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Glaciology

Lab 4 – Modeling Glacier Runoff

Group: [redacted]

Abstract

Although glaciers are crucial water sources in many parts of the world, their contributions to waterways and aquifers may significantly shift as our planet's climate continues to change. To better prepare for these hydrological shifts, it is imperative that we gain an understanding of how, when, and at what rate glacier runoff may change. In this lab, we used the Open Global Glacier Model (OGGM) to simulate glacier runoff across different atmospheric warming scenarios from the Hintereisferner Glacier in Austria over the next 300 years across. We find that if climate changes continue at a rate similar to those observed in the period of 1985-2015, Hintereisferner will likely disappear by approximately 2053. The climate must be about 1.1°C cooler in order for Hintereisferner to maintain equilibrium, thus preserving its hydrologic contribution.

Introduction

Water is a critical resource, and numerous communities across the globe depend upon glaciers to provide a significant portion of their fresh water throughout the year. As the climate warms, the reliability of these water sources may be drastically impacted (Immerzeel et al., 2020). In order to ensure that communities can effectively adapt – on the scale of both households and local and national politics – to changes in water availability, the rate and scale of the changes must be clearly understood. While many studies have investigated potential changes in glacier mass balance as a result of climate change (e.g. Geissler et al., 2021; Wijngaard et al., 2019), it is also crucial to specifically investigate glacier runoff and the way that changes in runoff may impacts communities and ecosystems.

Glacier modeling is a powerful tool to better understand glacier dynamics, particularly in a variety of conditions. These conditions can range from air temperature to basal drag, and the ability to easily simulate changes in such parameters can help us better predict the behavior of glaciers in the future. In this instance, we use the Open Global Glacier Model (OGGM) to simulate glacier runoff from the Hintereisferner Glacier in Austria. In particular, we investigate how the current climate scenario, as well as different potential climate scenarios, may impact the seasonality and overall amount of glacier runoff.

Methods

To model runoff from Hintereisferner, we first use its outline from the Randolph Glacier Inventory (RGI), a global database of glacier outlines, to initialize its shape and plot centralized flowlines. These data are then put into a 300-year climate model which is initialized with data randomly selected from the period 1985-2015. We plot glacier length, volume, and change in water storage over this time period. In addition to this, we plot the change in water storage in

Hintereisferner over an annual period when the glacier is in both equilibrium and while it's retreating.

In addition to modeling Hintereisferner based upon current climatic conditions, we also introduce climatic change in the form of a temperature bias term. In these runs, the model plots Hintereisferner's evolution in current conditions, as well as in a climate offset by the temperature bias term (e.g. warmer by 0.4°C). We adjust this parameter until we are able to effectively model the equilibrium state of Hintereisferner.

While valuable, this modeling study may not be able to fully encapsulate the conditions at play at Hintereisferner throughout the year or, indeed, the next 300 years. For example, our model assumes consistent conditions at the base of the glacier, which may well shift along with the climate. Moreover, our model does not account for changes in precipitation – in both amount and type – throughout the runs, which may positively or negatively impact glacier mass balance and runoff. The exact pattern of warming that Hintereisferner will experience in the next 300 years is also uncertain and may not align with the temperature changes based upon the 1985-2015 range used here to parameterize the model.

Results

We find that, in the current climate, Hintereisferner glacier will be in negative mass balance for approximately the next 50 years, at which point it reaches equilibrium at a scale much smaller than its current size. This can be contrasted with a cooler scenario, in which the temperature bias is -1.1°C (Figure 1). In this case, the glacier remains in its current equilibrium state. Intriguingly, the change in water storage capacity across the model run looks remarkably similar for both the default and -1.1°C scenarios when they reach equilibrium (Figure 1c).

In addition to interannual-scale patterns, we also find that the glacier modeled in the current climate experiences a more modulated change in water storage over the course of one year (Figure 2). That is, the default scenario increases its water storage capacity less during the winter and fall months than does the -1.1°C scenario and decreases its storage capacity by less than the colder scenario during the summer months.

