GEOPHYSICAL FLUID DYNAMICS

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Below are two project descriptions. Note however that my group only has room for one USRA recipient.

In either project, the awardee will use, or learn about, concepts in fluid dynamics and instabilities, partial differential equations, and scientific computing.

Requirements:

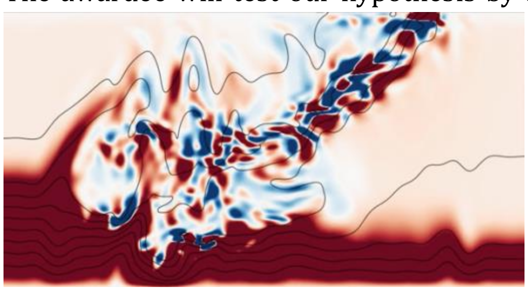
- 3rd year student and above.
- Some experience in scientific computing, ideally in Python. (We might use a code written in Julia, which is as easy, if not easier, than Python.)
- Knowledge in a classical field theory (e.g. classical electromagnetism or fluid dynamics; elementary wave theory) is strongly recommended. Not that I do **not** require knowledge in fluid dynamics.

PROJECT #1: EKMAN-INERTIAL INSTABILITY

Oceanic fronts, which populate the ocean's immediate sub-surface, are horizontal boundaries between water masses that differ e.g. by their density, temperature, and/or salinity. As far as oceanic flows are concerned, these fronts are relatively fragile, namely prone to hydrodynamic instabilities. These instabilities create turbulence, and within this turbulence a significant amount of energy is dissipated. This is why oceanic fronts are believed to be candidates to provide "missing dissipation", which oceanographers still cannot account for in the global oceanic energy budget. Physical oceanographers are still working hard to complete an inventory of all the possible instabilities that oceanic fronts may be subjected to, and to do so, they use idealized numerical simulations (i.e., thought experiments, run by computers) to test ideas.

Recent results within our group suggest that certain idealized numerical configurations feature an "artifical" instability we dubbed Ekman-inertial instability (Grisouard & Zemskova 2020) that manifests itself as a powerful along-surface current that prematurely reduces a front's free energy. While entirely physical, we believe that this instability is exacerbated when boundary conditions are not carefully considered, leading to an erroneous understanding of the demise of fronts.

The awardee will test our hypothesis by adapting a numerical configuration we use in our group (Atkinson, McWilliams & Grisouard, *in prep.*) to approach those of a handful of published work (Pham & Sarkar 2018; Grisouard 2018; Skyllingstad & Samelson 2020). And even though we described the Ekman-inertial instability as an artifact of the numerical configurations used by some authors, we will investigate scenarios under which this instability may happen in real life.



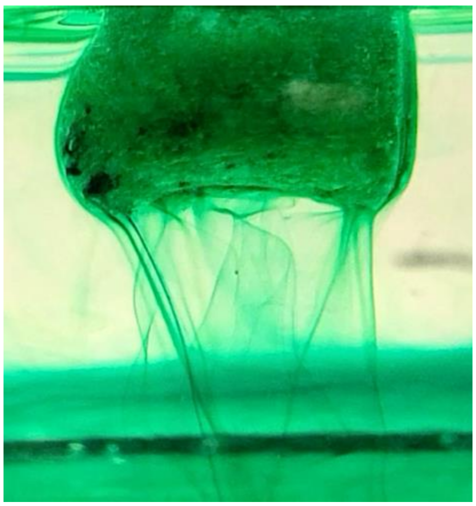
References:

1. Grisouard, N. & Zemskova, V. E. (2020). Ekman-inertial instability. *Phys. Review Fluids*, *5*(12), 124802. (EarthArXiv | doi)
2. Atkinson, E.; McWilliams, J. C. & Grisouard, N. Near-inertial echoes of ageostrophic instability in submesoscale filaments. *Under revisions, J. Fluid Mech.* (arXiv)
3. Pham, H. T. & Sarkar, S. (2018). Ageostrophic secondary circulation at a submesoscale front and the formation of Gravity Currents. *J. Phys. Oceanography*, *48*(10), 2507–2529. (doi)
4. Grisouard, N. (2018). Extraction of Potential Energy from Geostrophic Fronts by Inertial-Symmetric Instabilities. *J. Phys. Oceanography*, *48*(5), 1033–1051. (doi)
5. Skyllingstad, E. D. & Samelson, R. M. (2020). Instability processes in simulated finite-width ocean fronts. *J. Phys. Oceanography*, *50*(9), 2781–2796. (doi)

PROJECT #2L HOW DO ICE CUBES MELT?

Co-supervised with Prof. Erica Rosenblum (erica.rosenblum@utoronto.ca)

Understanding oceanic fluid dynamics is crucially important to understand how momentum and energy gets distributed in the climate system. They are strongly constrained by the density contrasts between water masses, by the rotation of the Earth, and by the boundaries of the ocean. In the polar oceans, the melting/freezing seasonal cycle of sea ice is also very important in understanding what sets the vertical structure of the ocean, and vice-versa: the climatological environment determines how fast the ice will melt in the warmer months.



Loosely inspired by these questions, this project will investigate how ice melts in water that is under rotation or not, and that is salty or not. Preliminary investigations with ice cubes in tabletop experiments indicate that the motion of the ice and of the water surrounding it are radically different depending on these parameters, in ways that are quite counterintuitive.

You will examine the impact of rotation and salinity on ice melt using numerical simulations and tabletop experiments. You will examine how these factors impact ice melt rate, ice rotation, and meltwater dynamics. You will perform numerical simulations using the Python code "Dedalus" (https://dedalus-project.org) that you will run on parallel computers using a configuration we developed over the past few months. You will also have the option to develop a more robust lab setup using record players, food colouring, ice cubes, table salt, and DIYnamics materials (https://diynamics.github.io/index.html).

Requirements: We highly recommend that you have notions of vector calculus and partial differential equations, as well as some basic experience in programming. Knowledge about fluid dynamics and advanced notions of Python will be useful, but not expected prior to the start of the project.

Bibliography

1. Hester E. W., McConnochie C. D., Cenedese C., Couston L.-A. & Vasil G. Aspect ratio affects iceberg melting. *Phys. Rev. Fluids* **6**, 023802 (2021).
2. De Abreu S., Cormier R. M., Schee M. G., Zemskova V. E., Rosenblum E. & Grisouard, N. Two-dimensional numerical simulations of mixing under ice keels. *The Cryosphere* **18**:7, 3159–3176, 2024. (doi)