# GrIML: A Python package for investigating Greenland's ice-marginal lakes under a changing climate

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Summary

The `GrIML` Python package is for processing classified water bodies from satellite imagery, and compiling classifications into a standardised inventory. It has been used to produce the Greenland ice-marginal lake inventory series, which maps the presence and extent of water bodies across Greenland that share a margin with the Greenland Ice Sheet and/or the surrounding ice caps and periphery glaciers since 2016 (How et al., 2025).
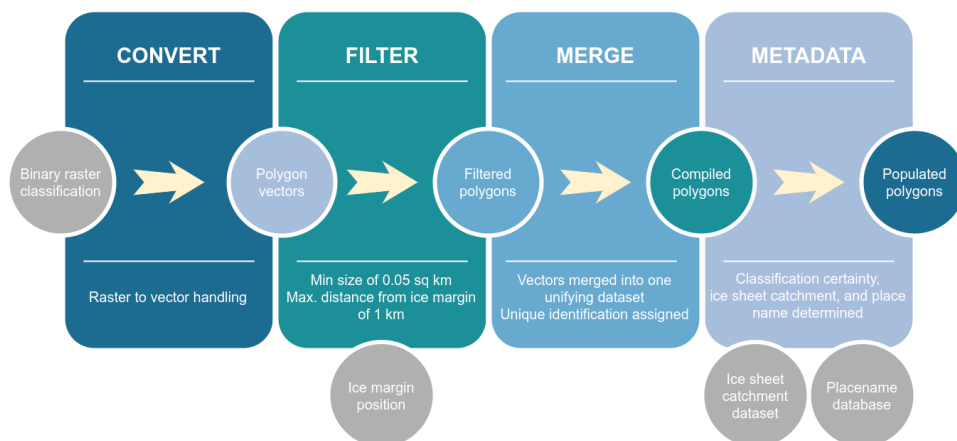
Figure 1: An overview of the GrIML Python package workflow for generating ice-marginal lake inventories. The boxes refer to the four main modules and processing stages (reading from left to right), the coloured circles represent intermediary results to each processing stage, and the grey circles represent additional inputs.

Initial rasterised binary classifications denoting water bodies can be inputted to `GrIML` to convert, filter, and merge into a unified ice-marginal lake vector dataset, populated with useful metadata and analysed with relevant statistical information (Figure 1). The workflow to produce the rasterised binary classifications is provided with the `GrIML` Github repository as both Javascript and Python scripts, which are run with Google Earth Engine.

Statement of need

`GrIML` meets four main needs of users in the remote sensing and cryospheric science communities:

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1. Provide a usable workflow for processing rasterised water body classifications
2. Document the criteria for classifying an ice-marginal lake
3. Showcase a transparent workflow that, in turn, produces an open and reproducible ice-marginal lake dataset that adheres to the FAIR principles (Wilkinson et al., 2016)
4. Produce inventories that map the areal extent and abundance of ice-marginal lakes across Greenland, which demonstrate ice-marginal lake evolution under a changing climate

There have been many different approaches to classifying ice-marginal lakes with remote sensing techniques (Andreassen et al., 2022; Chen et al., 2021; Dømgaard et al., 2024; How et al., 2021; Rick et al., 2022; Wieczorek et al., 2023). Packages exist for handling satellite and spatial data, such as GrIML's two key dependencies, Geopandas (Van den Bossche & others, 2024) and Rasterio (Gillies & others, 2013--), as well as others such as SentinelHub (Sentinel Hub, 2024) and Google Earth Engine (Gorelick et al., 2017). Remote sensing object classification and post-processing routines are usually available in connection with scientific publications, however, few are available as well-documented, reproducible and deployable packages. The `GrIML` Python package addresses this gap, for the benefit of the future generation of ice-marginal lake inventories and for others in the scientific community to adapt and use themselves.

