Three-phase models for thermal hydrology of frozen, variably saturated soils

Scott Painter (spainter@lanl.gov) - Los Alamos National Laboratory (PI), Satish Karra (Co-PIs).

Models for predicting carbon releases from thawing Arctic soils require reliable representations of soil moisture dynamics in the presence of freeze/thaw cycles and warming trends. Water in soils does not freeze completely at the nominal freezing temperature because capillary forces suppress the energy state of water in small pores, thus allowing some fraction of the water to remain unfrozen. Classical constitutive models that represent that phase partitioning are strictly applicable only to gas-free soils and are thus not adequate for general numerical models that must represent unsaturated conditions. New phase-partitioning models that are applicable to unsaturated conditions will be described. This relationship extends to unsaturated conditions established relationships for gas-free conditions by smoothing a thermodynamically derived relationship to eliminate a jump discontinuity at the freezing temperature. This relationship is shown to compare well with experimental data on unfrozen water content as a function of temperature for different total water content values. The new relationship has been combined with a modified non-isothermal Richards equation and implemented in the highly parallel PFLOTRAN code. The results based on this modified Richards three-phase flow solution are shown to compare well with data from two different column experiments.

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