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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.

Anonymous Referee #1

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General comments

Four soil samples from a Canadian permafrost site with minor physical property differences are exposed to freeze-thaw cycles, but only results of the last cycle are reported. Initial conditions and temperature and liquid water content during soil freezing and thawing are monitored. At the end of the experiment, the total water content (liquid water and ice)inferred from 4 cores taken is compared to the initial soil moisture conditions. Processes such as moisture migration during freezing are inferred from these data and a conceptual model is developed for the Canadian field site explaining water distribution and frost propagation on a peat plateau.

The manuscript is well written and contains an interesting data set. The soil-freezing characteristic, the relationship between unfrozen water content and temperature, is relevant for any mass transfer processes in frozen porous media. However, I have the following major concerns that need to be addressed:

- 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.
- The freeze thaw data of the lab experiment are new, but are explained in too many figures- one figure would suffice.
- Experimentally only one freeze-thaw cycle is run, producing results that may simply depend on initial conditions specific 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 field) model, primarily since frost heave was not measured.
- 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.

Specific comments

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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.

1 Introduction

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.

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 field sites?

Page 5390, Line 23: *cold plates..realistic field permafrost*..

It is very difficult to replicate field 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.

Page 5391, Line 16 and following:

The goals need to be refined after revision. I suggest omitting goal 4.

2 Methodology

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?

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

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 flux) should be given as values, it is difficult to extract this information from Figure 2.

How was the water level measured?

Line 15: *sampling ports for soil gas and water sampling..*

These data are not reported in the manuscript.

2.2. Experimental conditions

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

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 $\varepsilon$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 ε.

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.

Section 3.2. Soil freezing characteristics

Page 5396, Line 19: *started to freeze..*

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Freezing in Mesocosm 4 (5 cm depth) apparently started at -1˚C 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).

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 ε (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.

Page 5397, Line 4: *affected by water distribution*

What data or calculation is this statement based upon?

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

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.

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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.

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?

Page 5399, Line 9: Discussion of matric potential and Clausius-Clapeyron equation- not data are provided here which is this discussed here?

Line 25: *water loss..*

I suggest doing a mass balance that clarifies the loss and redistribution of total water.

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

Line 21: Start a new section with Scotty creek field data.

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?

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

Section 3.4.

I suggest merging this in or prior to section “SFC”.

Page 5401, Line 23: Role of thermal conductivity and heat flux plates

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I have general reservation of using heat flux plates in freezing soils since they only measure conductive heat flow. As a test I suggest to compare the total heat flux measured from the heat flux plates to the heat flux calculated from the soil's latent and sensible heat.

Page 5402, Line 2:*higher ice content◇ higher thermal K◇ quicker heat loss. . .*

These are qualitative statements whereas I would like to see some quantification. Furthermore, I expect at least some variability of water/ice content and physical properties which is not discussed.

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?

Specific comments to figures

Fig. 5: missing labels a-d.

Fig. 6-10. Provide same data as in figure 5

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

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 %.

Fig. 14. b) Too full and thus difficult to read. Figure caption needs English correction.

Literature

Bittelli, M., M. Flury, et al. (2003). A Thermodielectric Analyzer to Measure the Freezing and Moisture Characteristic of Porous Media.Water Resources Research**39**(2): 1041.

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Yoshikawa, K., P. P. Overduin, et al. (2004). Moisture Content Measurements of Moss (Sphagnum spp.) Using Commercial Sensors." Permafrost and Periglacial Processes**15**: 309-318.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 8, 5387, 2011.

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