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Energy conservative algorithm for phase change in freezing unsaturated soils using the hydrological model GEOtop

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GEOtop is a distributed physically-based hydrological model with coupled water and energy budgets, and is currently under development to suit the requirements of permafrost research in complex mountain terrains.
The phase transition is extremely important if the soil temperature in permafrost regions has to be modeled. At the same time, the transport of water and thus variable water (or ice) saturation are important in determining near-surface bulk soil thermal properties and thus the temperature evolution. In fact, the large amount of energy involved in phase change may strongly affect the energy budget and therefore the temperature in the soil. The heat equation with advection and phase change can be written according to the apparent heat capacity formulation as in Hansson et al 2004. When the temperature is below the depressed melting temperature given by the Gibbs-Thomson effect the freezing process begins, and, considering a no flux condition, the water suction depends on the freezing suction than can be parameterized using the Clausius-Clapeyron equation.
The main problem regards the fact that, within a few hundredth of degrees from the melting temperature, the thermal capacity (the derivative of the conserved quantity with respect to the independent variable) may increase of several orders of magnitude, the maximum value depending on the initial total water content and the soil hydraulic properties given by the Van Genuchten parameters. Therefore, the phase change transition causes high numerical oscillations from the frozen to the thawed state and vice versa. Thus, the problem requires a suitable numerical strategy.
. The numerical algorithm of the heat equation is written in a conservative way and follows a finite difference discretization with a Crank Nicholson scheme. The algebraic nonlinear equation is then solved with a Picard reiterative method.
The object of this contribution is describe an energy conservative algorithm for phase change in freezing unsaturated soils using the hydrological model GEOtop, and to test it against the analytical solution of the Neumann problem. Several runs of simulations will highlight the influence of the initial moisture content and the Van Genuchten parameters on the phase change transition.