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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.

GENERAL COMMENTS

(1) Experimental set up: Liquid water content in frozen peat is too high. 5-13 % of unfrozen water content in non-saline soils is typical for sand to loam material (Farouki

1981). In addition, some facts in the data could indicate problems with the experimental set up (details below). Were any tests made for radially or concentrically symmetric effects of the experimental set-up? Common in situations where a thermal gradient is generated across a phase change boundary, such effects would have an effect on measurement and core observations.

Response: (a) The 5-13 % was a transcription error. As seen from Figure 6, the residual water content range in frozen peat was ∼2-10 %. It is not uncommon to find unfrozen water content >10% in frozen peat even at temperatures close to -5 °C. Some examples are of Pavlova (1970), Derov (1968), and Gamayunov et al. (1990), wherein large quantities of unfrozen water have been reported. Apart from this, the soil water retention curves reported in Figure 1d of this study and many others for peat in the past (e.g., Irwin, 1968; Magnussen, 1994) show that peat holds >20 % water at tensions > 5 m. Further, as shown by Gray (1970) and Quinton et al. (2009), peat holds a significant amount of water in its fabric, as compared to more rigid mineral soils wherein the water is mostly held in spaces between the solid particles.

(b) We did measure temperature near wall and near center for one Mesocosm. This is shown in Figure 4. Although, there could still have been problems with the lateral heat leaks and thermal gradients across phase change boundary, the close comparison in Figure 4 shows that there was reasonable 1D change during the freezing experiments.

(2) The freeze thaw data of the lab experiment are new, but are explained in too many ïňĄgures- one ïňĄgure would sufïňĄce.

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).

(3) Experimentally only one freeze-thaw cycle is run, producing results that may simply depend on initial conditions speciïňĄc to the experimental set-up or initial conditions; relevance to real-world moisture dynamics, necessary for the jump to modeling, is not established. The data and discussion of the 1 D lab results are not sufficient to develop

a conceptual (2 D ïňĄeld) model, primarily since frost heave was not measured.

Response: We agree with the reviewer in principle that a 1D experiment may not be sufficient to propose a conceptual model involving complex 2-D processes at field scale. However, our lab investigations are supporting a long term field program active since 1999. The proposed conceptual model therefore is a result of understanding gained from the field studies and the observation of water movement towards freezing front in the lab experiments. This has been made clearer by introducing additional explanation on the field studies in the introduction section.

(4) Were cryotextures observed? If moisture migrated to the freezing front, then segregated ice would be produced. This would have been an easy method to corroborate observations made indirectly via TDR, which does not measure ice content.

Response: This could have been a method to corroborate observations made indirectly via TDR, which does not measure ice content. However, no observations of cryotextures were made. Yet, to further show that water moved during freezing we have added a new Figure (Figure 8) of the time series of unfrozen water content during two freezing and thawing cycles. Studies from Russian literature have also shown that significant water movement takes place in freezing peat (e.g., Gamayunov et al., 1990).

SPECIFIC COMMENTS

(1) Abstract Should be rewritten after major changes. The revised should focus on the results presented in this study. For example, vapor movement should be excluded in the abstract since no results are presented in the paper.

Response: Abstract has been modified.

(2) 1 Introduction

(2a) P5389, Line 15 and following: Additional literature on organic and mineral soils properties and moisture experiments is given at the end of this review. In contrast to organic soils, mineral soils (especially silts) are of higher interest for experimental

studies since they have a high amount of liquid water in frozen ground and thus enable moisture migration.

