Glaciology lab: Bed inclination and surface mass balance with OGGM

Lab report 2

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Introduction

Numerical models advance the study of glaciology by providing insights into processes that are difficult to directly observe and help forecast past and future changes to the cryosphere. Diagnostic models help constrain processes that control the behavior of an important glaciological system, while prognostic models forecast what will happen to a glacier in the future. Numerical models are important tools for answering questions like how much will glacier melt increase sea level rise over the next century and how do changes in bed topography affect glacier mass balance?

Theoretically, the steeper the slope of the glacier bed, the smaller in length and volume the glacier will be compared with a glacier with the same equilibrium line altitude on a shallower slope. The equilibrium line altitude (ELA) is the position where accumulation and ablation processes are balanced on the glacier, so the mass balance is zero at this altitude. When the ELA of a glacier decreases, it means that there is an increase in accumulation or decrease in ablation processes. Similarly, when the ELA of a glacier increases, it means that there is an increase in ablation or decrease in accumulation processes.

The Open Global Glacier Model (OGGM) is an open-source glacier model run in python. OGGM can model past and future glacier mass balance and changes in glacier volume and geometry. We employed OGGM to investigate ice on an incline and glacier mass balance.

We used a Jupyter Hub maintained on a cluster at the University of Bremen to access and run OGGM. The Jupyter notebook environment allows us to run a simplified educational version of OGGM and modify parameters within the model code to investigate ice on an incline and glacier mass balance.

Methods

Experiment 1.

We defined the geometry of the bed by choosing a bed slope and peak elevation (initially 0.1 and 3400m, respectively), with a linear bedrock profile from the top to the bottom. The bed has a rectangular cross-sectional shape with an initial width of 300m, meaning the glacial “valley” walls are straight and there is a constant width along slope of the glacier. We additionally set the slope of the glacier bed as 0.2 and 0.08. We define mass balance as the amount of ice added or removed over the entire glacier surface. For our OGGM model, we use a linear mass balance where above the ELA there is accumulation of ice and below there is ablation of ice.

Experiment 2.
We varied two primary mass balance parameters, the ELA and the mass balance gradient. The ELA represents the altitude on a glacier where accumulation processes balance ablation processes, so the mass balance is zero. The mass balance gradient is the change in mass balance with altitude. We varied the ELA by setting ELAs = [2700, 3000, 3200]. We varied the linear mass balance gradient by changing the grad variable.

Results

Experiment 1:
Varying the slope of the glacier bed resulted in changes to final glacier length and pattern of glacier growth over time. The steeper the bed slope, the shorter the final length of the glacier (Figure 1). Additionally, with a steeper slope of the bed the glacier grows faster initially, before reaching a sustained period of slow growth (Figure 1).

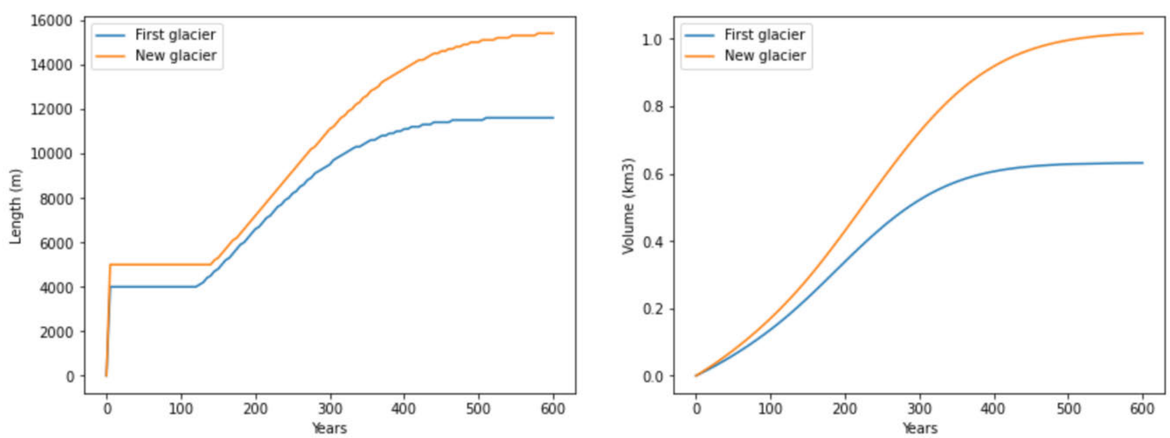

Figure 1. Number of years after glacier initialization versus glacier length (km) and volume (km3) for two difference bed slopes. The bed slope of the first glacier is 0.1 and the bed slope of the new glacier is 0.08.

