EARTHSCIENCES

# Regional impacts of supraglacial lake drainage on ice-flow dynamics

| | |
|---|---|
| **Primary supervisor:** | Laura Stevens |
| **Co supervisor(s):** | Ian Hewitt, Mathematical Institute |
| **Key words:** | glaciology, subglacial hydrology, Greenland Ice Sheet, geodesy |
| **Research theme(s):** | • Geophysics and Geodynamics<br>• Geodesy, Tectonics, Volcanology and related hazards<br>• Oceanography, Climate and Palaeoenvironment |
| **Eligible courses for this project:** | • Environmental Research (NERC DTP)<br>• Intelligent Earth (UKRI CDT) |

This project is well suited for a researcher interested in glaciology, geodesy, data analysis, and numerical modelling, who has a background in earth science, physics, mathematics, or related fields. Prior fieldwork experience and/or prior research in glaciology is not expected, nor is such experience required as a prerequisite for successfully completing this project!

## Overview

Mass loss from the Greenland Ice Sheet is accelerating, partly due to increases in the rate at which ice flows out to the ocean. Ongoing increases in the magnitude and spatial extent of surface melting play a complex role in this process: meltwater flows down through hundreds of meters of ice to the ice-sheet bed, lubricates the ice-bed interface, and modulates flow speeds on hourly to decadal timescales. As the area of the ice surface that endures melting continues to expand inland as the climate warms [*MacFerrin et al.*, 2019], a leading question is: *Will a larger area of the ice sheet receive injections of meltwater, and, if so, will this lead to faster flow?*

It has been hypothesized that meltwater reaching the ice-sheet bed could destabilize significant regions of the interior ice sheet [*Alley et al.*, 2005]. However, this hypothesis has not yet been tested by targeted observations or numerical modelling. Answering the question of whether, and when, the ice-sheet interior will *dynamically* respond to surface melt is vital for predicting future sea-level rise.

To tackle this question, a deeper understanding of the processes involved in moving meltwater into and through the subglacial drainage system is required. Rapid drainage of supraglacial lakes can deliver high rates of water to the bed over a few hours [*Das et al.*, 2008]. Moulins can deliver a constant supply of meltwater to the bed over the entire melt season. The ice-flow response to the combination of both lake and moulin meltwater inputs to the subglacial drainage system is not well understood on the local, regional, or continental scale. This is due, in part, to a lack of observations of lake-drainage events over a regional area and the difficultly of incorporating the high rates of water input to the ice-sheet bed during lake-drainage events (~400 $m^3$ $s^{-1}$) into drainage-system models.

To tackle these hurdles, this project will combine data analysis and numerical modelling approaches to quantify how ice-sheet basal sliding and stresses may be perturbed by subglacial water flow [*Stevens et al.*, 2015; 2024]. Are stresses in ice-sheet regions experiencing new surface melt large enough to trigger the drainage of lakes via hydrofracture? Might these stresses be caused by the basal water movement following the drainage of nearby lakes? The final, broad project goal is thus to determine how stress perturbations within the ice sheet can promote or inhibit the formation of new surface-to-bed meltwater pathways.

