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Mathematical modeling and numerical simulation of water–heat coupled movements in a snow cover–soil union

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ABSTRACT

Snow cover is a common and relatively stable land cover condition in winter for cold north regions in China. Snow cover has significant effects on water and heat transfers in frozen soil; it needs to be considered in the study of frozen soil water–heat coupled movements. On the basis of previous research results and physical process analysis of water and heat movements in snow cover and soil, a snow cover–soil union water–heat coupled movements model is established in this paper. The numerical simulation was conducted by using a finite difference method. The results indicate that the simulated values have a similar trend to the measured values and the numerical simulation had big relative errors. However, the average absolute errors of the total and liquid moisture content in frozen soil were all less than 4%, and that of the frozen soil temperature was 1.37 °C. The errors of the numerical simulation were still within the acceptable range. Thus, the snow cover–soil union water–heat coupled movement model constructed in this paper is rational.

1. Introduction

Snow cover is good heat insulation for soil. Soil water migration, heat transfer and freezing situations are all greatly influenced by snow cover. In a large part of Northeast China (especially in the cold regions of the three provinces in the northeast of China), snow cover with a certain thickness, which can exist for 2–3 months, usually covers the topsoil during soil freezing periods. As a cover condition, snow cover greatly affects the heat transfer and energy absorption (or dissipation) of the underlying soil. When snow melts, snowmelt infiltrating downward changes the water balance of the soil horizon. At the same time, snow cover itself passes through a series of physical change processes including snow accumulation, densification and melting, and water and heat movement are important among the physical processes. Thus, researches into soil water and heat movement and the condition of snow cover have important theoretical value and practical significance for agricultural industry in cold regions.

Energy and water inputs of a snow cover model are decided by the upper boundary conditions, namely the meteorological conditions at a position about 2 m away from the soil surface, and the lower boundary conditions, namely soil conditions. The upper and lower boundaries determine the dynamic action processes of the model [1,2]. Researchers at home and abroad have established many energy balance models for snow cover [3,4]. For a snow cover water and heat movement model, the most representative models at home and abroad include SNOW-17 [5], SNTHERM [6], the snow cover model constructed by Loth et al. [7] and IAP94 [8,9]. Until now, the most comprehensive and systematic snow cover energy–mass balance model has been that established by Anderson in 1976, which included net radiation, latent heat, sensible heat, heat transfers caused by precipitation and changes of heat storage in snow cover. Anderson also analyzed the laws of snow cover thickening and densification and the disciplines of snowmelt movement and infiltration in snow cover in his studies [5]. The

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