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Data analysis and hydrological modelling of frozen ground, shallow groundwater formation and river flow co-evolution at small watersheds of Russia in continuous, discontinuous permafrost and the zone of seasonal ground freezing

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Frozen ground distribution and its properties control the presence of aquifuge and aquifers. Correct representation of interactions between infiltrating water, ground ice, permafrost or seasonal freezing table and river flow is challenging for hydrological modelling in cold regions. Observational data of ground water levels, thawing depths in different landscapes or topographical units and meteorological information with high temporal and spatial resolution are required to analyze seasonal and interannual evolution of groundwater in active layer and its linkage to river flow. Such data are extremely rare in vast and remote regions of Russia. There are few historical datasets inherited from former USSR containing unique collection of long-term daily observations of water fluxes, frozen ground characteristics and groundwater levels. The data from three water balance stations were employed in our study with overall goal to analyze co-evolution of thawing layer, shallow groundwater and river flow by data processing and process-based modelling.

Three instrumented small watersheds are situated in continuous, discontinuous permafrost zones and at the territory with seasonally frozen ground. They present different climates, landscapes and geology. The Kolyma water-balance station is located in mountainous region of continuous permafrost in North-Eastern Russia. The watershed area of 22 km2 is covered by bare rocks, mountain tundra, sparse larch forest and wet larch forest depending on slope aspect and inclination. The Bomnak water-balance station (22 km2) is situated in discontinuous permafrost zone in upper part of the Amur River basin and characterized by unmerged permafrost. Dominant landscapes are birch forest and bogs. The Pribaltiyskaya water-balance station (40 km2) located in Latvia is characterized by seasonally frozen ground and is covered by mixed forest and arable land.

Process-based Hydrograph model was employed in the study. The model was developed specifically for cold regions. It describes all essential processes of land hydrological cycle including detailed algorithm of water and heat dynamics in soil accounting for water phase change. The model parameters relate to basin characteristics and could be assessed in the field. It allows avoiding parameters calibration and transferring model parameterization schemes to ungauged basins in similar conditions. The model was applied and tested against internal states of watersheds (snow, soil thawing/freezing, etc.) and runoff.

Different role of frozen ground in formation of shallow groundwater and river flow in continuous, discontinuous and non-permafrost area is highlighted by comparative analysis of observations and simulations in three studied basins. The changes of fractional input of surface and subsurface components into river flow during warm seasons were assessed for each watershed. We concluded that verified hydrological model with meaningful parameters that adequately describe river flow formation and internal hydrological processes and ground freezing/thawing in the catchment could be used in scenario simulations, future predictions and transferring the results between scales.