Glaciology lab: Bed inclination and surface mass balance with OGGM

Lab report 2

[redacted]

Introduction

Numerical models are used in glaciology for computational and explorative purposes. Some examples can include visualizing the relationship a glacier has with its physical domains both internally and physically. Another important aspect of numerical modeling within glaciology is that we can quickly and easily incorporate processes like mass balance that can compute quantitative information. Scientists often want information such as glacier length and mass change within an ice sheet.

The theoretical relationship between glaciers and their bed slope is that changes within the slope, increase or decrease, can control the glacier deformation and shape. Increases or steepening of the slope results in a thinner and lesser mass of a glacier. Decreases or flattening of the slope results in a thicker and larger mass of a glacier. Equilibrium line altitude (ELA) is the point in elevation that distinguishes the accumulation and ablation zone. When ELA changes position, accumulation and ablation adapt to an increase or decrease in volume change.

For this lab, we utilize Open Global Glacier Model (OGGM) to organize and execute numerical modeling of glaciers. Within the OGGM platform, we can define variable, collect information from a database within OGGM, use functions, plot results, and qualitatively analyze outputs with text chunks.

We can use and access OGGM through Jupyter Hub. Within Jupyter Hub, we can organize our work and files with notebook environments that allow us to execute numerical models and create plots to download and qualitatively analyze on reports or presentations. Jupyter Hub is maintained on a cluster at the University of Bremen to access and run OGGM.

Methods

For this lab, we analyze two experiments exploring glacier dynamics between its (1) bed geometry and (2) mass balance. The following experiments were performed in OGGM.

Experiment 1:

To explore the glacier and its bed geometry, we must define an initial spatial setting or boundary of the bed. Variables include bed slope, length, equilibrium line altitude, width, and height. Within numerical modeling, we begin by defining a resolution of grid points and spacing. We don't need to know the meaning behind it, but just know it creates the spacing we need for the bed profile and axes of interest. We use 200 grid points and 100-meter grid point spacing. Next, we set the glacier slope as 0.1 and the peak elevation at 3400 meters. With these values, we can create a linear bed profile from the top to bottom of the glacier and then define the distance along the glacier to set the x-axis. To define the glacier width, we use the package `RectangularBedFlowline` and set an initial width of 300 meters. We use this package for the glacier to have consistent glacial valley like walls for the width throughout the system. In addition, this package allows the height or depth of the glacier to be consistent. We now have our initial system seen in Figure 1.

