Response to Anonymous Referee 2

Referee comments shown as "RC:", author replies as "AR:".

General comments:

RC #1 GENERAL COMMENT: This manuscript investigates freeze/thaw dynamics in a soil profile for a 14-years time series of measured data from the UNISCALM-site on Svalbard with the aid of a numerical model. Specifically, for a homogeneous silt profile, the van Genuchten parameters α and n are varied in a reasonable range. Differences in thaw depth, water and ice content are interpreted i) for a quasi-synthetic test case using upper and lower boundary conditions measured in the field and ii) compared to field observations. The paper is very well written and fits well into the scope of The Cryosphere. I have one major concern which is the fit between measured and modeled data which – in my opinion - needs major revision or restructuring of the paper before the manuscript can be recommended for publication.

AR # 1 GENERAL COMMENT: *We thank Anonymous Referee 2 for valuable suggestions to improve and strengthen our paper; all comments have been thoroughly addressed in our responses below. With regard to the major concern regarding the comparability of model results and field site data, we revised the manuscript insofar as we removed text/paragraphs focusing on detailed quantitative comparison. Also, we rephrased the introduction and study aim to distinguish more clearly the character and claims of our work from that of a calibration study.*

Major comments:

RC #2 MAJOR COMMENT: Run in a quasi-synthetic mode, the model is very helpful for exploring the effects of variations in van Genuchten α and n on thaw depth as well as water and ice distribution throughout a silty soil profile (cf. Fig. 3). In this case, a rather simple test case is generated where modelled data depend only on the chosen parameterizations of the soil profile and the imposed upper and lower boundary conditions. With these simulations, processes can be interpreted based on the assumed conceptual model without real linkage to field observations and this is done very well in this study. However, as soon as simulations are compared to measured field data, especially Figure 4 shows that there are still large discrepancies between modelled data and observations and the model is not yet able to reproduce freeze/thaw processes observed in the field. For example, it is definitely not sufficient when summer data at one depth of the profile fit to summer simulations of one test case and winter data at the same depth of the profile fit to winter data of another test case. Here, the challenge is to set up a conceptual model and to find a parameterization that is able to reproduce observations (temperature, moisture, ice content) at all depths during the complete time series before processes occurring at the site can be interpreted and quantified safely. Finding such a paramterization could be quite some effort, so probably it is the better choice for this paper to reduce the study to the synthetic cases and remove the sections comparing measured and modelled data. The alternative would be to "calibrate" the model such that simulations are able to reproduce the field observations.

AR #2 MAJOR COMMENT: *It is not our intention or aim to conduct a model calibration; rather our general main objective is to investigate effects of different soil water retention properties on active layer dynamics. This site is chosen on the basis of previous initial investigations (Schuh, 2015) showing that the site is very dry and unsaturated and potentially highly influenced by cryosuction effects. Therefore in this study we conduct a scenario analysis where we investigate different van Genuchten parameter combinations applicable for the site conditions with the objective to improve the understanding of the physical processes governing the dynamics of an unsaturated active layer as found at/consistent with the UNISCALM site. We derive our simulation test cases from field information (temperature and pressure boundary conditions and sediment properties) and again use field site data (ALT and water content measurements as well as cryostratigraphic information) to place the analysis and model results in the context of this particular site. The comparison between field site observations* *and model results is done to classify the different scenarios with regard to certain field site characteristics, for example the measured water content at the field site (Fig. 4) is compared to simulations not only as an indicator for the correct amount of water in the system, but also to derive information on thaw progression.*

We revised the manuscript insofar as to avoid misinterpretations of our intentions with the study and the quantitative comparisons, starting by the introduction and a clearer statement of the purpose of our study (page 3, lines 30ff). We also eliminated the quantification of root mean squared errors (RMSE) for the differences between simulated and measured ground temperatures in section 3.3 (page 8, lines 30ff) and section 4.1 (page 9 lines 20) to avoid implications of a calibration study.

Specific comments:

RC #3: P 1, L 28: correct "temperatures"

AR #3: *Corrected: "temperatures".*

RC #4: P 2, L 26: Which controlling factors? Please add related information.

AR #4: *Information was added: "[…] key controlling factors of active layer development, mainly air temperature and solar radiation, […]."*

RC #5: P 3, L 18-21: The two specific aims are very closely related. Please reformulate the major aims of the study.

AR #5: *The objective of the study has been revised and reformulated as follows: "The aim is to study how soil moisture retention properties affect moisture and ice (re-)distribution as well as subsurface temperature and active layer thickness variations in the partially saturated active layer under multiple freeze-thaw cycles. In a scenario analysis approach, the different soil moisture retention properties are expressed through careful selection of relevant parameter values derived from field information, and simulation results are put in the context of the particular UNISCALM study site and other relevant permafrost environments." (page 4, lines 22ff).*

RC #6: P 4, L 29: correct "100 m x 100" m or "100 x 100 m2"

AR #6: *Corrected: "100 m x 100 m".*

RC #7: P 5, L 10: please add probe to Table 2

AR #7: *We previously stated the probe as ""DL6 Data Logger" in Table 2. This notation was misleading; we now changed it to "Delta-T profile probe" to comply with the text.*

RC #8: P 6, L 28: The vertical resolution of the model (0.1 m) is rather coarse. Especially, close to the ground surface, resolutions of 0.01 m or even less are often required to adequately reproduce temperature and moisture gradients. Did the authors check the performance of the model in this regard?

