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GEOL0362Z
November 30, 2021

Lab 5: Forecasting Glacier Water Resources with OGGM

Location: Boulder Glacier, WA, USA

Abstract

Glacial water resources are important in regions where it is the primary source of drinking water, tourism, and supporting larger urban areas. An area with an abundance of glaciers is Mount Baker, WA, USA and holds greater impact on the Seattle area. Within Open Global Glacier Model (OGGM), we can validate and project future changes of terminus position and volume within specific glaciers. For the Mount Baker glaciers, this lab closely analyzes changes in Boulder Glacier. The purpose of this lab is to validate changes in ice thickness, terminus position, and volume changes with climate variations in Boulder Glacier from 1975-2010 utilizing OGGM. I find that there are inconsistencies within OGGM projections and existing studies on Boulder Glacier, where this lab finds an overall increase in glacier volume and advancement in terminus position, while previous studies have observed consistent retreat within this period (Harper, 1993; Pelto & Brown, 2012). Despite having accurate standard model performance for the nearby glaciers, a way to eliminate inconsistencies within OGGM and real glaciers is by updating current RGI outlines and centerlines to be more representative of glaciers throughout time.

Introduction

The objective of this lab is to validate changes in Boulder Glacier terminus position from 1975-2010 with studies of Pelto & Brown 2012 and Harper 1993. In addition, this lab explores ice thickness changes and climate variability on volume changes during that period, which is something that was not reported in neither study. The main method used for this lab analysis utilized OGGM flowlines documentation `FlowlineModel` and `FileModel` which calculates changes in terminus position, ice thickness, and volume change over time along a glacier flowline.

The initial criteria used to choose Boulder Glacier was based on Randolph Glacier Inventory (RGI) ID data availability and existing literature. I had initial interest in the greater Cascade Range since there is an abundance of glaciers on Mount Hound and Mount Baker. In addition, these glaciers serve as water resources to millions of people in the Seattle and surrounding areas. Boulder Glacier is one glacier out of a group of glaciers on Mount Baker in Washington state. There is overlap within the Harper 1993 and Pelto & Brown 2012 studies geared toward changes in the Mount Baker glaciers. Harper 1993 studied glacier terminus changes and climate variations on Mount Baker from 1940-1990 through photogrammetric techniques. Pelto & Brown 2012 studied the mass balance loss, terminus behavior, longitudinal profiles, and accumulation area ratio of Mount Baker glaciers from 1990-2010. This overlap within both studies serves as a catalyst and motivation for this lab to further explore what climate variations and terminus changes looked during that time. In other words, this lab uses OGGM to serve as a validation of those changes and explores other climate scenarios on Boulder Glacier specifically.

Methods

Like previous labs, we access Boulder Glacier data within OGGM using its RGI ID. It's RGI ID is 'RGI60-02.17741' and it has a total area of 6.29 km^2 with the status of glacier or icecap and identified as a land-terminating terminus. Something to note about the RGI ID is that the RGI ID outline is initialized from 1975. This serves as the initial year for the study period for this lab and the balanced overlap between the two studies. All simulations are relative to the RGI outline and center flowline (Figure 1).