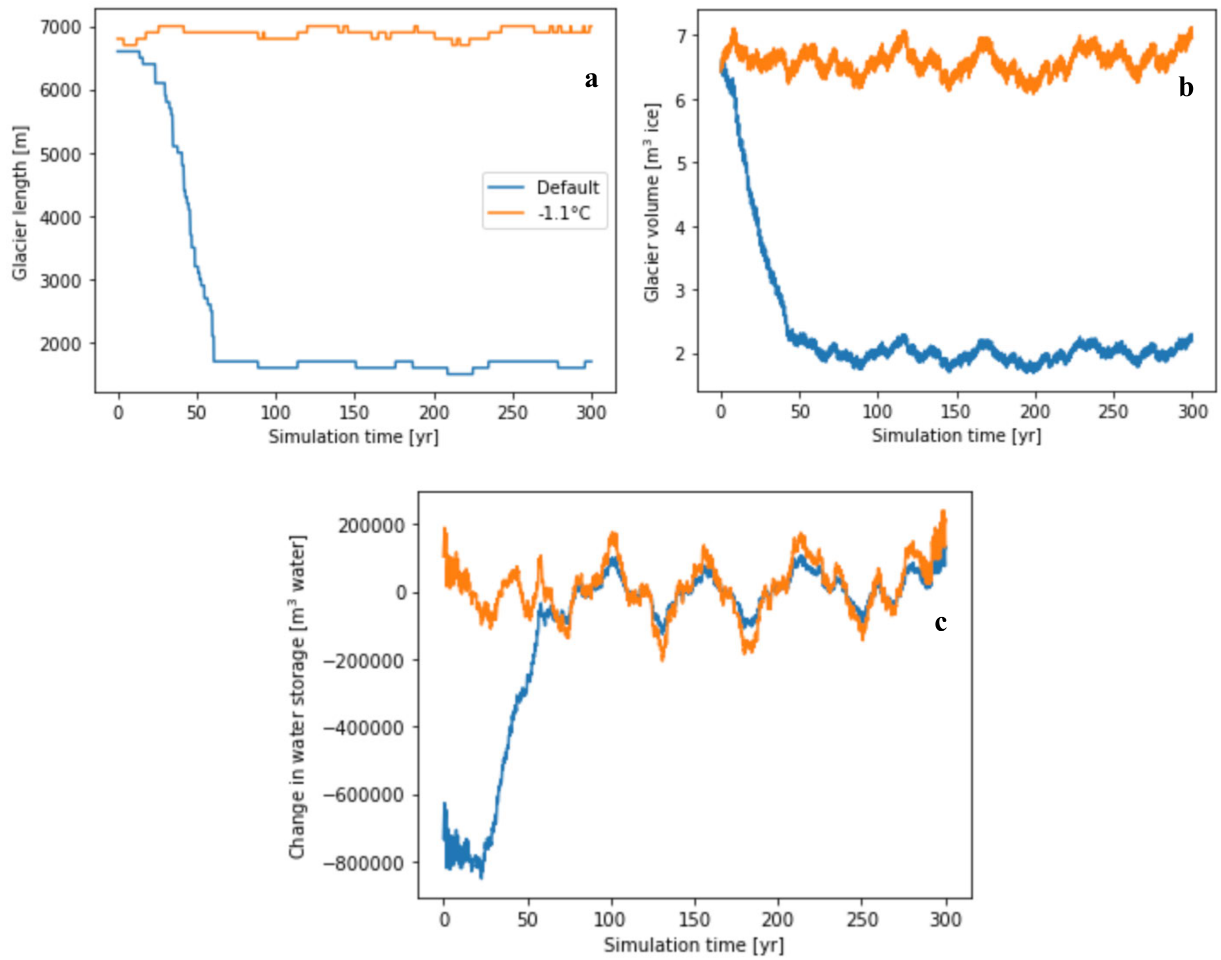

Figure 1. This figure shows comparison runs of the model based on the current climate (blue/Default) and based on a climate 1.1°C cooler (orange/-1.1°C) for glacier length (*a*), glacier volume (*b*), and water storage change (*c*). In the cooler climate, Hintereisferner remains in equilibrium with its current state, whereas in the current climate it shrinks over approximately 50 years before reaching equilibrium. Curiously, once both scenarios reach equilibrium, they experience the same cyclical changes in water storage capacity over the rest of the model run.

