources are used in the study. However, the manuscript would benefit from revisions to improve readability and clarity. Currently, the manuscript contains many terms and context that need to be explained to expand readership beyond

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immediate experts and to the diverse backgrounds of the readers of The Cryosphere. The minor comments below provide many examples.

Major comments =====

1. Many terms and concepts are provided without much context. I give several examples in the minor comments.
2. Organize the manuscript into sections according to the traditional structure of a scientific paper (Abstract, intro, study site, methods and data, results, discussion, conclusions). In the current paper, there is no clearly defined method section and sections 2 to 4 gradually move from introduction to results. a. For example, the section 3.2 title suggests this section contains background information about the study site. However, besides that background information it also explains how climate history was reconstructed. Separate these two so that the background info on lines 150-154 goes in a study site description section, and the rest in a methods subsection about reconstructed temperatures b. Another benefit of a dedicated method section is that you can provide an overview of the methods at the beginning providing the reader with a sort of road map.
3. None of the tables has captions. It should be possible for a reader to understand tables and figures based on the caption.
4. Adding a description of the model simulations (number of simulations, parameterizations etc). in the methods would be helpful for the reader to anticipate the results.
5. The simulations with the groundwater model need to be better explained. Clarify what scenarios were run and why. What is the significance of the 3 kyr catchment. How were they drawn in the first place? Figure 7 is very complicated and should be simplified and ideally split up into several figures. In the text, it is stated that each of the 12 zones were run with a different REq. However, the y-axis suggests that only three values were used. Explain why head is visualized with two different types of units?

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What is the purpose of the pie charts and all the information provided in the figure. It is difficult to cross-reference with the explanations in the text. Also provide context for the scenarios (max, min, mean). It is difficult to see the evidence in support of the conclusion that pingo's co-occur with regions of overpressure.

Minor comments =====

L13: "methane emissions/release"

L40: Clarify what "they" refers to, e.g. springs

L47-L50. Clarify where the liquid water is coming from if not from the surface (e.g. relic groundwater?)

L70: Here and other places. Be careful with using words like "this" without being more specific about what "this" refers too (here pressure). It is easy for the reader to get lost.

L72: Define "talik"

L73: "suggest that and open. . ."

L65-72: Somewhere here it would be good to explain the difference between open and closed pingo systems.

L75: be more specific about what "the system" refers to.

L82: Avoid abbreviations as much as possible. If you need the, make sure to write them out the first time they are mentioned.

L89: Explain what a "through-talik" is and how is it different than a "talik".

L112: Reformulate. It is not clear from Fig 2b that the sediments are fine-grained or pre-Cenozoic.

L116: What does "these" refer to. All layers or just the surface layers < 70 m? Needs clarification.

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L131: Explain the term "OSL"

L154: Specify period

L191: Clarify the source of these depth observations and the permafrost depths inferred from those observations.

L220: Expand abbreviations, i.e. explain what GMS 10.4 is

L252: Rephrase "validate the model we" (you are validating the model, not the code itself)

L253: Briefly explain the limitations of the analytical solutions (i.e. answering the question why can't you use these model for your study). Also summarize the findings about the model performance. Make sure to provide quantitative estimates of model performance (e.g. RMSE as in Supp. L79). Statements such as "relatively good performance" (Supp. L58) are not sufficient.

L271: Explain the term "A" in equation 6.

L281: Better define subzones. The text says that 12 subzones are defined. However, figure 12 does not show these clearly. Table 1 says nothing about subzones.

L293: Explain how you found out that porosity was the most important parameter

L311: Can a grid be one dimensional? Isn't it by definition 2D? I suggest rephrasing.

L312: It is not clear from Figure 4 where these 12 grids/columns are located. I suggest adding a point or arrow to identify the locations of the 12 grid/columns

L313. Table 1 shows site locations, not geological units. Do you mean table 3? Either way, explain how the names of the zones refer to the age. It is unclear. Provide a better connection to Figure 4. I suggest making a table with parameters for each of the 12 zones.

L319: Clarify that this grid is different from the one in the previous section.

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L331: Clarify how you dealt with the active layer at the surface (i.e. unfrozen too, but also inactivated?)

L331: Clarify the meaning of “raw” and how it differs from non-raw simulations

L333: The interpolation is unclear. What was interpolated, time or space? Explain.

L335: Be more specific and clarify. Isn't it the permafrost aggradation in m/s that is inferred from the freezing front?

L340: Table 2 does not mention “intermediate” values, only, min/mean/max for three materials. Clarify what porosity values were used, and why those were used over other values.

L371: Cross reference with tables so that the reader can check this statement. Also provide the name of the layer.

L374: What about the thermal properties. Also cross-reference with table.

L389: Explain how you know this was artesian.

L390: Explain how you know that hydraulic pressures were below hydrostatic as well as the significance of this.

L392: Explain the 3 kyr catchments. Why 3 and not 4 kyr? What is the significance of these “catchments”

L401: Rephrase and clarify. It reads as if both artesian and non-artesian determine spring sites and has small QREq and high K. Earlier it is written that most of the area was artesian.

L445: Clarify if the characteristic length is equal to l , and why 200 m was selected.

L453: Clarify. Perturbations of what

L536: Be specific about which scenarios you are referring to here.

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L547: Explain why max K values were used. In the previous text you argued for intermediate K values to be the most reasonable.

Comments on figures and tables =====

Tables: Add captions

Table 2: Be more specific about what source you used for what properties by using. The way it is done for porosity is great, do this for all parameters and other tables as well.

Figure S1 should be in the main article. However, I suggest creating different types of boxes in the flow chart to distinguish between data outputs and inputs, calculations/algorithms, and decisions. Make sure the groundwater model MODFLOW in the diagram

Figure 1: This is a great figure to illustrate the conceptual model. To improve., consider using another shading to identify permafrost

Figure 2 caption. Several words, terms, sites mentioned within parenthesis are unclear without context. Clarify the meaning/context of these, including: “temperature loggings”, “Sarkofagen”, “Breinosa”, “geophysics”. Be specific about what “Map data” you refer to, e.g. topographic data in panel a. Add at the end “description of the layers shown in cross sections A, B, and C”. Add compass to the map since directions are discussed in the text later. Also point out the direction towards Longyearbyen

Figure 3. Explain the time axis. Time in relation to what (i.e. what is time 0 = present day). Use colors instead of dashed lines. The grey shaded area of driftwood arrival is almost impossible to see, use colors for this too.

Figure 4: Clarify that the inset maps show the 1D simplifications of the model area. Choose one word to describe the 1D simplification (simplifications or interpretation). Explain the numbering of the subzones. Why does it start with zero and why is there a 10b. Why not go from 1 to 12? Explain everything shown in the figure, e.g. the red

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arrows pointing out pingo locations.

Figure 5: This figure shows better what the zones are. Something like this is needed in figure 4 but indicating all zones. Why not just label the zones 1, 2, 3 and so on. But you also need to explain in the caption what all elements in the figure are (including the zone map)

Figure 6: Clarify that the uncertainty fields are uncertainty due to porosity. Why are symbols included in the middle chart, but not in the top and bottom chart? Make the chart constant.

Figure 7: The nine scenarios need to be explained in the method section. Explain how they were selected and parameterized. The figure is difficult to understand. Simplify and split up into multiple figures and tables. What do the colors mean for the DH4 borehole?

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