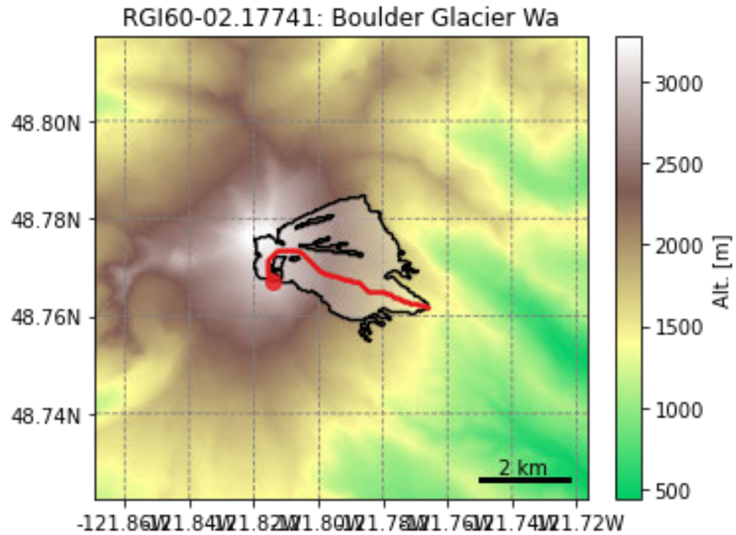

Figure 1. Topographical (m) outline (black) of Boulder Glacier, WA, USA relative to RGI data 1975 with its center flowline (red).

To explore terminus position changes, volume changes, and climate variability trends, this lab utilizes OGGM flowline documentation, previously used in Lab 3, and flowline geometry after a run with `FileModel`. With the `FileModel` can produce plots that show ice thickness on the glacier outline to have a two-dimensional, bird's eye view of the glacier surface profile (Figure 2). In addition, I utilized the `FileModel` documentation to visualize cross sectional changes over time along the center flowline.

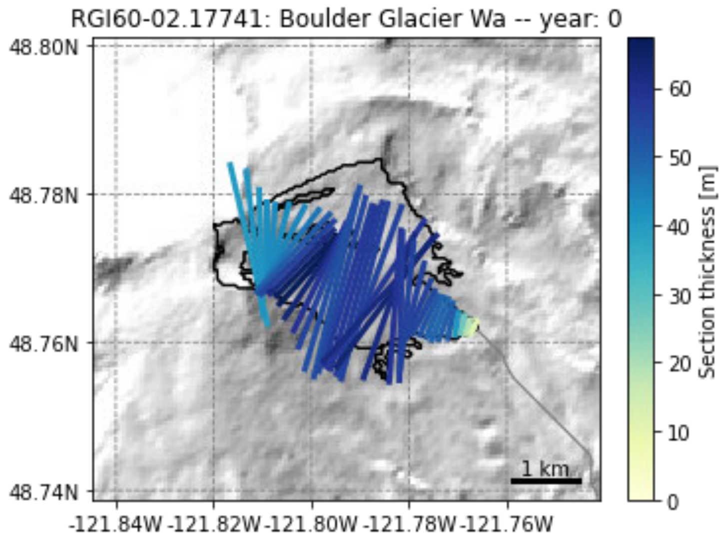

Figure 2. Ice thickness (m) of Boulder Glacier at its original RGI date and outline, 1975, with the terminus to the far east in the lightest color.

Like the previous lab modelling glacier water resources with OGGM, I use the same modules to simulate the climate variability factor using `run_random_climate` function from the `workflow` module. For this lab, the climate model simulation runs for 35 years, since the period of interest is 1975-2010, with the climate centered around 1975 and `unique_samples` set to True (see previous lab report for further information on random climate simulations).

Results

For ice thickness changes, there is a general decrease in ice thickness between 1975 and 2010 (Figure 3). However, a caveat to this figure is that it compares changes at two points in time which is not representative of changes during the period. Therefore, figure 4 explores ice thickness at three points, 1975, 1990, and 2010, and along the glacier centerline. This figure shows that ice thickness increases at all places along the centerline from 1975-1990, however there are mostly areas decreases in ice thickness along the centerline from 1990-2010 except near the terminus (3900-4000m).

For volume changes with no climate variation, or constant climate, there is an overall increase in volume that reaches an equilibrium around 2010 and 0.335 km^3 of water (Figure 5). However, volume changes with climate variation, or random climate, there is an initial decrease from 1975-1980, then a large increase from 1980-2000, but then the simulation ends with a large decrease from 2000-2010 with about 0.34 km^3 of water (Figure 6). Something interesting to note in figure 6 is that there is more volume projected in the random climate simulation than the constant climate reaching up to 0.37 km^3 of water.

