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GEOL0362Z
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Lab 4: Modelling Glacier Water Resources with OGGM

Group: [redacted] and [redacted]

Abstract

Our previous applications of Open Global Glacier Model (OGGM) are based in synthetic or theoretical glaciers, but we can utilize OGGM to explore real-world glaciers. In this lab, we explore seasonality of glacial runoff with a changing climate, as glaciers are a primary source of water for 1.9 billion people on Earth (Immerzeel et al., 2019). We analyze Columbia Glacier, WA, USA and find that with a climate centered around 2000 years, the glacier will rapidly retreat after 100 years and reach peak water, or equilibrium, where there will be little to no volume left. For Columbia Glacier to stay in equilibrium, we find through simulated climate that the temperature needs to cool by a factor of -0.8. Within Columbia Glacier, Huss & Hock 2018 predict negative monthly glacier runoff for Columbia Basin from January to April during 2050-2090, potentially on track with our OGGM simulation that the glacier will have little to no volume by 2100. Simulating and projecting different climate changes with glaciers is difficult, but we develop a larger intuition for how glacial resources differ annually and seasonally within Columbia Glacier.

Introduction

In previous labs, we modelled and observed glacier sliding and mass balance changes in a controlled environment. Those experiments are in an idealized setting where we can control the bed slope or simulate how often a glacier surge happens. However, it is equally important to understand how those experiments and findings are applied to real glaciers as they often do not have the same linear bed slope or same recurrence interval of surging or retreat. Therefore, the objective of this lab was to explore the changes in annual and seasonal glacial runoff with real-world glaciers in a changing climate. Specifically, we look at simulating Columbia Glacier, WA, USA through Open Global Glacier Model (OGGM) climate model runs. We utilize OGGM to access glacier Randolph Glacier Inventory to collect data on Columbia Glacier, 'run_random_climate' function to simulate a changing climate, and calculated changes in glacier water storage, length, and volume based on the climate simulations.

Water resources from glaciers move downstream into basins which 22% of the world population receives water from (Immerzeel et al., 2019). As a glacier retreats, water is released from its long-term glacial storage. This is a primary motivation for understanding how much water is left in glaciers as climate change impacts the seasonality of glacier retreat since so many people in the world depend on it (Huss & Hock, 2018). Overall, it is important to predict changes in glacier runoff as dry and wet seasons, or when accumulation and melt are at its peak, are impacted by climate change (Radić et al., 2014). Overtime, glaciers might not be able to accumulate as much snow and build up another inventory of long-term glacial water resources, impacting those who live downstream.

Like previous labs, 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. For this lab purpose, we utilize databases and climate models to access real glaciers and simulate volume, length, and water storage changes over time.

Methods

To study real glaciers in a changing climate, we look at different OGGM modules, mainly `cfg`, `utils`, `workflow`, `tasks`, and `graphics`. Next, we pick out a real glacier to simulate by accessing its Randolph Glacier Inventory (RGI) ID. RGI is a global database of glacier outlines, and we can access specific glacier data through the `utils` module and calling for the RGI ID. For this experiment, we decide to simulate Columbia Glacier in Washington, USA. Columbia Glacier is one glacier out of a group of glaciers on Mount Hood in Washington state. It's RGI ID is 'RGI60-02.18415' and it has a total area of 0.803 km^2, a minimum elevation of 1421 m, a median elevation of 1611 m, and a maximum elevation of 1748 m. This data is imported with the `utils` module and calling for the RGI ID.

To prepare the model simulation, the module `workflow` calls for the RGI ID data to initialize the glacier region. We can see the outline of Columbia Glacier and plot its center flowline that OGGM calculates (Figure 1).