The 2016-2023 Greenland ice-marginal lake inventory series was produced with the `GrIML` Python package to address knowledge gaps regarding sea level contribution, and provide an overview of regions where lacustrine ice loss and processes are prominent (How et al., 2025, In Review). The dataset consists of a series of annual inventories, mapping the presence and extent of ice-contact lakes across Greenland (Figure 2). The annual inventory series spans the entirety of Greenland, including all terrestrial regions. Thus far, there are 8 annual inventories, covering 2016 to 2023, with one inventory for each year. The `GrIML` package will continue to be used to produce future additions to the Greenland ice-marginal lake inventory series; in which case a standardised and version-controlled processing pipeline is essential (How et al., 2025).
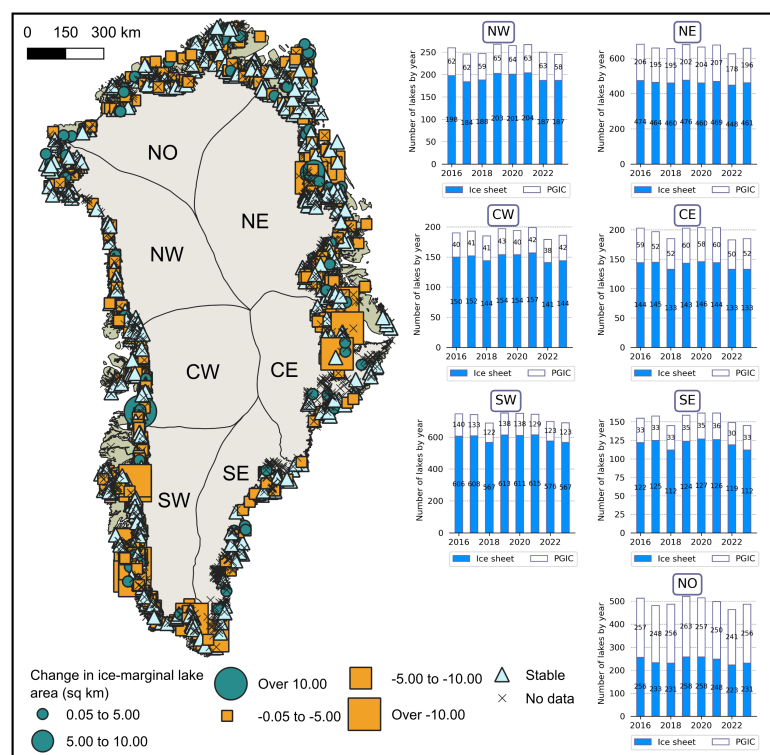
Figure 2: An overview of the Greenland ice-marginal lake inventory series, which maps the number of lakes and their size between the years of 2016 and 2023 (How et al., 2025). The map shows the location of each lake, with the symbol signifying area change over time, where green circles represent an increase in lake area, yellow squares represent a decrease in lake area, and white triangles represent an unchanged lake area. Crosshair points denote lakes where no area information is provided. The bar graphs show the change in number of lakes in each region. Base maps are provided by Moon et al. (2023) and region outlines are as defined by Mouginot & Rignot (2019).

Overview of package contents

GrIML has 4 main modules for processing from raster classifications to a vectorised inventory:

1. `Convert`: for converting binary raster classifications of water bodies to vectors
2. `Filter`: for filtering vectors by size and proximity to an object (i.e. an ice margin profile)
3. `Merge`: for merging vector classifications into one unified object (for example, when classifications cover a large area that needs to be split over multiple files)
4. `Metadata`: for populating vector classifications with various pieces of information, including identification number, placename, region, classification source, and certainty.

These 4 modules represent the 4 processing steps that should be executed in order to produce a standardised ice-marginal lake inventory. Each module contains the functions associated with each step (see Figure 3).
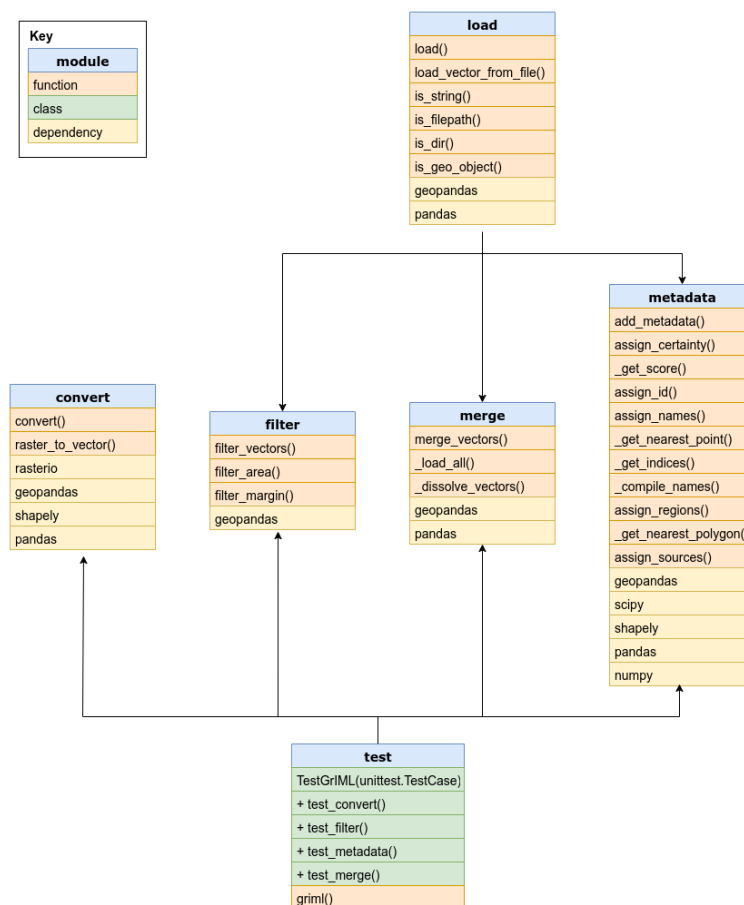
How. (2025). GrIML: A Python package for investigating Greenland's ice-marginal lakes under a changing climate. *Journal of Open Source Software*, *10*(111), 7927. https://doi.org/10.21105/joss.07927.

