Glaciology lab: Deformation, sliding, and surging in OGGM

Lab report 3

[redacted]

Abstract

Surging glaciers experience cyclical rapid accelerations in flow that result in changes to surface characteristics and morphology of the glacier. Surges have been linked to the thermal regime and basal sliding of the glacier but are poorly constrained. In this experiment we use OGGM to determine if Glen's creep parameter or the sliding parameter resulted in the development of a surging glacier and profile the resulting glacier. We found that modification of both Glen's creep parameter and the sliding parameter produce a surging glacier that varies in both length and volume through its surge cycle. Our results show that variations in length and volume change at different rates during the surge cycle, with elongation of the glacier likely resulting in mass loss as the terminus extends to lower elevations.

Introduction

A small percentage of glaciers worldwide exhibit a unique cyclical flow pattern, where they undergo short periods of fast flow that result in changes to surface characteristics and morphology followed by long periods of quiescence. These glaciers are called surge-type glaciers, with velocities sometimes observed on the order of 100m per day (Jiskoot, 2011).

The controlling mechanisms of glacier surges are poorly constrained but are in part influenced by the thermal regime and basal sliding of the glacier. Here we use Glen's creep parameter and the sliding parameter to investigate variances in glacier surges due to changes in glacier thermal regime and basal sliding, respectively. Glen's creep parameter (A) is a constant that relates shear stress to the rate of deformation, dependent on crystal size, impurities in ice, and ice temperature. The sliding parameter (fs) represents basal sliding, where there is a thin film of water between the ice and bedrock.

Numerical models are a useful approximation of processes that are difficult to directly observe and can help forecast future changes in the cryosphere. The Open Global Glacier Model (OGGM) is an open-source glacier model run in python. OGGM can model numerous glacier processes such as past and future glacier mass balance, changes in glacier volume and geometry, and different patterns of glacier motion. We employed OGGM to simulate a surge cycle of a glacier.

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 deformation, sliding, and surging.

Methods

We set up our experiment by defining the geometry of the bed by choosing a bed slope and peak elevation (0.1 and 3400m, respectively), with a linear bedrock profile from the top to the bottom. The bed has a rectangular cross-sectional shape, meaning the glacial "valley" walls are straight and there is a constant width along slope of the glacier. We use a linear mass balance model where the equilibrium line altitude is 3000m and the mass balance gradient is 4 mm/m. The runtime of our model is 600 years.

Following Cuffey and Paterson (2010) we set the Glen's creep parameter A equal to 2.4×10^{-24}. If A is 10 times larger, a smaller and "softer" glacier is generated, while if A is 10 times smaller, a larger "stiffer" glacier is generated (Figure 1). We set the sliding parameter fs equal to 5.7×10^{-20} which resulted in a smaller glacier in length and volume as compared with a glacier frozen to the bedrock (Figure 2).

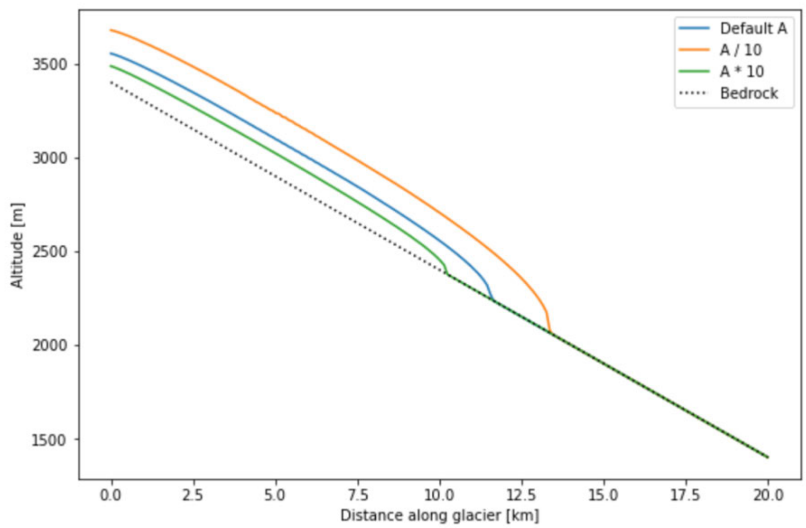

Figure 1. Variability in glacier profile of distance along glacier (km) versus altitude (m) for glaciers with different Glen's creep parameters.

