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Water resource contributions of the Cameron Glacier, New Zealand at different moraine postions

Abstract

Glacier runoff is an important part of many hydrologic regimes because the maximum runoff often coincides with otherwise low flow or drought periods. In this experiment, I use OGGM to model the Cameron Glacier in the Southern Alps, New Zealand to determine the water storage capacity of the glacier at different terminus positions, related to recessional moraines. I found in the current 1985-2015 climate the glacier will retreat for 50 years before becoming effectively extinct with a length and volume fluctuating around 0. The climate would need to remain 3.9°C colder and 5°C colder than the 1985-2015 average to readvance to the lengths were two sets of recessional moraines were deposited up valley, which is colder than suggested temperatures of 1°C warmer to -2°C based on the literature. The Cameron Glacier contributes the most runoff during the summer months with the largest form of the glacier contributing the largest water resources.

Introduction

Through the release of meltwater, glaciers constitute an important water resource both locally and globally. Nearly one-third of the world's population lives in a drainage basin that is glacierized (Huss & Hock 2018). Glacier runoff oftentimes displays a distinct seasonality with maximum runoff during the melt season and minimum runoff during snow accumulation. With the potential for maximum runoff to occur during seasons of drought or low flow, glacier runoff acts as an important buffer to interannual variability, historically providing a reliable water source to populations in glaciated catchments.

The Cameron Glacier is situated in a south-west facing cirque at the head of the Cameron Valley on the eastern front of the Southern Alps in New Zealand. Although the catchment is in remote region of the Southern Alps, trampers and mountaineers visit the valley and the Arrowsmith Station located at the mouth of the valley relies on water from the Cameron River. Here I explore how much runoff the Cameron Glacier contributes to the Cameron Valley catchment under different climate scenarios that reconstruct past glacial extents based on recessional moraine positions.

