Glaciology lab: Bed inclination and surface mass balance with OGGM

Lab report 2

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Introduction

Numerical models are useful in glaciology because they allow scientists to simulate (and thus study) processes which may otherwise be very challenging or impossible to observe. In addition to this, numerical models enable scientists to understand the implications of changes, such as a shifting MBG, without those changes actually taking place in the environment. Similarly to this, numerical models can help understand what may have happened in the past, or what may happen in the future. As a specific example, numerical models can help us understand how Alaskan tidewater glaciers might respond to an ELA which has increased in response to climate change.

Theoretically, a steeper bed slope beneath a glacier will result in that glacier being thinner and shorter than an otherwise identical glacier. A shallow bed slope will result in the ice moving less slowly from the accumulation zone to the ablation zone, thus allowing the glacier to retain more mass. The equilibrium line altitude (ELA) is the elevation at which annual accumulation and ablation is balanced (inputs = outputs), and can be thought of as the boundary between the accumulation zone and ablation zone. When the ELA increases a glacier will shrink, as the glacier has a smaller region in which to accumulate mass and a larger region in which that mass in ablating. Conversely, if the ELA decreases a glacier will grow larger, as there is now more area on which to accumulate mass and less from which to ablate.

In this lab, we use the Open Global Glacier Model (OGGM) to model glacial mass balance. OGGM is an open-source glacier model written in Python and is an accessible and useful tool for modeling glacial processes such as this. In particular, we used OGGM to investigate the role that bed geometry, ELA, and MBG play in controlling glacier mass balance. We accessed and ran OGGM through a Jupyter Hub maintained on a cluster at the University of Bremen. The Jupyter notebook environment allows us to combine text, code, and graphics into one intuitive interface. This makes it a relatively simple process to learn new glaciological concepts, represent them in computer code, and then visualize their results. It also helps to contextualize programming tasks for those who may be unfamiliar with coding in Python.

Methods

Experiment 1.

Geometry of the bed was defined in some of the first steps of Experiment 1. We assigned a value to ‘slope,’ which was then input alongside highest elevation – ‘top’ - and model resolution (‘map_dx’ and ‘nx’) to produce the desired bed orientation. Soon after, we also defined the width of the glacier bed (‘width’) and input it into a function alongside other values such as those above to produce a bed geometry. In this instance, we used the ‘RectangularBedFlowLine’ and ‘width = 3’ to simulate a rectangular bed that is 300 m wide.

The initial setting for bed shape was rectangular, and the initial width was 300 meters. I tried making the glacier wider (up to 5km) and adjusting the bed geometry, but ran into some errors with the latter endeavor, as a result of not having imported additional bed geometry functions. Mass balance was modeled by defining an ELA, an mass balance gradient, and inputting them both into the mb_model function. This allows OGGM to calculate where snow will accumulate, melt, or persist through the year.

To study glacier change over time, we adjusted the runtime of the model (1, 100, 150, etc. years). Since the model can't go back in time, we saved the surface height data for each run as arrays to plot later in order to directly compare back in time. A similar strategy can be used to simulate changes in ELA or MBG.

Experiment 2.

In this experiment, we adjusted the mass balance gradient (MBG) and the equilibrium line altitude (ELA). The MBG is the rate at which mass balance changes with altitude, where higher MBGs will result in larger glaciers. ELA is the elevation at which ablation and accumulation are balanced on the glacier – lower ELAs will likely result in larger glaciers in the same conditions. MBG and ELA were adjusted in the model by changing the terms as they were input into the LinearMassBalance function. This could be achieved by either adjusting the terms when they were first assigned to a variable (a more intuitive method), or changing them in the line where the function was called.

Results

Experiment 1:

The final glacier length is longer for shallower bed slopes, likely because the ice will advance slower at a shallower angle, allowing for more accumulation and thus greater length in identical rectangular valleys. While the slopes used in this experiment at first produce glaciers which behave in similar ways, glaciers with steeper slopes lengthen at slower rates than those with shallower slopes. Interestingly, steeper slopes gain glacier volume at a faster rate than gentler slopes. The relationships can be seen in Figure 1.

