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Modelling Sea Ice Formation and Mushy-Layer Convection with Adaptive Mesh Refinement

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Understanding the properties of young sea ice, and the mechanism by which it forms, is becoming increasingly important given the recent shift from multiyear to first-year ice. Sea ice is a porous material composed of ice crystals and an interstitial brine; a mushy layer. The dense brine tends to sink through the ice, driving convection. Downwelling at the edge of convective cells leads to the development of narrow, entirely liquid channels, through which cold saline brine is efficiently rejected into the underlying ocean. This brine rejection provides an important buoyancy forcing, which contributes to ocean mixing, the formation of deep water masses, and the maintenance of the Arctic halocline.

We consider numerical simulations of ice growth and convective brine rejection. This natural convection during sea ice formation leads to patterns of varying porosity and fluid flow across multiple scales, with brine channels occupying just a few percent of the the sea ice volume and evolving in time. Hence previous attempts to numerically simulate convective brine drainage have struggled to resolve the narrow brine channels at acceptable computational cost. To overcome this limitation, we use the Chombo software framework to implement a computational mesh which adapts to provide additional resolution near brine channels.

Using these techniques, we calculate the ice-ocean salt flux during steady-state growth and determine the sensitivity of the system to a number of key parameters. We find that the salt flux scales sublinearly with the porous medium Rayleigh number, a quantity which characterises the ratio of buoyancy forces to dissipative mechanisms. The convective desalination of sea ice promotes increased internal solidification, and we find that convective brine drainage is restricted to a narrow porous layer at the ice-ocean interface. In addition to moderating the salt fluxes to the ocean, this convective confinement may have important consequences for nutrient supply and sea ice ecology.