Figure 3: The GrIML Python package structure, including modules (blue), key module functions (orange), classes (green) and dependencies (yellow). Arrows between modules represent module dependencies, where the direction of the arrow indicates the dependency source (at the end of the arrow) and target (at the head of the arrow).

Usage

Installation

The `GrIML` Python package is compatible with Python 3.10, 3.11, and 3.12, and can be installed using pip:

```
$ pip install griml
```

Full installation instructions are provided at https://griml.readthedocs.io/en/stable/installation.html.

Tutorials and guides

Two sets of tutorials are provided with `GrIML` for: 1) Using the processing pipeline (https://griml.readthedocs.io/en/stable/tutorials/process_with_test_data.html) 2) Handling the produced dataset (https://griml.readthedocs.io/en/stable/tutorials/dataset_tutorial.html) 3) Inputting custom datasets (https://griml.readthedocs.io/en/stable/tutorials/using_custom_input_data.html)

The processing and custom input data tutorials guide the user through each processing step

from the initial raster classifications to a fully compiled ice-marginal lake dataset. The dataset tutorials provide an overview for how to handle and analyse an ice-marginal lake inventory produced with GrIML. This includes examples using the ice-marginal lakes dataset on the GEUS Dataverse (How et al., 2025), primarily handled with Geopandas (Van den Bossche & others, 2024) to create spatial plots and time-series (see Figure 4).
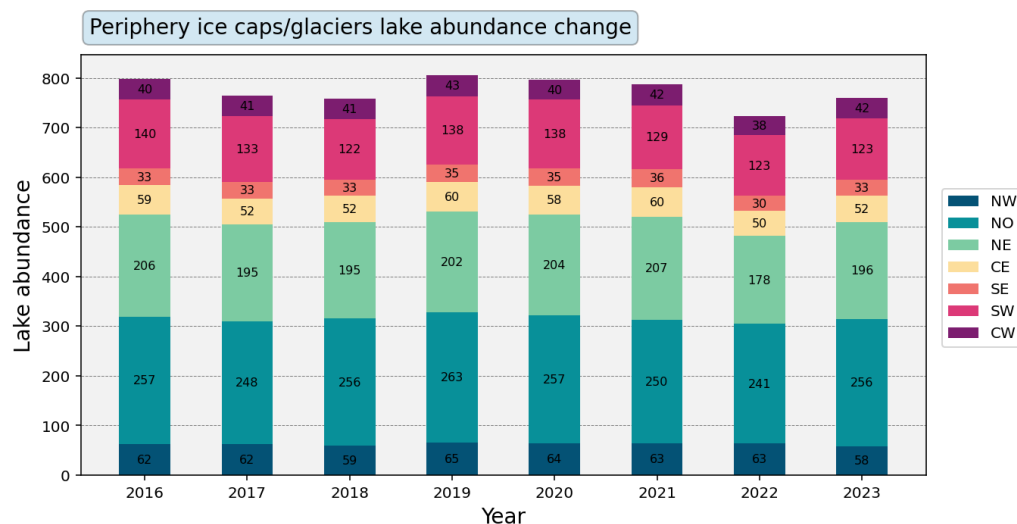

Figure 4: An example plot output from the dataset tutorial, where the change in the number of lakes across the ice-marginal lake inventory series is visualised. Each bar represents the number of lakes in one inventory year, with each coloured stage indicating the number of lakes for a given region.

Usage terms and conditions

If the GrIML package or the Greenland ice marginal lake inventory series are used to support results of any kind then we ask the authors to include references to the applicable publications:

- How, P. et al. (2025) *"Greenland Ice Marginal Lake Inventory annual time-series Edition 1"*. **GEUS Dataverse.** https://doi.org/10.22008/FK2/MBKW9N
- How, P. et al. (In Review) *"The Greenland Ice-Marginal Lake Inventory Series from 2016 to 2023"*. **Earth System Science Data. Discuss**https://doi.org/10.5194/essd-2025-18
- How, P. et al. (2021) *"Greenland-wide inventory of ice marginal lakes using a multi-method approach"*. **Scientific Reports** 11, 4481. https://doi.org/10.1038/s41598-021-83509-1

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Acknowledgements

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