The Cryosphere

Editor

Dear Prof. Hauck,

Please find attached our revised paper

“Permafrost saline water and Early to Mid-Holocene permafrost aggradation in Svalbard”.

We would first like to thank you and the two reviewers for the comments to our manuscript. Following the main comment of reviewer #2 about the thermal properties used in the model, we re-run the model with the suggested thermal conductivity of 3 W $(mK)^{-1}$. This resulted in even faster and deeper permafrost aggradation, confirming and enhancing our suggestion about the freezing of the Fresh Saline Interface (FSI) short time after exposure. We have incorporated and discussed these new results in the revised manuscript. All other comments were carefully taken care of and answered in order in the Reply to Reviewers.

We would appreciate if you consider this manuscript for publication in The cryosphere

Yours sincerely,

Dotan Rotem

We would like to thank and appreciate the comments of the two referees. We paste your comments and commented on each one of them, in bold letters. No. of Lines corresponds the clean version.

**Referee # 1**

The introduction constitutes a very complete assessment of the research background on the studied topics and objectives of the work.

The study area does not provide present- day climate data, which would help to frame to understand (past) simulated conditions.

**- We now added climate data in Lines 102-106.**

The methodological part is very well described, and the different steps of the research approach clearly exposed. Discussion is concise and summarizes the main findings, comparing it with other areas where Holocene permafrost dynamics has been also examined. Conclusions capture also the main findings of the paper.

It would be interesting to add what are the implications of these results for recently exposed (Late Holocene) areas, and how these data can be used to assess on the future evolution of permafrost in Svalbard (aggradation. vs degradation).

**- Thanks for this comment. We added implications to recently exposed permafrost in lines 566-568.**

Specific comments

Page 3, l. 50 – include also snow cover dynamics.
**- we mentioned it in the first version, and now we re-wrote it (Line 54)**

Page 3, l. 52 –warm-based glaciers.
**- Corrected (Line 51).**

Page 3, l. 54 –better to refer to Last Glacial Cycle than to the LGM.
**- Corrected (Line 55).**

Page 4, l. 86 – last glacial cycle
**- Corrected (Line 89).**

Page 4, l. 88 – are all ages calibrated (cal BP)?
**- All ages are cited from papers and they are all BP.**

Page 4, l. 102 – to better understand and frame the study cases presented later in the paper, present-day MAATs should be given here. Similarly, as also described in the Discussion, precipitation values should be included here.
**- present-day MAAT is now described in Lines 103-106 Current and past precipitation is presented in Line 106.**

Consider adding a picture of the study site (and maybe also of the cores) to help the reader better understand the environmental/sedimentological setting.
**- Picture was added to Figure 1b page 6**

**Referee # 2**

Major

1. The time step of 32,600 seconds is not 0.5 days as written in the text. Half a day is 43,200 seconds. Please check the simulations.

**- Thank you for pointing it out. Time step was 10,800 seconds (3 hrs). Corrected in Line 317**

2. I think the thermal conductivity is not correctly calculated and this can have a major impact on the results. In equation 2, the dry soil conductivity is used for the mineral fraction of the soil. However, the dry soil thermal conductivity is a bulk value. In this equation for saturated conditions, the "mineral thermal conductivity" should be used and this is typically around 3.0 W/(mK). Therefore, a value of 0.35 W/ (mK) is excessively low.

**- Thanks for this important comment. A recently published model used a similar thermal conductivity of 0.5 $W(mK)^{-1}$ for the Adventdalen quaternary sediments (Hornum et al., 2020). Nevertheless, we agree that a higher value should also be checked. Accordingly, we re-run the model with conductivity of 3.0 $W\ m^{-1}K^{-1}$. We explain it as a variable in lines 243-250 and we present the results in parantheses in lines 340-365 as well as in in Figure 7 and in the porosity figures 9-12 in the appendix. We discuss these results and the differences between them and those arrived at with 0.35 $W\ m^{-1}\ K^{-1}$ in Lines 366-367, 385-388 and 395-403.**

3. Because of the thermal conductivity error, I am skeptical of the permafrost aggradation rates. I am a little bit surprised that changing the porosity has such a small effect on the results, especially because the latent heat associated with such a change is significant. If the authors re-

run the simulations with the correct thermal properties, I hypothesize that, the permafrost aggradation rates would be more divergent when considering different porosities.

**- As discussed in Lines 340-365 and 464-491 and shown in Figures 7, 9-12 in most cases, freezing is much faster with the higher conductivity value. This is except for when using very low WFT (see Lines 524-528)**

4. The numerical model does not consider salt diffusion and therefore salts cannot migrate during the advance of the freezing front. While I do not expect the authors to incorporate salt diffusion into their model, I would appreciate some more discussion on this process. As the authors point out, ground freezing results in ionic exclusion, thereby increasing the porewater salt concentration. Consequently, this creates a porewater salt concentration gradient. Since the advance of the freezing front slows with time, the porewater salt concentration can be sufficiently strong at a particular depth to increase the porewater salinity and create a cryopeg or partially frozen conditions. How would the permafrost aggradation rates change if salt transport were included in the model? For coupled heat and salt diffusion models, consider the following paper: [https://doi.org/10.1029/2018JF004823](https://doi.org/10.1029/2018JF004823).

