Buoyancy-driven flow regimes for a melting vertical ice cylinder in saline water

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Abstract

The presence of salt in seawater significantly affects the melt rate and morphological evolution of ice. This study investigates the melting process of a vertical cylinder in saline water using a combination of laboratory experiments and direct numerical simulations. The two-dimensional (2-D) direct numerical simulations and three-dimensional (3-D) experiments achieve thermal Rayleigh numbers up to Ra_T = O(10ˆ9) and saline Rayleigh numbers up to Ra_S = O(10ˆ{12}). Some 3-D simulations of the vertical ice cylinder are conducted at Ra_T = O(10ˆ5) to confirm that the results in 2-D simulations are qualitatively similar to those in 3-D simulations. The mean melt rate exhibits a non-monotonic relationship with ambient salinity. With increasing salinity, the mean melt rate initially decreases towards the point where thermal and saline effects balance, after which it increases again. Based on the ambient salinity, the flow can be categorised into three regimes: temperature-driven flow, salinity-driven flow and thermal-saline competing flow. In the temperature-driven and competing flow regimes, we find that the mean melt ratefollows a Raˆ{1/4} scaling, where the subscript d denotes a response parameter. In contrast, in the salinity-driven flow regime, we see a transition from a Raˆ{1/4} to a Raˆ{1/3} scaling. Additionally, the mean melt rate follows a Raˆ{1/3} scaling in this regime. The ice cylinder develops distinct morphologies in different flow regimes. In the thermal-saline competing flow regime, distinctive scallop (dimpled) patterns emerge along the ice cylinder due to the competition between thermal buoyancy and saline buoyancy. We observe these scallop patterns to migrate downwards over time, due to local differences in the melt rate, for which we provide a qualitative explanation.

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