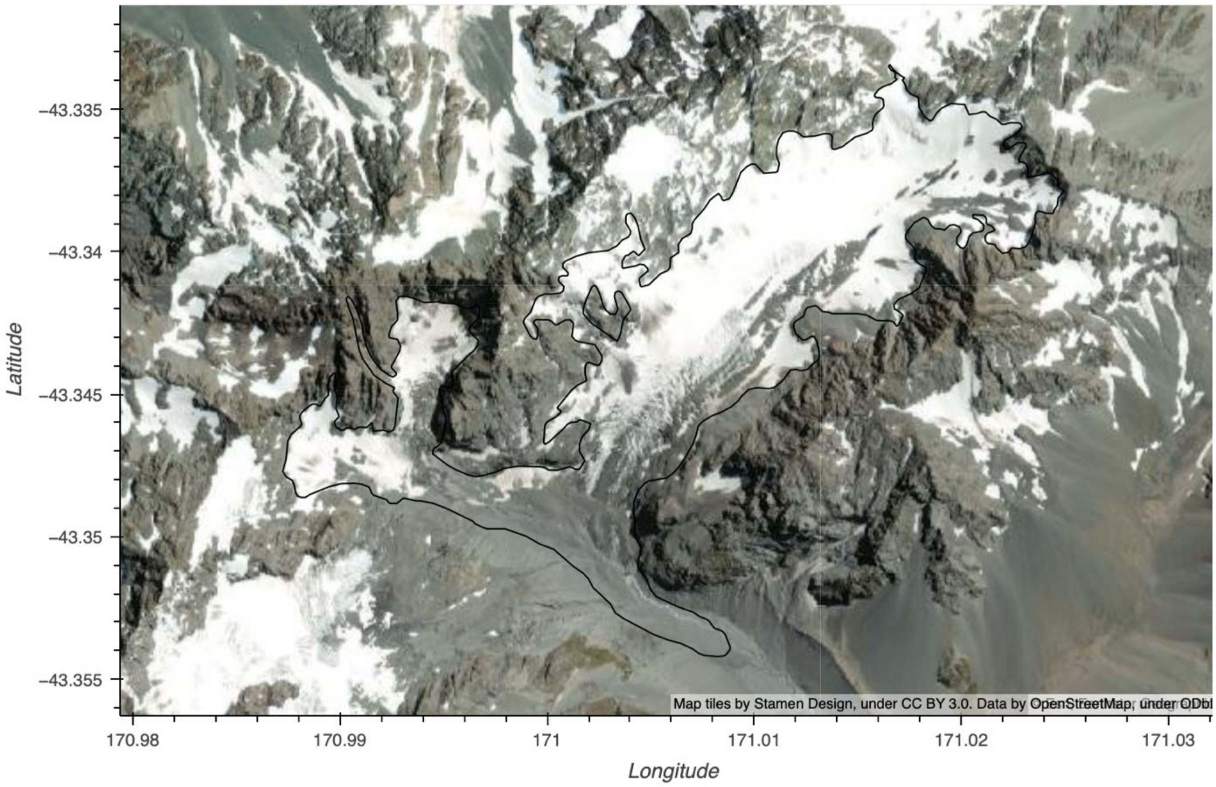

Figure 1. EsriImagery of the Cameron Glacier located in the Southern Alps of New Zealand with the RGI outline of the glacier shown as the black polygon.

Numerical models are a useful approximation for processes that are difficult to directly observe and can help forecast past and future changes to mass balance and water resources 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 glacier water storage capacities. I employed OGGM to model the amount of cooling from the present day climate required in the next 500 years for the Cameron Glacier to readvance to three different moraine packages and quantify the water storage capacity at those lengths.

We used a Jupyter Hub maintained on a cluster at the University of Bremen to access and run OGGM. The Jupyter notebook environment allows GEOL362 students to run a simplified educational version of OGGM and modify parameters within the model code to investigate runoff from real glaciers in the Randolph Glacier Inventory (RGI).

Methods

I first imported the required modules to initialize and run OGGM. To simulate the Cameron Glacier, I define it by its RGI ID: RGI60-18.03246. To visualize the glacier extent and RGI defined polygon we downloaded RGI glacier entity data for the Cameron Glacier, including the glacier outline from 1978 (Figure 2).

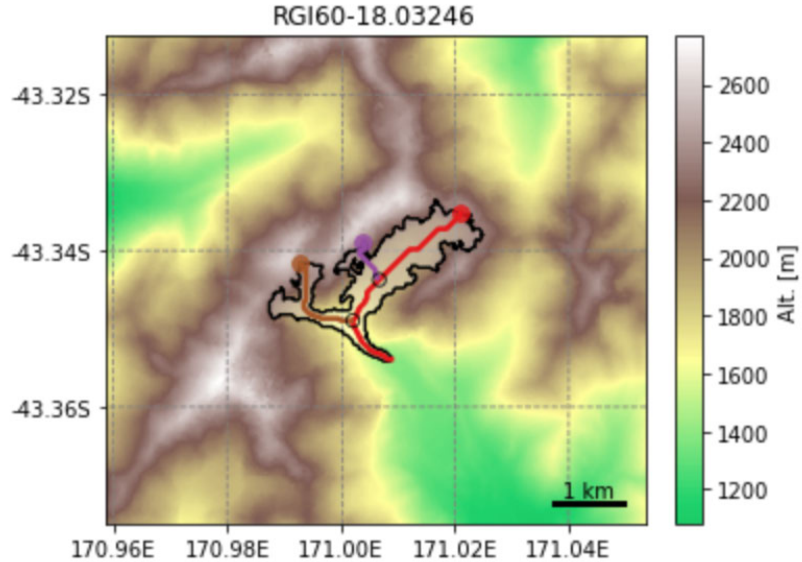

Figure 2. Glacier entity data the OGGM model uses for the Cameron Glacier, New Zealand. The glacier outline is shown as the black polygon with the main flowline displayed in red underlain by a hillshade of the surrounding terrain.

I loaded the RGI defined polygon into Google Earth Pro and mapped two series of prominent recessional moraines in the upper reaches of the Cameron Valley (Figure 3). The moraines were identified by lineations in the landscape with hummocky sides (often found in parallel sets), changes in vegetation cover or rock weathering color, and general hummocky terrain (Figure 4). Using the ruler tool, I measured the distance from the end of the current RGI flowline to the farthest point on each of the moraines and then added those lengths together to determine the necessary flowline length for the Cameron Glacier to reach the moraine positions (Table 1).

