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Icicle ripples: toward a model with impurities

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Icicles observed in nature and the laboratory often exhibit ribs or ripples with a wavelength close to 1cm around their circumference. Previous experiments on laboratory-grown icicles have shown that the existence of these ripples depends on the presence of (very small) concentrations of impurities in the feed water. However, all existing theoretical models of the icicle ripple instability have ignored the purity of the water.

We present a model of solid icicle growth incorporating the effects of impurities on the freezing point. This model is based on previous work that assumed a thin-film flow over solid ice. We introduce realistic, physically derived boundary conditions for both heat transfer and impurity concentration. A linear stability analysis of this model was performed numerically to high orders of ripple wavenumber.

We show that this more physically complete model of solid icicle growth cannot account for the 1cm wavelength of the ripple instability, because the effects of impurities are inherently too weakly coupled to the freezing dynamics. This suggests that a more complex model must be used, possibly one involving so-called "spongy" ice. Models of the freezing and growth of spongy ice are more strongly affected by impurities in the water. We propose experiments to look for the presence of spongy ice in laboratory-grown icicles in order to test this hypothesis.

Significance statement

Icicles are an ideal test-case for understanding the morphology of "wet" ice growth. We present theory and experiments on the icicle rippling instability and show that ripples cannot be explained by a straightforward extension of previous models. This is significant for mitigating the engineering hazards of wet ice formation.

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