Response: The experiments in mineral soils have been reported in large numbers as compared to peat. Organic soils are also of high interest, especially in the vast organic covered permafrost terrains. However, we do not agree that water movement does not take place in freezing peat. Our studies in field, isotopic data (which we can share) as well as data from frozen cores and TDR in this study show that there is definite water movement in freezing peat. Additionally, work of Gamayunov et al. (1990) also comprehensively shows water movement towards freezing front in freezing peat. Peat holds large amounts of water and Quinton et al. (2009) show that although there is reduction in flow networks with reduction in water content, flow networks continue to exist at lower water contents via connected water films. Also, moisture concentration gradients result in water movement via mechanisms explained by Gamayunov et al. (1990). This study was meant to answer if water movement towards freezing front occurs in frozen peat to support the understanding developed from field studies at our field site. This because there is no work till date that comprehensively shows such data other than work of Gamayunov et al. (1990).

(2b) Page 5389, Line 22: the mechanisms are poorly understood. . . Too general statement since the mechanisms are well understood, especially from past moisture migration lab experiments (see literature). Do you mean they are poorly understood at your site or generally at larger scale ïňĄeld sites?

Response: The statement has been modified. We did mean to say at our field site since we are still trying to understand the contributions from the intra-winter snowmelt and water movement towards the freezing front. The discussion now has been modified to improve the flow of discussion.

(2c) Page 5390, Line 23: cold plates..realistic ïňĄeld permafrost.. It is very difficult to replicate ïňĄeld conditions in the lab. Your experiment, similar to previous studies, simulates one directional freezing by forcing from colder air above, keeping the lower boundary constant at subzero temperatures.

Response: We agree with the observation of the reviewer that field conditions are very difficult to replicate in the lab. Our experiments are similar to the other column experiments in the sense that it simulates one directional freezing by forcing from colder air above, keeping the lower boundary constant at subzero temperatures. However, the difference is when we are able to maintain a water table over a frozen layer which is different than maintaining a water table on cold plate as the thermal properties near the lower boundary are going to be more realistic in our case. Also, in field there is a transition zone, rich in ice and overlying the permafrost, which is better represented in our case (see Shur et al. 2005). Therefore, although we maintain the temperature of the lower boundary as done in past column-experiments, our setup is physically more realistic than used in past experiments.

(2d) Page 5391, Line 16 and following: The goals need to be reïňĄned after revision. I suggest omitting goal 4.

Response: The conceptual model was proposed as a result of the understanding regarding the water movement towards freezing front in frozen peat. This was not clearly understood before and field studies in the past 10 years at our field site were not able to conclusively answer if water movement towards freezing front takes place. This study comprehensively shows that water movement towards freezing front occurs even in peat and thus we were able to combine our field knowledge with the results of this study to propose a simple conceptual model. This model will be updated with further understanding from future lab and field studies. We have modified the introduced in order to establish a link between the lab and field studies at our site.

(3) 2 Methodology

(3a) Page 5392, Line 21: The vertical hydraulic conductivity of saturated peat was measured for different depths in the laboratory using the cube method (Fig. 1c). This

was done on the lab samples or are these results from previous papers?

Response: Reference has been added. The vertical hydraulic conductivity (Fig. 1c) was determined on separate samples collected from our field site and the reference has been added.

(3b) Page 5393, Line 10: What is the purpose of using intermediate layers in this experiment? Using several layers (ïňĄeld sample on top of artiïňĄcial sample) might introduce sharp boundaries that affect the heat and water ïňĆow.

Response: The intermediate layers were introduced in order to achieve a minimum depth of 100 cm of the samples. We used undisturbed samples because it is difficult to pack peat in lab representing the structure of peat in field. However, we could not sample the undisturbed peat below the depth of frost table in August of 2007. Therefore, we used intermediate layers made out of humified peat to make up the remaining depths. This was done in order to have a sufficient depth of sample and frozen proxy permafrost below the section undergoing freeze-thaw samples. We agree that sharp boundaries could introduce unrealistic flow conditions; however the goal of this study was to establish if there is water movement towards the freezing front within the limitations posed by the experimental conditions. Discussion has now been modified to make these issues clearer.

(3c) Page 5393, Line 7: If these forcing data are not used, why are they mentioned here? Line 10: The depths of the sensors (temp, TDR, heat ïňĆux) should be given as values, it is difïňĄcult to extract this information from Figure 2. How was the water level measured?

