Living Planet Fellowship

BI-MONTHLY REPORT

Investigating Greenland's ice marginal lakes under a changing climate (GrIML)

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1 OBJECTIVES OF WORK

This bi-monthly report signifies the restart of GrIML after a year of parental leave. The project is therefore offset by one year exactly, with GrIML the nearing of the end of Year 1 (January 2024) according to the proposed project timeline (Fig. 1). By the end of Year 1, the following objectives should been completed:

a. An operational workflow for deriving ice marginal lakes across Greenland should have been developed
b. A 2017 test inventory of ice-marginal lakes should have been generated, with comparison to the pre-existing ESA CCI Glaciers (option 6) inventory from the same time period
c. Ice-marginal lake inventories for the other monitoring years should have been generated, or at least a plan for their generation should have been developed
d. Individual lake studies for the time-series analysis should have been identified

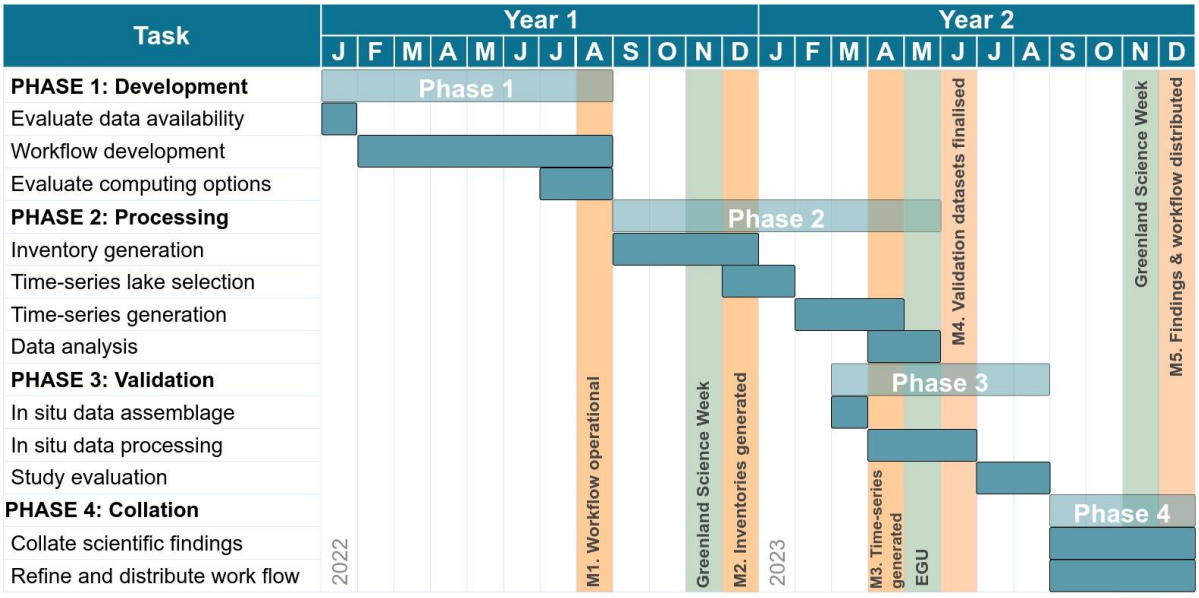

Figure 1. GrIML proposed project timeline. At the time of this bi-monthly report, we are nearing the end of Year 1 at the end of December 2023. Note that due to parental leave, the project is offset by one year exactly (i.e. end of Year 1 is January 2024, not January 2023; and the end of Year 2 is January 2025, not January 2024).

2 WORK PERFORMED

2.1 GrIML workflow used to generate 2017 inventory

The GrIML workflow has now been used to generate an initial ice-marginal lake inventory for 2017 (July-August 2017). This is a pre-filtered inventory, which incorporates the satellite imagery and detection methods specified in Table I. It is intended for this to match the existing ice-marginal lake inventory developed under the ESA CCI Glaciers (option 6) programme (now referred to as the CCI inventory) (How et al., 2021; Wiesmann et al., 2021).

