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Designing realistic surface boundary conditions for groundwater models in permafrost regions

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The presence of permafrost strongly influences the storage and movement of groundwater by confining groundwater flow to the unfrozen zones above and below permafrost and in taliks (i.e. perennially unfrozen zones). Permafrost thaw due to climate warming modifies hydrological processes by increasing hydraulic conductivity by several orders of magnitude. To improve our knowledge on the impact of climate change on northern hydrology and on the role of groundwater flow on permafrost thaw, groundwater modelling tools have been developed during the last decade to include freezing and thawing processes and its impact on soil properties. These models have revealed new insights into Arctic hydrological systems, but considerable uncertainty remains regarding the design and parameterization of surface boundary conditions that represent thermal and hydrologic climate change phenomenon at the land surface. The employed boundary conditions are usually very limited and not adapted to cold regions. Herein, we develop different sets of thermal and hydrologic surface boundary conditions adapted specifically for cold regions. These include a seasonally varying recharge boundary condition and a surface energy balance that considers different surface processes. We then test these boundary conditions in saturated and unsaturated conditions and compare the simulation outcomes with models in a similar setting using traditional boundary condition forms. From these analyses, we determine which boundary conditions exert a strong influence on the model outcomes and provide recommendations for which boundary conditions to use depending on the setting. This study provides the first guidelines to develop realistic and effective conceptual and numerical groundwater models in cold regions and will allow stakeholders to apply these models for different purposes such as managing water resources in the Arctic.