AR #8: *Numerical convergence is assured by careful selection of convergence criteria, combined with the use of robust numerical computation routines (for details we refer to Painter et al., 2016, which is now also cited in our revised version). The mesh resolution is selected based on model needs and intention/purpose of the investigation performed; here a mesh of 0.1 m is deemed sufficient since we focus on general active layer dynamics for homogeneous soil texture and using ground surface temperature as thermal boundary condition. As such, surface heat attenuation processes (snow cover, ponding, vegetation, etc) which otherwise may require more careful consideration of near-surface and surface mesh discretization are avoided.*

Painter, S.L., Coon, E.T., Atchley, A.L., Berndt, M., Garimella, R., Moulton, J.D., Svyatskiy, D., Wilson, C.J., 2016. Integrated surface/subsurface permafrost thermal hydrology: Model formulation and proof-of-concept simulations. Water Resources Research. doi:10.1002/2015WR018427

RC #9: P 6, L 31: please add reference for the chosen parameter set

AR #9: *References were added to Table 3:*

Andersland, O.B. and Ladanyi, B. (1994): An introduction to frozen ground engineering. Dordrecht (Springer), ISBN: 978-1-4757-2290-1.

Fitts, C. (2013): Groundwater science. 2nd edition, Oxford (Elsevier), doi: 10.1016/B978-0-12-384705-8.00016-9.

Freeze, R.A. and Cherry, J.A. (1979): Groundwater. Hemel Hempstead (Prentice), ISBN: 978-0133653120.

Huang, P.M.; Li, Y. and Sumner, M.E. (eds.) (2012): Handbook of soil sciences – properties and processes. 2nd edition, Boca Raton (Taylor & Francis), ISBN: 978-1-4398-0305-9.

Kirsch, R. and Yaramanci, U. (2006): Geophysical characterization of aquifers. In: Kirsch, R.(ed.), Groundwater geophysics - a tool for hydrogeology. Berlin (Springer), pp. 439-457,ISBN: 978-3-540-29383-5.

Ochsner, T.E.; Horton, R. and Ren, T. (2001): A new perspective on soil thermal properties. Soil Sci. Soc. Am. J. 65, pp. 1641–1647.

Schwartz, F.W. and Zhang, H. (2003): Fundamentals of ground water. New York (Wiley),ISBN: 978-0-471-13785-6.

Wesley, L.D. (2010): Fundamentals of soil mechanics for sedimentary and residual soils. Hoboken (Wiley), ISBN: 978-0-470-37626-3.

RC #10: P7, L 9-14: Please clarify initial condition: As far as I understand, capillary pressure was linearly interpolated with 0 hPa at 1.2 m depth and -120 hPa at ground surface?

AR #10: *We first put the water table at about -2 m by assigning a pressure of about -200 hPa as top boundary condition and then interpolating linearly with depth. Then we froze the model domain, resulting in the water table to move up to about -1.2 m. We clarified this in the manuscript by reformulating the describing the model setup (page 7, lines 27ff).*

RC #11: P 7, L 21: please correct: linearly

AR #11: *Done.*

RC #12: P 8, Sect. 4.1: Table 5 is not very well suited for comparing measured and modeled data. A plot like Figure 4 would be much more helpful for assessing the quality of the different models.

AR #12: *We took into consideration to display a graph of selected data only and to move Table 5 to the supplementary materials. Eventually we decided to keep Table 5 in the text. We believe that in the results section covering the differences in ALT with regard to certain retention properties it is important to show the complete findings, i.e. the two field site datasets and all seven model scenarios, including their statistical characteristics. This is not practicable in a plot due to the large number of simulation cases which obfuscates comparison. Also, since we would like to avoid the direct comparison between field observations and model results (see our response to major comment above [AR # 2]), we feel that the table is more suitable.*

RC #13: P 9, L- 13: correct “system”

AR #13: *Done.*

RC #14: P 9, Section 4.2: Case studies discussed in the text and shown in Fig. 4 are not the same. Simulations shown in Fig. 4 do not reproduce measured values.

AR #14: *The discussion regarding soil moisture development (Figure 4) has been revised and is now focused exclusively on those three scenarios shown in Figure 4. We also added a note to the caption of Figure 4 stating that "The remaining simulation cases (not shown) reside within the limits of the min and max cases." About the match between modeled and observed soil moisture please refer to our response to the major comment above (AR #2).*

RC #15: Sect. 5: The general discussion of the influence of α and n on the processes occurring in the soil profile is well done and okay as long as it is based on the synthetic cases.

AR #15: *Please refer to our response to the major comment concerning the comparison of simulations to field data (AR #2).*