Impact of permafrost thaw on hydrological connectivity between soils and surface waters

Lucie Germain[1,2], Sophie Opfergelt[2], Antoine Séjourné[3], Sarah Ollivier[3], & Laure Gandois[1]

[1] Center for Research on Biodiversity and Environment – Université de Toulouse – Toulouse INP – CNRS – IRD, Toulouse, France
[2] Earth and Life Institute – Université Catholique de Louvain, Louvain-la-Neuve, Belgium
[3] GEOPS – Université Paris-Saclay – CNRS, Orsay, France

ABSTRACT

In recent decades, permafrost degradation and changing freeze-thaw conditions have intensified the hydrologic cycle and changed hydrogeological processes in Arctic environments. The gradual deepening of the active layer, the lowering of supra-permafrost water tables, the expansion of taliks, and in some places the thawing of ice-rich permafrost, restructure existing pathways and create new ones for water flow and infiltration. In particular, the abrupt thaw of ice-rich permafrost causes localized ground subsidence, which redirects water towards collapsed areas, resulting in the formation of thermokarst lakes.

Such changes influence soil moisture regimes. Permafrost thaw and melting ground ice can lead to enhanced drainage and thus soil drying. On the contrary, concurrent land subsidence and thermokarst lake formation increase soil saturation. This results in either aerobic or anaerobic conditions, which strongly affect the type and magnitude of greenhouse gas emissions upon permafrost thaw. Additionally, in the active layer, sites of soil-water exchange serve as locations for organic carbon mobilization. These sites were previously considered connected during summer and isolated during winter. However, with Arctic warming, unfrozen winter soils may now provide new sites for organic carbon exchange between soil and soil pore water. This may extend the duration over which carbon in the active layer remains biogeochemically connected to lateral and vertical transport pathways.

This study aims to explore the evolving connectivity between aquatic and terrestrial ecosystems in the context of permafrost thaw. With the deepening of the active layer, soil water is expected to infiltrate mineral-rich horizons. To detect these hydrological changes, geochemical tracers of mineral weathering such as silicon isotopes ($\delta^{30}Si$) and radiogenic strontium isotopes ($^{87}Sr/^{86}Sr$) are well-suited. We analyzed these tracers in water samples collected during summer 2023 from lakes, ponds and soils in the areas of Beaver Creek, Yukon, Canada and of Churchill, Manitoba, Canada. These sites represent either mineral-rich or organic-rich contexts and display a gradient of permafrost degradation. In the Beaver Creek area, we compared a newly formed thermokarst lake to an older lake with long-standing soil-water connectivity but recent permafrost degradation nearby. In the Churchill area, geochemical tracers helped determine whether and how permafrost thaw influences water chemistry in trough ponds and larger depressions formed by recent ice-wedge polygons degradation.