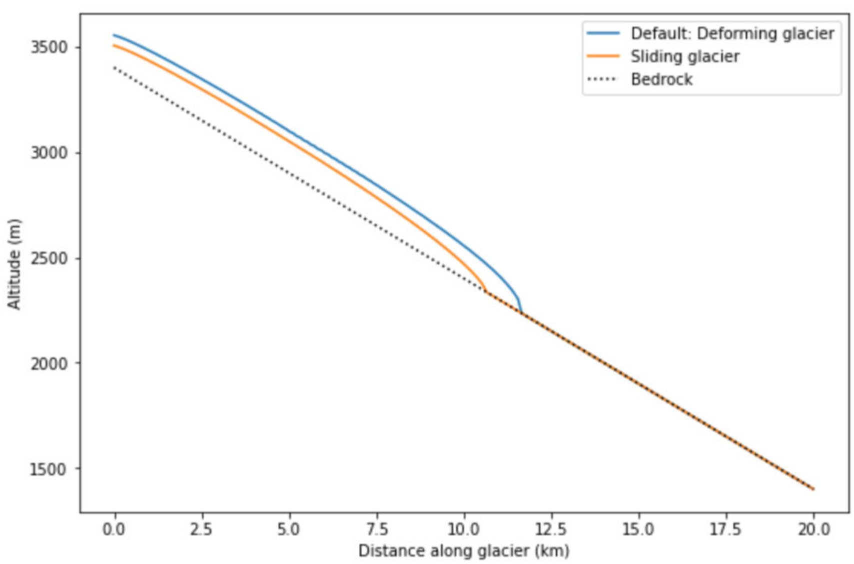

Figure 2. Variability in glacier profile of distance along glacier (km) versus altitude (m) for a sliding glacier and the default deforming glacier.

Jiskoot et al. (2000) suggest that a polythermal regime is conductive to surge-type glaciers in Svalbard. As such, we utilized Glen's creep parameter in our initial model run as the control for the surging period.

We define the glacier to surge for 10 years every 100 years. To switch between surge and quiescence periods we initialize a separate model for each state. The code is written to check if the next year is a surging year or not, and if the model needs to change, the new model is initialized using the intermediate shape saved from the most recent year of the last model. During a surge the parameter controlling the surge (either Glen's creep parameter or the sliding parameter) is increased tenfold by the surge multiplier.

Results

The evolution of a surging glacier is distinct from the non-surging glacier we modeled in Lab 5. Both glaciers exhibit a period of initial growth where the length and volume increase at a fast rate. However, after this period of fast growth, the non-surging glacier reaches a period of sustained slow growth and never loses length or volume. Conversely, the surging glacier has cyclical periods of rapid growth in length that align with surge periods and slow loss in length during quiescence periods (Figure 3). The volume of the surging glacier also has periodic gains and losses in volume, with a change from gaining to losing volume that aligns with the surge period (Figure 3).

