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GEOL 362Z
Dec. 1, 2021

Lab Number 5: Modeling Meltwater Production of Dokriani Glacier, central Himalaya, India with OGGM

Abstract

Glacier runoff has important societal implications. I wished to conduct hydrological assessment on a Himalayan glacier, because it is close to my home, and it helps my understanding of water resource contribution from Himalayan glaciers. The goal of this lab is to conduct case study on Dokriani Glacier and investigates how does changing climate input influence glacier runoff outputs. I conducted two sets of simulations using Open Global Glacier Model (OGGM), one under random climate and the other under projected climate with outputs from Global Climate Models (GCMs). I found that simulation with projected climate is able to produce more nuanced and realistic result than the random climate simulation, such that it is better able to present local climate. I also found that comparing simulations with projected climate and random climate generates intuitions about the mechanisms of GCMs and random climate. My result suggests the importance of comparison between idealized climate model and projected climate model in understanding modelling mechanism and generating physical intuitions.

Introduction

This is a self-designed lab focusing on glacial water resources. I have chosen to explore the meltwater production of Dokriani Glacier in central Himalaya, India, on the topic of how does changing climate influence glacier runoff of Dokriani glacier until the end of the century. In the previous lab, we investigated the influence of changing climate on glaciers' annual and seasonal changes using the Open Global Glacier Model (OGGM), *run_random_climate* function, focusing on glaciers' storage capacity. In this lab, I will use the experimental *run_with_hydro* function from OGGM v1.5 (find description of Open Global Glacier Model from previous labs) and investigate the difference in runoff project between using OGGM's random climate setting and climate output data from Global Climate Model.

Global Climate Models (GCMs), or Global Circulation Models, are mathematical models that simulate the circulation of Earth's atmosphere and are commonly used in glacier modeling to provide climate context. For this lab, the climate model output used for the projected climate simulation is from the fifth phase of Coupled Model Intercomparison Project (CMIP5). CMIP5 outputs were generated to address scientific questions raised in Intergovernmental Panel for Climate Change Fourth Assessment Report and Fifth Assessment Report (Taylor et al., 2012). Representative Concentration Pathways (RCPs) are a set of emission scenarios containing emission, emission and land-use, accessible through CMIP5 outputs. The RCP simulated in this lab is RCP2.6, which signals a radioactive forcing level of 2.6 W/m^2 (van Vuuren et al., 2011).

Run_with_hydro is an experimental OGGM function that produces hydrological mass balance output by adding mass-balance and runoff diagnostics into output files. On OGGM's tutorial online on this function, the developers explain that they are confident in the accuracy of its output despite the fact that it could be improved in efficiency. There also lacks official function documentation for *run_with_hydro* as of the time of writing.

Dokriani Glacier (30° 50' 35" N, 78° 49' 30" E), is located in central Himalaya with an area of around $7km^2$, and elevation between 3910m a.s.l. and 6200m a.s.l. It is a compound valley type glacier. Currently, Dokriani Glacier is bounded by left and right moraines and is debris-covered. Dokriani Glacier experiences ablation season between May and September and corresponding peak water production season between July and August. The local Himalayan climate has huge influence on the glacial meltwater production (Kumar et al., 2014) (fig 1).

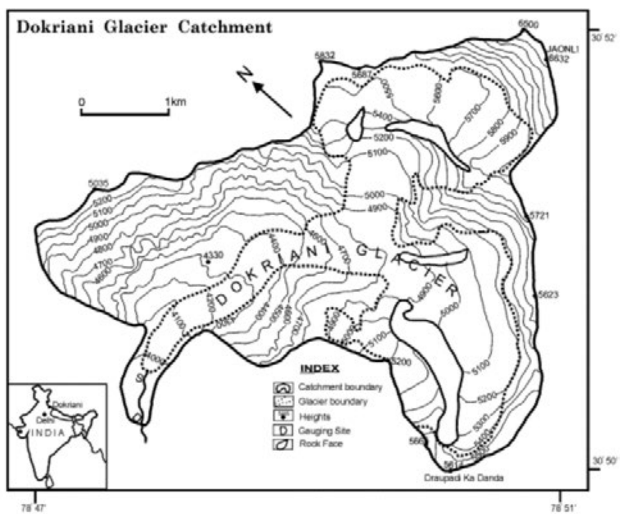

Figure 1: Location map of the area showing Dokriani Glacier catchment (Thayyen et al., 2005).

