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GEOL0362Z
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Lab 3: Modelling Glacier Sliding with OGGM

Group: [redacted] and [redacted]

Abstract

Surging glaciers represent a small percentage of glaciers that experience short periods of faster ice flow that result in rapid advance and retreat of the glacier front. These are unique glacier settings that experience different flow than most glaciers and have a cycle of surging and non-surging. It is sometimes challenging to model this surge characteristic because they are poorly understood. Not all surging glaciers undergo the same decadal cycle. In addition, the flow of ice is difficult to capture both computationally and within observations. We attempt to simulate glacier surging through Open Global Glacier Model through two main processes: internal deformation of ice and basal sliding. We find that basal sliding is the most prominent control on surging glaciers as it controls glacier length and shape. Previous work shows that basal sliding is the most prominent control on surging glaciers. Surging glaciers are difficult to model, but we develop a larger understanding of how basal sliding influences glacier behavior and shape.

Introduction

Glacier movement is influenced by two main processes: internal deformation of ice due to its own weight, and gravity, and basal sliding. The purpose of this lab is to investigate how to simulate realistic glacier surges through those main processes in Open Global Glacier Model (OGGM). The objective of this lab was to simulate a glacier surge cycle controlled by a flow parameter.

A surge is a short period of glacier advancement. These periods occur in decadal cycles and can last between 1 to 15 years. Glacier surges can result in a change of bed morphology and surface characteristics due to the faster glacier flow. The two flow parameters that can possibly influence a surge cycle are defined as Glen's creep parameter and basal sliding.

Glen's creep parameter is a constant that relates to shear stress to the rate of deformation within a glacier. The value of the constant can change depending on crystal size, fabric, concentration and types of impurities, and temperature. Basal sliding happens when there is a water film between the bottom of the glacier and the bed. This occurrence can also change glacier movement or deformation. Due to the water film, there is a difference in friction between the ice and bed that can control the sliding, or movement, of the glacier.

Like our previous lab, we utilize Jupyter Hub that is maintained on a cluster at the University of Bremen to access and run OGGM. This Jupyter notebook environment allows us to execute the numerical models and analyze its outputs. Within OGGM, we can define variables, collect information from a database within OGGM, and utilize models that create the mass-balance and shape we need to define a realistic glacier.

Methods

To study surging cycles, we should begin by creating a simple glacier system, or a control. From our previous lab, we define a simple glacier system with a linear decreasing slope, a peak elevation of 3,400 m, an equilibrium line altitude of 3,000 a.s.l., and a mass balance gradient of 4 mm/m. This is accomplished by using OGGM functions RectangularBedFlowline, LinearMassBalance, and FlowlineModel.

To account for the two glacial flow processes studied in this experiment, internal deformation and basal sliding, we can use Glen's creep parameter and a sliding parameter. As previously stated, Glen's parameter can change based on a range of factors (temperature, crystal size, etc.). To understand how this parameter changes glacier shape, we can multiply the parameter by a factor of 0.1 and 10 and compare the differences with a default or control glacier we created in the last lab. We generally see that decreases in Glen's creep parameter results in larger glacier shape and increases results in smaller glacier shape (Figure 1). These two different glaciers are just one of many examples of how Glen's creep parameter can change glacier movement or deformation depending on the range of factors previously listed.

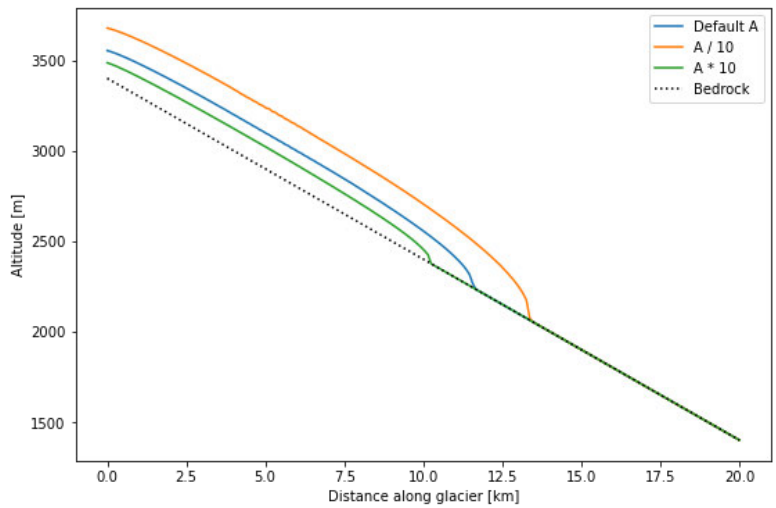

Figure 1. Differences in glacier shape based on changes in Glen's creep parameter. Default A is a control glacier, A/10 is a fraction of the Glen's creep parameter, and A*10 is an amplified value of Glen's creep parameter.

