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Discussions

Interactive comment on "Liquid water infiltration into a layered snowpack: evaluation of a 3D water transport model with laboratory experiments" *by* Hiroyuki Hirashima et al.

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Response for Reviewer 2

This paper presents model simulations performed with a recently developed 3D model for water movement through snow (published by the authors in 2014), to simulate recently published detailed experiments by Avanzi et al., 2016. These simulations show good agreement with the experimental results, for water content, timing, preferential flow, and ponding of water at capillary barriers. The results demonstrate that the recently developed model represents the complex physics of unsaturated flow in snow quite well, as long as the snow material properties (grain size, density, etc) are known.

There are a few additional steps that the authors could likely easily take, which would greatly improve this manuscript. I would highly recommend these improvements before publication:

1) The authors compare their simulations to simulations using the operational SNOWPACK model, and argue that their representation of preferential flow allows more accurate estimates of water flow timing and liquid water content. However, they use the SNOWPACK model without the recent improvements in this area (e.g. Wever et al, 2016; Wurzer et al, 2017), although these papers are cited. To complete this study, they should compare their small scale 3-D model with the most recent SNOWPACK model, which includes these improvements.

Response: Thank you for constructive comments. The first reviewer also suggested to add SNOWPACK simulations with the dual domain approach and we agree with both of you that including this scheme would enhance the impact of the work. We have already performed such simulations, which will be included in our revised manuscript. The variables of interest of this new comparison will be water content profiles and liquid water arrival at the snow base. The discussion section will be modified as suggested.

2) A sensitivity analysis would be very helpful. The authors use the measured grain sizes (from seiving) used in the experiment, and report these values to 0.001 mm. In nature, grain sizes are typically measured to 0.1mm, and models of grain growth are unlikely to be accurate to better than 0.5mm. It would be very helpful to see how sensitive their model results are to variations in grain size on the order of 0.1mm.

Response: We agree with you. We will perform additional simulations with changes in grain size in the order of 0.1 mm for both layers. A discussion about changes in thickness of water ponding layer, water content distribution, and arrival time at sample base will be then included in the manuscript.

3) A recent similar paper using a different model, by a different group, also used the Avanzi et al, 2016 experiments and attempted to reproduce their results with a 2-D

snow heat and mass flow model: Nicolas R. Leroux , John W. Pomeroy , Modelling capillary hysteresis effects on preferential flow through melting and cold layered snowpacks, Advances in Water Resources (2017), doi:10.1016/j.advwatres.2017. 06.024. While the Leroux and Pomeroy paper was not published at the time this paper was submitted, now that it is accepted and online, it would be useful for the authors to cite and discuss the differences between their model and this one.

Response: In the revised manuscript, we will consider the Leroux and Pomeroy paper and add a discussion about the difference between those and our results as follows:

“The main difference between the two models is the number of dimensions considered, i.e., 2D in Leroux and Pomeroy (2017) and 3D (this paper). While Leroux and Pomeroy's model also include temperature and melt-freeze processes, this is not expected to play a role here as the validation experiments were performed in isothermal conditions. In natural snow, water flow shows lateral spreading, especially at capillary barriers, which creates complex three-dimensional stratigraphic features at grain/layer scale. Furthermore, when 3D preferential flow paths form in dry snow, wet snow area is proportional to the square of preferential flow size and inversely proportional to the square of the distance between paths (see Fig. S1). In case of a two-dimensional simulation, wet snow area will be, on the contrary, proportional to preferential flow size and inversely proportional to the distance between paths (see Fig. S1). Considering a 3D geometry can, therefore, help to define the necessary parameterizations of preferential flow effects needed to inform models with a reduced number of dimensions.“ This discussion is supported by the figure, which will be added as Fig. S1 in the Supplement. (see attached supplement file)

4) A more thorough discussion of model resolution would be appropriate. At the resolution of this model, it is unlikely modeling could be performed at the basin scale. How do the authors envision this new understanding of liquid water movement in snow, to impact large scale snow models? How could this understanding be implemented (emperically?) in operational modeling contexts?

Response: Thank you for this important advice. We agree with you that the scale of this model is still not suitable for direct applications at the basin scale. We will include a specific discussion about this in sub-section 4.3, or in an additional sub-section about future work.

“Our results show that this model is capable of reproducing detailed water infiltration at sample scale, i.e., considering micro-scale heterogeneity. On the other hand, the intrinsic scale of this process and computational efforts make it still not suitable for basin-scale simulations. This limitation could be overcome by synergies with existing physics-based hydrologic models for snow-dominated catchments, e.g., Alpine 3D (Lehning et al., 2006). Currently, SNOWPACK is used as a part of Alpine3D for simulation of accumulation/ablation patterns of snowpack. In this paper, comparison between laboratory experiments, a 3D model and SNOWPACK were performed and contributed to highlight model limitations and possible avenues of future developments, e.g., an underestimation of flow path cross-sections. While a 3D model cannot reproduce the entire range of natural variability of liquid water flow in snow, it can help to replicate and understand this process in conditions that are difficult for experiments, e.g., larger sample sizes and/or a more complex stratigraphy. This may contribute to define new parameterizations for dual domain approaches that could be then fully included in catchment-scale models. Also, we will try to apply this model at the basin scale by increasing the element size. While this will hamper the representation of single preferential fingers, we expect the model to be able to correctly reproduce other relevant features of water flow at slope scale such as lateral flow. This could help to understand liquid water flow around concave/convex portions of the landscape. ”

Detailed line-by-line edits/suggestions are in the attached PDF. Please also note the supplement to this comment: https://www.hydrol-earth-syst-sci-discuss.net/hess-2017-200/hess-2017-200-RC2- supplement.pdf

Response: Thank you for detailed suggestions. We have welcomed your suggestions in the manuscript and are going to address your comments in the revised paper.

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