Methods

I started the investigation by reading in default parameters from OGGM's configuration files which would configure global parameters for the model runs for the entire investigation. Then I defined the working directory, "WaterResources", a local folder with defined file path to store all output data locally. To access glacier outline data from Randolph Glacier Inventory and initiate the glacier directory, I first identified the RGI-id of Dokriani Glacier from GLIMS Glacier Viewer. Using the RGI-id, I initiated the glacier directory. Using *tasks.init_present_time_glacier* function, I created a stand-alone numerical glacier, with glacier outline data collected from the year 2000 for this particular glacier, ready to be used in model run.

Using *run_with_hydro* experimental function, I conducted two sets of simulations with different climate conditions: random climate and projected climate through data outputs from GCMs. With random climate simulation, the climate of each year is generated from randomly shuffling climate of past 11 years. More detailed description of random climate can be found in the previous lab report describing function *run_climate_climate*. With projected climate simulation, GCMs output data were downloaded and bias-corrected, and model run was started at the end of the historical run, which is year 2000 for Dokriani Glacier. RCP 2.6 was selected for the projected climate.

With each set of simulation, I investigated into annual runoff (megaton, Mt) and monthly runoff (megaton, Mt). For annual runoff, I created separate pandas DataFrames for all the annual

(1D) variables. With this DataFrame, I produced two separate plots showing the change in total annual runoff over the simulation time (100 years) and change in total annual runoff by categories over time, from 2000 to 2100. I selected four categories pertaining to glaciers' liquid runoff: snow melt on areas that used to have glacier coverage but are now glacier-free, snow melt on glaciers, liquid precipitation on areas that are now glacier-free, and liquid precipitation off glaciers. These categories correspond to variables *melt_off_glacier*, *melt_on_glaicer*, *liq_prcp_off_glacier* and *liq_prcp_off_glacier*. For monthly runoff, I also produced two types of plots for analysis. I plotted the annual cycle (each month of the year) of runoff for year 0, 30, 60, and 99 from the 100-year simulation period. I also created area plots showing proportions of runoff from each of the four categories at first 10 years and last 10 years of the simulation.

Lastly, I plotted a collection of spaghetti plots showing total runoff from each climate projection scenario (RCP 26, RCP 45, RCP 60, RCP 85).

Results

1. Simulation with random climate

Annual total runoff (from all categories) undergoes cyclical fluctuations and generally continued decrease over simulation time from around 14 megatons of average fluctuation value to a stabilized fluctuation value of around 12.5 megatons (fig 2).

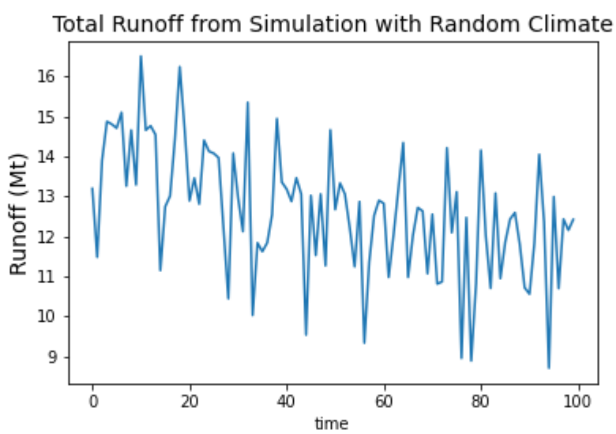

Figure 2: Total runoff from 100-year simulation with random climate

At the beginning of the simulation, melt off glacier and liquid precipitation off glacier occupy no percentage of total runoff. Over time, these two values increase as melt on glacier and liquid precipitation on glacier decreases in both amount and percentage of total runoff (fig 3).

