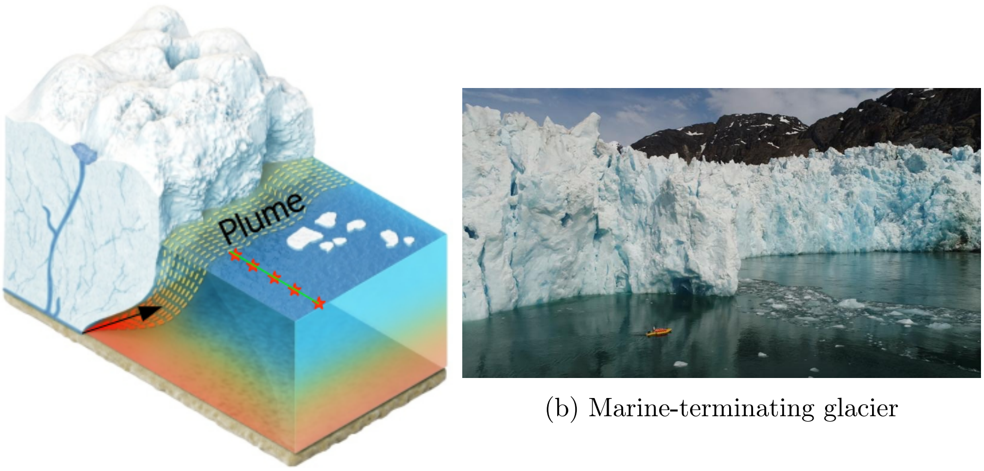
Project - Ice-Ocean Interaction

1 Project Description

A hot topic in climate research right now is to model how a melting outlet glacier affects the surrounding ocean. The ocean water is warmer than the ice sheet and therefore melts the ice. The meltwater from the ice is fresher (i.e., less salty) and colder than the ocean water. Cool water is heavier than warm water, but fresh water is lighter than salty water. It turns out that the salt concentration has a bigger impact on the weight of the water which results in meltwater being lighter than ocean water. A buoyant *plume* of meltwater will therefore form near the ice and rise upwards, see Fig. 1.



(a) A plume rising up along an ice cliff

(b) Marine-terminating glacier

Figure 1: Ice-ocean interaction

In this project you will study the properties of the water of a typical fjord outside the Greenlandic Ice Sheet. Specifically, you will compute the temperature T, salinity S at the ocean surface. Due to the water circulation that the plume is creating, the surface water is moving away from the ice. An expedition has measured the water velocity right outside the buoyant plume as well as at a distance of 250, 500, 750 and 1000 meters away (marked with red stars in Fig. 1a). The measurement data is presented in Table 1. The expedition

distance from plume (m)	0	250	500	750	1000
measured velocity (m/s)	0.030	0.032	0.031	0.027	0.029

Table 1: Velocity measurements at the ocean surface outside the glacier

distance from plume (m)	0	1000
Temperature (°)	-1.1	1.0
Salinity (PSU)	34.1	35

Table 2: Temperature and salinity measurements

also measured the water temperature, T, and salinity, S, right outside the plume, as well as 1000 meters away from the plume. The data is presented in Table 2.

Your task is to find and plot the temperature ($°C$), salinity (PSU), and density (kg/m^3) along the green line, i.e. from the plume at x=0 to a distance of 1000 meters away from the plume. You should motivate your choice of numerical parameters and methods.

Assuming that the water is completely stratified, i.e. that it is not mixing in the vertical direction, the temperature is governed by the following tracer equation

$$\frac{\partial C}{\partial t} = \nu \frac{\partial^2 C}{\partial x^2} - \frac{\partial (u(x)C)}{\partial x} = 0, \tag{1}$$

where C is either the temperature T or the salinity S, t is time, x is the distance from the plume, and u is the horizontal, outward velocity. Let us assume that the dynamics of the water is not changing in time, i.e., a steady state has been achieved so that $\frac{\partial C}{\partial t} = 0$. The parameter ν is governing how much the water is mixing in the horizontal direction due to turbulence - in this case $\nu = 100$.

The density of ocean water, $\rho(T, S)$, is a non-linear function but is usually approximated by a "linear equation of state". You can find the expression for the density in equation 23 of the following study:
`https://gmd.copernicus.org/articles/9/2471/2016/`
The paper describes an intercomparison experiment, where different climate models are used to simulate the same ice-ocean interaction scenario so that model differences can be spotted. The values needed for the equation of state is given in table 4 in the paper.

Hint: It can be difficult to solve an ODE with a coefficient that is a non-smooth function of the independent variable.
Hint: The numpy functions `diag` and `matmul` can be useful.

2 Rules

- You have to work in groups of 2-3. It is not possible to submit individually. You can write in the forum "Find project group" on the course webpage to get together with someone.
- If you use any built-in function for implementing a numerical method, you must be able to describe how that numerical method works. If the built-in function uses a numerical method that we have not discussed during the course, you *must* include an extra half a page of information about that method (assuming 12 pt font), see next section.
- Your report should comply with the guidelines given in the next section.
- Deadline is 22md of May, 19.00.
- If the project is handed in after the deadline it is automatically failed.
- The project will be handed in on the course webpage. Make a zip-file of your report **in pdf-format** and code and include your names in the filename of the zip-file.
- You have to be prepared to answer questions on your hand in in orally, if the teacher has any inquiries.

3 The hand in should include

- A velocity, temperature, salinity and density plot, along the whole x-axis $x \in [0, 1000]$
- At least a page (assuming 12 pt font) on **which** numerical methods you chose to solve the problem of plotting velocity, T and S, together with any discretization parameters (e.g., number of points). If you have used a built-in python function which does not implement a numerical method we discussed during the course, you *must instead* write one whole page on this method *instead of a half.* Simply stating the name of the method is not enough, you must have an idea of how it works.
- At least half a page stating **why** you chose that/those methods and at least one pro and one con of the chosen method.

4 If you need help:

- You may ask the teachers questions but the teacher might decide to not answer the question. If you are stuck on pure programming parts the teachers should give you hints as this is an examination of numerical methods and not programming.