Table I. Satellite sensors/products and detection methods used to generate the 2017 test GrIML inventory of ice-marginal lakes incorporated into the GrIML workflow

Satellite sensor/product	Classification method	Active years	Spatial resolution
Sentinel-1	SAR (Synthetic Aperture Radar) backscatter thresholding	2014-present	10 m
Sentinel-2	Multi-spectral optical indices thresholding	2015-present	10 m
ArcticDEM mosaic	Hydrological sink analysis	N/A*	2 m

** The ArcticDEM mosaic is a product derived from optical stereo imagery spanning acquisitions between 2009 to 2017 (Porter et al., 2018)*

An ice margin mask is needed to filter out unconnected lakes. The same ice margin mask will be used in order to achieve a like-to-like comparison to the CCI inventory; being the MEaSURES GIML 15 m ice mask (produced from imagery between 1999-2001) with a 1 km buffer (Howat et al., 2014; Howat, 2017).

2.2 Lakes selected for the GrIML time-series analysis

As part of GrIML Phase 3, time-series will be produced for selected ice-marginal lakes at a high temporal resolution. The purpose of this is to investigate individual lake dynamics, for which results are of scientific and/or societal interest.

Two lakes have been selected thus far, based on synergies with other projects. Preliminary work has already been conducted on these lakes in order to keep with other project timelines.

2.2.1 Hagen Bræ nunatak lake, NE Greenland

An ice-marginal lake located on Hagen Bræ (ESA CCI ice-marginal lake inventory lake id 2531) has been observed with interesting GLOF drainage cycles, which may play a role in the glacier's surge-type behaviour.

The lake is an unnamed lake situated in a nunatak approximately 60 km upstream from the glacier terminus. The lake is approximately 25.81 sq km (about the area of JFK Airport), holding a substantial storage of glacial meltwater compared to nearby supraglacial lakes that form and drain seasonally.

Initial analyses suggest that the lake drains roughly every 3 years (Table 1), with the most recent drainage in 2021 coinciding with a dramatic slowdown in ice flow indicated by Sentinel-1 ice velocity records (Solgaard et al., 2021)

Table II. Drainage events identified at the Hagen Bræ nunatak lake

Drainage period	Full/partial drainage	Platform identified from
03 - 12/09/1988	Partial	Landsat 5
29/08 - 07/09/1992*	Full	Landsat 5
12 - 19/04/1998	Partial	Landsat 5
25/07/2001 - 29/05/2002*	Full	Landsat 7/ASTER
27/07/2004 - 03/06/2005*	Full	Landsat 7/ASTER
23 - 30/07/2008	Full	Landsat 7
28/08/2011 - 14/06/2012*	Full	ASTER/Landsat 7
24/09/2014 - 16/03/2015*	Full	Landsat 8/9
17 - 25/08/2018	Full	Sentinel-2
11 - 17/08/2021	Full	Sentinel-2

**Drainage period is affected greatly by scene availability and therefore does not accurately reflect the actual duration of drainage*

It is proposed to investigate the influence of GLOFs on ice dynamics at Hagen Bræ, using the constructed ice-marginal lake time-series alongside other analysis (see Table III).

