Three-dimensional convection, phase change, and solute transport in mushy sea ice

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Sea ice is a porous mushy layer composed of ice crystals and interstitial brine. The dense brine tends to sink through the ice, driving convection. Downwelling at the edge of convective cells leads to dissolution of the ice matrix and the development of narrow, entirely liquid brine channels. The channels provide an efficient pathway for drainage of the cold, saline brine into the underlying ocean. This brine rejection provides an important buoyancy forcing for the polar oceans, and causes variation of the internal structure and properties of sea ice on seasonal and shorter timescales. This process is inherently multiscale, with simulations requiring resolution from O(mm) brine-channel scales to O(m) mushy-layer dynamic scales.

We present new, fully 3-dimensional numerical simulations of ice formation and convective brine rejection that model flow through a reactive porous ice matrix with evolving porosity. To accurately resolve the wide range of dynamical scales, our simulations exploit Adaptive Mesh Refinement using the Chombo framework. This allows us to integrate over several months of ice growth, providing insights into mushy-layer dynamics throughout the winter season. 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. This layer evolves as the ice grows thicker over time. Away from this interface, stagnant sea ice consists of a network of previously active brine channels that retain higher solute concentrations than the surrounding ice. We investigate the response of ice growth and brine drainage to varying atmospheric cooling conditions, and consider the potential implications for ice-ocean brine fluxes, nutrient transport, and sea ice ecology.