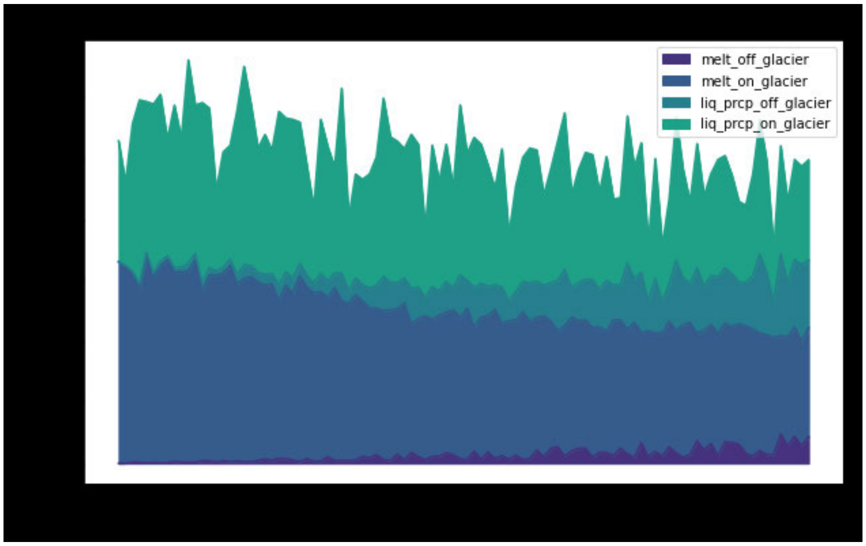

Figure 3: Area plot of total runoff by categories from 100-year simulation with random climate

Percentage of total runoff occupied by meltwater production on glaciers shrink and percentage of total runoff occupied by meltwater production off glaciers grow between the first 10 years and last 10 years of the simulation (fig 4).

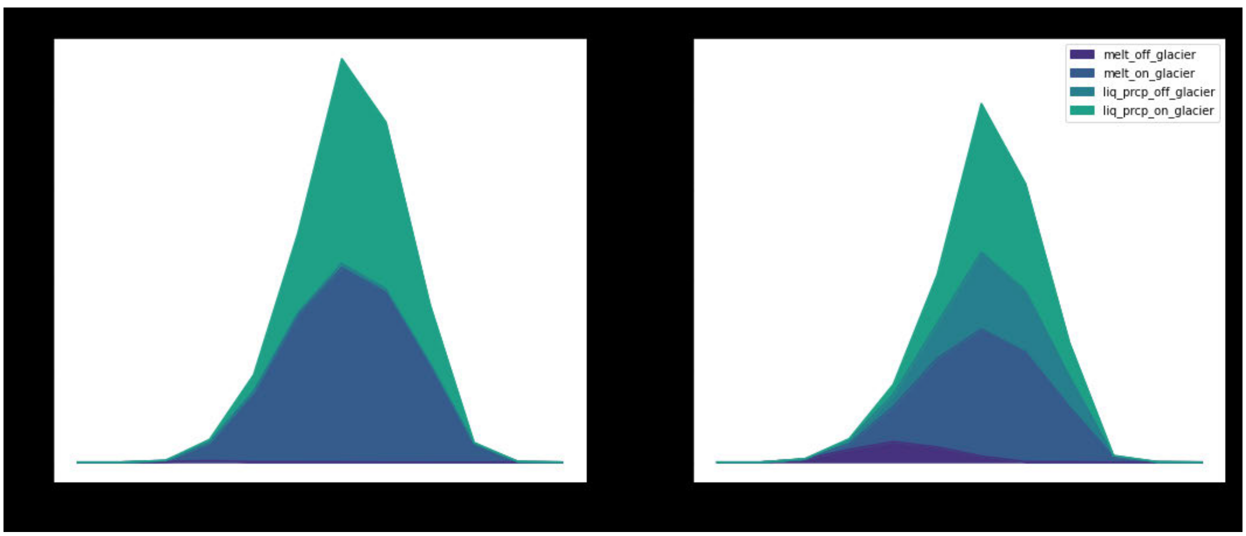

Figure 4: Annual cycle of runoff by categories of first 10 years and last 10 years from 100-year simulation with random climate

2. Simulation with projected climate – RCP 2.6

Annual total runoff (from all categories) fluctuates largely over the first 80 years of simulation period and decrease in the last 20 years.