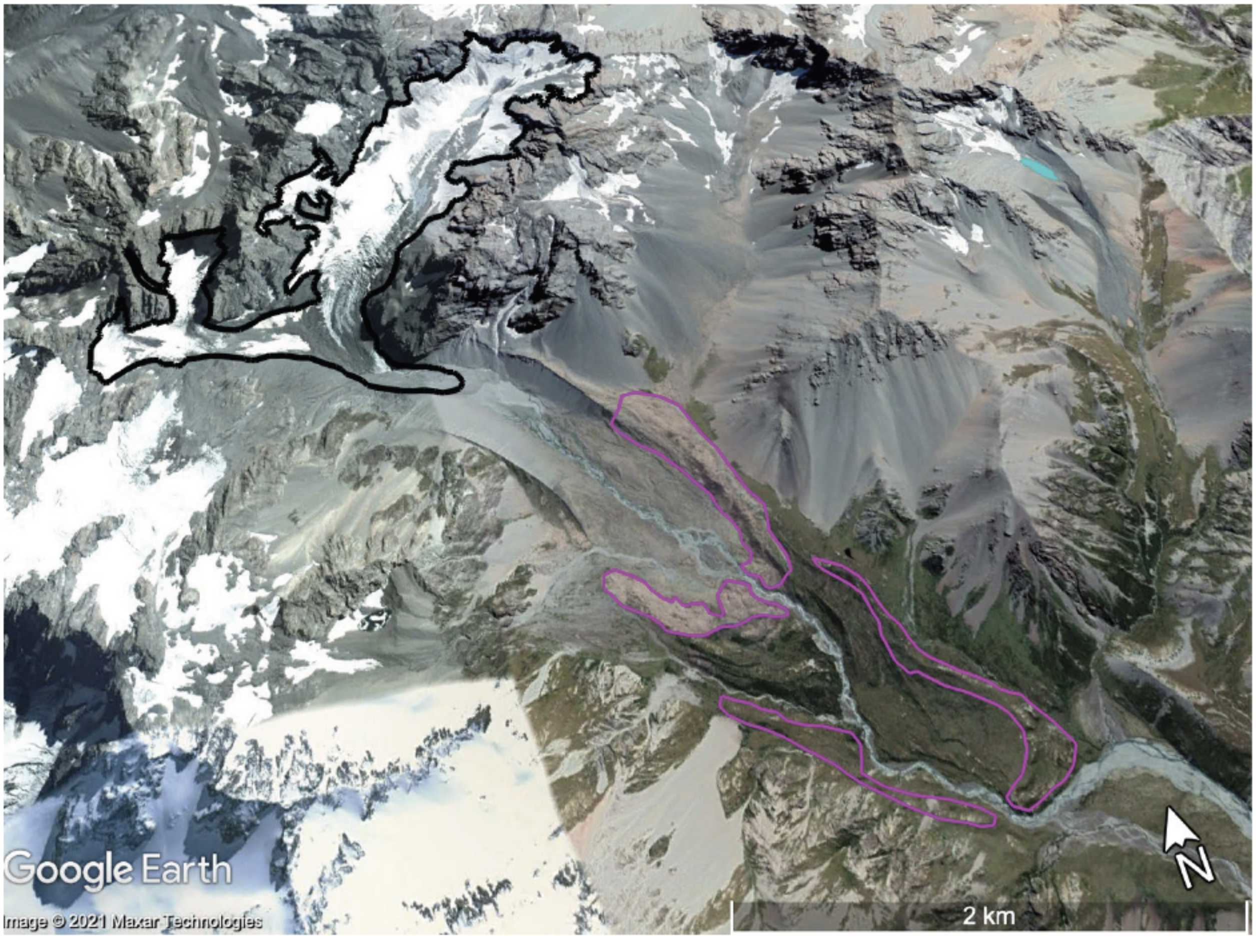

Figure 3. Google Earth Imagery showing the outline of the Cameron Glacier (black polygon) and two prominent recessional moraine packages (pink polygons), situated in the Cameron Valley, New Zealand.


Figure 4. Moraines in the Cameron Valley identifiable by their hummocky texture. Photos by [redacted] on her journey to the Cameron Hut and Cameron Glacier alongside the Cameron River in the Cameron Valley.

Table 1. Required flowline length of the Cameron Glacier to reach the upper and lower moraine packages mapped in Figure 3.

	Upper moraine package	Lower moraine package
Flowline length (m)	4920	6010

To prepare the model run I initialize glacier regions specific to the Cameron Glacier. Next, I run a random climate for 300 years changing the mass balance yearly, that uses randomly selected years centered around 2000 (1985-2015) and store monthly mass balance elevation feedback data. To explore the climate context for changing water resources at different moraine positions I introduce a temperature bias of -3.9 °C and -5°C. I rerun the model with the temperature bias, shifting each of the 300 years 3.9°C colder and 5°C colder. The model outputs glacier length (m), glacier volume (m^3 ice), and change in water storage (m^3 water) in monthly timesteps for the 300 year runs. To analysis change in water storage, we convert annual sums of change in water storage (m^{-1}).

