Geophysical Research Abstracts
Vol. 12, EGU2010-9283-1, 2010
EGU General Assembly 2010
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The thermodynamics of freezing soils

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In this work a throughout derivation of the soil freezing process is performed, from the thermodynamic equilibrium to the derivation of the water and ice content in the ground. Starting from a capillary tube schematization for the soil and the findings of Loch (1978), the generalized Clapeyron equation may be directly obtained by the Gibbs-Duhem identity. In this equation, however, the ice pressure complicates the formulation as it adds an unknown to the thermodynamic equilibrium. The only way to obtain the common generalized Clapeyron equation often used in literature is to hypothesize the behavior "freezing=drying" as proposed by Miller (1963). In this case the pressure at the ice-water interface is equal to the air-water interface, and so the ice pressure may be set constant and equal to the zero gauge pressure given by air pressure.
This assumption, often tacitly assumed in literature, implies precise limitations on the physical processes that may be dealt with. In particular, frost heave may not be modeled.
The objective of this work is to derive the thermodynamic equilibrium of the ice and water phases in a porous medium, to clarify the "freezing=drying" assumption and to propose a fully explicit formulation for the equilibrium where the ice pressure is added to the set of unknowns.