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A local thermal non-equilibrium model for rainwater-infiltration into the snowpack

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Rainwater infiltration into the snowpack is complex to describe because of the strongly coupled thermo-hydraulic processes involved and the intrinsic multiphase nature. However, amount and temperature of liquid water infiltrating into the soil is an important factor for soil physics and can cause flooding during the runoff.

While the snowpack might show some sub-freezing thermal gradient, the infiltrating rainwater has an above-freezing temperature. To suitably describe such situations, we extended existing partly-saturated flow models including freezing and melting to cover local thermal non-equilibrium (LTNE) models. In LTNE models, each distinct phase or mixture is described by its own set of thermal parameters and heat transport mechanisms. Heat transfer between the phases is calculated explicitly by a heat transfer coefficient.

We consider the snowpack as a porous medium whose pores are filled with a pore mixture of air, liquid water, and ice. These separate phases of the pore-mixture are assumed to be in thermal equilibrium with each other, but there might be a temperature difference with respect to the snowpack. This allows us to model freezing and melting of liquid water and ice of the pore mixture separately from the melting of the snowpack. This decision is based on the fact, that frozen rainwater has a different crystalline structure and different parameters than the snowpack. Melting of the snow is also included and fully coupled with the hydraulic and thermal state of the pore mixture. Other mechanisms which might cause snow melting, e.g. heat radiation, are neglected due to the short duration of a rain event.

The model does not only allow a suitable description of the non-equilibrium initial and boundary conditions but also gives further insights into the thermal interaction between the phases. Through the dynamic volume fraction of the snowpack, the resulting governing equations are more complex, and more strongly coupled, than for comparable situations of water infiltration into the soil at sub-freezing temperatures, on which the derived model is based on. In this work, we present the derivation of the model and discuss the newly introduced thermal coupling terms between the phases. The model is applied to simple test-scenarios to showcase the benefits of the new model approach. Model limitations are also discussed.