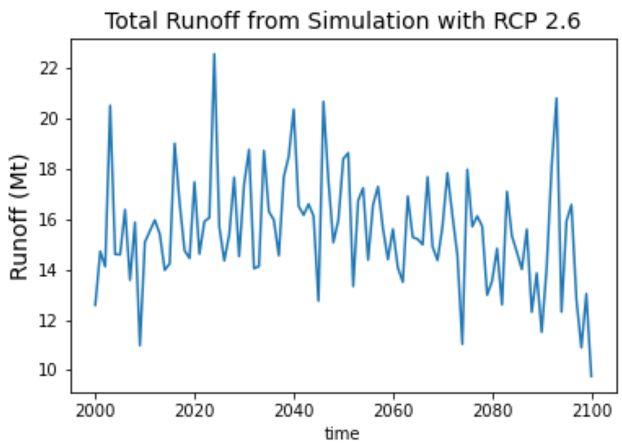

Figure 5: Total runoff from 100-year simulation with projected climate scenario RCP 2.6

Liquid and solid precipitation increase in percentage of total runoff over time. Liquid percentage off glacier takes up most of the total runoff at the end of the simulation.

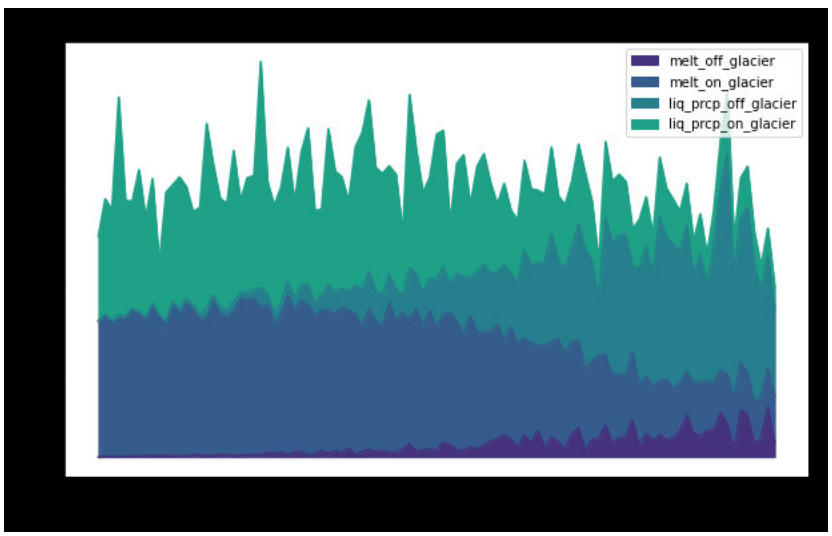

Figure 6: Area plot of total runoff by categories from 100-year simulation with projected climate scenario RCP 2.6

Annual cycle from random climate and projected climate exhibit similar pattern in the first 10 years of the simulation. In the last ten years, all four categories of total runoff increase and then decrease over simulation time. Melt on and off glacier take up smaller percentage of total runoff than liquid precipitation on and off glacier.