Response: The forcing data now support the water movement shown by TDR data in Figure 8. A new table has been introduced to give the depths of sensors (Table 2). Water level measurements have been clarified.

Line 15: sampling ports for soil gas and water sampling.. These data are not reported in the manuscript.

Response: The info regarding ports has been removed.

(4) 2.2. Experimental conditions Page 5394, Line 1 and following: Part of this information is repeated again in section 3.1. (Initial conditions)

Response: Repetitions have been removed.

(5) 2.3. TDR calibration This section, including Figure 3, does not provide any new results, but cites results from past research papers. The relationship between "and temperature has been examined in detail by many authors (see list at end). I suggest shortening this section, including omitting Figure 3. Equations should be given for the temperature correction and water content calculation from ".

Response: Section has been shortened and the old Fig. 3 has been removed. Equation used to convert relative permittivity to water content is given.

(6) Page 5395, 5396 Line 13 and Line 1: Only one set of cores was taken (close to the wall) which should be taken into account in the discussion.

Response: This has been mentioned during discussion.

(7) Section 3.2. Soil freezing characteristics

(7a) Page 5396, Line 19: started to freeze.. Freezing in Mesocosm 4 (5 cm depth) apparently started at -1ËŽC which only takes place in freezing point depressed media (for example, high salinities). Thus, it could potentially indicated problems with the experimental set up, including sensor problems. Furthermore, TDR and temperature probes could be located at different depths, especially considering that one freeze thaw cycle already had been run (displacement due to heave and subsidence).

Response: We acknowledge the fact that the temperature sensors could be slightly displaced and therefore have modified the discussion.

(7b) Line 23: with residual liquid water contents between 0.05 and 0.13.. Liquid water content in peat should resemble more or the less liquid water content of ice. Your reported values seem much too high and I thus expect that the calculation of liquid water content from “(not shown in the paper) is questionable. Alternatively, does the peat sample include a high proportion of mineral soil which could also explain the wide range in porosities? Unfortunately, no information on soil texture is given for the used soil core.

Response: Residual water content issue has been discussed in response to General Comment # 1.

(7d) Page 5397, Line 4: affected by water distribution What data or calculation is this statement based upon?

Response: This was actually reported based on the fact that water movement in soils can act as an apparent perturbation to the liquid water content-temperature relationship. However, because this cannot be supported in any other way and as pointed by the second reviewer that SFC's are not a good way to detect water movement, we have shortened the discussions on SFC by excluding this part.

(8) Figures 5-9 include the same information (6-10is repeat/enlargement of 5); I suggest to omit ïňĄgures 6-10and enlarge ïňĄgure 5. The SFC curve parameters should be given. As the authors write, these “it is important for numerical studies”.

Response: Figures 6, 7, 9, 10 have been removed. The VG parameters are mentioned in Figure 7.

(9) Page 5398 3.3. Frost induced water distribution How much of this process can indeed be inferred from soil liquid water content and temperature only? A reduction in water content indicates the conversion to ice and not necessarily implies migration. In situ total water content measurements (ice fraction; see literature at end) would have been valuable additional parameters.

Response: The comparison of central and near edge sensors in Mesocosm 2 points to a fair performance of the experimental setup. We believe that there still could have been some lateral heat leak problems, but not to an extent wherein a depth at 25 cm would have been affected within the first hour. Also, if there was major lateral effects occurred, all depths would be affected similarly and therefore would not be reduction at specific depths only. We believe that the reduction at depth 25 cm is real and is a result of water movement upwards.

(10) Statements such as migration due to “potential gradients”, differences in “hydraulic conductivity”, “extremely low hydraulic conductivities” seem rather speculative and are not supported through data or calculations.

Response: Quantitative analysis based on sample calculations is presented in section 3.3.