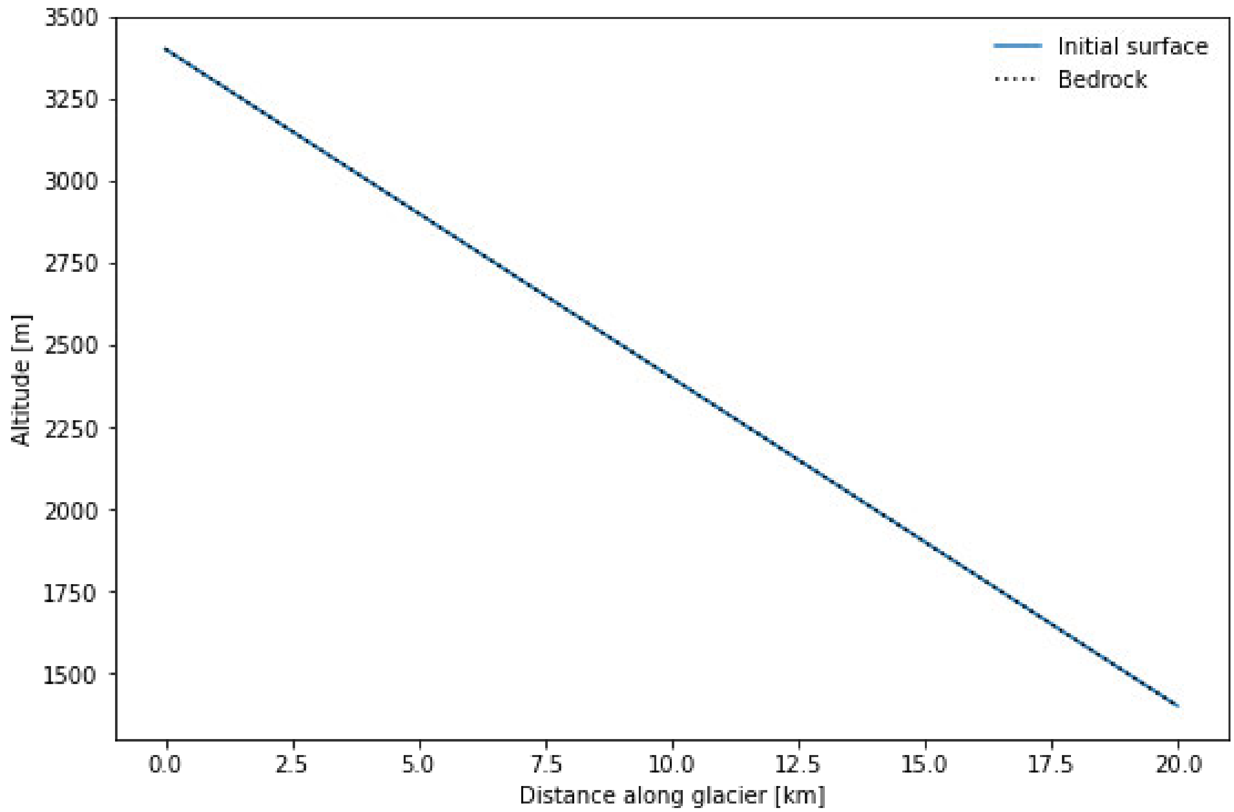

Figure 1. Initial glacier bed geometry profile and surface for a simple, linear bed profile used in our experiments.

These variables allow OGGM to calculate total glacier length, area, and volume. We want these variables and outputs to see changes within the system. Changes can be made to the system like increasing or decreasing the slope value. In addition, there can be a different top altitude value to fit different settings like mountain or marine-terminating glaciers.

After defining an initial bed geometry, we must define a mass balance for the entire system, or glacier surface. This is to account for accumulation (mass gain) and ablation (mass loss) which is relative to a defined ELA. Anything above the ELA is mass gain while below is mass loss. Different glaciological settings have different ELAs, however we define the ELA to be 3000 meters in altitude for experiment 1. We then define an altitude gradient to be 4 mm/m. Altitude gradient allows the system to calculate the mass balance at any altitude, or over the entire glacier profile. We now have a linear mass balance (Figure 2).

