Applied Glaciology – Assignments part 1

Fall Semester 2023

Instructions

The assignment consists of five individual tasks including various questions. The tasks build upon each other but the means of proceeding if you get stuck somewhere are provided. The hints will facilitate the work. Every question will be rated with a different number of points, indicated with "[x pts]" at the beginning of every question.

To solve the assignment, you may want to use a computer scripting language – just choose your favourite one! For sure, any of *Python, R, Julia, IDL, Matlab*, etc. will do. The exercise is also solvable without scripting. In that case, a GIS software (e.g. *QGIS* or *ArcGIS*) will help. You may even solve everything with *Excel*, but this would be going the hard way.

All auxiliary data required for the assignment are found on the course's *moodle*-page (`https://moodle-app2.let.ethz.ch/`), which is also the means by which your assignment solution is to be handed in.

The submitted solution shall contain one single `.pdf`-file and, optionally, a `.zip`-container with relevant source-code. When submitting, please use the naming convention defined in the corresponding moodle-section.

IMPORTANT:

- You might **work on the assignment in a group of up to three persons**. *"Up to"* means that, if you prefer, you can also work alone, or in a pair.
- To define your group, please use the corresponding moodle activity.
- Make sure to register to a group even if you decide to work alone! This is to facilitate the submission of your answers.
- Since all members of a given group will receive the same degree, we will **keep the same groups throughout the semester**, i.e. you should not change group for the next assignments.
- The exercise will be graded upon the submitted `.pdf`-file (and not the submitted code). Thus, make sure that the file **includes a thorough explanation for how you obtained the results**. The code itself is meant as supporting information, but won't be graded as such.
- Make sure that the name of every group member appears on every page that is submitted.

The **deadline for submitting Assignment 1 is Wed 25 October 2023, 08:00**. The results will be discussed in the last lecture of the semester (20.12.2023).

Introduction

The assignment focuses on the course's part "Glaciology and Hydropower". In a nutshell, you will quantify past changes of a given glacier, use the information to calibrate a simple mass balance model, and use that model to make a prediction of the glacier's evolution.

1. Geodetic glacier mass balance

Use the geodetic method for computing the mass balance of Fieschergletscher for the period 1980-2009. If you don't recall what the geodetic method is, refer to the "Glossary of glacier mass balance and related terms" [1]. To convert the volume change to mass change, you can assume a density of $850\,\mathrm{kg\,m^{-3}}$.

Question 1 [6 pts]: How large was the specific mass change rate experienced by the glacier during the period?
Express your result in units of "m water equivalent per year" ($\mathrm{m\,w.e.\ a^{-1}}$), and make sure to explain what assumptions you did for computing this number.

Hint: For converting from kg to m w.e. you can consider the average glacier surface for the two given years.

Note: For this task, you will need the files `dem_fiescher_1980.asc`, `dem_fiescher_2009.asc`, `glacier_mask_fiescher_1980.asc`, and `glacier_mask_fiescher_2009.asc`. The `dem_*` files are Digital Elevation Models (DEMs) of the glacier surface, providing elevation information on a regular grid. The `glacier_mask_*` files contain binary information telling whether a given grid cell is covered by ice (1) or not (0). All files are given in *Esri grid* [2] format and most programming language will have a function to read them (correct, this might require some googleing ;-)).

2. Meteorological data

Retrieve a homogenized temperature and precipitation time series in monthly resolution for a meteorological station that you consider to be representative for the glacier. The time series shall cover the period since 1935, since that will be needed later. Note that only a few stations exist with such long-term time series.

Question 2 [5 pts]: Which data did you chose and why?
Make sure to state the `url` from which you downloaded the data, and to discuss the choice of the station that you selected.

Hint: In Switzerland, homogenized long-term station data are distributed by MeteoSwiss.

3. Melt model calibration

Use the meteorological time series retrieved in Question 2 to calibrate the Degree Day Factor (DDF) of a simple temperature index model. Go back to the the lecture notes or refer again to the "Glossary" if you don't recall what such a model is.

