Review for the manuscript 'An energy-conserving model of freezing variably-saturated soil' by Dall'Amico et al.

This manuscript describes the theoretical bases, numerical techniques and some tests of a set of coupled energy and water transfer equations with phase change involved. It is indeed an important topic in cryospheric study and a problem that limits the applications of many land surface models and hydrological models in cold regions. The authors claimed that they suggested a 'new energy-conserving model', but this reviewer found out it is actually a 'new numerical scheme' for existing energy and water transfer equations. Such numerical techniques could potentially be very useful if its benefits over previous published schemes (e.g. Zhao et al. 1997; Hansson et al. 2004) were properly demonstrated. However, all the tests demonstrated in this study were still limited in the testing conditions of previous works and the results did not show sufficient improvements over Zhao or Hansson's schemes. As for the presentation quality, this reviewer finds that the manuscript is clearly written, well structured and easy to follow. In general, this reviewer would like to see such kind of study to be published in *The Cryosphere* or other peer reviewed cold region journals, but not in the current form. The authors need to provide more evidences or tests to convince the readers it is indeed an 'energy conserving' and improved numerical scheme. Following are some specific comments and a few technique corrections.

(a) Based on the descriptions in sections 2 and 3 (L. 15 P. 1245 to L. 11 P. 1254), I did not see any new energy or mass balance equations or new coupling method compared to those in Zhao et al. (1997) or in Hansson et al. (2004). However the numerical techniques presented in sections 4 and 5 (L. 12 P. 1254 to L. 28 P. 1259) are different from the previous studies. If this is the case, I would suggest a title "An energy-conserving numerical scheme of freezing variably-saturated soil" or something similar, to be more precise.

(b) In order to demonstrate the model's capability, this study presented tests in some 'imagery' media such as pure water, clay, silt and sand, and a lab experiment from Hansson et al. (2004). These tests did not go beyond the conditions of Zhao et al. (1997) or Hansson et al. (2004) and the tests results did not show apparent improvements over the 'old' schemes. According to the review by Zhang et al (2009), two major limitations of coupled energy and water transfer numerical schemes in frozen soil application are: (1) their success in non-uniform soil conditions; (2) its convergence behavior and efficiency in some large flux conditions such as snow melt infiltration. If the numeric scheme of this study could demonstrate its success in any of above conditions, its potential applications in cold region land surface and hydrological modelling could be enormous. Such testing data are rare, but still possible (e.g. Zhang et al, 2009).

(c) The authors claimed that the 'new model' is energy conservative, but made no effort to test it. It would be more convincing if the authors could supply some energy balance analysis for some of the tests to prove it.

(d) L. 10-11 P. 1247: 'to our knowledge this equation has never been fully derived from a thermodynamical point of view leaving some doubt on its limitations'.

I think the derivation of Zhao et al., 1997 was from a thermodynamical point of view, and quite similar to this study.

(e) L. 22-23 P. 1247: ‘The energy equation with freezing soil in the above considered literature is always written in a non-conservative form’.
It seems to me that all the energy balance equations in this study (Eq. 16), or in Zhao et al. (1997, Eq. (1)) or in Hansson et al. (2004, Eq. (7)) are similar and all energy conservative. The only difference is that this study presented in a more generalized 3D form while the other two presented in a specific 1D form.

(f) Eqs. 5 in P. 1249: I believe that you missed L_f in the two terms from right.

(g) Eqs. 6 in P. 1249: Needs more explanation for H () term.

(h) Fig. 3 P. 1273: Check the legends of line style for ‘An’ and ‘Sim’. They are not differentiable.

References

Hansson, K., Simunek, J., Mizoguchi, M., Lundin, L., and van Genuchten, M.: Water flow and heat transport in frozen soil numerical solution and freeze-thaw applications, Vadose Zone Journal, 3, 693–704, 2004.

Zhang, Y., Carey, S. K., Quinton, W. L., Janowicz, J. R., Pomeroy J. W. and Flerchinger, G. N. Comparison of algorithms and parameterisations for infiltration into organic-covered permafrost soils, Hydrology and Earth System Sciences 14, 729-750, doi:10.5194/hess-14-729-2010, 2009.

Zhao, L., Gray, D. M., and Male, D. H.: Numerical analysis of simultaneous heat and mass transfer during infiltration into frozen ground, Journal of Hydrology, 200, 345–363, 1997.