(11) Line 22: reduction of water content.. Why is there a reduction of water content prior to freezing (Figure 9). Why is the soil at 25 cm freezing prior to 5 cm?

Response: See response to (9) above.

(12) Page 5399, Line 9: Discussion of matric potential and Clausius-Clapeyron equation no data are provided here which is this discussed here?

Response: We are not sure of the comment by the reviewer here.

(13) Line 25: water loss.. I suggest doing a mass balance that clariïňĄes the loss and redistribution of total water.

Response: Mass balance calculation could be done only for one core. This is discussed in section 3.3.

(14) Page 5400, Line 6-13: Interesting results, but no data on magnitudes or processes (including potential secondary ice formation) are shown in this paper.

Response: Discussion on vapour movement has been removed.

(15) Line 21: Start a new section with Scotty creek ïňĄeld data.

Response: Done.

(16) Line 21, Figure 12: Water content was measured in a pit and through analysing two cores. (i) the liquid water content in “peat” is much too high unless it is at least partly thawed (unlikely in April) (ii) how much spatial variability exists for the initial moisture content? (iii) high variability between total water content of the cores, especially in upper part. How was total porosity determined and where is it discussed?

Response: We have measured spatial variation in moisture content in the past. However, the moisture content in local areas is fairly similar spatially at the onset of winter. We have discussed the issue of residual water content in response to general comment (1a) already. For more details please see Quinton and Hayashi (2008).

(17) Line 25: Storage change determined from core 1 and 2 or average value?

Response: Average. Wording has been changed.

(18) Section 3.4. I suggest merging this in or prior to section “SFC”.

(19) Page 5401, Line 23: Role of thermal conductivity and heat ïňĆux plates I have general reservation of using heat ïňĆux plates in freezing soils since they only measure conductive heat ïňĆow. As a test I suggest to compare the total heat ïňĆux measured from the heat ïňĆux plates to the heat ïňĆux calculated from the soil’s latent and sensible heat.

Response: Heat balance calculations were done as per Hayashi et al. (2007) and it was indeed found, as originally reported by Hayashi et al. (2007), that there is an error in heat flux plate values and those obtained from heat flux calculations. Figure 13 has been modified and discussion in section 3.5 has been changed.

(20) Page 5402, Line 2: higher ice content} higher thermal K} quicker heat loss. . . These are qualitative statements whereas I would like to see some quantiïňĄcation.

Furthermore, I expect at least some variability of water/ice content and physical properties which is not discussed.

Response: This particular section is indeed more qualitative because we did not measure the water content and change in water content below 52 cm in these two mesocosms. Given that there is no data, the discussion cannot be supported quantitatively. Therefore, we have modified the section by omitting this discussion and rather focus on the temperature evolution of the Mesocosms.

(21) Line 20: Conceptual model The results of this study are important, but limited to 1 D freeze thaw cycles whereas your diagram shows complex 2 D processes. Are any frost heave measurements (in addition to the 10 cm frost heave mentioned in the conclusion) available?

Response: No frost heave measurements were done. The reasoning behind proposing the conceptual model has been already explained in response to general comment # 3 and specific comment # 2d

(22) SpeciïňĄc comments to ïňĄgures (22a) Fig. 5: missing labels a-d.

Response: labels have been added.

(22b) Fig. 6-10. Provide same data as in ïňĄgure 5

Response: Already addressed.

(22c) Fig. 11. C) should have same y axis as others; is there a chance to add variability/standard deviation on the graph?

Response: Axis has been changed. No std. dev is possible as there is only one set of data.

(22d) Fig. 12. The observed unfrozen moisture is too high for a peat soil (> 10 %). Unfrozen water content in frozen soils with highest liquid content (frozen clay soils) does not exceed 10 %.

Response: Bill can you respond? I have already given some reasoning in response to general comment # 1.

(22e) Fig. 14. b) Too full and thus difïňĄcult to read. Figure caption needs English correction.

Response: Figure 14 b) has been removed.

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