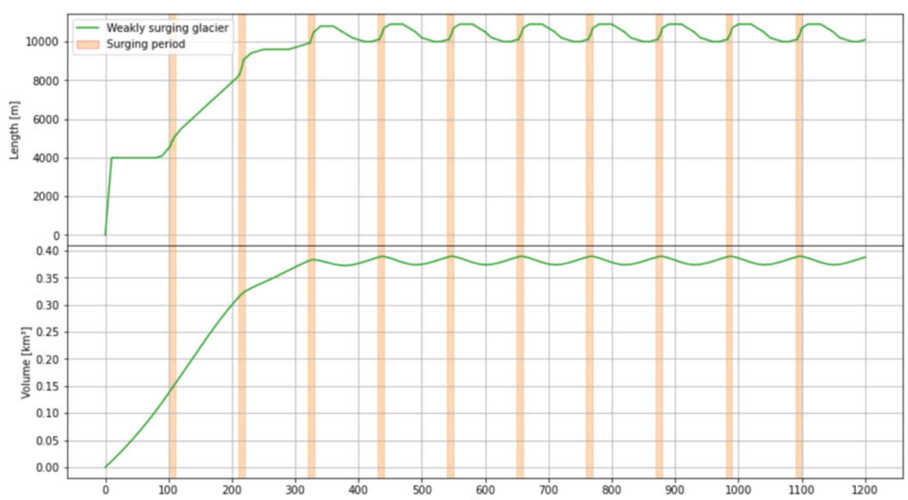

Figure 3. Change in glacier length (km) and volume (km^3) over time for a surging glacier controlled by Glen's creep parameter.

The shape of a surging glacier is also distinct from that of a non-surging glacier (Figure 4). The profiles of the non-surging deforming glacier and sliding glacier have the thickest height in the accumulation zone and thin towards their snouts in the ablation zone. The profile of the surging glacier is more uniform along the length of the glacier, with more mass towards the snout and less mass towards the accumulation zone compared to non-surging glaciers (Figure 4).

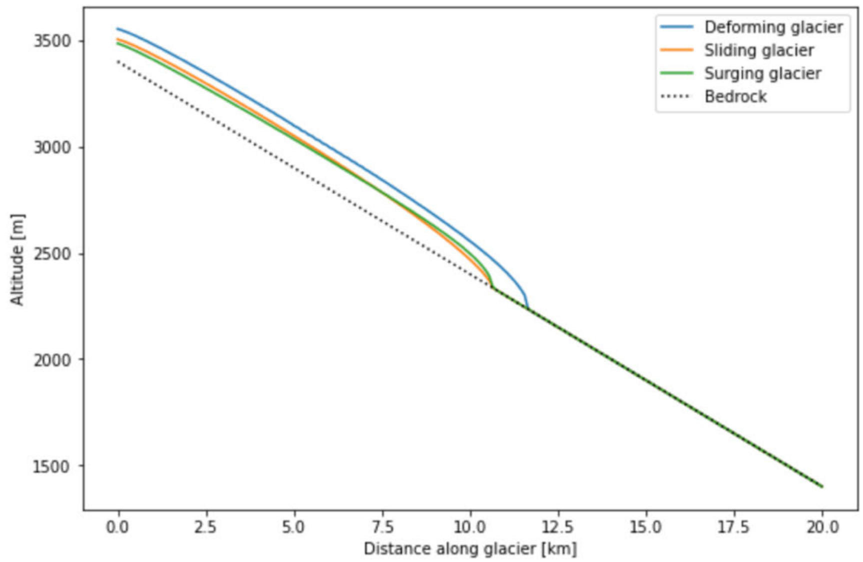

Figure 4. Variability in glacier profile of distance along glacier (km) versus altitude (m) for a sliding glacier, default deforming glacier, and surging glacier controlled by Glen's creep parameter.

Discussion

Surging glaciers exhibit a unique length and volume signal throughout the surge cycle. It is important to change the timestep we are modeling the glacier at during the surging period because surges are short-lived compared with the long periods of glacier quiescence. If we used a 100-year timestep the resolution of the model would be too coarse to resolve the 10-year surge.

The volume and length signals of a surge glacier vary at different rates during the surge cycles. During a surge, the length of the glacier increases at a fast rate and the signal coincides with the start of the surge period. Conversely, there is a lag time between surge onset and a change to the volume of the glacier. The volume of the glacier peaks at approximately the midpoint of the surge period, before decreasing. The increase in length likely coincides with the surge because the glacier is transporting mass downslope at a much faster rate than during the quiescence period, resulting in the glacier becoming more elongated. As more mass reaches lower elevations, the glacier probably starts to ablate more from its terminus region resulting in a delayed loss of volume part way into the surge period.