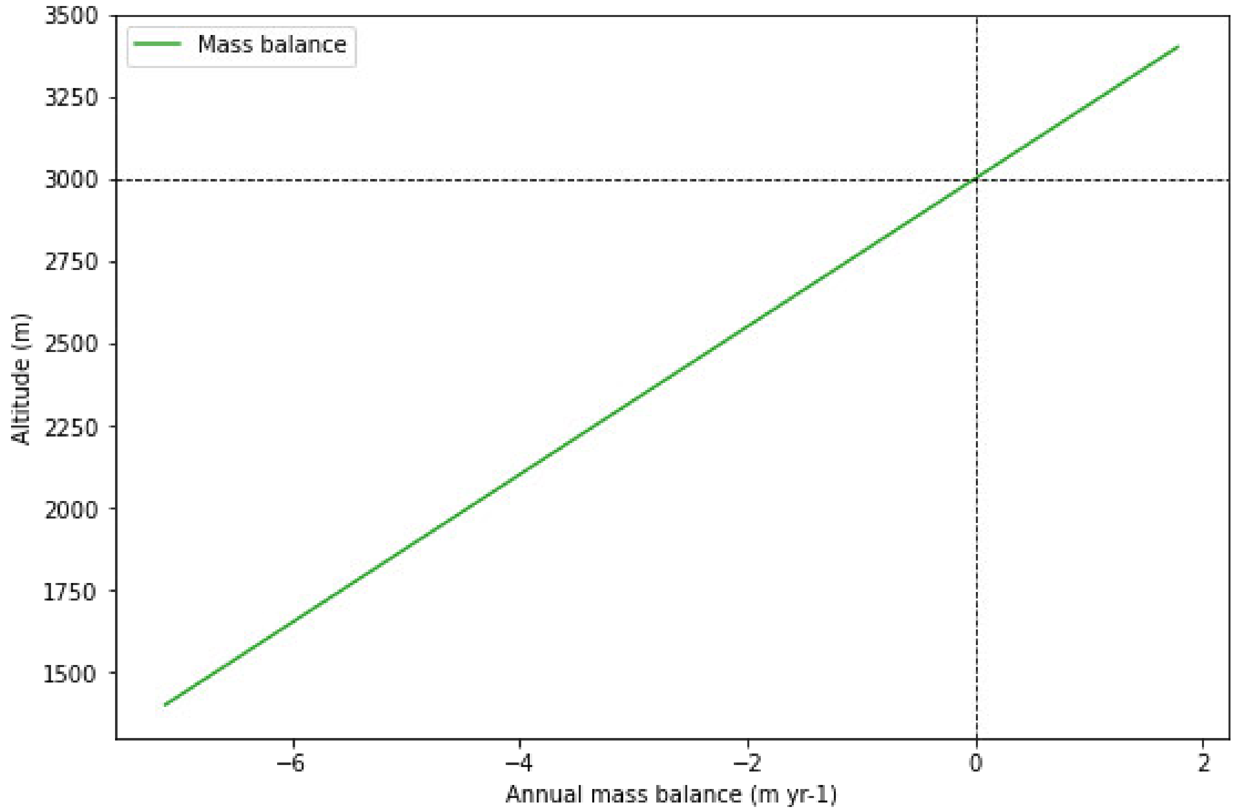

Figure 2. Mass balance along a glacier profile with an ELA of 3000m and altitude gradient of 4 mm/m. The intersection of 0 annual mass balance and 3000 m in altitude represents the transition of ELA from positive annual mass balance (accumulation) and negative annual mass balance (ablation).

To study this system throughout time, we use a flowline model that calculates glacier growth with an initial bed geometry, mass balance model, and time. With an initial time of 0 years, the time variable can be explored in decadal to centennial timescales. The full glacier set up for experiment 1 within OGGM can be seen in Figure 3.

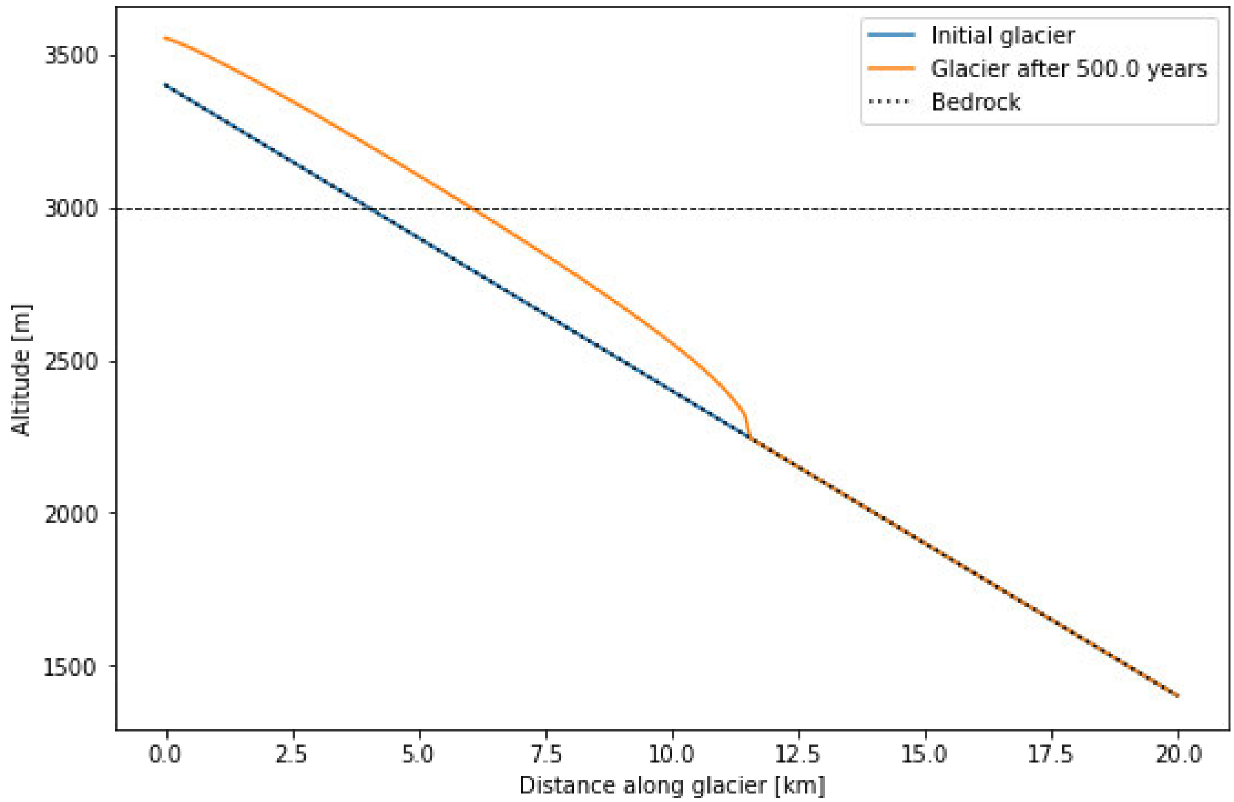

Figure 3. Glacier profile after 500 years of growth compared to its initial profile.

