Ice melting into seawater

I. BACKGROUND

Melting of glaciers and ice shelves is contributing to sea level rise, although projections of this contribution to future sea level rise remain very uncertain. Ice melting into seawater is an interesting fluid dynamical problem where the thermodynamic properties of seawater, ocean stratification, and the geometry of the ice boundary can dramatically alter the flow.

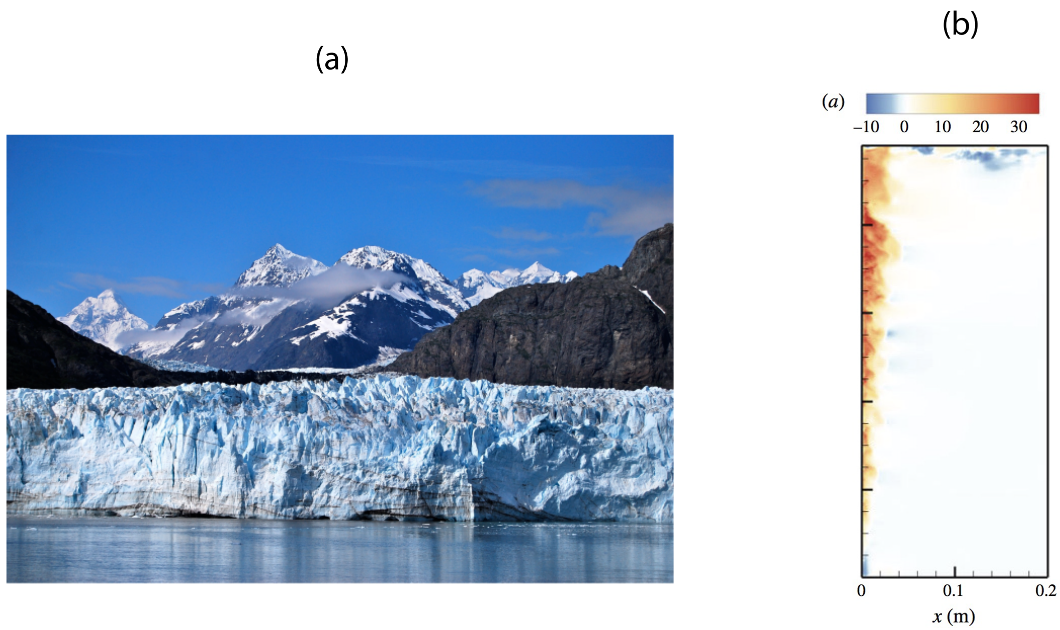

FIG. 1: (a) Margerie Glacier, Glacier Bay, Alaska, (b) Vertical velocity along the edge of a melting vertical ice face from Gayen et al.[1]

II. INTRODUCTION

When ice melts into the ocean, the meltwater is generally colder and more fresh than the surrounding seawater. The density of the meltwater relative to seawater depends on the nonlinear equation of state. At the low temperatures typical of the ocean at high latitudes, salinity changes have a stronger influence on density than changes in temperature. As a result, fresh meltwater is generally less dense than seawater. This can have either a stabilizing or destabilizing effect. For example, at a vertical ice face characteristic of the edge of a glacier (see Fig. 1a), meltwater will rise along the edge of the ice in a (possibly turbulent) buoyant plume. In contrast, the meltwater that forms beneath a flat sheet of sea ice would tend to suppress turbulence and mixing through the strong stable density gradient associated with the contrast with the seawater below.

III. VERTICAL ICE FACE

Figure 1(b) shows the vertical velocity from a 3D direct numerical simulation reported in Gayen et al.[1] (the PDF is in the project folder). The simulations were inspired by lab experiments from Kerr and McConnochie[2]. Here, uniform seawater is exposed to a vertical ice face at the left side of the computational domain. The top and bottom of the domain have rigid walls. As the ice melts, buoyancy meltwater rises up along the ice face forming a turbulent plume.

We can start by mimicking one of the simulations from Gayen et al.[1] using 2D Diablo. Consider a domain size of $1m$ in y and 0.3m in x. Use two tracers, one for temperature and another for salinity and relate changes in each to changes in density using a linear equation of state:

$$\rho = \rho_0(\beta S - \alpha T), \tag{1}$$

where ρ_0 is a reference density and α and β are the thermal expansion and haline contraction coefficients. If the temperature and salinity of the water are uniform at the start of the simulation and equal to $T_w = 2.3°C$ and $S_w = 35PSU$, then the thermal expansion and haline contraction coefficients are $\alpha \simeq 8.4 \times 10^{-5}°C^{-1}$ and $\beta \simeq 7.8 \times 10^{-4} PSU^{-1}$.

Consider a flow in a box with no-slip boundary conditions on all sides. We can crudely approximate conditions at the ice edge by setting the temperature and salinity both to 0 with Dirichlet boundary conditions. Use homogeneous Neumann boundary conditions for temperature and salinity at the other boundaries for no-flux boundary conditions. You will probably want to stretch the grid to get higher resolution near the walls. It would be a good idea to create a new stretching function in *create_grid.m* to cluster gridpoints at the ice face with lower resolution away from the ice.

As a starting point, use a domain size of 1m in the y (vertical) direction and 0.1m in x. Since we are using dimensional units, you can set $Re = 1/\nu$, where $\nu = 1e-6\text{m}^2/\text{s}$ is the approximate kinematic viscosity. Note that the simulation will be under-resolved but should still capture some important features of the flow. Since the simulations are already under-resolved, set the Prandtl number of both temperature and salinity to 1 (you can change this later). Do you see a transition to turbulence? What happens as the melt water begins to collect at the top of the tank?

IV. SUGGESTIONS

A. Stability of wall-jet

Decrease the Reynolds number (or equivalently decrease the domain size) and look closely at the wall-bounded jet before it transitions to turbulence. How does its size and shape vary with the Reynolds and Prandtl numbers? You could analyze the stability of this jet profile. Does the most unstable mode roughly match what you see in the simulations?

B. Stratified interior

Try adding a stable stratification (using either temperature or salinity) to the ambient fluid through the initial conditions. Do you see mid-depth intrusions? How fast do they spread?

C. Ice-shelf boundary layer

The underside of an ice-shelf (the floating extension of a grounded ice sheet) is often associated with relatively low slope angles (i.e. the ice is nearly flat but gently slopes upward). Simulate the flow beneath a melting ice sheet by changing the direction of the gravitational vector in your simulation. You will probably want to change the boundary conditions on the boundaries perpendicular to the ice face to be periodic which will allow the flow to develop over a longer time period since the acceleration will be slower than in the case with a vertical ice face.

V. REFERENCES

[1] B. Gayen, R. W. Griffiths, and R. C. Kerr, Journal of Fluid Mechanics **798**, 284 (2016).

[2] R. C. Kerr and C. D. McConnochie, Journal of Fluid Mechanics **765**, 211 (2015).