Table III. Proposed analysis approaches of the Hagen Bræ hydrology and dynamics

Analysis	Approach	Dataset/s	Associated project/institution	Status
Ice-marginal lake extent	Manual delineations	Sentinel-1, Sentinel-2, Landsat 5-9	GrIML (GEUS)	In progress
Ice marginal lake bathymetry	Altimetry	IceSat-2	PROMICE* (DTU)	Complete
Supraglacial lakes extent	Automated delineations	Sentinel-2	GrIML (GEUS)	In progress
Ice velocity	InSAR	Sentinel-1	ESA 4D Greenland /PROMICE* (GEUS)	Complete
Hydraulic potential	Bed-surface elevation analysis	ArcticDEM, Bed Machine	GEUS	Complete

**Programme for Monitoring of the Greenland Ice Sheet, https://promice.dk*

2.2.2 Nordbosø and surrounding lakes, SW Greenland

Several ice-marginal lakes exist around the lateral margins of Eqalorutsit Kangilliit Sermiat, near Narsarsuaq in South Greenland. Fieldwork conducted in early 2023 (PI Nanna Karlsson, funded by Villum) focused on detecting submarine basal melt at the glacier terminus using a new UAV/AUV approach. Basal melt is suspected to have been detected, however, this may also be indicative of meltwater from elsewhere. Given supraglacial lake formation does not occur until later in the melt season (I.e.

May-September), the only other possible origin of meltwater in this glacier's catchment area is from ice-marginal lake drainages. Therefore, this region is of interest to study to confirm whether melt discharge is related to basal melt and/or ice-marginal lake drainages.

Five ice-marginal lakes in the region were selected to construct time-series for, in the period where meltwater measurements were conducted (January to April 2023). Four of these lakes are unnamed, whilst the largest is called Nordbosø. Attempts were made to detect lake extent using the GrIML workflow, however, it was not possible to delineate extents given the time of interest is early pre-melt season and the GrIML workflow is not trained on snow- and ice-covered lakes. Because of this, lake extents were manually delineated from Sentinel-2 and Landsat-9 imagery using the GEEDiT toolbox (Lea, 2018).

Initial results presented in Figure 2 suggest that the five ice-marginal lakes in this region are unchanging over the time-series, with little variability in areal extent between January and April 2023. This work will be continued by refining the time-series, and constraining the uncertainty in these manually-delineated lakes (with a quantified error added to the plot)

