

Sea Water Freezing Modes in a Natural Convection System

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Sea ice is crucial in many natural processes and human activities. Understanding the dynamical couplings between the inception, growth and equilibrium of sea ice and the rich fluid mechanical processes occurring at its interface and interior is of relevance in many domains ranging from geophysics to marine engineering¹. Here we experimentally investigate the complete freezing process of water with dissolved salt in a standard natural convection system, i.e., the prototypical Rayleigh-Bénard cell. Due to the presence of a mushy phase, the studied system is considerably more complex than the freezing of freshwater in the same conditions².

We measure the ice thickness and porosity at the dynamical equilibrium state for different initial salinities of the solution and temperature gaps across the cell. These observables are non-trivially related to the controlling parameters of the system as they depend on the heat transport mode across the cell. We identify in the experiments 5 out of the 6 possible modes of heat transport. We highlight the occurrence of brine convection through the mushy ice and of penetrative convection in stably stratified liquid underlying the ice. A one-dimensional multi-layer heat flux model built on the known scaling relations of global heat transport in natural convection systems in liquids and porous media is proposed. It allows, given the measured porosity of the ice, to predict the corresponding ice thickness.

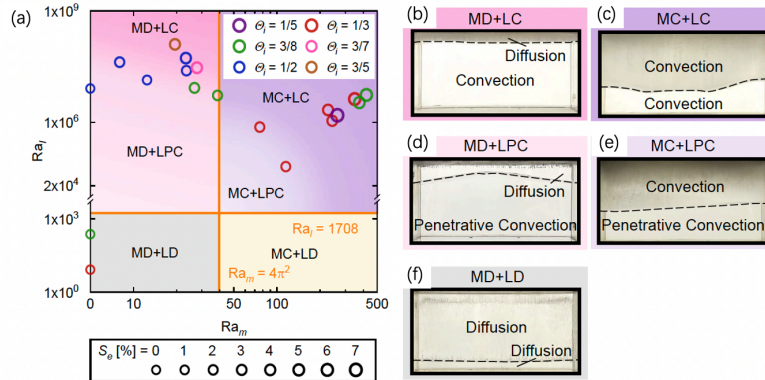


Figure 1: (a) Phase-space diagram based on the two effective control parameters, Ra_m (Rayleigh number in the mushy phase) and Ra_l (Rayleigh number in the liquid phase). Different circle sizes are used to distinguish the different S_e . There are in total 6 heat transport modes of the system. Our experiments fall within 5 cases. (b-f) Images from the experiment for typical cases corresponding to the 5 observed heat transport modes.

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¹Feltham et al., Geophys. Res. Lett. **33** (14) L14501 (2006)

²Wang et al., Proc. Natl. Acad. Sci. USA **118** (10), e2012870118 (2021)