Experiment 2:
The shape of the glacier and water storage potential is dependent on the ELA and the mass balance gradient. The higher the ELA, the smaller the glacier for both length and volume (Figure 2b). After 600 years, the terminus of the glacier with an ELA of 2700 m was approximately 12.5 km behind the glacier with an ELA of 3200 m and had a smaller height above the bed slope (Figure 2b). For two glaciers with the same ELA and different mass balance gradients, we would expect the larger mass balance gradient to store more water (Table 1).

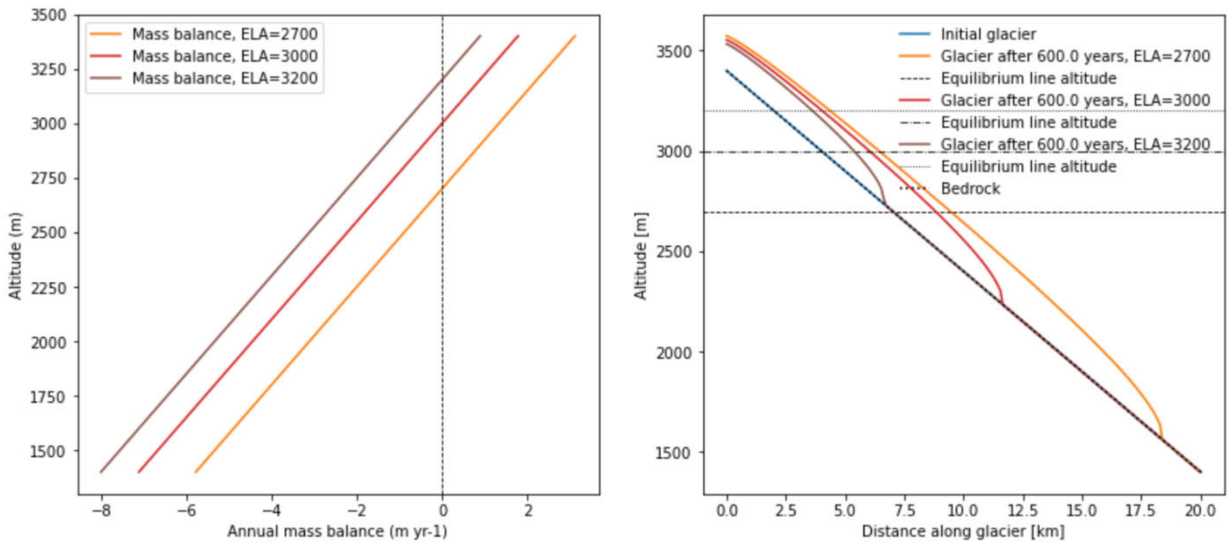

Figure 2. a) Annual mass balance gradient (m/yr) versus altitude (m) for ELAs of 2700m, 3000m, and 3200m. b) Distance along glacier (km) versus altitude (m) for ELAs of 2700m, 3000m, and 3200m.

Table 1. Variations in mass balance gradient (MBG) and the resultant glacier length (m), volume (km3), and water equivalent (m.w.e.).

MBG	length	volume	equivalent water
0.3	4000.0	0.025744	2.316948e+10
4.0	9500.0	0.521354	4.692187e+11
15.0	12900.0	0.941441	8.472969e+11

Discussion

The numerical glacier in OGGM and the glacier goo from lab 1 have numerous similarities and differences. Both models are able to simulate glacier flow down various bed slopes over time. However, the glacier goo lab was aimed at constraining the velocity of the goo, which was not a parameter we investigated in OGGM. The OGGM model was able to simulate the ELA and mass balance gradient of a glacier, while the glacier goo had a static volume.

The OGGM model is a useful simplification of a real glacier, but real glaciers are more complex than the model accounted for. A real glacier has a much more complex bed geometry and slope than the constant linear rectangular bed slope. Additionally, in nature glaciers do not have linear mass balance gradients or static ELAs over hundreds of years. By combining our OGGM experiments with our glacier goo experiments we can gain insights into how a glacier flows down slope in terms of deformation and velocity and its response to climatic variables.

Conclusions

The OGGM model demonstrated that glaciers are sensitive to changes in bed slope, ELA, and mass balance gradients. The steeper the slope of the bed, the shorter the final length of the glacier. The higher the ELA, the smaller the glacier for both length and volume. Finally, the larger the mass balance gradient, the larger the glacier length and volume. Climate is a main factor that controls ELAs and mass balance gradients of glaciers, and as climate warms, we expect ELAs to retreat to higher altitudes and mass balance gradients to increase for surviving glaciers.