Simulation and parameterisation of turbulence at rough ice-ocean boundary layers

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The melting of ice sheets has made a significant contribution to sea level rise over the last half-century, and is projected to increase further in the coming decades based on various estimates for future carbon emissions. However, the magnitude of this increase is uncertain due to the complexity of the climate system and the inability of large-scale ocean models to resolve small-scale turbulent processes. These processes must instead be *parameterised* using simple models. In particular, the parameterisation of turbulent heat transport (and the ensuing melt rate) at ice-ocean interfaces is a key source of uncertainty.

Current parameterisations are based on theory for turbulent heat transport over smooth plates, but recent observations at both tidewater glaciers and floating ice shelves have revealed distinct roughness patterns on the ice surface. The observed patterns, which feature dimples of about 10cm in length, are most commonly observed in regions of fast melting, making accurate modelling of their effect on the flow vital. By combining the current state-of-the-art knowledge for flow over rough surfaces with the development of new simulation techniques, this project aims to provide an improved description of turbulence at the ice-ocean interface.

The development of so-called ‘scalloped’ ice surfaces has been observed in laboratory experiments of both natural convection (where the flow is driven by the buoyancy of the meltwater) and forced convection (where there is some dominant external flow). However, recreating this setup in a simulation has proved more challenging. Previous studies have attempted to use diffuse-interface models such as the phase-field model to simulate the melting interface, but this technique enforces a strict limit on the simulation time step, which limits the scale of the simulation. We aim to develop an *immersed boundary method* to simulate the evolving ice-water boundary, which allows for direct calculation of the heat fluxes at the interface and reduces the limitation on the time step. The immersed boundary method will also allow us to investigate how the ice conductivity may affect the geometric properties of the emergent roughness.

Relevant reading

[1] M. Bushuk, D. M. Holland, T. P. Stanton, A. Stern, and C. Gray, “Ice scallops: a laboratory investigation of the ice–water interface”, J. Fluid Mech. **873**, 942–976 (2019).

[2] A. Malyarenko, A. J. Wells, P. J. Langhorne, N. J. Robinson, M. J. M. Williams, and K. W. Nicholls, “A synthesis of thermodynamic ablation at ice–ocean interfaces from theory, observations and models”, Ocean Model. **154**, 101692 (2020).

[3] L.-A. Couston, E. Hester, B. Favier, J. R. Taylor, P. R. Holland, and A. Jenkins, “Topography generation by melting and freezing in a turbulent shear flow”, J. Fluid Mech. **911**, A44 (2021).

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