Experiment 2:
To explore mass balance in a glacier system, we change mass balance by using different ELA and mass balance gradient values. With changes in ELA and mass balance gradient, there are different glacier length and volume outputs. Different mass balance gradients show different rates of accumulation and ablation of a glacier. Changing the mass balance gradient is the primary parameter being changed in the model for this experiment. We use all previous initial settings from experiment 1 and expand on them here with the mass balance gradient.

Results

Within experiment 1, we see that the glacier length and growth depend on increases and decreases in the bed slope (Figure 4). When the slope increases, or steepens, the glacier is shorter in length with less volume. When the slope decreases, or flattens, the glacier is longer in length with more volume. Looking at figure 4, we see that within 600 years a slope value of 0.1, the glacier length evolves to reach about 12000 meters while a glacier with a slope of 0.2 only reaches about 4000 meters. In addition, their respective volume growth over 600 years is approximately 0.6 km^3 and 0.15 km^3.

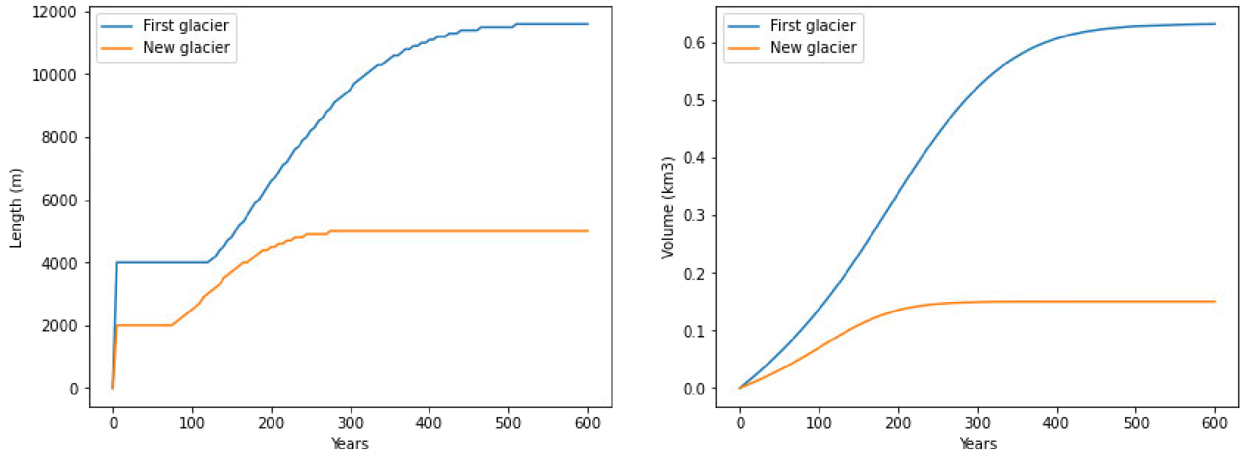

Figure 4. Comparison of glacier length and volume with different bed slopes. The first glacier has a bed slope of 0.1 while the new glacier has a slope of 0.2.

Within experiment 2, we find that the shape of the glacier changes according to different ELA values (Figure 5). In general, a smaller ELA value results in the glacier having a longer length where there is more area for accumulation and ablation. A larger ELA value results in a smaller glacier length where there is less area for accumulation and ablation to take place. Figure 5 shows that a larger ELA value of 2700 has a longer glacier length compared to an ELA of 3200 which is shorter. This difference in growth is also seen in the annual mass balance rate. Larger ELA values have a large negative, or faster rate, of annual mass balance compared to smaller ELA values. For example, an ELA of 3200 at around 1500 meters of altitude has an annual mass balance of -8 m/y while an ELA of 2700 has an annual mass balance of -6 m/yr. Differences in mass balance gradients but with the same ELA value can be summarized in Table 1. The general relationship here is that a larger mass balance gradient (MBG) results in a glacier with a larger length, more volume, and more water equivalent. For example, we can look at a glacier with an MBG of 0.3 has a length of 4000 meters compared to a glacier with an MBG of 15 has a length of 12900 meters.