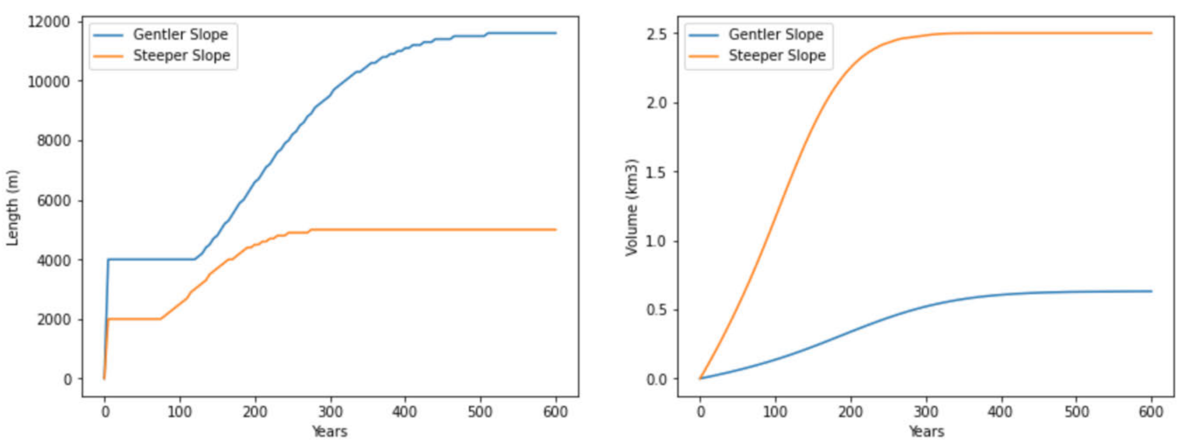

Figure 1: This figure shows the relationships in volume and length change over time for 2 glaciers of slope 0.1 (gentler) and 0.2 (steeper). While both glaciers behave relatively similarly with regard to length right at the start of the model run, the role bed slope plays in controlling glacier length quickly becomes apparent. On the other hand, the different slopes result in a relatively quick divergence of glacial volume over the model run.

Experiment 2:

A lower ELA will result in a thicker and longer glacier, as it allows more mass to accumulate above the ELA before being conveyed down the glacier to the ablation zone. The overall shape of the glacier (a consistent thickness for most of its length, sloping down at its snout). We would expect a glacier with a larger MBG to store more water than one with a smaller MBG, assuming all other dimensions are the same. This is because a larger MBG allows for more mass accumulation with elevation, resulting in thicker and longer glaciers. This can be seen in Table 1, which was produced as part of the second experiment.

	MBG	length	volume	equivalent water
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 2: This table shows the modeled results of 3 glaciers which are identical apart from their mass balance gradient (MBG), shown in the first column in mm/m. As MBG increases (that is, becomes steeper), length (m), volume (km^3), and water equivalent (km^3) all increase as well.

Discussion

Overall, bed geometry, ELA, and MBG are instrumental in controlling the mass balance, and thus size and water storage capacity, of glaciers. These experiments complement those undertaken in the glacier goo lab by taking into account the concept of mass balance. The goo glacier lab neatly simplified visual of how glaciers move, but did not incorporate the ways that accumulation or ablation impact glacier shape. On the other hand, the OGGM model represents the role that mass balance plays in shaping glaciers, but does not account for glacier motion in our use of it.

Our OGGM modeling experiments helped identify the way that changes in bed geometry, ELA, and MBG impact glacier mass balance, but in a highly idealized setting. For example, our models assumed a constant width of the glacier, as well as constant bed slope, friction, and geometry, some of which we were able to account for in the goo glacier lab by adding obstacles or local bed lubrication. Despite this limitation, our modeling experiments showed that an increase in MBG will result in longer, thicker glaciers, whereas an increase in ELA will result in shorter, thinner glaciers.

Taken together, the goo glacier and OGGM experiments can help us to better understand factors at play in the motion of glaciers. Incorporating the two can offer representations of the motion of glaciers and their response to local fluctuations in bed conditions (from the goo glacier), as well as the way that changing ELA or MBG values can impact the mass balance of glaciers (from the OGGM experiments).

Conclusions

OGGM is a powerful and accessible tool for simulating the mass balance of glaciers. In these experiments, we adjusted the bed slope, width, ELA, and MBG of glaciers to better understand their role in controlling mass balance and related metrics such as glacier thickness, length, and water storage. Gentler bed slopes, lower ELAs, and higher MBGs will result in larger, thicker glaciers which can positively impact communities which depend on glaciers as water sources.