For this task, you can make the following assumptions:

- Precipitation can be modelled with a "block rain model" (see lecture notes) and the time series retrieved in Question 2.
- Snow and rain can be distinguished through a threshold temperature of $T_0 = 2\,°\mathrm{C}$.
- The temperature at any elevation can be computed from the data retrieved in Task 2 and by using a temperature lapse rate of $dT/dz = 6.5\,°\mathrm{C\,km}^{-1}$.
- Melt occurs for temperatures above $0\,°\mathrm{C}$.
- Every month has $365/12 \approx 30.42$ days.
- The provided DEMs both refer to October.
- The glacier surface can be described with the DEM of 2009 and does not change in time.

Question 3.1 [7 pts]: What was your procedure to calibrate the DDF?
Make sure to provide a step by step explanation and to mention any assumption.

Question 3.2 [6 pts]: What value (and unit) do you obtain for the calibrated DDF, and how does it compare to values reported in the literature?
Make sure to have "days" somewhere in the units for the "Degree *Day* Factor", and compare your result against at least two published DDF values (provide the corresponding references). Discuss what might be at the origin of the differences that you find (if any).

Question 3.3 [6 pts]: Reflect upon the various assumptions that were necessary for the calibration. Which assumptions are likely to introduce a bias? In what direction do the individual biases go, and which assumption are likely to introduce the largest biases?

<u>Hint 1</u>: What you want is to choose a DDF such that the model reproduces the total glacier mass change that you determined in Question 1.

<u>Hint 2</u>: You can perform your computations at monthly resolution.

<u>Hint 3</u>: Reflect whether you want to consider a distributed modelling approach (i.e. if you want to consider every grid-cell of the glacier separately) or not (e.g. if you only want to consider the mean glacier elevation, for example). Make sure to discuss this point in Question 3.1.

<u>Hint 4</u>: If you did not solve Task 1, you can assume an average glacier mass balance rate for the period 1980-2009 of -0.50 m w.e. a^{-1}. If you did not solve Task 2, you can use the time series `sample_meteo_time_series.txt`.

4. Mass balance reconstruction

Use the model calibrated in Task 3 and the same meteorological time series as above to reconstruct the annual mass balance of the glacier for the period 1935-2022. Express the results in m w.e. a^{-1}, and refer the annual values to the hydrological year (1 Oct. – 30 Sep.). Plot your results.

Question 4 [7 pts]: What are the (i) cumulative and (ii) average glacier mass balance (in m w.e. and m w.e. a^{-1}, respectively) and what do you observe in the yearly time series?
Check whether you can discern trends, and whether there are periods or individual years that stand out.

<u>Hint 1</u>: If you did not solve Task 3, you can assume DDF = 5 mm w.e. $(°\mathrm{C\,d})^{-1}$.

<u>Hint 2</u>: For this task, you can neglect any changes in glacier geometry.

5. Future projection

Use volume-area scaling to estimate the volume of the glacier for the year 2009. Then use the mass balance time series that you computed in Task 4 for computing the mass change until 2022. For the future, assume that the glacier mass balance rate (in m w.e. a^{-1}) will remain the same as it was on average over the past 30 years (period 1992-2022).

Question 5.1 [4 pts]: What was the glacier volume in 2009?
Express you results in km^3.

Question 5.2 [6 pts]: Based on your projection, when (year) will the glacier have lost 50% of the volume it had in 2009?
Use "Hint 1" below, and discuss whether the resulting "projection" is likely to be an under- or overestimate, and why.

Question 5.3 [4 pts]: Can you think of a strategy that avoids the simplification given in "Hint 1"?
Explain how you could avoid the assumption of a constant area, and what additional information, tools, or methods (if any) you would need for that.

Hint 1: As a simplification, you can assume that the glacier area remains constant at the 2009 level.

Hint 2: If you did not solve Task 4, you can use the time series in the file `sample_massbalance_time_series.txt`.

Hint 3: Pay attention to the units for the glacier mass balance rate and the glacier volume.

Hint 4: If you need to convert glacier volume to mass, assume a mean glacier density of $900\,kg\,m^{-3}$.

References

[1] J. Cogley, R. Hock, L. Rasmussen, A. Arendt, A. Bauder, R. Braithwaite, P. Jansson, G. Kaser, M. Möller, L. Nicholson, and M. Zemp. *Glossary of glacier mass balance and related terms.* UNESCO-IHP, Paris, 2011

[2] https://en.wikipedia.org/wiki/Esri_grid