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Laboratory and numerical experiments on water and energy fluxes during freezing and thawing in the unsaturated zone

Hartmut Holländer (1), Md. Montasir Islam (1), and Jirka Šimunek (2)

(1) Department of Civil Engineering, University of Manitoba, Winnipeg, Canada (hartmut.hollaender@umanitoba.ca), (2) Department of Environmental Sciences, University of California Riverside, Riverside

Frozen soil has a major effect in many hydrologic processes, and its effects are difficult to predict. A prime example is flood forecasting during spring snowmelt within the Canadian Prairies. One key driver for the extent of flooding is the antecedent soil moisture and the possibility for water to infiltrate into frozen soils. Therefore, these situations are crucial for accurate flood prediction during every spring. The main objective of this study was to evaluate the water flow and heat transport within HYDRUS-1D version 4.16 and with Hansson's model, which is a detailed freezing/thawing module (Hansson et al., 2004), to predict the impact of frozen and partly frozen soil on infiltration. We developed a standardized data set of water flow and heat transport into (partial) frozen soil by laboratory experiments using fine sand. Temperature, soil moisture, and percolated water were observed at different freezing conditions as well as at thawing conditions. Significant variation in soil moisture was found between the top and the bottom of the soil column at the starting of the thawing period. However, with increasing temperature, the lower depth of the soil column showed higher moisture as the soil became enriched with moisture due to the release of heat by soil particles during the thawing cycle.

We applied vadose zone modeling using the results from the laboratory experiments. The simulated water content by HYDRUS-1D 4.16 showed large errors compared to the observed data showing by negative Nash-Sutcliffe Efficiency. Hansson's model was not able to predict soil water fluxes due to its unstable behavior (Šimunek et al., 2016). The soil temperature profile simulated using HYDRUS-1D 4.16 was not able to predict the release of latent heat during the phase change of water that was visible in Hansson's model. Hansson's model includes the energy gain/loss due to the phase change in the amount of latent energy stored in the modified heat transport equation. However, in situations when the thermal heat gradient was large, the latent heat was not the key process, and HYDRUS-1D 4.16 was predicting better soil temperatures compared to Hansson's model. The newly developed data showed their usefulness for the evaluation and validation of the numerical models. We claim that these laboratory results will be useful for the validation of numerical models and for developing scientific knowledge to suggest potential code variations or new code development in numerical models.

References:

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