Varying the sliding parameter instead of Glen's creep parameter also results in the development of a surging glacier. The volume and length signals of the sliding parameter controlled surging parameter are more pronounced than those of Glen's creep parameter (Figure 5). There is approximately a 2000m change in length of the sliding surging glacier during a surge; comparatively the Glen's creep parameter surging glacier experiences approximately 1000m change in length. Additionally, there is approximately a 0.05 km^3 change in volume of the sliding surging glacier during a surge compared to the Glen's creep parameter surging glacier changing approximately 0.025 km^3 in volume.

Both the Glen's creep parameter and sliding parameter resulted in the development of a surging glacier. Therefore modifying either parameter was a correct choice for this lab.

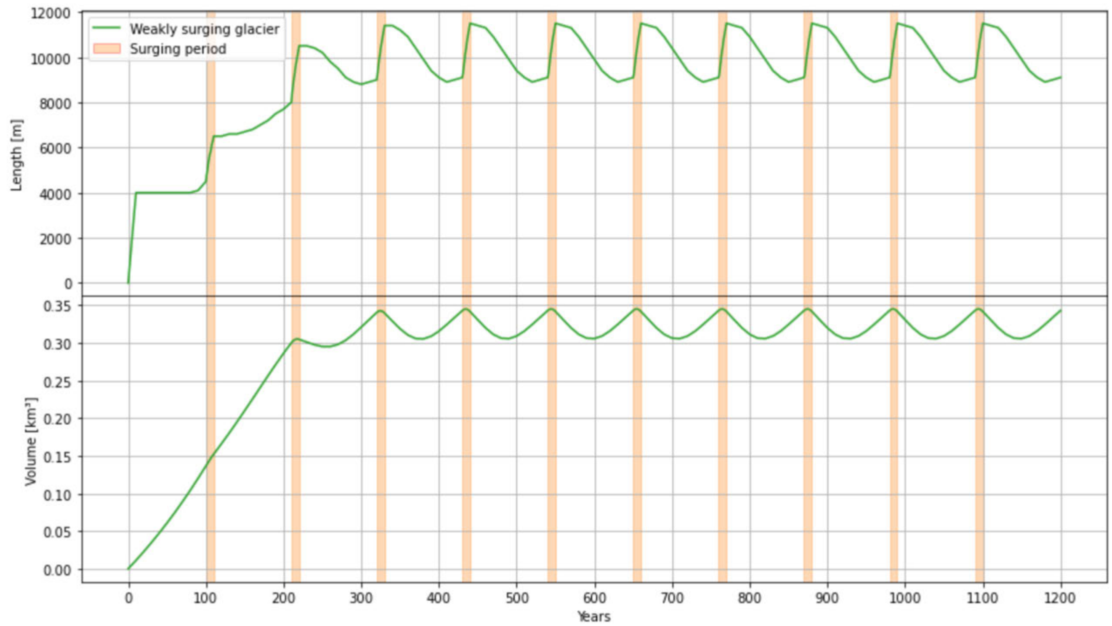

Figure 5. Change in glacier length (km) and volume (km^3) over time for a surging glacier controlled by the sliding parameter.

Conclusion

The OGGM model demonstrated that surging glaciers are controlled by both the thermal regime and basal sliding of the glacier through modification of Glen's creep parameter and the sliding parameter. A surging glacier controlled by the sliding parameter results in more pronounced length and volume changes during a surge period than a glacier controlled by Glen's creep parameter. Length and volume signals vary at different rates during a surge; in part the increasing length of the glacier results in loss of volume during a surge due to more mass at lower elevations where more ablation occurs.

References

Jiskoot, H., Murray, T., and Boyle, P., 2000. Controls on the distribution of surge-type glaciers in Svalbard. *Journal of Glaciology*, 2000. **46**(154): p. 412-422.