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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Understanding the Mass, Momentum and Energy Transfer in the Frozen Soil with Three Levels of Model Complexities" *by* Lianyu Yu et al.

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General comments

The considered work deals with the physics of the heat and water transfers in seasonally frozen soils, and in particular with the importance of the descriptions of the couplings that occur in these transport phenomena, from the basic couplings due freeze/thaw of the pore water (latent heat of solidification/liquefaction, impact of freezing on the hydraulic properties) to finer effects such as those related to heat gradient induced water flow or to the water vapor fluxes, and even to the effect of dry air flow. Thermo-hydrological transfers modeling in seasonally frozen soils is a complex prob-

lem with various important implications as it is well explained in the introduction section, and the handling of couplings is one of the major difficulties for their numerical simulations, thus I feel that the scope of the manuscript is appropriate for a submission to HESS.

The authors propose a comparative analysis of numerical simulations of ground thermo-hydrological status in a mountain frozen soil field site for which observations are available for a winter season. After a brief description of the considered field site and of the numerical models to be used, the obtained numerical results are presented. Finally the comparison of results obtained with various physical assumptions embedding various level of complexity of the multi-physics couplings involved allows the authors to make a discussion on the trade-off that must be made between the accuracy of the simulations and the complexity of the modeling approach.

The goal of the work and its real interest for the study of cold regions hydrology are clearly described, while the proposed methodology is relevant for such a purpose. Nevertheless some critical information are missing in the descriptions of the equations and of the numerical procedures, which damages the completeness of the manuscript, and prevents the reader to assess the range of validity of the conclusions. Moreover the domain of applicability of these conclusions in terms of biogeoclimatic contexts should be better discussed. Thus I suggest a major revision of this manuscript prior to publication. One can find below the specific comments on which are based the previous statement, along with a few technical corrections.

Specific comments

Abstract:

l22 : 'air-flow induced water (...) transport (...) is negligible': what is the difference with vapor flow, that have been stated as significant in the previous sentence ? Please clarify.

2. Methodology 2.2 Mass and energy transport in unsaturated soils

l105-109 : The latent heat due to water freeze/thaw introduces necessarily a coupling between heat transport and water transport, since the latent heat term in the thermal equation depends on the water content of the porous medium. The effect of soil ice on soil hydraulic properties induces also a coupling between heat transport and water transport, since the hydraulic properties then depend on the temperature of the porous medium (at least whether the temperature is above or below 0°C). Thus the name 'uncoupled' is inappropriate for describing the set of equation in the most simple model ('unCPLD' model), and its use is not in line with the common practices in the field of cryohydrogeological modeling (e.g.: Grenier et al., 2018). In fact both 'unCPLD' model and 'CPLD' model are coupled thermo-hydrological models, but the latter embeds more coupling effects than the former. Basic coupled model (BCM) versus Advanced coupled model (ACM) might be a better terminology for instance ?

C. Grenier, H. Anbergen, V. Bense, Q. Chanzy, E. Coon, N. Collier, F. Costard, M. Ferry, A. Frampton, J. Frederick, J. Gonçalvès, J. Holmén, A. Jost, S. Kokh, B. Kurylyk, J. McKenzie, J. Molson, E. Mouche, L. Orgogozo, R. Pannetier, A. Rivière, N. Roux, W. Rühaak, J. Scheidegger, J.-O. Selroos, R. Therrien, P. Vidstrand, C. Voss, 2018. Groundwater flow and heat transport for systems undergoing freeze-thaw: Intercomparison of numerical simulators for 2D test cases. Adv. Water Resour., 114, 196-218.

l103 – section 2.2 : a clear presentation of the boundary conditions used for each considered equations in each models is missing. As they are important information for the understanding of the numerical results, they should be added. Numerical convergence studies (meshes resolutions, used time steps, ...) must also be evocated here: in order to compare the results of different models, it is important to control that the truncation errors are comparable between each models (and small compared to the discussed inter-model discrepancies!).

3. Results

l172 and following : The numerical results in terms of computed evapotranspiration depend critically on the way to parameterize evapotranspiration, which is not presented in the paper. Various descriptions could be used here. For instance, and among many others, an empirical one emphasizing the role of vegetation could be find in Orgogozo et al., 2019, or a theoretically derived one in the case of purely evaporative processes could be find in Duval et al., 2004. The mathematical expressions and input data used to compute the evapotranspiration in each model should be described in the manuscript. Without these key information, it is not possible for the reader to interpret the given results.

F. Duval, F. Fichot, M. Quintard, 2004. A local thermal non-equilibrium model for two-phase flows with phase-change in porous media. International Journal of Heat and Mass Transfer 47 : 613-639.

L. Orgogozo, A.S. Prokushkin, O.S. Pokrovsky, C. Grenier, M. Quintard, J. Viers, S. Audry, 2019. Water and energy transfer modelling in a permafrost-dominated, forested catchment of Central Siberia: the key role of rooting depth. Permafrost and Periglacial Processes 30 : 75-89.

4. Discussion

l244 : The first sentence is wrong: the vapor transfer processes are not the only sources of couplings between thermal and hydrological transfers in porous media when freeze/thaw of the pore water occurs, see also my first comment on section 2. Methodology.

ll254-l264 : Here is the explanation for the difference of amplitude of diurnal cycle between models. It seems to me that this is the key point of the discussion (evocated already numerous times in the manuscript, e.g;: l141, l147, l163), but somewhat hard to follow. It should be rewritten in a clearer way, may be with explicative schemes ?

l274 : 'hydraulic conductivity' increase due to 'airflow from the atmosphere to the soil'

? Please give a short explanation.

5. Conclusion

l286-290 : The strong point made about evapotranspiration highlights the need to give to the reader all the relevant information about the handling of the evapotranspiration sink terms in each model (see also my comment for the section 3. Results). Please discuss also the transpirative component of evapotranspiration.

l296-301 : The domain of applicability of the presented study should be better discussed. For instance, a point is made about the freeze/thaw mechanisms of permafrost while the studied field site is not in a permafrost affected area. The relative importance of the vapor flow, the thermal effect on water flow and the airflow should be more discussed with respect to the biogeoclimatic context (e.g. : more important in climate with long freezing/thawing periods or with long periods with surface temperature oscillating around 0°C), and in the context of the existing literature (e.g.: Karra et al., 2014).

S. Karra, S.L. Painter, P.C. Lichtner, 2014. ThreeâĂŘphase numerical model for subsurface hydrology in permafrostâĂŘaffected regions (PFLOTRANâĂŘICE v1.0). The Cryosphere 8(5) : 1935-1950.

Technical comments :

The English language should be improved, although I am not a native English-speaking person so maybe I am making a mistake on that point. For instance it seems to me that the vegetation development cannot be 'closed' (l29). As another example I think that 'the best water resources management' or 'a better water resources management' could be used but not 'the better water resources management' (l33). A reread by an English editing service might be helpful.

l40 and also in other places (e.g.: l42, l51) : Citations should be re-ordered (2006 before 2010).

l138 : Fig1. The figure is not clear enough. Firstly it is difficult to decipher the different

curves for 5, 10 and 20 cm depth – CPLD curve is nowhere visible (if it si beneath the CPLD-Air curve, make this one discontinuous). The legend should also be clearer for the obs. Secondly I didn't got the 'earlier stepping in / stepping out of the frozen period', may be they should be pointed out in the figure itself.

l147 : Fig2. Same formal remarks that for Fig1.

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