As previously stated, the sliding parameter represents the occurrence of a water film between the ice and bed interface. To understand how the sliding parameter changes glacier shape, we can multiply the parameter by a factor of 0.5 and 2 and compare the differences with the same control glacier. We generally see that a smaller sliding parameter results in a larger glacier, and a larger sliding parameter results in a smaller glacier shape (Figure 2).

We chose to simulate a surge cycle through the basal sliding parameter. Murray et al. 2003 showed that basal sliding "dominates flow during the active phase of glacier surging" due to differences in calculated and measured creep velocities within the Svalbard tidewater glacier. In addition, this is a common finding by Sevestre and Benn 2017 where "glacier surges occur in response to internally driven oscillations in basal conditions." Therefore, we simulate surge cycles through the basal sliding parameter.

We define the glacier surge cycle as surging for 10 years and then slow flowing for 100. We analyze the glacier throughout 10 surge cycles which adds to a total time length of 1,200 years. The change in surge cycle is modeled through a loop statement that processes the evolution of the glacier. The model uses an if else (elif) statement to see if the year currently run in the model subtracted from the previous year is 1 or 10. This difference shows whether the model is experiencing a surging or non-surging year. The time step in the model is as follows: for surging periods, the model will collect data for each year within the 10 years of surging, for non-surging periods, the model will collect data for every 10 years within the 100 years of non-surging.

Within this same loop, we can decide which flow parameter we want to the model to simulate. We can comment out the model option for Glen's A or sliding parameter within the experiment to see slow flow and surges.

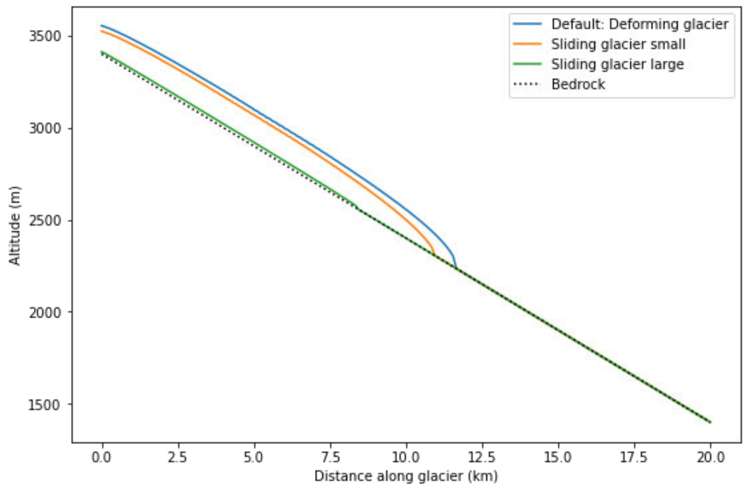

Figure 2. Differences in glacier shape based on changes in basal sliding parameter. Default deforming glacier is a control glacier, sliding glacier small is a fraction of the sliding parameter, and sliding glacier large is an amplified value of the sliding parameter.

Results

Changes in the sliding parameter either reduces or intensifies the amplitude of the surge cycle. We tested surge multiplier values of 5, 10, and 15, and compared the length and volume of the resulting glaciers simulated in OGGM (Figure 3). For a surge multiplier of 5, we see that the average surge length changes from 10,000 to 11,000 meters and the volume changes between 0.35 and 0.37 km^3. For a surge multiplier of 10, the average surge length changes from 9,000 to 11,000 meters and the volume changes between 0.3 and 0.35 km^3. Finally, for a surge multiplier of 15, the average surge length changes from 8,000 to 12,000 meters and the volume changes between 0.27 and 0.32 km^3. Compared to our previous lab, we see that surging glaciers tend to cycle between varying lengths and volume throughout time while our control glacier stays at a constant length and volume.

Changes in the surge multiplier results in different lengths of the glacier. In general, surging glaciers are thinner up glacier and thicker down glacier. This can be seen through the intersection between the surging and sliding glacier relative to the control deforming glacier (Figure 4). Using the same surge multipliers of 5, 10, and 15, we see different glacier lengths of approximately 11.0, 11.5, and 12.0 km respectively.