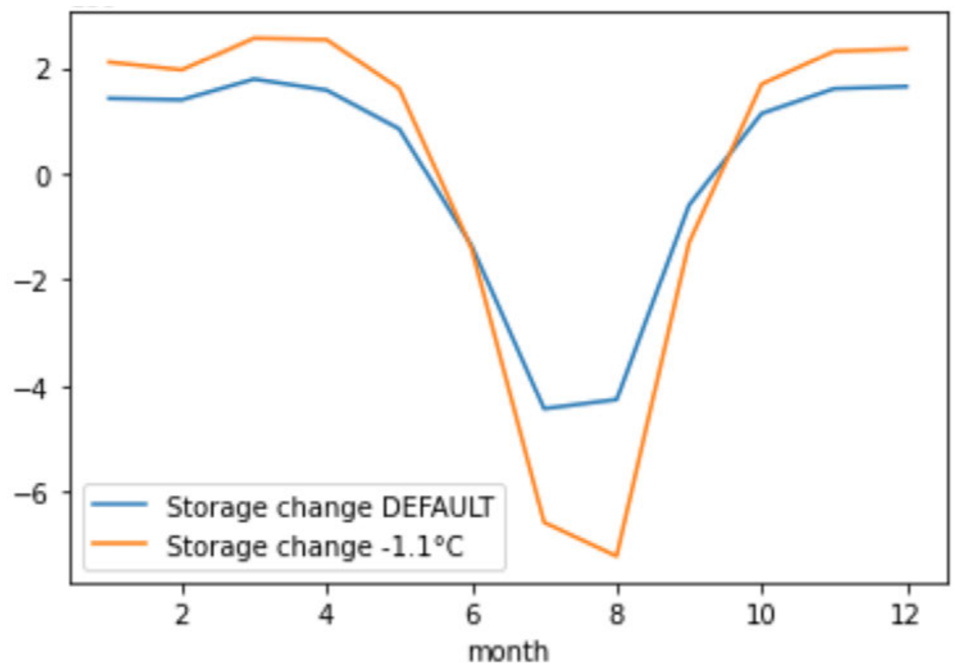

Figure 2. This figure shows changes in water storage in m^3 throughout the year for Hintereisferner glacier in a climate scenario based on current conditions (Blue/Default) and in a scenario 1.1°C cooler (Orange/-1.1°C). The cooler scenario exhibits lower lows and higher highs, possible due to an expansion of its ablation zone resulting in a greater melt area as it advances down the valley, along with an expansion of the accumulation zone, allowing more mass to be incorporated into the glacier.

Discussion

Overall, our findings suggest that glacier runoff will decrease substantially over the next several decades if action is not taken to slow the impacts of climate change. This could have drastic effects for individuals and communities that depend on Hintereisferner for their water sources. If the global temperature were to cool by 1.1°C, the current glacial runoff level from Hintereisferner could be maintained in equilibrium, with minor fluctuations. As it stands, Hintereisferner will likely shrink to less than a third of its current length & volume (Figure 1) in the next 50 years before reaching another equilibrium.

While profound, this estimate may not be completely accurate as it does not account for changes in precipitation or basal conditions over the model run. Since there will likely be more rainfall as the climate warms, decreasing accumulation while increasing melting and basal sliding, it is likely that the ultimate equilibrium state of Hintereisferner will be below the length and volume modeled here. The inclusion of terms to account for changes in precipitation, changes in basal drag as a result of increased or decreased lubrication or lithospheric adjustments, or for changes in the ice's physical properties controlling flow, the prediction of Hintereisferner's future water resource contributions could be improved.

Once each simulation reaches equilibrium, however, they exhibit comparable behavior in change in water storage. It is important to note that this is distinct from absolute water storage – the larger glacier modeled in cooler conditions will store much more water by nature of being longer and having a greater volume. This distinction likely explains the similarity, as the two glaciers experience the same modeled boundary conditions aside from temperature (precipitation, ablation, etc.), and thus are subject to comparable fluctuations controlling water storage.

The differences in water storage change observed in both studies may be driven by large differences in glacier length in each scenario. Since Hintereisferner grows larger in the -1.1°C scenario, it has much more of its length in the ablation zone than in the default scenario. This may lead to the greater magnitude of change observed in this scenario when compared to the default (Figure 2), as the accumulation areas would not be expected to change drastically but the smaller glacier has a relatively smaller proportion of its length in the ablation zone, leading to less overall melting. On the flip side, the relatively smaller increase in ablation zone size due to a cooling of the atmosphere may be responsible for the slightly greater winter and fall water storage observed in the -1.1°C scenario. In this case, the greater area in which snow consistently falls contributes to Hintereisferner's increase in mass balance. Additionally, some of these observed changes may be a result of the time it takes Hintereisferner to adjust to equilibrium during the default scenario, as the monthly water storage change is based on an average of the 300-year model run.

Although OGGM offers us an extremely powerful tool with which to understand future climate scenarios and their role in controlling glacier runoff, multiple strategies must be employed to gain a complete understanding of the hydrological future. For example, modeling studies such as this one should be cross-referenced with observational data for the overlapping period. Hintereisferner is a well-observed glacier, so there are likely readily available glacier length & thickness data, and possibly even discharge measurements, to compare with those metrics modeled in this study. As climate change progresses, continuing to monitor these conditions will be valuable in verifying (or not verifying) the findings of this study.

Conclusions

We find that the current climate conditions will result in a marked decrease in the length of Hintereisferner glacier over the next 50 years, until it again reaches equilibrium. A climatic cooling of 1.1°C is needed to maintain the glacier in equilibrium at its current extent. Although the overall difference in size of Hintereisferner in these two scenarios is large, the interannual cycle of water resource change when the glacier is in equilibrium is nearly indistinguishable. However, the changes in water storage within a year are noticeably different, with the -1.1°C scenario exhibiting higher highs in the winter and fall months and lower lows in the summer months. This work should be supplemented with observational studies in order to compare the findings discussed here to the real world manifestations, both in order to validate the model, as well as to better understand what scenario may actually be playing out over time.

Literature Cited

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