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Spatially distributed tracer-aided modelling of dynamics in storage and water ages in a permafrost influenced catchment

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Permafrost strongly controls hydrological processes in cold regions, and our understanding of how changes in seasonal and perennial frozen ground disposition and linked storage dynamics affects runoff generation processes remains limited. Storage dynamics and water redistribution are affected by the seasonal variability and spatial heterogeneity of frozen ground, snow accumulation and melt. Stable isotopes are useful to quantify the dynamics of water sources, flow paths and ages, yet few studies have employed isotope data in permafrost-influenced catchments. Here, we applied the model STARR (Spatially distributed Tracer-Aided Rainfall-Runoff model) which facilitates fully distributed simulations of hydrological storage dynamics and runoff process, isotopic composition and water ages. We adapted this model to a subarctic catchment in Yukon Territory, Canada, with a time variable implementation of field capacity to include the influence of thaw dynamics. A multi-criteria calibration based on streamflow, snowpack and isotopes was applied to validate three years of daily data. The integration of isotope data in the spatially distributed model provided the basis to quantify spatio-temporal dynamics of water storages and ages underlying the importance of thaw layer dynamics in mixing and damping the melt signal. By using the model conceptualisation of spatio-temporal variant storages, this study demonstrates the value of tracer-aided modelling to capture thaw layer dynamics and to quantify storage and age dynamics in permafrost environment for the first time.