
Melting and freezing in a convective cell

Enrico Calzavarini*¹

¹Laboratoire de Mécanique de Lille – Université des Sciences et Technologies de Lille - Lille I – France

Abstract

For decades, Rayleigh–Bénard thermal convection has been a central paradigm in the study of nonequilibrium systems, providing a framework for understanding instabilities, chaos, and the transition to turbulence. In the fully developed regime, the flow is both unpredictable, with a huge number of active degrees of freedom, and strongly self-organized, featuring boundary layers, large-scale coherent structures, and thermal plumes penetrating a disordered core.

Recent research trends focus on coupling Rayleigh–Bénard convection with other physical processes. These approaches are often motivated by the idea of leveraging the well-established understanding of the Rayleigh–Bénard system to address open questions inspired by geophysical and environmental phenomena.

In this context, motivated by the currently observed rapid changes in the cryosphere due to global warming, it has been natural to ask what effects arise when the walls of a convective cell are allowed to undergo phase changes, transitioning from the solid to the liquid state or vice versa. What is the nature of the interaction between phase-change processes and convective transport? Although convective dynamics typically evolve on timescales much faster than those of melting or solidification, even a slow evolution of the phase front can substantially alter the flow structure and the associated transport mechanisms.

In the case of pure water, additional complexities stem from its peculiar equation of state, in which the temperature of maximum density does not coincide with the solidification temperature, giving rise to a buoyancy force whose direction, and not only its intensity, depends on temperature. The problem becomes even more complex for saltwater, which solidifies by forming an evolving porous medium, thereby introducing new timescales and a richer interaction between the convective flow and the phase front.

In this talk, I will present a synthesis of recent numerical and experimental studies on convection coupled with melting and solidification, conducted in collaboration with the group of Chao Sun (Tsinghua University, Beijing), highlighting the main results obtained and the open perspectives.

*Speaker