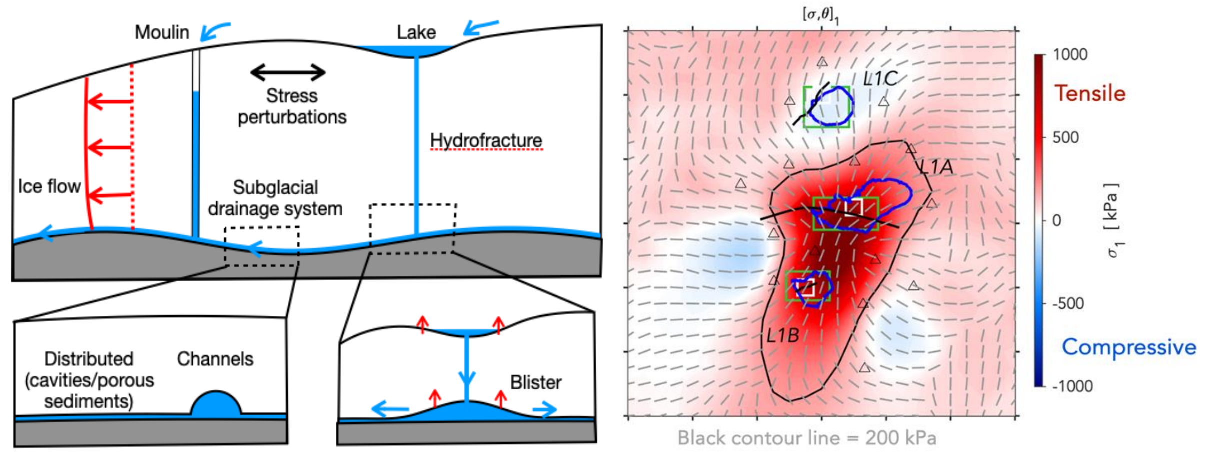


*Figure 1. A fundamental challenge remains in understanding how water moves through the drainage system, and whether this movement causes stress perturbations in the overlying ice. (left) Ice-sheet cross section showing moulin and lake-drainage pathways for surface meltwater to reach the bed. Insets highlight different drainage-system components: (bottom left) distributed and channelized drainage and (bottom right) a water-filled blister. (right) Modelled maximum principal stress of the ice-sheet surface during the drainage of two supraglacial lakes (L1A, L1B) via hydro-fracture constrained by (black triangles) GNSS observations (from Stevens et al., 2024).*

## Methodology

Our approach lies at an exciting intersection between field observations and numerical modelling. The researcher will first use field observations to quantify the ice-flow response to supraglacial lake drainage events and moulin meltwater inputs to the ice-sheet bed [e.g., *Stevens et al.*, 2015; 2024]. This task will involve analysing timeseries of ice-sheet surface displacements from an array of on-ice GNSS receivers deployed from May 2022–September 2023 around of a set of lakes and moulins in West Greenland. Next, field data and meltwater reanalysis products will be used to motivate and constrain numerical modelling of the movement of water through the subglacial drainage system [e.g., *Hewitt*, 2013; *Stevens et al.*, 2018; 2022]. The final goal will be to determine when and how this water movement causes changes in both ice-sheet basal sliding and ice-sheet stresses.

## Timeline

**Year 1**: NERC DTP Core Training Programme; literature survey; initial analysis and inversion of GNSS data; local-scale subglacial hydrology modelling; satellite remote sensing of lake-drainage timing; presentation of research at a national conference (e.g., International Glaciological Society–British Branch).

**Years 2 and 3**: Further GNSS analysis, including the impact of spatiotemporally clustered hydro-fracture events on ice flow and ice-sheet stress on a regional scale; initial writing of papers for international journals; presentation of research at international conferences (e.g., EGU, International Glaciological Society).

**Year 4**: Integration of GNSS and subglacial hydrology modelling components; thesis completion; continued writing of papers for international journals; presentation of research at an international conference (e.g., AGU).

## Training & Skills

The supervisory team are leaders in observational glaciology (L. Stevens) and mathematical models applied to glaciers and ice sheets (I. Hewitt). As part of this project, you will learn how to analyse GNSS data of ice-sheet surface deformation nearby lake-drainage events. The data analysis and interpretation will involve collaborations with faculty, postdoctoral scientists, and graduate researchers in the US and the UK. You will also be trained in the use of sophisticated computational modelling techniques that enhance our understanding of ice flow and subglacial-hydrology processes. You will receive training and guidance on how to analyse, interpret, and synthesize observational data and model output, how to present scientific results, and how to write scientific papers for publication.

## References & Further Reading

Alley et al. (2005), Access of surface meltwater to beds of sub-freezing glaciers: preliminary insights, *Ann. Glaciol.*, *40*, 8–14.

Das et al. (2008), Fracture Propagation to the Base of the Greenland Ice Sheet During Supraglacial Lake Drainage, *Science*, *320*, 778–781.

Hewitt (2013), Seasonal changes in ice sheet motion due to melt water lubrication. *Earth Planet. Sci. Lett.* 371, 16–25.

MacFerrin et al. (2019), Rapid expansion of Greenland's low-permeability ice slabs. *Nature, 573*, 403–407.

Stevens et al. (2015), Greenland supraglacial lake drainages triggered by hydrologically induced basal slip, *Nature*, *522*, 73–76.

Stevens et al. (2018), Relationship between Greenland Ice Sheet surface speed and modeled effective pressure, *J. Geophys. Res. Earth Surf.*, *123*, 2258–2278.

Stevens et al. (2022), Tidewater-glacier response to supraglacial lake drainage, *Nature Communications*. 13:6065.

Stevens et al. (2024), Elastic stress coupling between supraglacial lakes, *J. Geophys. Res. Earth Surf.*, 129, e2023JF007481.

## Further Information

Laura Stevens (laura.stevens@earth.ox.ac.uk) and Ian Hewitt (hewitt@maths.ox.ac.uk).