Transition from a classical to ultimate regime of melting: analogies to Rayleigh–Bénard turbulence

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Abstract

Melting in the presence of turbulent flows is fundamental to a diverse range of geophysical and industrial problems of interest. Here, the practical challenge faced is how one can extrapolate the findings gleaned from simulations and laboratory-scale experiments to the much larger scales of interest in geophysical and industrial contexts. Conventionally, this is achieved through the extrapolation of scaling laws derived from simulations, experiments, and theory. These extrapolations, however, are only meaningful if no transition occurs from one scaling law to another. Such dilemmas are clearly exemplified by Rayleigh–Bénard Convection (RBC) for example, where there is a transition from a classical regime of weaker heat transport, to a so-called ultimate regime with enhanced heat transport. Here, we will unveil the existence of an analogous transition when considering the melting of ice balls in homogeneous isotropic turbulence, combining results from both experiments and direct numerical simulations. The combined dataset spans nearly four decades in the inertial sphere Reynolds number, Re $\approx$ 30 to 46,000, enabling scaling transitions to be robustly identified. One can show that determination of the melt rate is distilled to a problem of determining the heat transport (the Nusselt number Nu) as a function of the turbulent driving (the Reynolds number Re), providing a direct analogy to RBC where one typically seeks to determine Nu as a function of the thermal driving (the Rayleigh number Ra). We demonstrate this connection to RBC quantitatively, showing a transition in the melt rate from a laminar-type boundary-layer scaling to a turbulent-type boundary-layer scaling: a transition from so-called classical melting to ultimate melting.

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