Paleoenvironmental reconstructions and greenhouse gas characterization in permafrost aquatic systems of Central Yakutia (Siberia)

Keywords:

permafrost, thermokarst, paleolimnology, greenhouse gases, Siberia

Abstract (short description):

Central Yakutia (Siberia) contains one of the thickest and ice-richest permafrost in the world, and the region is currently experiencing important landscape changes. Among the major impacts of these changes is the mobilization of organic carbon caused by permafrost thawing, resulting in greenhouse gas (GHG) emissions to the atmosphere. However, there is a high heterogeneity in ages, sources, and emission rates of GHG in space and time. With this thesis we aim to investigate this complexity in a representative landscape unit along three major axes: 1) GHG characterization, 2) permafrost dynamics, and 3) lake evolution.

Context:

Central Yakutia is a land of climatic extremes. Average amplitude of monthly temperatures is around 60 °C between January (mean -41 °C) and July (mean 19 °C). Annual precipitation is generally low (~ 200 mm) but can vary and is mainly concentrated during the summer. Permafrost is continuous, thick (> 500 m deep), and can be extremely rich in ground ice (50-90 % by volume), as represented by Pleistocene ice wedges of > 10 m in vertical extent. Nearly half of the landscape has been affected by thermokarst (thawing of ice-rich permafrost) since the early Holocene, resulting in the formation of thousands of partly drained depressions known as alases. However, recent thermokarst activity, related to natural landscape evolution, increasing air temperatures and/or human-induced landscape modifications (agriculture, clear-cutting), is also occurring in the region, as shown by the presence of numerous small and young, fast developing lakes and retrogressive thaw slumps along lake shores. The landscape is thus highly dynamic; yet the competing driving factors (climate vs. local geomorphology or vegetation development) and the timing of such changes (gradual vs. rapid/threshold) are complex to characterize and quantify at the regional scale.

Frozen soils contain globally twice as much carbon as the atmosphere. Greenhouse gases (CO_2, CH_4) can be emitted in great quantities in thawing permafrost landscapes, especially from the bottom sediments of seasonally anoxic aquatic ecosystems where methanogens (CH_4-producing bacteria) are thriving. Gas ebullition and diffusion through the water column are generally the main emitting mechanisms in thermokarst lakes, although their specific contribution can greatly vary between sites, waterbody types and time of the year. This will dictate the proportion of CH_4 to CO_2 emitted, thus the amplitude of the potential feedback on climate from permafrost thaw. Thermokarst landscapes can thus be considered as biogeochemical ‘hotspots’ and are at the forefront of recent and ongoing climate changes.

Objectives:

The main objective of this PhD project is to study processes and feedbacks between permafrost degradation, lake development and greenhouse gas production in a typical landscape unit of Central Yakutia at a high spatial and temporal resolution level. Combining present-day characterization (gases, water, sediments and soil) with paleoenvironmental reconstructions, the project will investigate three main axes (resulting in three thesis chapters/papers):

1) Age, sources and fluxes of greenhouse gases in lakes of different origins/ages (from early Holocene alas lakes to modern thermokarst lakes).
2) Past and present permafrost dynamics in the landscape, especially progressive *vs*. abrupt disturbances (ex. gradual ground surface subsidence *vs*. rapid thaw slumps).
3) Lake inception and development through time, especially sediment inputs and water balance (ex. evaporation or drainage events).

Methods overview:

1) Sampling of dissolved and ebullition gases (CO_2, CH_4) at the end of the ice-free season (between summer thermal stratification and fall overturn).
   Analyses: gas chromatography (quantity, composition); stable isotopes (^{13}C, ^{2}H – sources); radiocarbon dating (^{14}C age).
2) Sampling of permafrost (cross-section, cores) and active-layer monitoring along representative lake shores and in open areas between lakes.
   Analyses: ground ice content (mass/volume), organic matter content, C and N, grain size analysis, radiocarbon dating (plant remains), ground temperature.
3) Lake sediment coring, sediment traps (optical and/or homemade), bathymetry, lakewater chemistry and physical properties.
   Analyses: loss-on-ignition (LOI) and carbon analyses (TC/TOC), microfossils (diatoms/pollens), X-ray diffraction (XRD), X-ray fluorescence (XRF), C and N (elemental + stable isotopes), and radiocarbon dating for sediments. Ions, major/minor elements, dissolved organic matter/carbon (DOC/DOM), stable isotopes, and basic profiles (T, O_2, pH, conductivity) for water.

Thesis supervision:

The thesis will be supervised by **Frédéric Bouchard** (paleolimnology and biogeochemistry) and **François Costard** (periglacial geomorphology) at Géosciences Paris Sud (GEOPS), and by **Christine Hatté** (geochemistry and paleoclimatology) at the Laboratoire des Sciences du Climat et de l’Environnement (LSCE). The project will be conducted in the context of the project ‘*PEGS’ – PErmafrost and Greenhouse gas dynamics in Siberia* (2018-2022) funded by the ‘Make Our Planet Great Again’ initiative, for which a strong collaboration between LSCE and GEOPS scientists is being developed.

National and international collaborations:

- Antoine Séjourné (GEOPS): permafrost, thermokarst, fieldwork in Siberia
- Christelle Marlin (GEOPS): cold-region hydro(geo)logy, geochemistry
- Christophe Grenier (LSCE): hydro(geo)logy, modelling, fieldwork in Siberia
- Boris Biskaborn (Alfred Wegener Institute, Germany): paleolimnology
- Daniel Fortier (Université de Montréal, Canada): periglacial geomorphology
- Isabelle Laurion (INRS-ETE, Canada) : greenhouse gas dynamics

Candidate profile and skills:

- Background in geology, geochemistry, or a related discipline in Earth sciences
- Experience in fieldwork, working in remote locations, good physical shape
- Oral and written skills in English
- Experience in statistical analysis and R (or willing to learn it)
- Efficiency in GIS and/or remote sensing an asset
- Motivation, curiosity, self-reliance

Tentative schedule:

- Fall 2018 (October): official start of the project.
- Winter-summer 2018: literature review, fieldwork prep.
- August/September 2019: field season 1.
- Fall 2019 – Summer 2020: lab analyses, doctoral exam, fieldwork prep.
- August/September 2020: field season 2.
- Fall 2020 – Summer 2021: lab analyses, paper writing.
- Fall 2021: thesis submission (initial), thesis defense, final submission.

Funding:

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