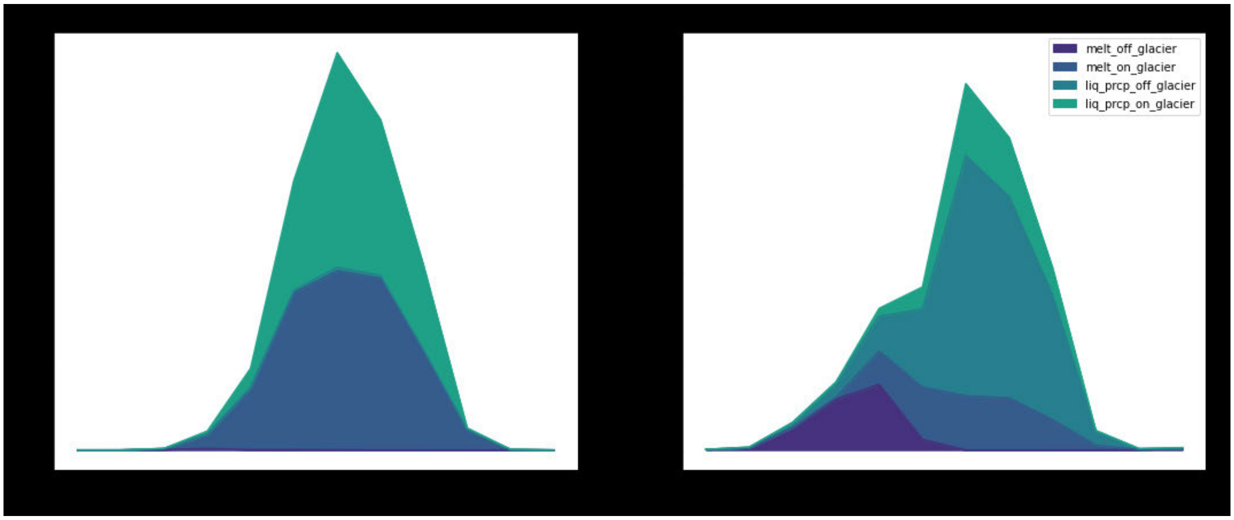

Figure 7: Annual cycle of runoff by categories of first 10 years and last 10 years from 100-year simulation with projected climate scenario RCP 2.6

3. Peak Water projection of Dokriani Glacier

Peak water projection shows different amounts and time of peak water with different climate scenarios.

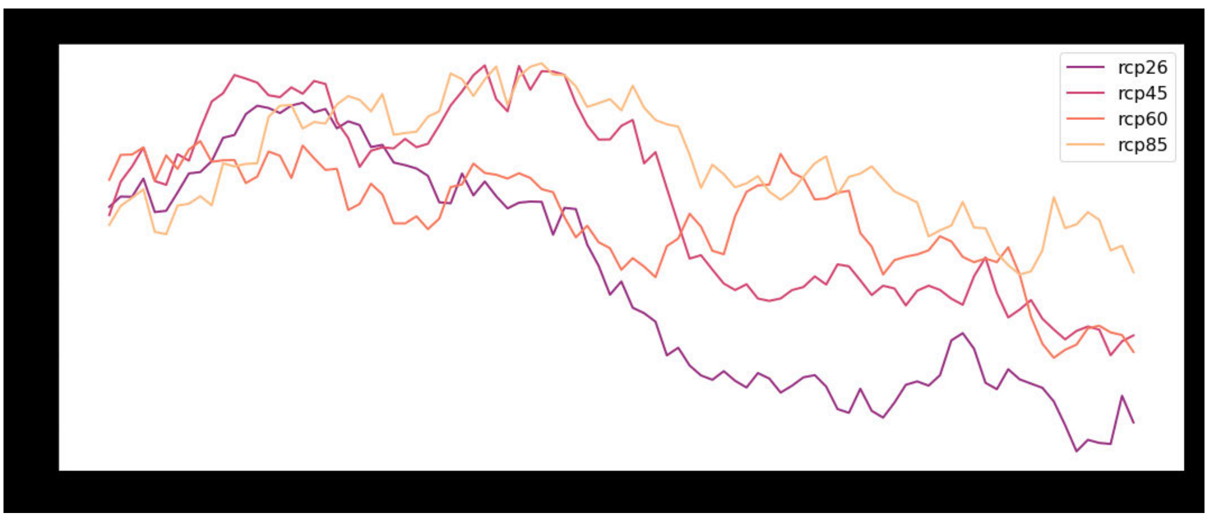

Figure 8: Annual runoff of Dokriani Glacier under different emission pathways, RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5.

Discussion

Both random climate and projected climate simulation produces downwards trends of runoff from Dokriani Glacier (fig 2 and fig 6). There is less runoff decrease in projected climate than random climate. Since random climate is generated from randomly shuffling of historical climate, it is expected that random-climate simulation would still create observable patterns of steady runoff decrease (fig 2). In contrast, simulation with projected climate produces runoff outputs under emission scenario of RCP2.6, which is a more specific and reality-based climate output.

In both total runoff over time by categories, percentage of precipitations on glacier shrink and percentage of precipitations off glacier grows. This is expected since in both simulation, climate projections lead to shrinking glacier mass. However, under projected climate simulation, precipitation off glacier ends up taking a dominating percentage of the total runoff at the end of simulation and melt off glacier also takes up a greater percentage of total runoff. As a result, precipitations off glacier take up most of the total runoff, and precipitations on glacier take up a small percentage. In contrast, under random climate, despite the shrink in total runoff, precipitations on glacier still take up most of the total runoff. To better understand the difference in categories percentage of total runoff, I plotted the glacier volume change during both simulations. The glacier volume under projected climate decreases more than that under random climate. Consequently, less glacier areas and volumes receive less precipitations on glacier (fig 10).