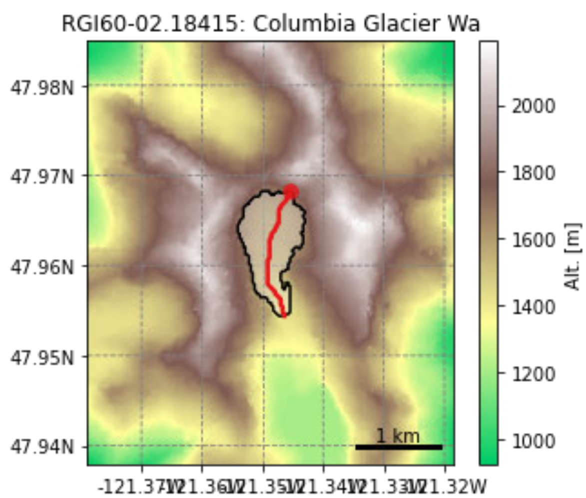

Figure 1. *Topographical (m) outline (black) of Columbia Glacier, WA, USA relative to RGI data 1958 with its center flowline (red).*

One caveat about RGI ID is that certain glacier outlines are outdated more than others. For example, Hintereisferner Glacier in Austria RGI glacier outline is from 2003, while Columbia Glacier is from 1958. This means that all simulations will be modelled relative to that outline date, 1958, and along its center flowline.

To study the climate variations, we utilize `run_random_climate` function from the `workflow` module. We run the model simulation for 300 years based on a climate during the period 1985-2015 centered on the year 2000. This means that the random climate period is changing relative to 2000. Another thing to note about the climate function is the `unique_samples` parameter is set to "True" which means that the random mass-balance year will only be available once per random climate period-length. In other words, we want the climate to be changing per each climate period-length.

Another simulation that we modelled is changes in temperature bias. The `temp_bias` parameter in the climate function can change the temperature of the climate to favor colder or warmer temperatures. A colder temperature bias is less than 0 while a warmer temperature bias is greater than 0. This value ranges from -1.5 to 1.5 without the model crashing.

The differences between settings used in a theoretical simulation versus those applied for real glaciers are the different data types and physical setup. In our theoretical simulations, we had to define boundaries and grid resolutions for the glacier we wanted. We had control over the slope of the bed topography, the mass balance gradient, and other dimensions like the length and height. However, with real glaciers, those measurements are already captured and so the main setup is behind the parameters for the simulation. For this lab, those simulation changes are the climate variables previously stated.

Results

Changes in the climate simulation (without the temperature bias) over 300 years results in Columbia Glacier retreating rapidly for the first 100 years and then reaching an equilibrium (Figure 2). For the glacier length, we see approximately 150-year intervals of advance, but then leveling off to 0-250m in glacier length around year 275. The glacier volume tells us that there is little to no volume, staying between about 0-0.3 m^3, in Columbia Glacier after 100 years of glacier retreat although there is variability among the length and water storage which should mean that there would be more glacier volume. Looking closer at changes in water storage over the climate simulation, we see that Columbia Glacier loses a lot of mass during the retreat phase, or first 100 years of the simulation, and then reaches an equilibrium phase (Figure 3).

Looking closer at seasonality trends, we see that there is more runoff with retreating glaciers than those that have reached peak water runoff or equilibrium (Figure 4). We explore more of these seasonal changes by analyzing monthly changes in water storage, temperature, and precipitation. In general, we see that the warmest temperatures, 12.5C, are associated with the summer months (June-August), where changes in water storage (-400000 m^3) and precipitation (50 mm/month) are lowest (Figure 5). We also see than peak precipitation is from November to January.

For simulations with a temperature bias of -0.8, we generally see that Columbia Glacier stays in equilibrium, but the annual change in water storage is somewhat similar to the glacier that retreats rapidly in previous simulations without the temperature bias (Figure 6). There is somewhat of an interval like behavior with the temperature bias where Columbia Glacier has major increases and decrease in water storage between -15000 and 15000 m^3 of water.