For terminus changes, I also compared changes across the three points, 1975, 1990, and 2010, along the glacier centerline profile (Figure 7). There are little to no changes between 1975-1990, but there is about a 100m advance (~3900m to 4000m) in terminus position from 1990-2010. Something interest to note about this figure is that the overall glacier shape (thickness) does not vary between the three points in time. Another unique result is that the terminus advancement moves from northwest to southeast (Figure 8).

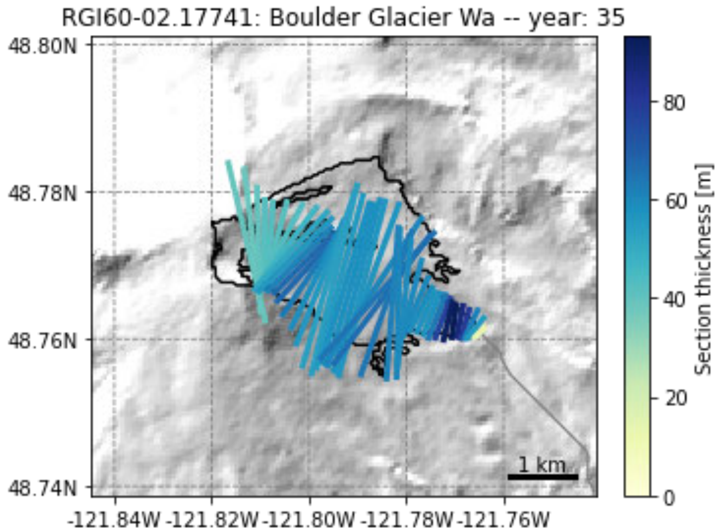

Figure 3. Ice thickness (m) of Boulder Glacier in 2010 relative to the 1975 RGI ID outline, with the terminus to the far east.

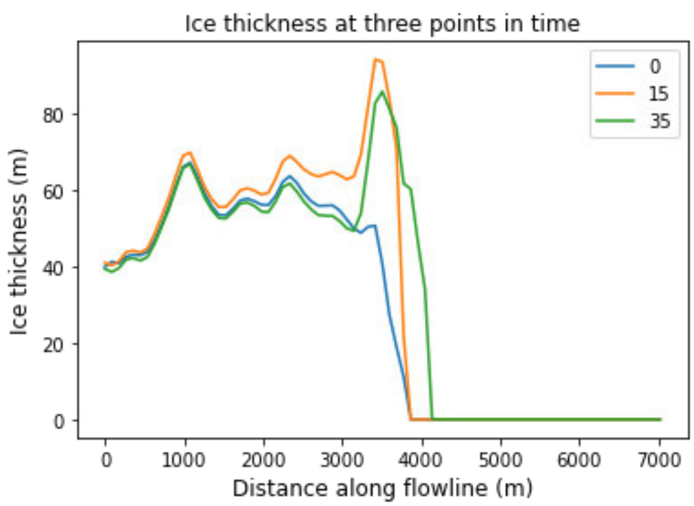

Figure 4. Ice thickness (m) along flowline at of Boulder Glacier at 1975 (blue), 1990 (orange), and 2010 (green).

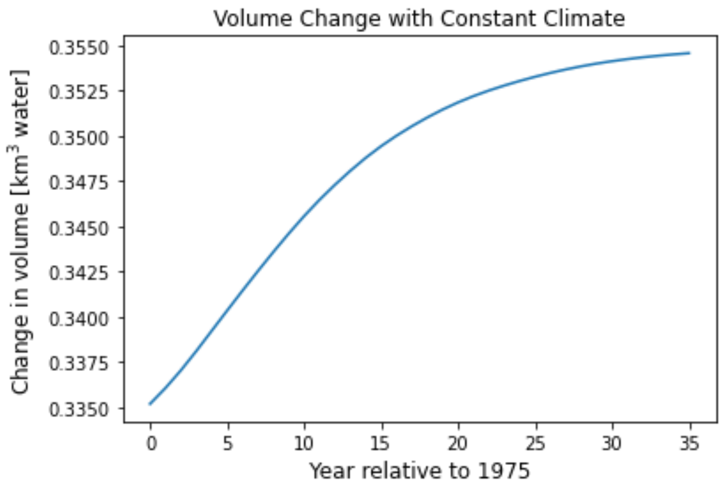

Figure 5. Volume change (km^3) of Boulder Glacier with constant climate simulation.

