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Hydrology and Earth System Sciences Discussions

Interactive comment on "Effects of freezing on soil temperature, frost propagation and moisture redistribution in peat: laboratory investigations" *by* R. M. Nagare et al.

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We would like to thank the anonymous referee for the comments. We retrieved all comments from the text of the anonymous reviewer and numbered them to be able to reply to each comment individually. Please, ïňĄnd our response to the review comments below.

SPECIFIC COMMENTS

(1) Page 5391, Line 10: Setting a proxy permafrost layer as the bottom boundary condition is interesting. How did you control the temperature of the proxy permafrost

layer? If there was no ïňĆux- or temperature-control condition for this layer, it differed from classical freezing experiments in the initial condition only, and the heat ïňĆux through the soil remained unrealistic.

Response: The temperature of the proxy permafrost was controlled by keeping in contact with air in lower chamber maintained at -1.9 °C.

(2) Experimental setup: At which depth were the sensors placed? The bottom condition of the proxy permafrost layer is unclear.

Response: Depths are now mentioned in Table 2.

(3) Page 5392, Line 20: The saturated hydraulic conductivity is important; however, the relationship between hydraulic conductivity and bulk density is more useful for evaluating this experiment. Furthermore, the relationship between hydraulic conductivity and water content (the unsaturated hydraulic conductivity) should be indicated for the following discussion of water ïňĆow.

Response: Unsaturated hydraulic conductivity relationship is now given in Figure 2. Please note that this was a model obtained by Zhang et al. (2010) during their numerical study of infiltration in frozen peat and was only validated numerically. The model is based on van Genuchten's equation and was obtained by fitting into measured unsaturated hydraulic conductivities of peat from a similar site and does not include K reduction due to ice formation.

(4) Page 5392, Line 22: The water retention curve is Fig. 1d, not 1c. How can a tension of 1 mm be measured?

Response: The value at 1 mm tension represents the saturated water content of the samples An arbitrary value of 1 mm is chosen to represent a very low tension value in the logarithmic scale.

(5) Page 5395, Line 7: the inïňĆuence of ice on apparent dielectric permittivity was not considered owing to the inability of estimating pore ice content. When the water

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content is relatively low, the inïňĆuence of ice on dielectric permittivity is small and can be neglected. However, high ice content (initial water) > 0.5 m3/m3 is not negligible. The unfrozen water content of peat in Figure 5 is too high when the initial water content is high. Moreover, the amount of residual water appears to be approximately on the order of the initial water content due to the ice permittivity.

Response: We agree with the reviewers comment about the influence of high ice content (initial water) > 0.5 m3/m3. However, due to no data on the final water content at different stages in the experiments, it is difficult to correct all the curves for all time points. Although there is some error introduced by presence of ice, we believe it is not as significant to affect the overall understanding of the processes through such column experiments. We have modified the discussion of TDR use to include the magnitude of error in unfrozen water content calculations.

(6) Page 5396, Line 13: A linear temperature proïňĄle was achieved by maintaining air temperature in lower and upper chambers at... The temperature proïňĄle is difïňĄcult to see from Figure 11. Showing the temperature and moisture proïňĄles at important times such as 0, 1, 4, 43, 61, 69, 281, and 2000 hr would help to clarify the water and heat ïňĆow in the mesocosms. Setting the lower chamber to a constant temperature and establishing a linear temperature proïňĄle seems to be the same as the classical soil-freezing experiments found in the literature, not a realistic boundary condition. Where is the innovation mentioned at Page 5391, Line 8?

Response: Water movement is not estimated based on SFC's. SFC's were used as one of the ways to show that water moves in peat. The frozen cores as well as TDR data for freeze-thaw cycles was used to comprehensively establish that water moves in freezing peat as well. As compared to mineral soils, there are no studies (except Gamanuyov et al., 1990) that have comprehensively shown water movement in freezing peat. This is an important issue for hydrological studies in the organic covered permafrost terrains. Our main aim was to understand if water movement occurs, which we comprehensively show though the frozen cores as well as TDR data in Figure 8.

By having a proxy permafrost we are able to represent the thermal properties of the transition zone even in laboratory. We have attempted to study water movement from this zone as well as future studies will attempt to study the buffer function of the transient layer as described by Shur et al. 2005 and Harris et al. 2008. Yet, we have modified the discussion to make it clearer.

(7) 3.2 Soil freezing characteristics: SFC changed with bulk density; TDR readings were affected by the high ice content. These issues should be ïňĄxed before approximating the SFCs as a single curve, which is actually useful for numerical studies. As mentioned by Low, the SFC conforms to a single curve at equilibrium. However, some data at depths that froze rapidly (for example, 5 cm in M1 and 5 and 55 cm in M4) suggest behavior under non-equilibrium states.

Response: See response to comment # 5.

