Lab 3 – Deformation, Sliding, and Surging

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Abstract

Glacier surging is a regular, yet not well-understood process in which glacier flow rapidly accelerates. Surging of glaciers can result in changes in glacier geometry as well as glacier mass balance. In this lab, we use the Open Global Glacier Model (OGGM) to simulate the surging of glaciers, spurred first by a change in Glen's creep parameter and then by a change in the sliding parameter. We find that adjusting each parameter produces a comparable response in both glacier length and glacier volume, but that changing the sliding parameter results in a greater magnitude of change in these metrics. This suggests that changes in both Glen's creep parameter and the sliding parameter may be responsible for triggering glacier surges, which aligns with established findings in the scientific literature.

Introduction

In this lab we used OGGM to investigate the role that Glen's creep parameter (a temperature-influenced factor) and the basal sliding parameter (a meltwater-influenced factor) play in controlling glacier surging. OGGM is an open-source glacier model written in Python and is an accessible and useful tool for modeling glacial processes such as this. 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.

Numerical models, such as OGGM, are useful tools in glaciology because they allow scientists to simulate (and thus study) processes which may otherwise be very challenging or impossible to observe. Glacial bed processes are historically very challenging to study, as it is notoriously difficult to access the base of a glacier, and glacier surges occur on a cyclical timeline, presenting more challenge in their study. OGGM helps address some of these challenges by making it easier to adjust the basal sliding and creep parameters specifically and frequently, thus allowing us to study the impact of certain changes on otherwise identical surging glaciers.

Glen's creep parameter (A) impacts the amount and rate of internal deformation within a glacier, and is controlled by a variety of factors, including temperature. If this parameter increases, more internal deformation occurs, the glacier will shrink, and it will accelerate. If this parameter is decreased, less internal deformation will occur, the glacier will decelerate, and it will grow. On the other hand, the sliding parameter (f_s) impacts how much the glacier slides along its bed. In a scenario where the glacier is frozen to its bed this is zero, but it will increase as water is introduced to the glacier base, lubricating the contact between ice and bed. This causes the glacier to accelerate and shrink.

Methods

In this lab, OGGM was initialized as in prior labs, with a slope of 0.1 and 200 grid points spaced 100 meters apart. The ELA was set to 3000 m, and the mass balance gradient to 4 mm/m. We went on to run a series of 1200 year models, with a 10-year surge period simulated every 100 years. While the standard time step of our OGGM model is 10 years, many glacier surges occur on timescales which are shorter than this, necessitating the 10-year surge period modeled with 1-year timesteps. In the first run, we kept the basal sliding parameter at its constant, and increased

Glen's creep parameter tenfold. After that, we instead increased the sliding parameter tenfold, keeping the creep parameter constant. With each run, we plotted the changes in glacier length and volume over the time period studied, and also plotted the profiles of the surging glaciers alongside that of a glacier experiencing basal sliding and internal deformation, as well as the profile of a glacier only experiencing internal deformation.

Results

We found that adjusting the basal slip parameter and Glen's creep parameter resulted in comparable patterns of changes in glacier length and volume, although at different magnitudes (Figure 1). In both cases, glacier length increases sharply during the surge period, plateaus briefly, then decreases slowly once the surge period ends, with the cycle starting over upon initiation of the next surge period. Glacier volume peaks at roughly the middle of the surge period and reaches a minimum about halfway between surge periods, with an even gain and loss of volume throughout. For both metrics (volume & length), changing the basal sliding parameter results in a greater magnitude of change. Glacier volume was slightly smaller (peaking at around 0.34 rather than 0.39 km^3) when the basal sliding parameter was adjusted rather than Glen's creep parameter. By comparison, the maximum glacier length remained roughly constant when changing each parameter, but glacier length reached a lower minimum when basal slip was adjusted (9000 m vs. 10000 m).