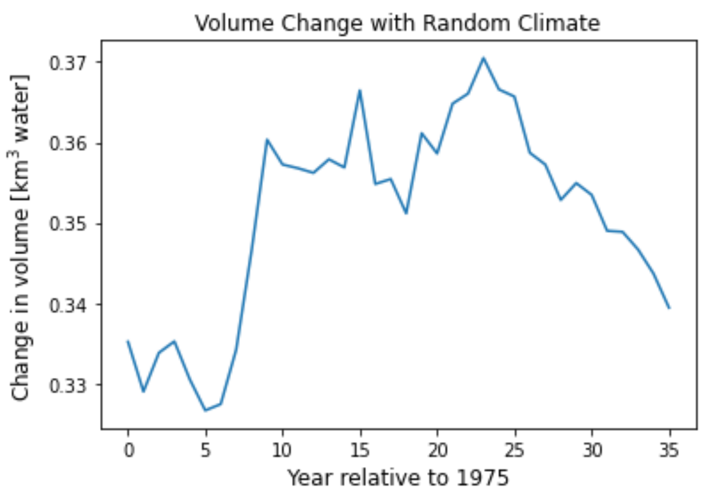

Figure 6. Volume change (km^3) of Boulder Glacier with random climate simulation.

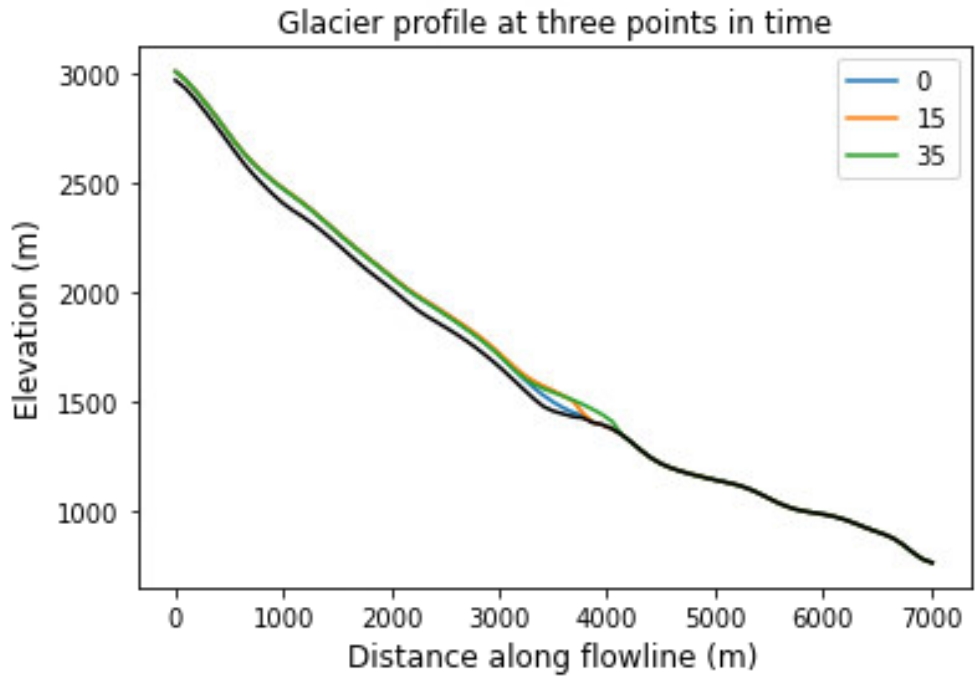

Figure 7. Boulder Glacier profiles changes at 1975 (blue), 1990 (orange), and 2010 (green).

