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Numerical simulation of water–heat coupled movements in seasonal frozen soil

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ABSTRACT

In view of the insufficiencies of existing research into soil water and heat movements in seasonally frozen soil regions, water–heat coupled movements in seasonally frozen soil were studied by using a numerical simulation method. On the basis of viscous flow theory for liquid water in porous media and the heat balance principle, one-dimensional seasonal frozen soil water–heat coupled movements were modeled. A finite difference method was then performed to give the fully implicit finite difference form of the model. Finally the water status and the heat status of the seasonally frozen soil in the study area on November 3 2008 were simulated and tested. The results indicated that the simulated values of moisture and temperature for seasonally frozen soil had the same trends as the measured values, and the average relative errors of the soil temperature and moisture simulation were 9.67% and 9.54% respectively, which are both less than 10%. Thus, the one-dimensional seasonally frozen soil water–heat coupled movements model constructed in this paper and the numerical computation method are rational and reliable.

1. Introduction

Soil seasonally freezing is a conventional natural phenomenon. The area of the seasonally frozen soil region in China is 5.137×10^6 km^2, accounting for 50% of the total area. Soil water movement and heat transfer during the process of soil seasonally freezing have a high significance in agriculture, water resources and environment systems, and have an especially high significance for agricultural industry in cold regions.

Being affected by the experiment conditions, experimental analysis methods used to study water and heat movements in unsaturated seasonally frozen soil have certain limitations. However, theoretical analysis methods based on unsaturated soil hydrodynamics study the laws of dynamic changes for water and heat in unsaturated soil by means of establishing mathematical models for water–heat coupled movements in frozen soil system and solving the models by using numerical simulation. Thus, the method has universality and flexibility [1]. Water migration, water phase transition and heat transfer in soil freezing–thawing processes affect each other. In studying soil freezing–thawing processes, only comprehensively investigating the coupling effects of soil water and heat can yield true characterization of the objective physical mechanisms and laws of their movements. Currently the mathematical models describing soil water–heat coupled movements in freezing–thawing processes are mainly of two types: one type is the mechanism models based on viscous flow of liquid water in porous media and the heat balance of soil [2–6]; the other type is the thermodynamic models based on the water and heat fluxes of soil described as by irreversible thermodynamics theory [7]. The models of the first type cannot describe the divergence induced by ice lenses and models of the second type have poor suitability for conditions of lower subzero temperatures. In view of the engineering applications, a model of the first type was used in this study.

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