The University of Oxford Department of Earth Sciences

EARTHSCIENCES

UNIVERSITY OF OXFORD

Drainage dynamics of neighbouring Greenland supraglacial lakes from satellite remote sensing observations

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Key Words	Glaciology, Remote Sensing, Hydrology

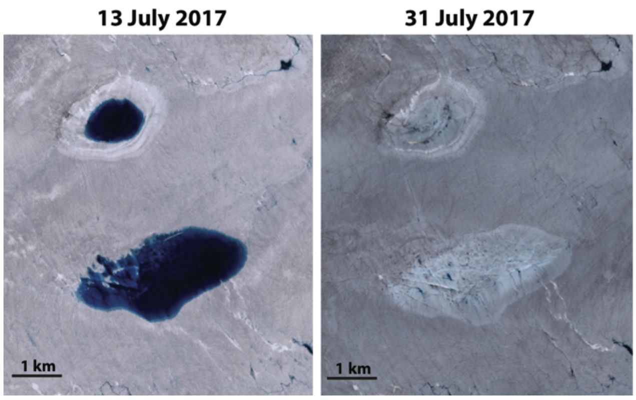
Overview

Mass loss from the Greenland Ice Sheet is accelerating, partly due to increases in the rate at which ice flows out to the ocean [*King et al.*, 2020]. 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 ice 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?*

Although it is possible for water to hydro-fracture to the bed through thick, cold ice [*Das et al.,* 2008], whether it happens in any particular location is controlled by the stress state of the ice [*Stevens et al.,* 2015]. For example, it is currently unclear how vulnerable the thicker, inland regions of the ice sheet are to hydro-fracture. While it has been hypothesized that surface-to-bed meltwater injection in the ice-sheet interior could destabilize significant regions of the ice sheet [*Alley et al.*, 2005], this has not been tested by targeted observations. Answering the question of whether, and when, the Greenland Ice Sheet interior will *dynamically* respond to surface melt is vital for predicting future sea-level rise [*Meredith and Sommerkorn*, 2019].

To tackle this question, a deeper understanding of the processes involved in getting surface meltwater to the bed is required. Rapid drainage of supraglacial lakes generates new surface-to-bed meltwater pathways [*Das et al.*, 2008]. The expanding range of supraglacial lakes has been tracked in satellite imagery over recent decades [*Howat et al.*, 2013]. However, the locations of emerging inland lakes may not correlate well with where the meltwater stored in the lakes reaches the bed [*Stevens et al.*, 2015]. Currently, rather than rapidly draining to the bed, inland lakes mostly drain supraglacially for 10s of kilometres, before entering lower-elevation, pre-existing surface-to-bed pathways [*Poinar et al.*, 2015].

A fundamental challenge in predicting the ice sheet's dynamic response to the formation of upper-elevation supraglacial lakes is quantifying the drainage timing, dynamics, and volume of these supraglacial lakes. Are upper-elevation lake drainages triggered by the drainage of neighbouring or lower-elevation lakes? And, how do upper-elevation lake drainages contribute to subglacial drainage system evolution?



Satellite images of two neighbouring supraglacial lakes. A project goal is to quantify the volume and drainage dynamics of populations of supraglacial lakes. Images are from ESA Sentinel-2, with left image showing two lakes prior to drainage and right image showing two empty lake basins. Additional smaller lakes, supraglacial streams, and surface fractures are visible.

Methodology

The student will use observations from satellite remote sensing, pressure sensors within supraglacial lakes, and numerical modelling to measure the transfer of water to the ice-sheet bed in regions of existing and emerging supraglacial lakes. This project will involve collaborations with US researchers, and will be in coordination with an active field campaign on the Greenland Ice Sheet. The student will combine high temporal resolution (minutes) pressure sensor data with regional satellite images at lower temporal resolution (days to months) to determine the drainage characteristics of a population of neighbouring lakes. The student will investigate a regional area of lakes in coordination with the active field campaign, as well as regions of emerging supraglacial lakes across the Greenland Ice Sheet. Finally, the student will ideally incorporate forward modelling techniques in supra- or subglacial hydrology [*Stevens et al.,* 2018] to test interpretations of remote sensing observations and field data.

