Living Planet Fellowship

BI-MONTHLY REPORT

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

Penelope How

Geological Survey of Denmark and Greenland (GEUS)

Prepared by **Penelope How**
Approved by **Signe Bech Andersen & Andreas Ahlstrøm**
Reference **BR_GrIML**
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1 OBJECTIVES OF WORK

GrIML is currently in Phase 1, focusing on workflow development with the following objectives:

a. Evaluate processing platforms/packages for workflow processing, including the availability of suitable satellite image data
b. Migrate and adapt the ice marginal lake workflow from How et al. (2021)
c. Assess options for cloud computing integration into the revised workflow

There has been a large focus on the oblique time-lapse photogrammetry workflow in these past two months, which is intended to serve as validation for the generated ice-marginal lake inventories. Whilst it was intended to perform this task later in the project timeline, opportunities arose for this work to be incorporated into publications (as described subsequently) and was hence brought forward in the schedule.

2 WORK PERFORMED

A time-lapse photogrammetry workflow was proposed in the GrIML project outline (specifically in Section 1.4: Methodology), validating the remote sensing classification of ice marginal lakes with those derived from oblique time-lapse images. The workflow is adapted from PyTrx, a Python package for extracting photogrammetric measurements from oblique imagery, with specific applications in water classification (How et al., 2017; 2020).

Work has been undertaken to begin the adaptation of PyTrx for classification of ice marginal lake extents, with two key objectives to expand PyTrx's applications to include:

1. Water level classifications (Goldstein et al., In Review)
2. Snow and ice classifications (Messerli et al., In Review)

Both these applications are important to PyTrx's future use in identifying ice marginal lakes from oblique time-lapse images, as water bodies that often contain icebergs or are snow/ice covered.

2.1 Water level classifications

PyTrx's applications have been expanded in the last two months, culminating in the submission of two publications for peer review. In Goldstein et al. (In Review), water level delineations are performed using PyTrx to extract river levels from Inglefield Land (Northwest Greenland). These measurements were subsequently validated against river stage data collected using an in-situ pressure transducer installed in the river (Fig. 1).

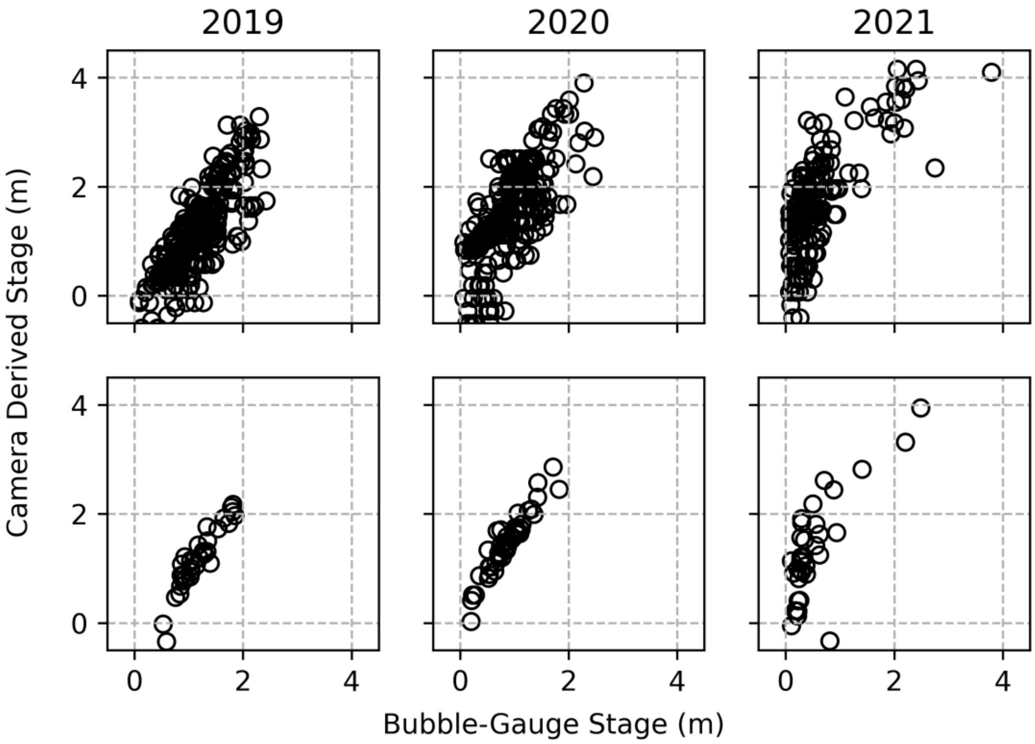

Figure 1. River stage estimates from time-lapse images plotted against in situ pressure transducer river stage data. Data presented at 3-hour intervals (top row) and averaged 24-hour intervals (bottom row) from 2019, 2020 and 2021. Figure from Goldstein et al. (In Review).