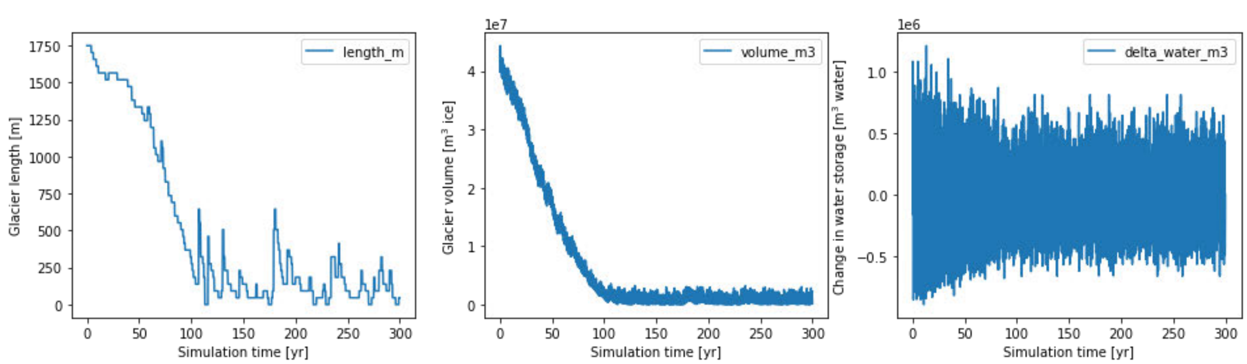

Figure 2. *Changes in Columbia Glacier length, volume, and water storage over 300 years of model simulation.*

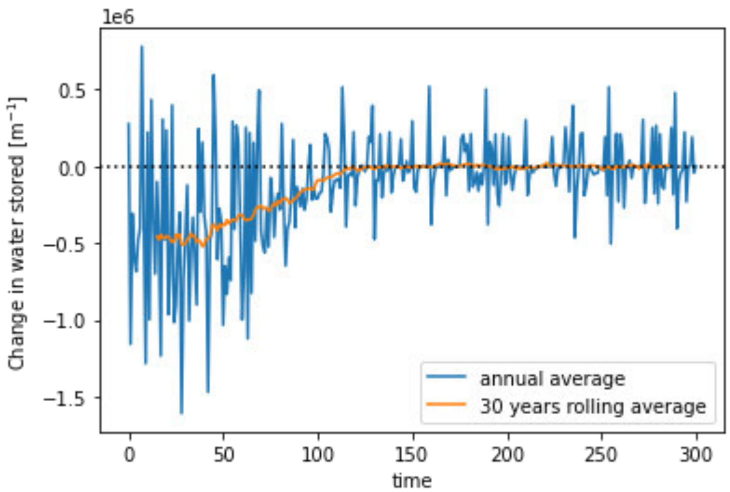

Figure 3. *Changes in Columbia Glacier water storage over 300 years of model simulation comparing annual average (blue) and 30 years of rolling average (orange) water storage changes.*

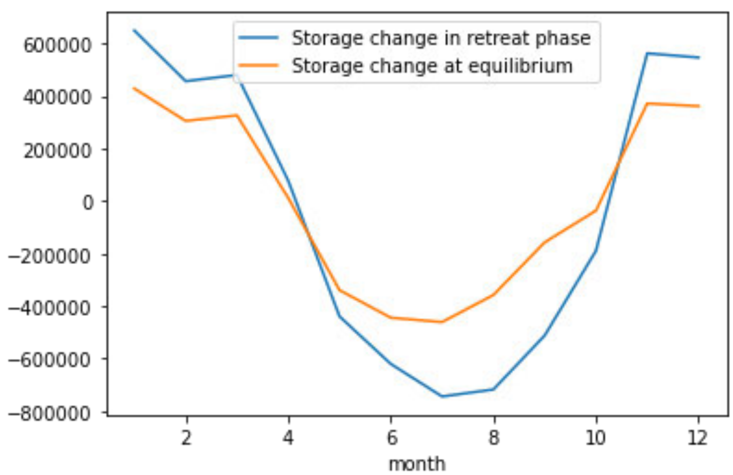

Figure 4. *Water storage change in retreat phase (blue) and in equilibrium (orange) Columbia Glacier.*

