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Modeling rain-on-snow experiments using coupled water and heat flow

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Modeling rain-on-snow (ROS) events accurately is important for flood and avalanche prediction. Modeling of rainwater infiltration into snowpack is difficult due to its strong thermal coupling and phase transition. Additionally, complex flow characteristics, such as preferential flow and capillary barriers further complicate the predictability of water flow and thus runoff behavior.

Recently, liquid water flow in snowpack has been modeled using the Richards Equation, which has long been used to model porous soil systems. The use of the Richards Equation allowed the simulation of capillary barriers and with the help of perturbations of hydraulic properties based on grain size and density even preferential flow could be reproduced. Most approaches, however, neglect heat flow or assume local equilibrium heat between the phases. Under most natural conditions, rainwater has a higher temperature than the snowpack. We developed a coupled water and heat flow approach with the ability to accurately account for the temperature of the infiltrating rain using a local non-equilibrium heat approach thereby defining the boundary condition closer to reality.

To test the approach, we conducted dye-tracer sprinkling experiments in mountain areas of the Czech Republic to simulate rain-on-snow events. We took temperature measurements at different snow depths to obtain continuous mixture temperatures and estimated the grain size distribution manually with crystal cards. We present modeling results using data from these rain-on-snow experiments, where we compare results with the non-equilibrium and equilibrium heat flow and discuss potential limitations and further data/measurement requirements.