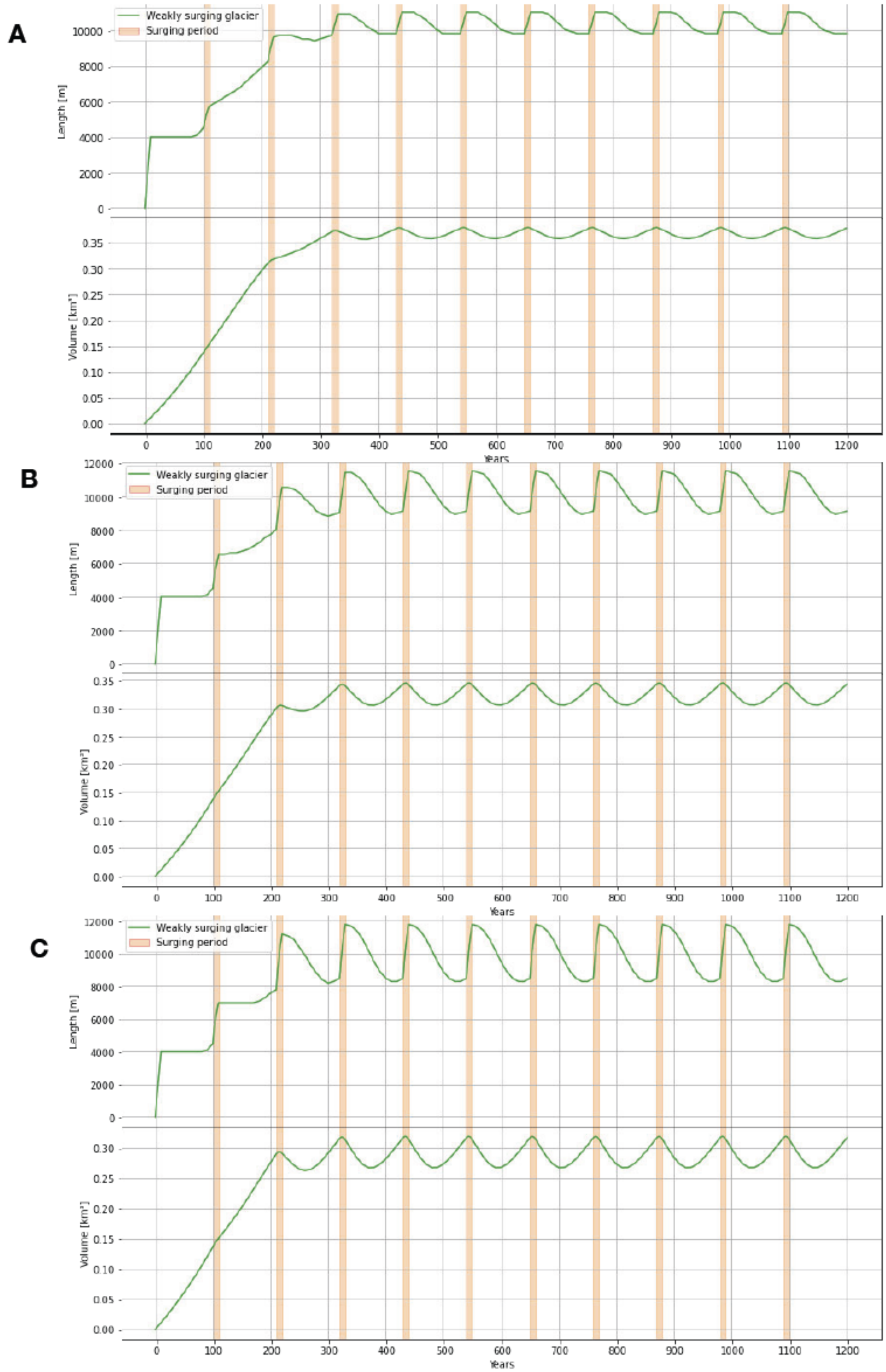

Figure 3. Surge cycle length and volume over time for surge multipliers (A) 5, (B) 10, and (C) 15. Orange vertical lines indicate the 10-year surging period.

