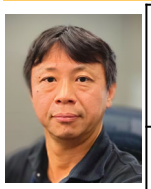
【Grant-in-Aid for Scientific Research (S)】

Future Trajectories of Boreal Forest Ecosystems: Transient Biosphere Responses to Permafrost Thaw



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Project Information	Project Number : 25H00454　Project Period (FY) : 2025-2029 Keywords : Boreal forests, permafrost thaw, global warming, greenhouse gas emissions

Purpose and Background of the Research

●Outline of the Research

In the Arctic-Boreal region, where warming is progressing up to four times faster than the global average, it is projected that by the 2070s, permafrost in the surrounding areas will have largely disappeared. During the thawing process of permafrost, the decomposition of soil organic matter is expected to accelerate, raising concerns about increased emissions of CO_2 and CH_4. However, according to the IPCC AR6, the estimated amount of carbon released from this region is associated with very low confidence. The lack of experimental data required to advance the performance of future projection models remains a major barrier to resolving this issue.

This study focuses on boreal forests in Alaska—one of the hotspots of permafrost thaw—and addresses the following scientific questions:

- How will various functions of plants and soils undergo transient changes in response to rapid warming and changes in surface soil conditions in the near future?
- How are greenhouse gas emissions, which contribute to accelerated warming, associated with transient changes in biological functions?

●Research objectives

- Focusing primarily on evergreen coniferous forests, we aim to elucidate the transient responses of biosphere functions—such as greenhouse gas (CO_2 and CH_4) emissions—to permafrost thaw
- Based on the observational results, we will model changes in biosphere functions under progressing permafrost thaw and improvement guidelines for land surface (ecosystem) models.

- *Experiments under controlled environmental conditions*
- *Multi-site field experiments in boreal forest ecosystems*
- *Proposal of a new model for bio-environment interaction processes*

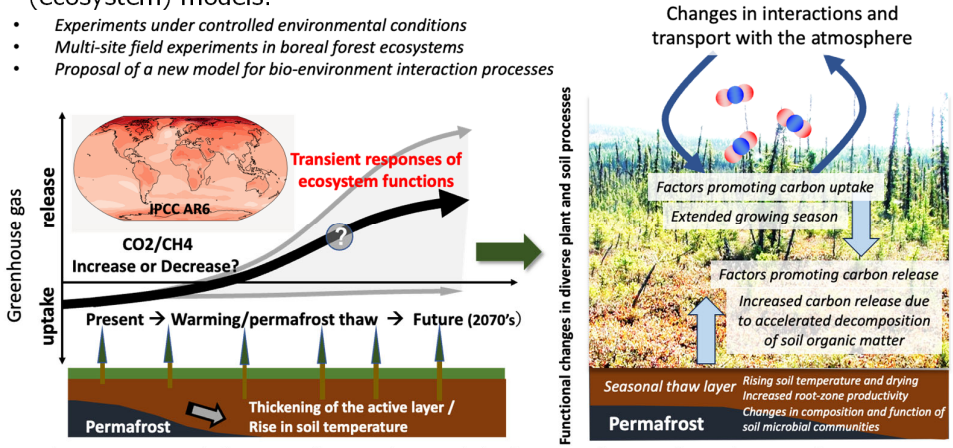

Figure 1.Research framework to understand the impact of permaforst thaw on the ecosystem functioing and greenhouse gas emission

●Novelty of the research

In a prior study led by PI, we developed a field experimental system to examine ecosystem responses to permafrost thaw by installing underground heating devices. The permafrost thawing experiment began in spring 2023. The experimental site consists of two adjacent plots: a "warming plot" where the soil is heated by underground heaters, and a "control plot" with no heating. The comparative analysis between these plots allows for the evaluation of the ecological impacts of permafrost thaw.

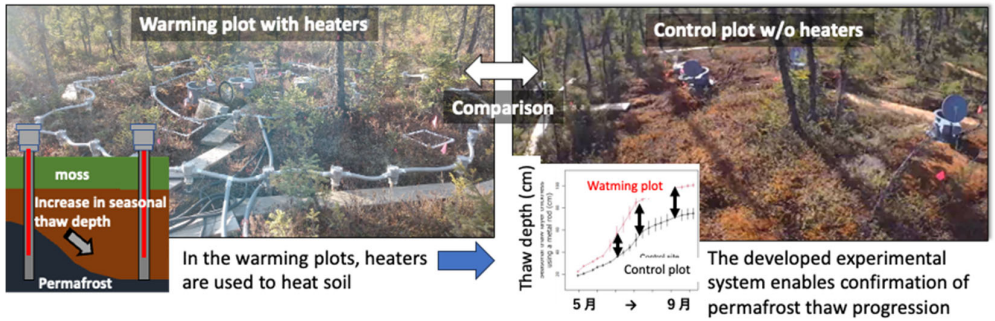

Figure 2. The field experimental site used in this study. Heaters are installed around the warming plots to gradually increase the temperature within the area.

Expected Research Achievements

This study focuses on evergreen coniferous forests in interior Alaska to investigate transient responses of biological functions and greenhouse gas fluxes by integrating field observations, laboratory incubations, and numerical modeling. Theme A analyzes CO_2 and CH_4 emissions, isotopic ratios, and microbial functions under controlled temperature and moisture conditions. Theme B compares warming and control plots to monitor gas fluxes, phenology, root dynamics, and litter decomposition, with additional small-scale warming plots nearby. Theme C validates land surface models at site scale using observation data. The integrated findings will clarify how permafrost thaw alters ecosystem functions and greenhouse gas dynamics, contributing to improved prediction models.

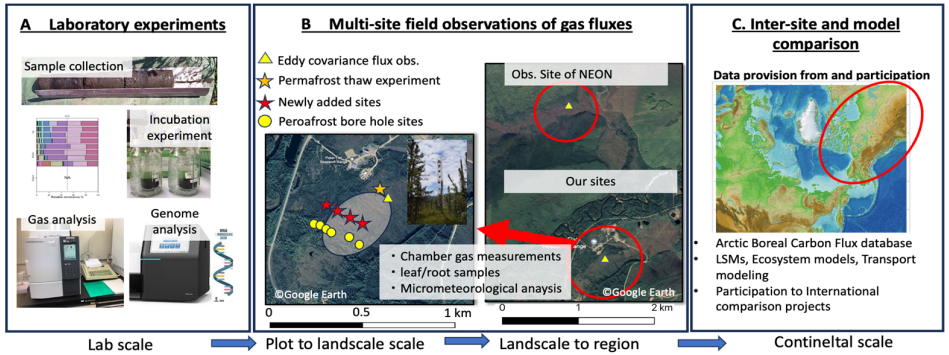

Figure 3. Overview of the Research Implementation. Through the three sub-themes A, B, and C, this project proposes fundamental bio-environment interaction processes that can be incorporated into future prediction models.

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