A semi-automated Canny Edge Detection approach (Canny, 1986) was developed to determine the the water level position, using pixel value contrast between the land and water to delineate the intersecting boundary (Goldstein and How, 2022). The methodology performed well in consistent lighting, retrieving water level positions for 72.3%, 63.0% and 47.9% of images from 2019, 2020, and 2021, respectively. In cases of extreme or inconsistent lighting, water level positions were manually delineated.

There is good correlation between the image-derived water levels and the in-situ river stage measurements, with an average r^2 value of 0.77 (±0.067 m) across the three monitoring years (Fig. 1). The image-derived water levels capture diurnal, seasonal, and interannual fluctuations in river stage. The image-derived water levels are a slight over-estimate relative to the in-situ measurements, which is likely to be the product of unavoidable error in the georectification process. Such error is inherent with all photogrammetric measurements and is limited as much as possible with camera optimization routines like those offered in PyTrx (Messerli and Grinsted, 2015; Schwalbe and Maas, 2017; How et al., 2020).

2.2 Snow and ice classifications

Snow patches and snowlines were delineated from oblique time-lapse images acquired from Qasigiannguit, a small mountain glacier in Southwest Greenland, and presented in Messerli et al. (In Review). Snow patch/line positions were analyzed and compared to weather station and mass balance observations to examine how snow cover evolution impacts on mass loss.

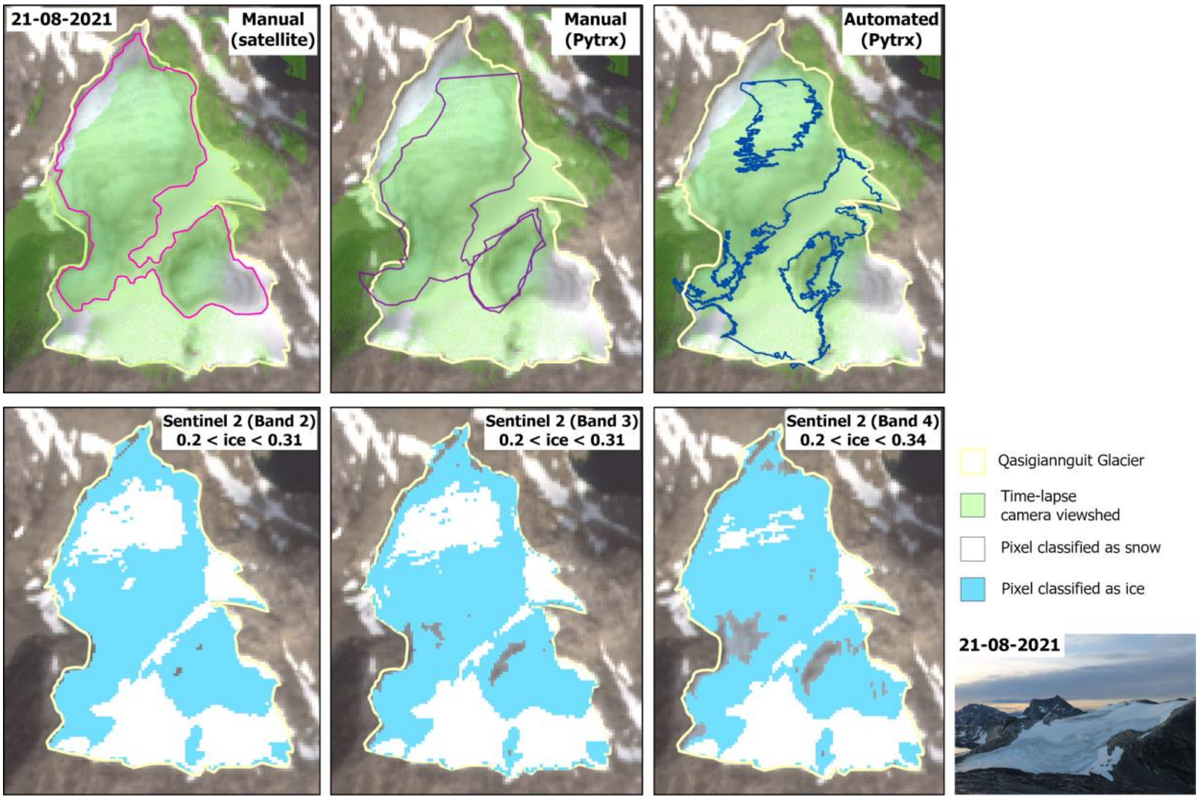

Figure 2. Snow cover mapped at Qasigiannguit Glacier from oblique time-lapse images and a coinciding Sentinel-2 image from 21/08/2021. Manual delineations and automated pixel thresholding were computed from the oblique imagery using PyTrx, whilst manual delineations and visible band thresholding were computed from the Sentinel-2 imagery. Figure taken from Messerli et al. (2022).