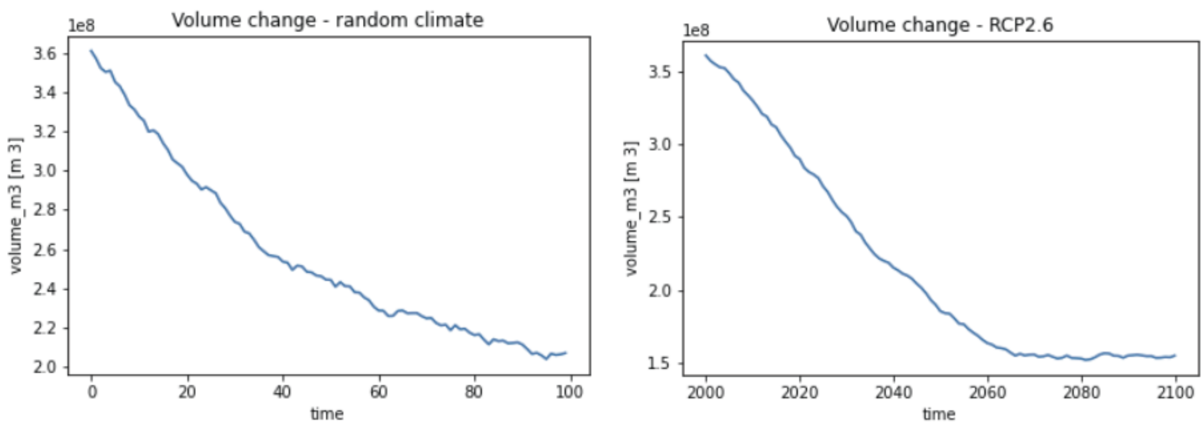

Figure 9: Volume change in random climate and projected climate simulations

The annual runoff cycle under random climate has more steadied and uniform spread between categories of runoff than projected climate. Random climate simulation maintains the annual cycle aligning with a normal distribution, by which runoff in all categories increase in summer and decrease in winter. The last 10 years of projected climate simulation, however, showcase decrease in rate of increase for liquid precipitations on and off glacier for April and May, peak of melt on and off glacier for April and May, sharp increase in liquid precipitations on and off glacier between June and July, gradual decrease in melt on and off glacier between May until the end of the year, while sharp decrease in liquid precipitations on and off glacier until the end of the year (fig 7). This presents that projected climate from GCMs are able to produce more nuanced and complicated runoff projection that might correspond with better local climate projections.

Literature from past research tells us that Dokriani Glacier experiences monsoonal season that sets in around July 25th until the end of September (Thayyen et al., 2005). This would explain the large amount of precipitation off glacier between this period under projected climate simulation. Studies suggest that runoff from Dokriani Glacier peak in August (Azam & Srivastava, 2020), which rough corresponds with my result, though both figure 4 and 7 indicate an earlier runoff peak in July. Researcher have also concluded that rainfall contributes to roughly 44% of total runoff, and ice melt contributes to roughly 22% of total runoff (this study also includes snow melt into total runoff) (Azam & Srivastava, 2020). The large percentage of rainfall contribution and smaller percentage of melt contribution to runoff corresponds with my result (fig 7).

RCP with larger radioactive forcing level indicates more greenhouse gas emissions and thus higher atmospheric temperature. I suspected that peak water would be reached earlier, and runoff output would be greater under RCP with smaller value. However, my result reverses my expectation (fig 8). I interpret this as a result of high contribution from precipitation as a result of monsoonal climate that Dokriani Glacier is in. As atmospheric temperature increases, precipitation in this region increases, increasing glacier accumulation and producing greater runoff amounts. However, I did not find literature on peak water analysis of Dokriani Glacier, so better understanding of local climate, and interaction between the glacier and local climate is needed to generate sound analysis of peak water trends with different RCPs.

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