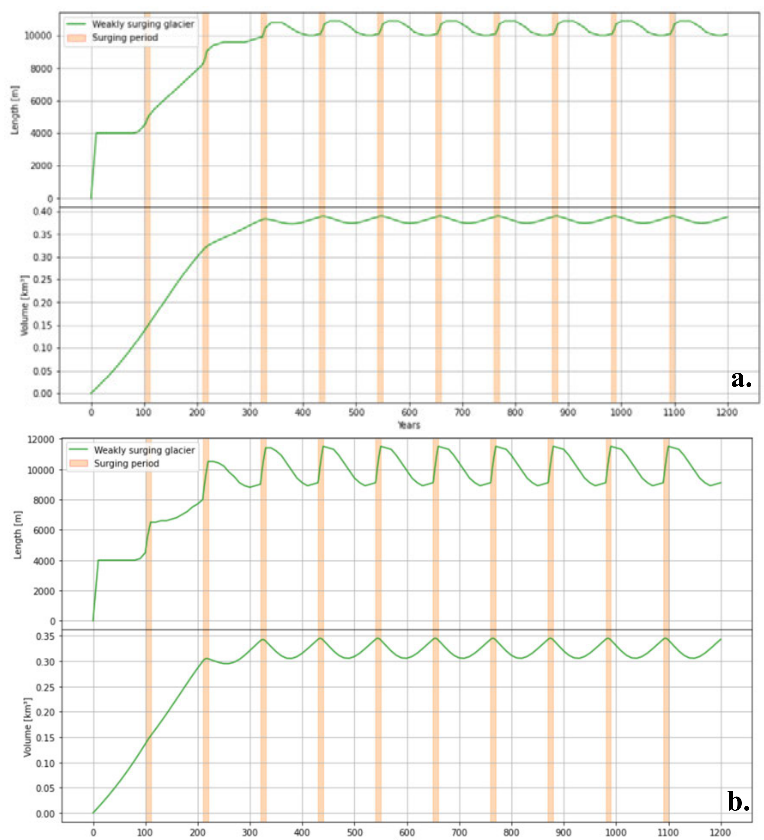

Figure 1. Panel *a* shows variation in glacier length and volume over the 1200-year model run when Glen's creep parameter was changed, whereas panel *b* shows the same metrics when the basal sliding parameter was adjusted instead. There is noticeable similarity in the pattern of cycling for length and volume, although the magnitude of change is greater when the basal sliding parameter was adjusted.

In addition to glacier length and volume, the shapes of surging glaciers were impacted by adjusting each parameter. In both cases, surging glaciers were flatter (thinner upslope and thicker downslope) and slightly longer than non-surging glaciers. Adjusting the basal slip parameter produced a longer and flatter glacier than did adjusting Glen's creep parameter Figure 2).