Results

With random climates from 1985-2015 for the next 300 years, the Cameron Glacier retreats for the next approximately 50 years, losing about 3000 m in length and 10^7 m^3 of ice volume, constituting a total loss of the glacier (Figure 5). As the glacier loses mass and volume, there is also a decreasing trend in the change of amount of water stored per year for the 50 years it retreats before the 30-year rolling average sits at 0 m^{-1}, meaning there is no change in water storage (Figure 4 panel c).

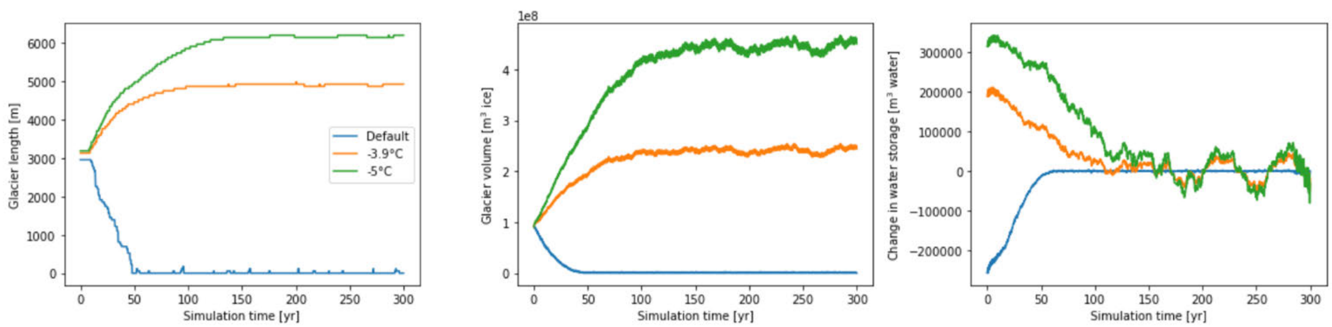

Figure 5. Cameron Glacier length (m), volume (m^3 ice), and change in water storage (m^3 water), in the current 1985-2015 climate (blue lines) compared to in a climate 3.9°C colder (orange lines) and 5°C colder (green lines).

For the Cameron Glacier to reach equilibrium at the upper set of moraines, the climate needs to be 3.9°C colder per year. If the climate were 3.9°C colder per year, the Cameron Glacier would maintain a length of approximately 4900 m and an approximate volume of $2x10^7$ m^3 of ice (Figure 5). The advance phase of the glacier is approximately the first 100 years of the model run, before the glacier reaches equilibrium for the remaining 200 years of the model run at its increased length and volume.

For the Cameron Glacier to reach equilibrium at the upper set of moraines, the climate needs to be 5°C colder per year. If the climate were 5°C colder per year, the Cameron Glacier would maintain a length of approximately 6000 m and an approximate volume a little above $4x10^7$ m^3 of ice (Figure 5). The advance phase of the glacier is approximately the first 125 years of the model run, before the glacier reaches equilibrium for the remaining 175 years of the model run at its increased length and volume. With a larger volume and length, the Cameron Glacier experiences slightly larger in magnitude changes in water storage capacity through the model run.