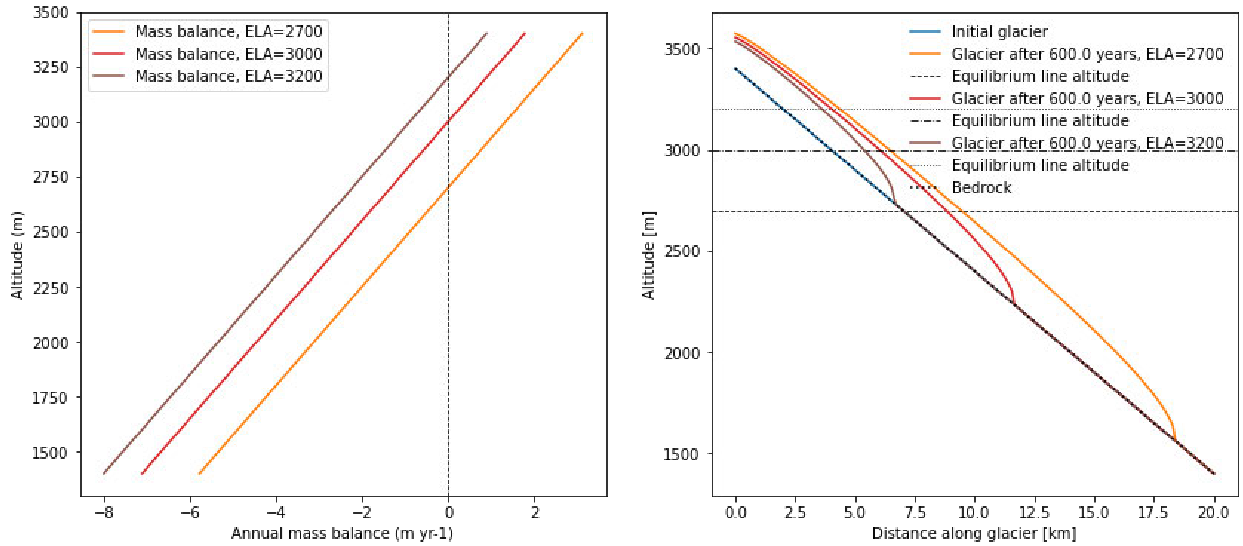

Figure 5. Annual mass balance (left) and distance along glacier (right) according to different equilibrium line altitude values. The different colors represent different ELA values and their respective glacier shapes and mass balance after 600 years of accumulation.

	MBGs	length (m)	volume (km^3)	equivalent water (m^3)
0	0.3	4000.0	0.025744	2.316948e+10
1	4.0	9500.0	0.521354	4.692187e+11
2	15.0	12900.0	0.941441	8.472969e+11

Table 1. Different mass balance gradients with their respective glacier outputs of length, volume, and equivalent water storage.

Discussion

Within our experiments, we find that properties of glacier bed geometry and mass balance can change glacier shape. Using a numerical glacier model in OGGM, we were able to define a glacier and constrain the dynamics of interest. We can simulate a linear bed topography with different slope values to see how a glacier can be larger or smaller. In addition, we can account for changes in mass balance dynamics of accumulation and ablation with respect to different equilibrium line altitudes. We find that increases in bed slope result in shorter glacier length and height, while decreases in bed slope result in longer glacier length and thickness. Regarding equilibrium line altitude, we find that larger ELA values result in a smaller glacier while smaller ELA values result in a larger glacier. Finally, increases in mass balance gradients can result in larger glaciers while decreases in mass balance gradients can result in smaller glaciers.

Comparing to our previous glacier goo lab, we see similarities and differences within how a glacier interacts with its bed geometry. We see in both lab experiments that changes with slope can either increase or decrease the speed the glacier deformation. However, we cannot define or see the accumulation and ablation zones in the glacier goo. In addition, we cannot pinpoint an equilibrium line altitude separating the two zones. One of the larger differences between these two experiments is that the numerical model can calculate glacier evolution on multi-decadal to centennial timescales. In our glacier goo, we were making glacier dynamic observations and calculations based on a few minutes of glacier deformation.

These experiment results demonstrate how real glaciers around the world are controlled by different geometric domains whether they are bed slope, mass balance gradients, or equilibrium line altitude. However, something important that was not included in this experiment was a climate parameter. Glaciers experience different climate based on their location. What we generalize within OGGM reflects a mountainous glaciological setting. Overall, we can takeaway a larger intuition for bed topography controls and mass balance calculations for different glaciological settings and what parameters matter the most in our research question or goal.

Conclusions

We find a general relationship of how a glacier evolves according to its bed slope, equilibrium line altitude, and mass balance gradient. We find that increases in bed slope result in smaller glaciers, while decreases in bed slope result in larger and thicker glaciers. Within ELA dynamics, larger ELA values result in smaller glaciers while larger ELA result in larger glaciers. Finally, smaller MBGs result in smaller glaciers while larger MBGs result in larger glaciers.