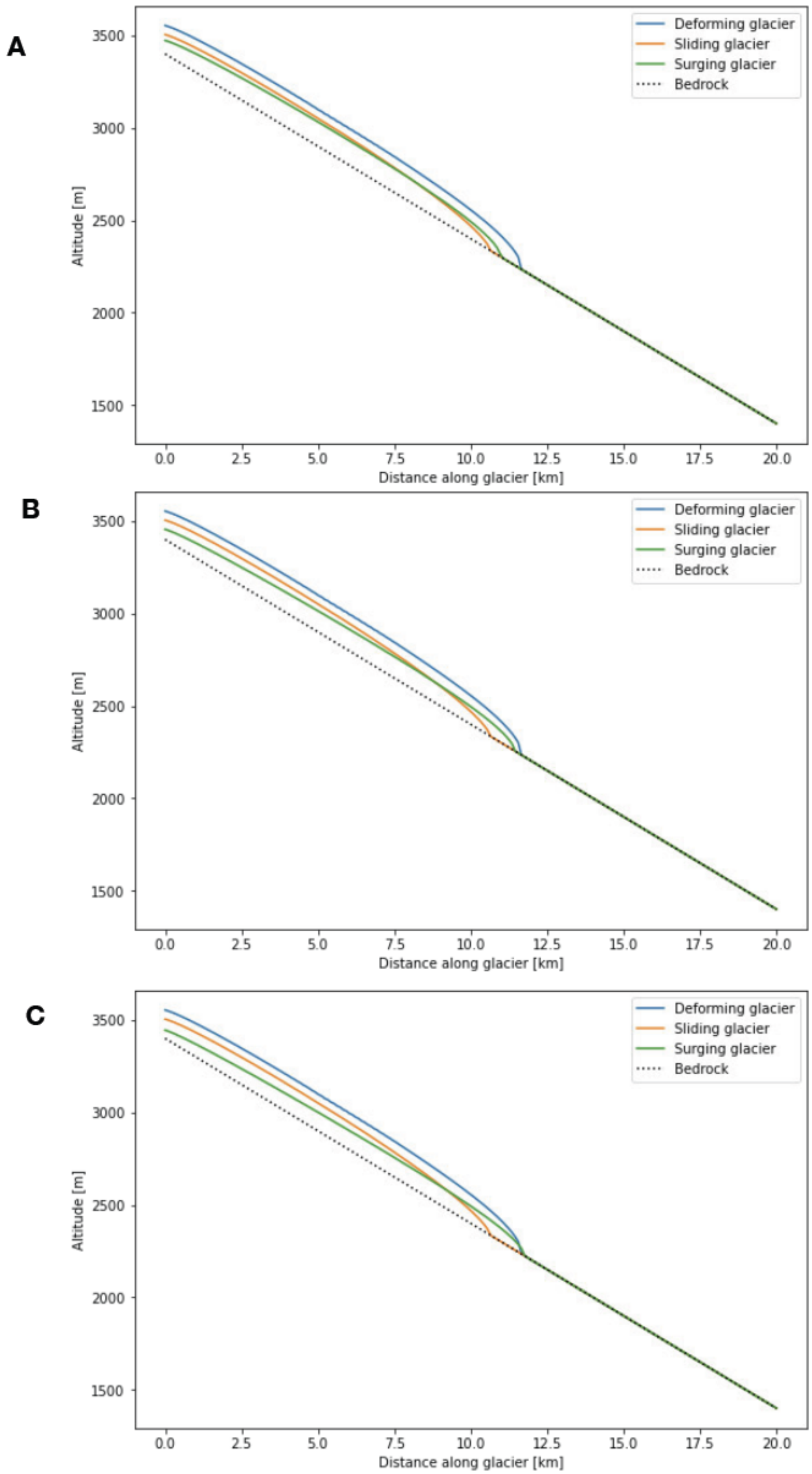

Figure 4. Glacier length profiles of deforming, sliding, and surging glaciers for surge multipliers (A) 5, (B) 10, and (C) 15.

Discussion

Within this lab experiment, we find that surge cycles can be simulated in OGGM. In addition, we can compare differences in length and volume with surge multipliers. We generally find that increases in the sliding parameter result in longer glacier lengths. However, something that is interesting among the different surge multipliers is that there is an increase in range with increase in multiplier value. For example, the surge multiplier of 5 had a range of 1,000 m in length and 0.2 km^3 in volume, while the multiplier of 15 had a range of 4,000 m in length and 0.5 km^3. This might be due to increase in length amplitude where a range of lengths need to be represented by a range of volumes. I would expect there to be a linear increase of length and volume, but the relationship here can be seen as a growing range of possible values.

Over time, we see that there is the same cycle of surging and non-surging period. It is important to have a time step during the surging period to visualize the rapid change in close detail. By using the same scale for surging vs. non-surging, the model loop might skip or miss a key change within the period were most interested in, which is the 10 years of rapid surging.

The shape in glacier length and volume vary across the glacier profile. We generally see that surging glaciers are thinner up glacier and thicker down glacier noted by the intersection of the surging and sliding glacier. We also see that both surging and sliding glacier are smaller in size and length than the previous lab, or deforming glacier in Figure 4. The differences in shape can be due to a variety of reasons. One is that in surging glaciers, most of the length and volume change is happening closest to the terminus where the same range is cycling. In other words, the ablation zone is experiencing the most change. Another reason for the differences in shape is that there is not the same friction experienced across all three glaciers. The deforming glacier has no water film, the sliding glacier has a water film, but the surging glacier has a water film and rapidly advances and recedes throughout time. This can also mean that there is an increase in ice velocity, thus flow parameter, that controls the glacier length and volume.

References

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