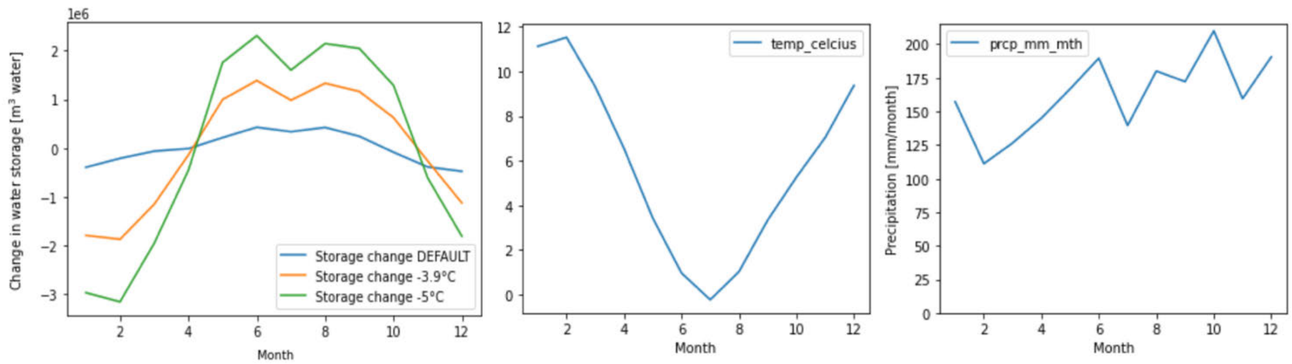

Figure 6. Change in water storage (m^3) over a year for the Cameron Glacier in the 1985-2015 climate and in a climate 3.9°C colder and 5°C colder with the temperature and precipitation for the 1985-2015 climate. Note that precipitation remains constant over the model runs and the temperature graph is simply shifted down by the different constants for the temperature bias model runs.

Compared to the baseline 1985-2015 climate, the colder climates result in a larger change in water storage capacity from the winter to summer (Figure 6). Temperature is at a low May through July, corresponding to the period of largest water storage capacity gain, while water storage capacity is at a low in February, corresponding to the end of the Southern Hemisphere summer. Reduced precipitation in July results in reduced water storage capacity during the winter.

Discussion

For the Cameron Glacier to readvance to the position of upper and lower moraine packages, the temperature needs to be 3.9°C and 5°C colder than the 1985-2015 climate, respectively. At these colder temperatures, the Cameron Glacier contributes a larger amount of water to the catchment and has a higher water resource storage capacity. Additionally, the change in water storage capacity annually is greater the colder the temperature bias and larger the Cameron Glacier, meaning the glacier dischargers more meltwater into downstream environments, while also accumulating more mass during the winter. Most of the precipitation the region receives comes during the winter and early spring, meaning that glacier runoff comprises a relatively higher percentage of runoff and stream flow than in a region where precipitation is high while glacial melt is high.

Numerous previous studies have identified the same package of at least two recessional moraines and have used techniques such as Be^{10} dating and lichenometry to date the features to the Lochaber, Marquee, and Arrowsmith advances during the Holocene (approximately 14,000 to 10,000 years ago) with a finer resolution of over 10 moraine ridges marking a succession of progressively less-extensive glacial advances (Putnam, 2012). Using a median time of 12,000 years ago, Kaufman et al. 2020 predict a mean surface temperature 1°C warmer to -2°C for 30 to 60° South. These temperatures are warmer than the ~4 to 5°C temperatures I found sustained the enlarged Cameron Glaciers, however OGGM only varied temperature without changes to other climate parameters like precipitation and these values are at different spatial resolutions.

The accuracy of the OGGM model is likely reduced by the outdated polygon used from 1978, the Cameron Glacier has retreated farther upvalley and detached from the smaller two flowlines as shown in satellite imagery (Figures 1&3). The snout of the glacier is also becoming debris covered, the potential reduction in mass loss due to insulation of ice from rock is probably not accounted for in OGGM (Figure 7).

Figure 7. The snout of the Cameron Glacier!

Conclusion

The OGGM model of the Cameron Glacier in the Southern Alps, New Zealand demonstrated in the current 1985-2015 climate the glacier will retreat for 50 years before becoming effectively extinct with a length and volume fluctuating around 0. The climate would need to remain 3.9°C colder and 5°C colder than the 1985-2015 average to readvance to the lengths were two sets of recessional moraines were deposited up valley, which is colder than suggested temperatures of 1°C warmer to -2°C based on the literature. The Cameron Glacier contributes the most runoff during the summer months with the largest form of the glacier contributing the largest water resources. Overall, the OGGM model offers a good method to approximate different terminus positions of the Cameron Glacier.

References

Huss, Matthias, and Regine Hock. “Global-Scale Hydrological Response to Future Glacier Mass Loss.” *Nature Climate Change* 8, no. 2 (February 1, 2018): 135–40.

Kaufman, Darrell, Nicholas McKay, Cody Routson, Michael Erb, Christoph Dätwyler, Philipp S. Sommer, Oliver Heiri, and Basil Davis. “Holocene Global Mean Surface Temperature, a Multi-Method Reconstruction Approach.” *Scientific Data* 7, no. 1 (June 30, 2020): 201.

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