(8) Figure 5, 7, 8, 9, 10: Figures 5, 7, 8, 9, and 10 show mostly the same data. Consider reducing the number of graphs. Similarly, Figures 4 and 11 can be combined.

Response: Additional figures have been removed (old Figure # 6, 7, 9, 10) and necessary ones have been added/edited (new Figure # 2, 4, 5, 8, 13).

(9) Page 5397, Line 25 et seq.: The unsaturated hydraulic conductivity is important to water ïňĆow. How much higher would the hydraulic conductivity need to be to explain the difference? Quantitative discussions are preferable. Additionally, are there any inïňĆuences from the water table difference?

Response: Discussion has been modified. Hydraulic conductivity data is shown in Figure 2 and hydraulic conductivities are mentioned in discussion. Also, a sample calculation and quantification of water movement from potential gradient have been quantified in section 3.3. Please note that the K model was obtained by Zhang et al. (2010) during their numerical study of infiltration in frozen peat and was validated numerically. The model is based on van Genuchten's equation and was obtained by

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fitting into measured unsaturated hydraulic conductivities of peat from a similar site and does not include K reduction due to ice formation.

(10) Page 5397, Line 27: To indicate water ïňĆow, proïňĄles are more useful than SFCs. It is difïňĄcult to see the ïňĆow rate and direction using SFCs only.

Response: Although, it is true that such a method of visualization can be useful, in experiments like ours wherein the time of experiment is really long and the lateral influence of heat loss cannot be guaranteed, it is difficult to understand the water movement from profiles at different time points. There is always a problem with some water freezing due to lateral effects and therefore it is not possible to ascertain the amount of water moving towards freezing front. For the same reason, the cores taken at the end of the freezing front and the water content time series (Figure 8) are a better proof to understand if water moved. Understanding whether water movement occurs in freezing peat was the key objective of this study. There is not much work on peat in laboratory to comprehensively establish if water movement towards freezing front takes place in peat except the work of Gamayunov et al. (1990).

(11) Page 5398, Line 3: Freezing reduces the soil pore pressures signiïňĄcantly due to changes in surface tension, temperature sensitivity of contact angles and increase in volume as water transforms to ice. Freezing reduces pore-water pressure because soil retains the unfrozen water (e.g., Dash et al. 1995). The effects of surface tension and contact-angle changes are minimal. Volume expansion from water to ice increases pore pressure.

Response: Discussion has been modified.

(12) Page 5398, Line 8: ...must have resulted from potential gradient How great a potential gradient can cause the loss of water from the 25-cm depth interval?

Response: Discussion has been modified in section 3.3.

(13) Page 5398, Line 17: As it is difïňĄcult to see the detailed temperature proïňĄle in

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Figure 11, water ïňĆow can not be estimated with the freezing state, potential gradient, and hydraulic conductivity.

Response: We have added Figure 8 (unfrozen water content time series) to further support the data obtained from cores. As stated earlier, the major objective of this paper was to show that water movement in freezing peat takes place. Also see discussion in response to comment # 10.

(14) Page 5398, Line 26: extremely low hydraulic conductivities How much? Low water content in the deeper layer would also affect the lower water ïňĆow.

Response: Figure 2 has been added to show the hydraulic conductivity - water content relationship and discussion in section 3.3 has been modified.

(15) Page 5399, Line 16: ...extended to peat What differences between peat and soil can extend the established theory?

Response: Discussion has been modified.

What we meant to point is comparison between the CCE derived suction and observed suction in peat. William (1967) show that suction obtained in frozen state of different soils varies. For peat, an example would be the findings of Quinton et al. (2009) on the mechanisms of water retention in mineral and peat (SLS vs SS systems as explained in Gray, 1970). An experiment similar to William (1967) with frozen peat could clarify the differences between observed and CCE obtained suction for freezing peat.

(16) Page 5399. Line 26 to Page 5400, Line 3: The relationship between the ïňĄgures and hydraulic conductivity is not clear.

Response: Figure 2 added, discussion modified.

(17) Page 5400, Line 8: This could indicate water evaporation or sublimation from the mesocosms. However, there was no evidence of vapor ïňĆow in the mesocosms, as we are unsure where evaporation occurred during the experiment.

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Response: We agree to the speculative nature of discussion and therefore have omitted the vapour transport part.

(18) 3.4 Soil temperature and frost propagation The thermal conductivity and latent heat are important to heat ïňĆow. How did the thermal conductivity of the peat used in this experiment change? What were the observed inïňĆuences of the lower boundary condition on heat ïňĆow? Quantitative discussions are preferred.

Response: Section omitted because we do not have data below 55 cm in each of the mesocosms. Therefore, the observed differences cannot be backed up with data and were explained based on possible reasons for such differences. However, because this sounds speculative in absence of data we have decided to remove the section.

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