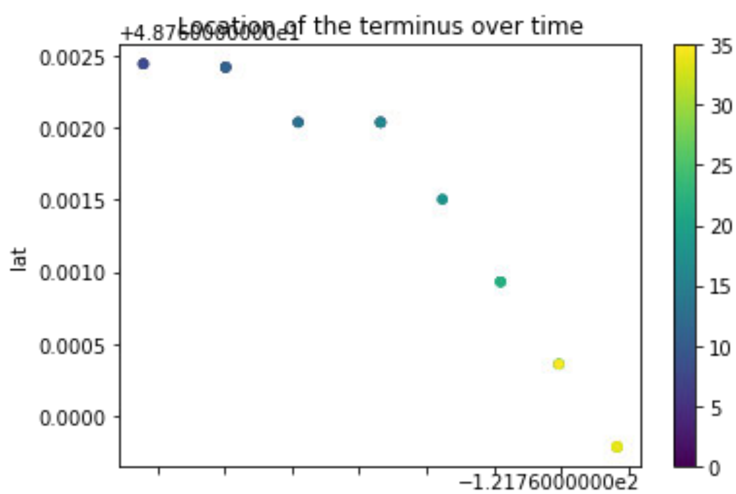

Figure 8. Location (latitude and longitude) of Boulder Glacier terminus changes from 1975-2010 (0-35), advancing from northwest (dark color) to southeast (light color).

Discussion

Within these simulations of Boulder Glacier, I generally find terminus advancement and volume increases with constant climate between 1975-2010. However, there is inconsistencies across all three parameters investigated (terminus position, ice thickness, and volume). For example, the ice thickness decreases over the entire glacier comparing the first and last year (figures 2 and 3). However, ice thickness is largest in the middle of the simulation in 1990.

Furthermore, terminus position advances within the period. This is consistent with the increase in volume change with constant climate from 1975-2010. However, volume changes with random climate variations are not as linear and have an overall decrease in volume.

Comparing these results with Harper 1993, there is terminus advancement at Boulder Glacier that began in 1954 which advanced about 747 m, then began a retreat in 1987 of 55m. Comparing this with Pelto & Brown 2012, there is an overall retreat of Boulder Glacier of 520 m from 1979-2009. This is interesting to compare across the two studies and this lab result, because OGGM should have predicted an overall retreat in terminus position and thus volume change. The only result that tracked this overall retreat is the ice thickness, but only compared at two points: 1975 and 2010.

These differences show that using OGGM flowline modules is a simplified version of the real glacier and what researchers measure in the field. In addition, these measurements in OGGM are predicted against the RGI date relative to 1975 and the centerline at that time. This is interesting to see such differences since the standard mass balance calibration within OGGM tracks a generally accurate and representative model performance for the nearby glaciers (Easton, Rainbow, and Spider).

Conclusion

Within this lab, I simulated Boulder Glacier with OGGM for changes in volume with climate variations, terminus positions, and ice thickness. I found that there are inconsistencies between the OGGM results from this lab and the two studies analyzing changes in Mount Baker glaciers despite OGGM having an accurate model performance for the glaciers nearby Boulder Glacier. When analyzing a specific glacier, it is important to cross reference across multiple studies and see how OGGM performs against it. These differences in OGGM can be improved by updating RGI ID outlines and centerlines that are more representative of the glacier today or throughout time.

References

Harper, J. T. (1993). Glacier Terminus Fluctuations on Mount Baker. *Glacier Terminus Fluctuations on Mount Baker*, *25*(4), 332–340. https://doi.org/10.1080/00040851.1993.12003019

Pelto, M., & Brown, C. (2012). Mass balance loss of Mount Baker, Washington glaciers 1990–2010. *Hydrological Processes*, *26*(17), 2601–2607. https://doi.org/10.1002/HYP.9453