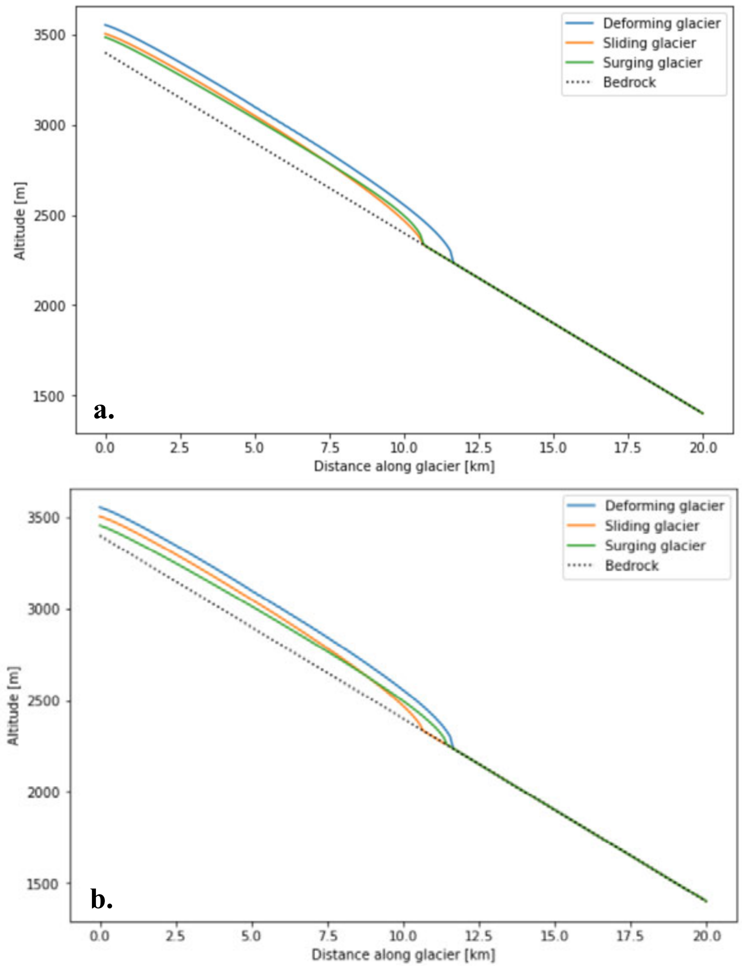

Figure 2. This figure shows variations in final glacier profile over the 1200-year model run for a surging glacier, a glacier that is deforming and sliding, and a glacier that is only deforming. Panel *a* shows that when Glen's creep parameter is changed, the surging glacier flattens only slightly and can be compared to panel *b*, where the sliding parameter was changed, resulting in a more pronounced flattening and elongation of the surging glacier.

Discussion

The results of our modeling experiment offer intriguing insights into the morphology and cyclical nature of surging glaciers. Of particular interest is the steady state cycling exhibited by glaciers when either Glen's creep parameter or the sliding parameter is increased. By comparison, non-surging glaciers have been shown to plateau at a stabilized volume and length by around 500 years, with little change beyond that (Hawkins & Kluetmeier, Lab 2). As noted above, both parameters result in this regular increase and decrease of ice volume and length, albeit at different magnitudes. This aligns with existing literature, which suggests that either the thermal regime of a glacier (e.g. Quincey *et al*., 2011) or the subglacial hydrologic regime (e.g. Kamb *et al.*, 1985) may control the glacial surging process.

In both scenarios, the maxima and minima occur at about the same time with respect to the surge period. Curiously, glacier volume peaks in the middle of the surge cycle – a time when the glacier is advancing most rapidly. This indicates a time lag between the acceleration of glacier velocity and the actual acceleration of melt. As the glacier speeds up during a surge period, it sends a larger than normal 'pulse' of ice downstream in the glacier towards the ablation area. As its advance is limited by glacial velocity and melting is not instantaneous, the 10 year surge period is over by the time that 'pulse' reaches the ablation zone and significantly melts. Thus, most of the volume loss seen in this cycle doesn't actually occur during a surge period. Eventually, the 'pulse' of ice sent by the surge melts fully and the glacier begins to regain mass, until another surge period restarts the whole process.

The pattern seen in glacial length throughout surge cycles is more intuitive than that observed in glacial volume. The sharp increase in glacier length towards the end of the surge period is a result of the glacial acceleration elongating the glacier. However, once the surge period ends and the glacier returns to its 'normal' velocity, the portion of the glacier that lengthened further into the ablation zone than normal during the surge period melts away. Eventually, the next surge period restarts the cycle.

The similarities seen in model outputs when varying Glen's creep parameter and the sliding parameter suggest that both temperature and subglacial hydrology play a role in glacier surges. While studies which use models, such as OGGM, to understand glacier surges offer valuable insights into these events, they must be combined with comprehensive field- and satellite-based campaigns in order to fully elucidate the role of various factors in glacier surges.

Conclusion

The observed model outputs for glacier length, volume, and profile indicate that both temperature and subglacial hydrology may play a role in triggering and maintaining glacier surges. However, changing basal sliding parameter rather than Glen's creep parameter resulted in more pronounced changes, suggesting that subglacial hydrologic regime shifts may exert more control on glacial surges than temperature changes. Additionally, the cycling observed in glacier volume suggests that there is a lag between glacial surge periods and associated ablation, while the cycling observed in glacier length indicates a more immediate relationship between surging and glacier length. Further work with a variety of techniques (modeling, remote sensing, fieldwork, etc.) is needed to better understand the impact of sliding and deformation on glacier surges.

Literature Cited

- Kamb, B., Raymond, C. F., Harrison, W. D., Engelhardt, H., Echelmeyer, K. A., Humphrey, N., Brugman, M. M., & Pfeffer, T. (1985). Glacier Surge Mechanism: 1982-1983 Surge of Variegated Glacier, Alaska. *Science*, *227*(4686), 469–479. https://doi.org/10.1126/science.227.4686.469
- Quincey, D. J., Braun, M., Glasser, N. F., Bishop, M. P., Hewitt, K., & Luckman, A. (2011). Karakoram glacier surge dynamics. *Geophysical Research Letters*, *38*(18). https://doi.org/10.1029/2011GL049004