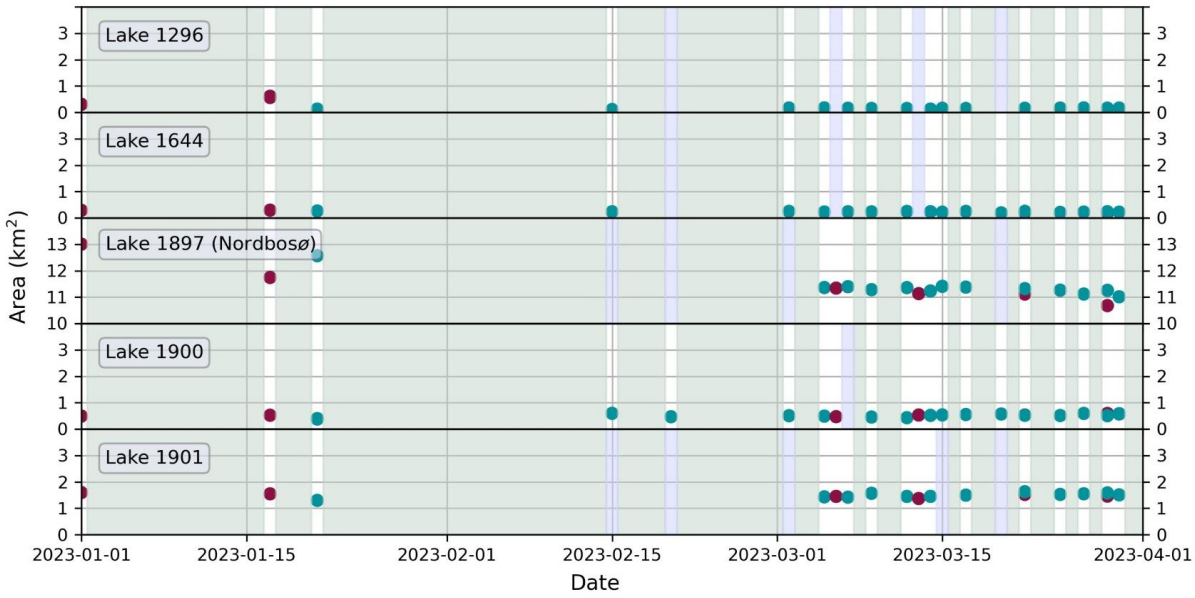

Figure 2. Preliminary time-series of ice-marginal lake extents from the catchment of Eqalorutsit Kangilliit Sermiat, near Narsarsuaq in South Greenland, from January to April 2023. Red points denote delineations from Landsat imagery (30 m spatial resolution), whilst blue points denote delineations from Sentinel-2 imagery (10 m spatial resolution)

3 CONCLUSIONS

This report signifies the final report from Year 1 of the GrIML project before the mid-term report (due January 2024). In this time, a unified workflow has been developed for mapping ice-marginal lakes across Greenland using three classification methods. This has been implemented for the test year of 2017, pending the final filtering steps, and will be evaluated against the CCI inventory. Two lakes for detailed time-series analysis have been identified – the Hagen Bræ nunatak lake (NE Greenland), and Nordbosø and surrounding lakes in the Eqalorutsit Kangilliit Sermiat glacier catchment (SW Greenland) – with scope for others to be added. The time-series analysis also provides synergies with other ESA initiatives (e.g. ESA 4D Greenland) and external projects (e.g. PROMICE).

4 REFERENCES

How, P. *et al.* (2021) Greenland-wide inventory of ice marginal lakes using a multi-method approach. *Sci Rep*. **11,** 4481. https://doi.org/10.1038/s41598-021-83509-1

Howat, I. M. (2017) MEaSUREs Greenland Ice Mapping Project (GIMP) land ice and ocean classification mask, version 1 [GimpIceMask 15 m tiles 0-5]. NASA National Snow and Ice Data Center Distributed Active Archive Center, Boulder, Colorado USA. https://doi.org/10.5067/B8X58MQBFUPA

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Porter, C., *et al.* (2018) ArcticDEM, *Harvard Dataverse* **V1**. https://doi.org/10.7910/DVN/OHHUKH

Solgaard, A. *et al.* (2021) Greenland ice velocity maps from the PROMICE project. *Earth Syst. Sci. Data*, **13**, 3491–3512. https://doi.org/10.5194/essd-13-3491-2021

Wiesmann, A. *et al.* ESA Glaciers Climate Change Initiative (Glaciers_cci): 2017 inventory of ice marginal lakes in Greenland (IIML), C*entre for Environmental Data Analysis V***1** (2021). http://doi.org/10.5285/7ea7540135f441369716ef867d217519

5 PUBLICATIONS AND TALKS

5.1 Research publications

- Karlsson, N. B., Mankoff, K. D., Solgaard, A. M., Larsen, S. H., **How, P.**, Fausto, R. S., & Sørensen, L. S. (2023). A data set of monthly freshwater fluxes from the Greenland ice sheet's marine-terminating glaciers on a glacier–basin scale 2010–2020. *GEUS Bulletin*, **53**. https://doi.org/10.34194/geusb.v53.8338

5.2 Talks and posters

- How, P. et al. (2023) An inventory of ice-marginal lake across Greenland. *Mapping The Arctic 2023, Nuuk, Greenland*.
- How, P. et al. (2023) Recent advances in monitoring the Greenland Ice Sheet. *Greenland Science Week 2023, Nuuk, Greenland*.

5.3 Supervision

- Ph.D. supervision to Connie Harpur (Leeds University) on "Controls on the dynamics of Greenlandic lake terminating glaciers", 2023-2026
- M.Sc. thesis evaluator for Ethan Carr (University of Colorado Boulder) on "Ice Marginal Lakes in Greenland: Quantifying the Impact of Glacial Lake Outburst Flood Events"