Timeline

Year 1: NERC DTP Core Training Programme, initial code development and data analysis of satellite imagery and altimetry.

Years 2 and 3: Remote sensing data analysis, pressure sensor data analysis, subglacial hydrology modelling, presentation of research at international conferences (EGU, IGS).

Year 4: Integration of remote sensing, pressure sensor, and subglacial hydrology project components, thesis completion, papers for international journals, presentation of research at an international conference (AGU).

Training & Skills

The supervisory team are leaders in observational glaciology (L. Stevens) and physical oceanography (Helen Johnson).

As part of this project you will learn how to process and analyse satellite remote sensing data from a variety of optical, radar, and laser altimeter sources: Landsat, Sentinel-1, Sentinel-2, and ICESat-2, among others. Data analysis and interpretation will involve collaborations with researchers and graduate students in the US in conjunction with an active Greenland field campaign. You will also be trained in the use of forward modelling techniques that enhance our understanding of subglacial hydrology processes. You will receive training and guidance on how to analyse and interpret data and model output, how to present scientific results, and how to write scientific papers for publication.

References & Further Reading

Alley, R. B., T. K. Dupont, B. R. Parizek, and S. Anandakrishnan (2005), Access of surface meltwater to beds of sub-freezing glaciers: preliminary insights, *Ann. Glaciol.*, *40*, 8–14.

Das, S. B., I. Joughin, M. D. Behn, I. M. Howat, M. A. King, D. Lizarralde, and M. P. Bhatia (2008), Fracture Propagation to the Base of the Greenland Ice Sheet During Supraglacial Lake Drainage, *Science*, *320*, 778–781.

Howat, I. M., S. de la Peña, J. H. van Angelen, J. T. M. Lenaerts, and M. R. van den Broeke (2013), Brief Communication: Expansion of meltwater lakes on the Greenland Ice Sheet, *Cryosph.*, *7*, 201–204.

King, M. D., Howat, I. M., Candela, S. G., Noh, M. J., Jeong, S., Noël, B. P., ... and A. Negrete (2020), Dynamic ice loss from the Greenland Ice Sheet driven by sustained glacier retreat. *Communications Earth & Environment*, *1*, 1-7.

Poinar, K., I. Joughin, S. B. Das, M. D. Behn, J. T. M. Lenaerts, and M. R. van den Broeke (2015), Limits to future expansion of surface-melt-enhanced ice flow into the interior of western Greenland, *Geophys. Res. Lett.*, *42*, 1800–1807.

MacFerrin, M.J., H. Machguth, D. van As, C. Charalampidis, C. M. Stevens, A. Heilig, … and W. Abdalati (2019), Rapid expansion of Greenland's low-permeability ice slabs. *Nature, 573*, 403–407.

Meredith, M. P., and M. Sommerkorn (2019), Special Report on the Ocean and Cryosphere in a Changing Climate, Chapter 3: Polar Regions, *IPCC Spec. Rep. Ocean. Cryosph.*, 173.

Stevens, L. A., M. D. Behn, J. J. McGuire, S. B. Das, I. Joughin, T. Herring, D. E. Shean, and M. A. King (2015), Greenland supraglacial lake drainages triggered by hydrologically induced basal slip, *Nature*, *522*, 73–76.

Stevens, L. A., I. J. Hewitt, S. B. Das, and M. D. Behn (2018), Relationship Between Greenland Ice Sheet Surface Speed and Modeled Effective Pressure, *J. Geophys. Res. Earth Surf.*, *123*, 2258–2278.

Further Information

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This project is well suited for a student interested in glaciology, remote sensing, data analysis, and/or numerical modelling with a background in geosciences, physics, computer science, or related fields.