Proposition de sujet de stage de M2 / Thèse

Modèle expérimental de lac sous-glaciaire: compétition convection horizontale et verticale

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Subglacial lakes (SL) are pockets of high-pressure cold-temperature water trapped between the polar ice sheets and continental bedrocks. They are buried under several kilometers of ice (about 2 km on average) and can be as large as Lake Michigan in the United States. To date, almost 700 subglacial lakes have been detected in Antarctica and 64 have been found in Greenland.

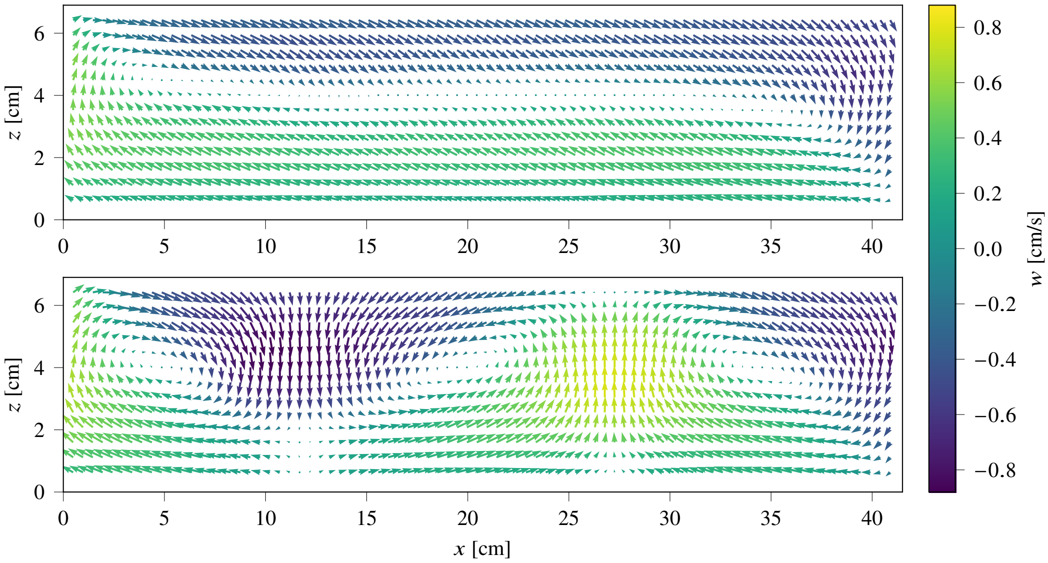

Figure 1: Experimental mean flow field obtained from CIV on the shadowgraph images. Top: one roll at $\Lambda = 1.1 \times 10^{-4}$, in the HC-dominated regime. Bottom: three rolls at $\Lambda = 4.1 \times 10^{-6}$, in the RBC-dominated regime.

The lake geometry controls SL hydrodynamics at leading order. SL are subject to geothermal heat fluxes, on the order of $60\,\mathrm{mW/m^2}$ across Antarctica — with low heterogeneity at SL scales, which drive vertical flows whose intensity primarily depend on water depth. They are also subject to quasi-horizontal flows along the ice-water interface, when the interface is tilted and owing to the pressure-dependence of the freezing point. These flows intensify as the interface length increases. The influence of geothermal heating (combined with depth) and interface tilt (combined with length) on SL hydrodynamics can be quantified through two key dimensionless parameters, which are the flux Rayleigh number Ra_F and horizontal Rayleigh number Ra_L, given by

$$Ra_F = \frac{g\alpha F H^4}{k\nu\kappa}, \quad (1)$$

$$Ra_L = \frac{g\alpha\beta\gamma L^4}{\nu\kappa}, \quad (2)$$

respectively. Here, L is the lake length, H is the water depth, F is the geothermal flux, g is surface gravity, α is the thermal expansion coefficient, γ is the interface slope, $\beta \approx 10^{-3}$ K/m is the rate of change of the freezing temperature with depth (linked to the pressure increase with depth), k is thermal conductivity, and ν and κ are viscosity and thermal diffusivity.

In the lab, we investigate experimentally the flow structure in a Rayleigh-Bénard Convection cell where, additionnally, a horizontal temperature gradient is imposed on the top plate[1]. This is a model system for the dynamics in subglacial lakes where this competition between RBC and HC is the main driving force[2].

[1] Rabaux et al, Submitted to JFM, https://hal.archives-ouvertes.fr/hal-04927403
[2] Couston et al, J. Fluid Mech. (2022), https://amu.hal.science/hal-03938544

We use Water or Fluorocarbon FC-770 as the working fluid, and evidence a hysteretic transition from a RBC flow structure to a HC flow structure when the ratio of the horizontal heat flux to the vertical heat flux, Λ is varied,

$$\Lambda = \frac{\lambda k}{F}, \tag{3}$$

where λ is the horizontal temperature gradient, k is the heat conductivity and F is the vertical heat-flux. One key advantage of FC-770 is that its Prandtl number is of order $O(10)$, similar to the conditions in the subglacial lakes. In the case of subglacial lakes in Antartica or Greenland, the expected values of Λ are between 10^{-5} and 5×10^{-4}.

This project is part of a LIO Labex project, in collaboration with T. Alboussière, S. Labrosse and Y. Ricard from LGL laboratory. We will build and operate a new larger cell, to study the dynamics of the flow structure as a function of the aspect ratio.