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Evaluation and enhancement of the frozen soil parameterization in the Noah Land Surface Model over the Source Region of the Yellow River

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The Source Region of the Yellow River is located in the mosaic transition zones from seasonally frozen ground to, discontinuous and continuous permafrost on the northeastern Tibetan Plateau. Recently, significant degradation of frozen soil was reported with the properties of reduction in areal extent and thinning of frozen soil, which inevitably affect the water resources and grassland ecosystems in this area. In this study, to investigate the potential impact of frozen soil dynamics on the land surface water and heat exchanges, the Noah Land Surface Model was employed to simulate the freezing and thawing of soil using observational data spanning the period from September to December 2008 and recorded at the Maqu monitoring network over an area of approximately 40km$\times$80km in the Source Region of the Yellow River. The results indicate that the Noah Land Surface Model is capable of providing good simulations of the evolution of temperature and liquid water content in frozen soil, although the soil moisture is under-estimated. To achieve more reasonable estimation of soil water by the Noah Land Surface Model, two soil thermal conductivity parameterizations (Johansen's parameterization in Noah and de Vries's parameterization), three soil hydraulic conductivity equations (Campbell's equation in Noah, Clapp and Hornberger's equation and van Genuchten's equation), two unfrozen water parameterizations (Noah original form of the freezing-point depression equation and a more general form of the freezing-point depression equation), and two frozen soil permeability schemes (Noah original form and a scheme that introduces the concept of an exponential fractional permeable area and thus uses the total soil moisture to compute the hydraulic properties of the soil) were evaluated. Furthermore, the θ-based form of the Richard equation in the Noah Land Surface Model was substituted by the ψ-based form of the Richard equation to diagnose the impact of the typical soil stratification phenomenon on the freezing and thawing processes over the northeastern Tibetan Plateau.