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Editorial: The cold regions in transition: Impacts on soil and groundwater biogeochemistry

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Editorial on the Research Topic
The cold regions in transition: Impacts on soil and groundwater biogeochemistry

Global climate warming disproportionately affects the ecosystems of the high-latitude cold regions, which can facilitate agricultural expansion, urban growth, and natural resource development, adding growing anthropogenic pressures to cold regions' landscapes, soil health, and biodiversity (Hansen et al., 2010; IPCC–Intergovernmental Panel on Climate Change, 2021; Pi et al., 2021). The terrestrial ecosystems in northern cold regions, including Arctic and subarctic regions, comprise components that are especially vulnerable to warming—snow cover and permafrost—as well as soil microbial communities adapted to cold temperatures. These changes are accompanied by changes in vegetation cover, the thermal regime of soils, fluxes, and timing of nutrient export to aquatic ecosystems, emissions of greenhouse gases (GHGs), and the mobilization of organic carbon and geogenic contaminants, among others (Edwards et al., 2007; Brooks et al., 2011; Hayashi, 2013; Kurylyk et al., 2014). Consequently, elucidating how these changes affect soil biogeochemical processes and fluxes is essential for predicting carbon and nutrient availability in subsurface and impacts on groundwater and surface water quality (Matzner et al., 2008; Cochand et al., 2019). For instance, the often-reported spring pulses of dissolved carbon and nutrients in cold regions' terrestrial ecosystems reflect the cumulated effects of hydro(bio)geochemical processes on the belowground pools of bioactive elements, the dynamic response of the soil microbial community to changes in hydrology and geochemistry that accompany spring snowmelt, and associated water quality and ecological impacts (Henry, 2007, Henry, 2008; Hayashi et al., 2013; Kurylyk et al., 2014; Lundberg et al., 2016). Thus, climate warming generates a set of interrelated changes in (hydro)geophysical properties, hydro(geo)logical flows, biogeochemical processes, and ecosystem functions in the world's cold regions.

Research on how cold regions' microorganisms respond to shifts in environmental conditions is of particular importance for anticipating how a warming climate will affect the biogeochemical cycling of carbon, nutrients, metals, and pollutants in the Earth's cold regions. Quantifying the variability in cold region processes remains challenging but is, however, critical to unravel the linkages between climate warming and biogeochemical responses in cold climate ecosystems. The complex interconnections of hydro(bio) geochemical processes in cold regions also poses multiple challenges to their realistic representation in Earth system models. Thus, future climate uncertainties highlight the need to develop and couple cutting edge-experimental approaches to biogeochemistry-hydrology models to identify and predict the major controls on soil biogeochemical functioning in cold regions under variations in the magnitude and timing of snow processes, ice cover, permafrost thaw, and freeze-thaw cycles. However, significant uncertainties prevail in quantifying and predicting the hydro(bio)geochemical processes of terrestrial ecosystems in cold regions. Further advances in the predictive understanding of how cold regions' processes, functions, and ecosystem services respond to climate warming and land-use changes require multiscale monitoring technologies coupled with integrated observational and modeling tools.

This Research Topic brings together hydrologists, biologists, ecologists, soil scientists, biochemists, and geochemists to share research in various areas that advances our mechanistic understanding of the subsurface hydro(bio)geochemical processes and microbial-plant interactions in cold regions, with an emphasis on the fate and transport of carbon, nutrients, and micro-pollutants in response to climate change in cold region ecosystems. The resultant Research Topic of papers covers a broad snapshot of our understanding of how biogeochemical transformations and the movement of water in cold regions impacts the concentration and mobility of nutrients, microbial community dynamics, carbon cycling, and GHG emissions. The assembled papers provide important new information that addresses critical knowledge gaps on the role of dynamic climatic and hydrological conditions on modulating (bio) geochemical processes of nutrients, carbon fluxes, as well as the coupling/decoupling of microbial and plant interactions in sub-snow and cold region environments.

The impact of climate warming and environmental change on hydrological processes and subsequent impacts on soil and groundwater biogeochemical cycling are apparent and all papers in this Research Topic showcase the complex nature of biogeochemical functioning and hydrochemistry in cold regions under current and future climate change. Several authors highlighted the complex controls and interactions of the winter warming and freeze-thaw cycles on hydrological and biogeochemical processes. Coppolino et al. investigated the impacts of freeze-thaw cycles on reactive soil phosphorus fractions and microbial activity for a riparian floodplain wetland soil using the controlled experiments to identify how repetitive freeze-thaw cycles may shift pools of soil phosphorus and impact microbial responses to phosphorus. Their results support that soil freeze-thaw cycles have the potential to modify phosphorus dynamics. Liu et al. examined the impact of freeze-thaw cycles on hydro-physical properties and dissolved organic carbon fluxes from peat soils. This study illustrates how the changes in peat physical and hydrological properties during the winter conditions play important roles in water flow and nutrients export in peatlands. Badewa et al. quantified and compared the greenhouse gas fluxes from agricultural soil amended with biobased residues and nitrogen fertilizer during the spring freeze-thaw events. Their results show that the greenhouse gas production is significantly less when biobased residues like compost replaces widely used nitrogen fertilizer during spring freeze-thaw events in cold temperate regions.

Several authors demonstrated the effects of winter warming and freeze-thaw cycles on nitrogen leaching and microbial communities in soils. Green et al. assessed the effects of winter pulsed warming and snowmelt on nitrogen cycling in agricultural soils. Their field-scale lysimeter experiment results show that increased winter pulsed warming and snowmelt over the non-growing season causes increased loss of nitrogen from agricultural soils as nitrous oxide emissions in silt loam soils and nitrate leaching in loamy sand soils. Using the same field-scale lysimeters designed to study ecosystem services from agricultural soils, Lapierre et al. further investigated the effect of simulated winter warming and soil types on nitrate leaching from cover crops for both loamy sand and silt loam soils. Their results demonstrate that winter pulsed warming can influence overwinter drainage for both soil types, but the nitrate leaching only in the loamy sand soil. Krogstad et al. and Jensen et al. examined the effects of freeze-thaw cycles on nitrogen, sulfate, and chloride leaching from fertilized and unfertilized soil columns and evaluated the impact on the microbial community compositions. Their experiment and model results show that freeze-thaw cycles promote nitrifying conditions in the upper oxidized portion of the fertilized soil columns and microbial community composition remained stable independent of nutrient availability despite the nitrification observed.

With > 30 authors, this Research Topic identifies some key priorities for future research in cold regions' biogeochemical transformation and processes. This Research Topic highlights the need for a more detailed understanding of the transient response of biogeochemistry to climate warming in soils of cold climate terrestrial ecosystems. The authors emphasize the need for more integrated research efforts into the physical, hydrological, and climatic processes that regulate cold regions biogeochemical processes. The further development of interdisciplinary linkages between the hydro-physical setting and biogeochemical processes is considered essential for a process-based and mechanistic understanding of cold region functions and the feedbacks associated with these linkages require further studies.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

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