**We did not include salt diffusion in our model, a process that will reduce WFT as freezing progresses. It can explain the reason for partially frozen samples extracted from the epigenetic section, we added the extracted core condition to table 1. Including salt diffusion, we assume the freezing front may have advanced somewhat slowly than suggested by our model.**
**- We discuss it shortly in lines 493-496.**

5. Please add a conceptual diagram of the Ghyben-Hertzberg approximation and include two panels (1 with permafrost and 1 without permafrost). This would really help the reader visualize how the fresh-saline interface is expected to look in unfrozen and frozen environments.

**The diagram is presented as figure 8 page 26**

6. If available, could you please include ground temperature data with the geochemical ground ice data in Table 1? At the very least, were in-situ frozen and unfrozen conditions recorded during drilling? Please add this information.

**- We did not measure ground temperatures during drilling. We did add a column to table 1. Referring to the frozen state of the retrieved cores.**

Minor:
Line 13: Should “valley” be capitalized?
**- Corrected, (Line 12).**

Line 45: Consider rephrasing to “below 0 °C”.
**- Corrected, (Line 45).**

Line 51: Consider pointing out that permafrost can form in taliks beneath lagoons, as well as beneath bottom-fast ice conditions in shallow water. Consider the following paper: Solomon, S. M., Taylor, A. E., & Stevens, C. W. (2008, June). Nearshore ground temperatures, seasonal ice bonding, and permafrost formation within the bottom-fast ice zone, Mackenzie Delta, NWT. In Proceedings of the Ninth International Conference on Permafrost, Fairbanks, Alaska (Vol. 29, pp. 1675-1680). Fairbanks: Institute of Northern Engineering, University of Alaska Fairbanks.
**A sentence was added it appears in lines 52-54 and the reference was added to the reference list.**

Line 51: Replace “permafrost usually” with “permafrost is usually”. **Corrected, (Line 51).**

Line 54: Replace “Barents Sea” with “the Barents Sea”. **Corrected, (Line55).**

Line 68: You mention that groundwater flow is practically impossible in continuous permafrost areas. Can you make a few comments about groundwater flow in cryopegs in continuous permafrost and if this is relevant to Svalbard?.

**- following your comment, several sentences were added including references. It appears in lines 70-74 and the reference was added to the reference list.**

Line 93: Replace “Exposed surface” with “The exposed surface.” **Corrected, (Line 96).**

Line 95: Replace “Active layer thickness” with “The active layer thickness.” **Corrected, (Line 99).**

Line 103: The units for “km” should not be capitalized. **Corrected, (Line 112).**

Line 104: Replace “Permafrost section” with “The permafrost section.” **Corrected, (Line 114).**

Line 105: Replace “1 to 5.5” with “1.0 to 5.5” **Corrected, (Line 115).**

Figure 1: Please improve the resolution and include a higher quality figure.
**It is in high resolution in my computer I embed it in the file in low resolution to avoid large file size. I’ll send it to TC.**

Line 118: Replace “with serial” with “with a serial.” **Corrected, (Line 134).**

Line 140: Replace “afresh” with “a fresh.” **Corrected, (Line 155).**

Line 149: Should “Pingo” be capitalized? **Yes**

Line 153: Please comment on why the high ratio of Ca/Cl and SO4/Cl at a depth of 5.45 m is enigmatic.
**- It may present former active layer - permafrost table zone were elements may concentrate (e.g. Cary and Mayland, 1972; Kokelj et al., 2002). We have added it in the manuscript, thanks (Lines 167-169). Citations are included in the reference list.**

Table 1: Please add a row for “standard seawater composition” to help put the results in context. **We have added it.**

Line 225: Please be consistent. In the text, water freezing temperature (WFT) is used and in some of the figures (e.g., Figure 3) Tf (freezing point) is used. **We have changed it in the diagram and in the text line 198.**

Table 2: Careful with the units of thermal conductivity. The units should be W/ (mK). **We have changed it to W $m^{-1}K^{-1}$, Thanks.**

Table 2: Please use appropriate notations for multipliers and exponents. The table looks a little messy. **We have corrected it see table 2.**

Line 320: Please define “winter inflection point.”
**- Inflection point is the minimum value shown by the curve deepen with time. The word winter was a mistake and we took it off (Line 345)**

Line 320: Replace “freezing front” with “the freezing front.” **Corrected, (Line 346).**

Figure 4: Please add labels for panels “a”, “b”, and “c.” **We have added it, thanks.**

Line 380: Replace “When freezing” with “When the freezing”. **Corrected, (Line 425).**

Line 383: What do you mean by “low water activity?”
**- A water activity value of unity indicates pure water, whereas a water activity value of zero indicates the total absence of 'free' water molecules; the addition of solutes consistently lowers the water activity. Nevertheless, we decided to take it out.**

Line 389: For simplicity, why not state the eutectic point of the $H_2O$-NaCl system (-21 °C)? **- - - This is also a possibility, but we prefer to leave it like that.**

Line 427: Replace “Less saline” with “The less saline”. **Corrected, the sentence was changed (Line 474).**

Line 428: I suggest replacing “exposure” with “sub-aerial exposure.”. **Corrected, (Line 474).**

Line 429: Replace “when rebound” with “when the rebound.” **Corrected, Line 475).**

Line 463: Replace “Assuming groundwater” with “Assuming the groundwater.” **Corrected, (Line 503).**