Three-phase numerical model for subsurface hydrology in permafrost-affected regions
Response to Reviewer #2

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Comment 1: While model formulation has been explained in detail in the manuscript it appears to be building upon previously published papers by the authors Painter 2011, Painter 2012 and Painter and Karra 2013. Its not apparent from the manuscript as to what parts of the formulation presented in the current manuscript are new from the previous papers.

Response: There are two major aspects of the current work that are new compared to previous works – 1) the balance equations (mass and energy), we use a three-phase, single component formulation, and 2) the constitutive model for phase-partitioning. The specific differences between Painter 2011, Painter 2012 and Painter & Karra 2011 and the present paper are as follows:

1. Painter 2011 presents a three-phase (liquid water-ice- water vapor), two-component (air-water) formulation. In the current work, we present a three-phase (liquid water-ice-water vapor) *single-component (water)* formulation, that is, unlike Painter 2011 we do not track air. For this we present a modified non-isothermal Richard's model for tracking the water in the three different phases. Furthermore, for phase partitioning, a new *implicit* constitutive model has been used that is different from Painter 2011. The implicit constitutive model used in this paper belongs to a class of models discussed in Painter & Karra 2013 (see item 3 below).
2. Painter 2012 is a review paper on the challenges for modeling the various coupled physical processes involved in the hydrology of permafrost-affected landscapes that need to be addressed. As such, there is little modeling in this paper. In the revised, we plan to compress the summary of the Painter et al. 2012 paper.
3. Painter & Karra 2013 addresses the thermodynamical approach to derive a class of new constitutive models for phase-partitioning of water component under freezing and under unsaturated conditions. This class of models is shown to predict an important aspect seen in experiments where liquid water content is seen to be a function of total water content under freezing; this is something that the constitutive models for phase-partitioning in Painter 2011 and Dall'Amico 2011 cannot predict. The present work uses a particular implicit constitutive model that belongs to the class of models in Painter & Karra 2013.

Comment 2: van Genuchten, 1980 model has been employed for the soil retention curve ($S*$) in Equation 8a. Form of van Genuchten model used in the paper (Equation 9) is for calculation of effective saturation (instead of saturation). It can be inferred from Equation 9 that residual saturation has been assumed to be zero in the formulation. However, manuscript does not mention/discuss any such assumption. For the purpose of clarity it would be helpful to discuss such assumptions in the text.

Response: This will be clarified in the text.

Comment 3: Comparisons in the Figure 2 has been referred to but without any discussion at all. Differences in the water content at the cold end of the tube has been acknowledged, no explanation for why that's happening in the model has been offered besides references to previous studies with similar observations.

Response: This will be clarified in the text.

Comment 4: While experimental set up has been noted, there is no mention of initial and boundary conditions that were used for the simulations.

Response: The initial and boundary conditions have been specified in the text under Section 3 (see lines 23 to 27 of page 13 and line 1 of page 14).

Comment 5: Section 4.2 describes the modeled domain with talik in the text but without a visual its very difficul to understand the set up. A figure showing the simulation set up would be helpful for the readers.

Response: The description of the set-up (geometry, initial and boundary conditions) is in page 15 lines 5-17). The model set-up is fairly trivial and we feel a figure for the model set-up is redundant.

Comment 6: Section 5 examines the effect of vapor diffusion using a simulation set up. Due to the poor quality graphics its hard to interpret the plots corresponding to different times.

Response: These will be re-plotted. Also, the issue with the legend is explained in the response to comment 9 below.

Comment 7: Even with a 3000yr simulation time, the thickness of frozen layer in Figure 6(a) appears to be a really small and not chaging much over time. Temperature at the bottom of the domain appears to be increasing over time even when a -5C temperature is being applied at the top. Is that because of the geothermal flux boundary at the bottom. Please provide discussions to explain the figures and what may be going on with physics.

Response: Yes, the temperature in the domain increases due to the geothermal flux. This will be clarified in the text.

Comment 8: Section 2.4 Page 160 Line 25: Please check if Xg should be Xwg.

Response: Yes, this will be fixed.

Comment 9: Figure 5 and 6 legends are difficult to read. Its to understand the lines corresponding to different times on the plot.

Response: The figures have been shrunk by the editorial office when they had re-formatted the submitted paper (the submitted paper was in single column format using Copernicus style) to a discussion format (as now seen online). The figures in the original submitted version look legible. We will work with the editorial office to ensure that the figures and legends are set to a more legible size.

Comment 10: Figure 8 and 9 requires sub-figure captions to explain what they are. They currently are difficult to read. Legends are not legible.

Response: See response to comment 9.