PyTrx's automated pixel thresholding was explored to evaluate its accuracy in detected snow cover from bare ice, alongside manual delineations using PyTrx's interactive plotting portal and band thresholding from Sentinel-2 imagery (Fig. 2). Whilst the automated PyTrx workflow is efficient, the accuracy of snow cover delineations is variable due to inconsistent light conditions; for example, periods of low light and sun glare off the snow/ice surface.

Manual delineations from PyTrx correlated closely with the Sentinel-2 derived snow classification. For this reason, manual delineations were adopted for the classification of snow cover on bare ice in this work. However, development of a more sophisticated automated classification is ongoing in PyTrx. Working examples of the PyTrx's snow/ice classifications are now available with the newest release of PyTrx (v1.2.4; How, 2022).

3 CONCLUSIONS

Oblique time-lapse photogrammetry workflows have been developed from pre-existing functionality in PyTrx, a Python toolset for deriving measurements from oblique imagery. These two workflows build upon existing pixel classification approaches to derive water level and snow cover information from proglacial rivers and glacier surfaces, respectively (Goldstein et al., In Review; Messerli et al., In Review). The combination of these two approaches is the basis of a classification workflow for deriving ice marginal lake surface areas from oblique time-lapse images, where lakes can have challenging classification due to ice and snow cover.

The developed classification workflow will be adopted in Phase 3 of GrIML to form part of the validation from in situ data. Not only will this provide an expansion of the PyTrx toolset, but could also contribute to improving the temporal resolution of ice-marginal lake time-series.

4 REFERENCES

How, P. *et al. (*2017) Rapidly changing subglacial hydrological pathways at a tidewater glacier revealed through simulataneous observations of water pressure, supraglacial lakes, meltwater plumes and surface velocities. *Cryosphere* **11**, 2691-2710. https://doi.org/10.5194/tc-11-2691-2017

How, P. *et al.* (2020) PyTrx: A Python-based monoscopic terrestrial photogrammetry toolset for Glaciology. *Front. Earth Sci.* **8:21**. https://doi.org/10.3389/feart.2020.00021

Messerli, A. and Grinsted, A. (2015) Image georectification and feature tracking toolbox: ImGRAFT. *Geosci. Instr. Method. Data Sys.* **4**, 23-34. https://doi.org/10.5194/gi-4-23-2015

Messerli, A. *et al.* (2022) Mapping snowline evolution with time-lapse imagery at Qasigiannguit. *Nunatsinni Ilisimatusarnermik Siunnersuisoqatigiit, NIS (Greenland Research Council) internal report*

Schwalbe, E. and Maas, H.-G. (2017) The determination of high-resolution spatio-temporal glacier motion fields from time-lapse sequences. *Earth Surf. Dynam.* **5**, 861-879. https://doi.org/10.5194/esurf-5-861-2017

5 PUBLICATIONS AND TALKS

5.1 Research publications

- Carrivick, J.L., How, P., Sutherland, J., Cornford, S., Lea, J., Tweed, F., Grimes, M., and Mallalieu, J. (2022) Ice-marginal proglacial lakes across Greenland:

present status and a possible future. *Geophys. Res. Lett.* 49 (12), 2022GL099276R. https://doi.org/10.1029/2022GL099276

- Goldstein, S.N., Ryan, J.C., How, P., Esenther, S.E., Pitcher, L.H., Lewinter, A.L., Overstreet, B., Kyzviat, E.D., Fayne, J., Smith, L.C. Proglacial river stage derived from georectified time-lapse camera images, Inglefield Land, Northwest Greenland. *In Review*.
- Messerli, A., Arthur, J., Langley, K., How, P. and Abermann, J. Snow cover evolution at Qasigiannguit Glacier, southwest Greenland: a comparison of time-lapse imagery and mass balance data. *In Review*.

5.2 Software/code publications

- Goldstein, S.N. and How, P. (2022) sethnavon/PyTrx_Minturn_Elv: Minturn River Stage Data (minturn_elv1.1). *Zenodo*. https://doi.org/10.5281/zenodo.6560889
- How, P. (2022) PennyHow/PyTrx: PyTrx v1.2.4 (pytrx1.2.4). *Zenodo*. https://doi.org/10.5281/zenodo.6624346

5.3 Invited talks

- Ice marginal lakes in Greenland, guest lecture presented at DTU Space, Denmark