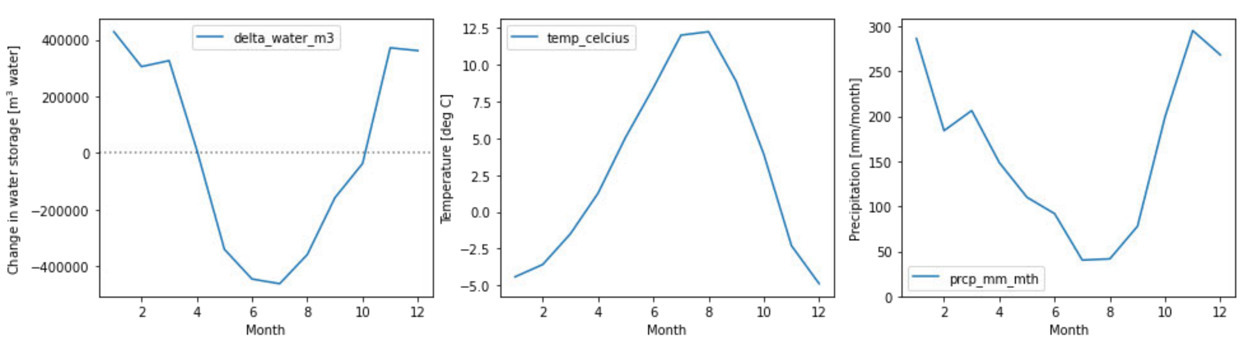

Figure 5. *Seasonal changes in Columbia Glacier water storage, temperature, and precipitation.*

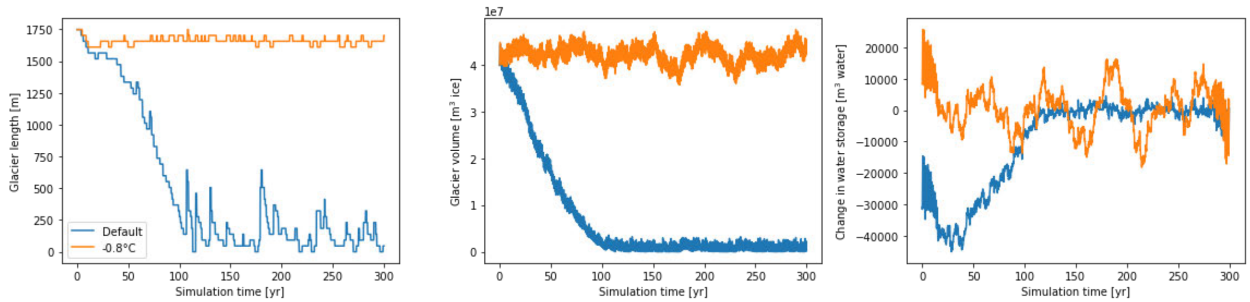

Figure 6. *Changes in Columbia Glacier length, volume, and water storage comparing temperature bias (orange) and without temperature bias (blue) simulations.*

Discussion

Within this lab, we find that with a simulated climate model glacial runoff from Columbia Glacier reaches equilibrium, or peak water, after 100 years of rapid retreat. This is a common finding with Huss & Hock 2018 where glaciers in equilibrium are gaining as much mass as they lose. In other words, there is no glacial runoff once a glacier has reached peak water. In addition, we find that there is more runoff with retreating glaciers than those that have reached peak water. This may be because there is more ablation area for larger or thicker glaciers, and so there it is more area to melt. Within our temperature bias simulations, we find that Columbia Glacier will need a cooler climate to stay in equilibrium and have no volume or length change. However, water storage will behave cyclical, after an initial retreat, and then have major increases or decreases in the range of -15000 and 15000 m^3 of water. Seasonality trends show that there is more runoff with retreating glaciers and summer months have the most negative water change. This is a comparable finding with Huss & Hock 2018 as they predict negative monthly glacier runoff for Columbia Basin from January to April during 2050-2090. This is interesting to see since water storage and precipitation in Columbia Glacier begin to decline in March in our simulations.

The performance of the OGGM mass balance model for Columbia Glacier performed relatively well in terms of calibrated and cross validated `t_star` values as they follow the same trend of measured annual mass balance. However, some factors that may lead to a skewed performance of the model can include an RGI ID outline from 1958. This outdated outline and a center flowline relative to that date can impact future simulations since the glacier may be in a different terminus position or the basin may have reduced significantly.

Conclusion

Overall, we explored how glacier length, volume, and water storage can change over time based on a climate simulation. In general, annual and seasonal glacial runoff looks different as annual averages may seem like very small changes, but seasonal changes can produce more runoff as the glacier continues to retreat. For Columbia Glacier, we find that changes in water storage decrease dramatically during the summer months, implying that glacial runoff is a source of water in the summer.

References

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