The effect of salinity on melting

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Abstract:
In this talk we will focus on the melting dynamics of controlled experiments and simulations in canonical geometries to further our understanding of the melting processes. In particular, we will showcase for a variety of setups (with different symmetries and degrees of freedom) that the inclusion of salinity has a major effect on the melting process. Not only is the melting rate and the flow around the object modified, but also the dynamics of the morphology is drastically changed.

Keywords: melting, salinity, thermal convection

Introduction:

Global warming and the ocean currents have a major influence on the melt rate of the ice caps, which then have an strong influence on the albedo of the ice caps, the ocean currents, and the rising sea levels, driving each other. For better climate change predictions we therefore need to improve the prediction of the melting of ice around the poles in the form of iceberg and ice shelf melting [1, 2]. It is therefore paramount to have a detailed understanding of the fluid dynamics of the melting of glaciers, ice shelves, sea ice, and icebergs. The

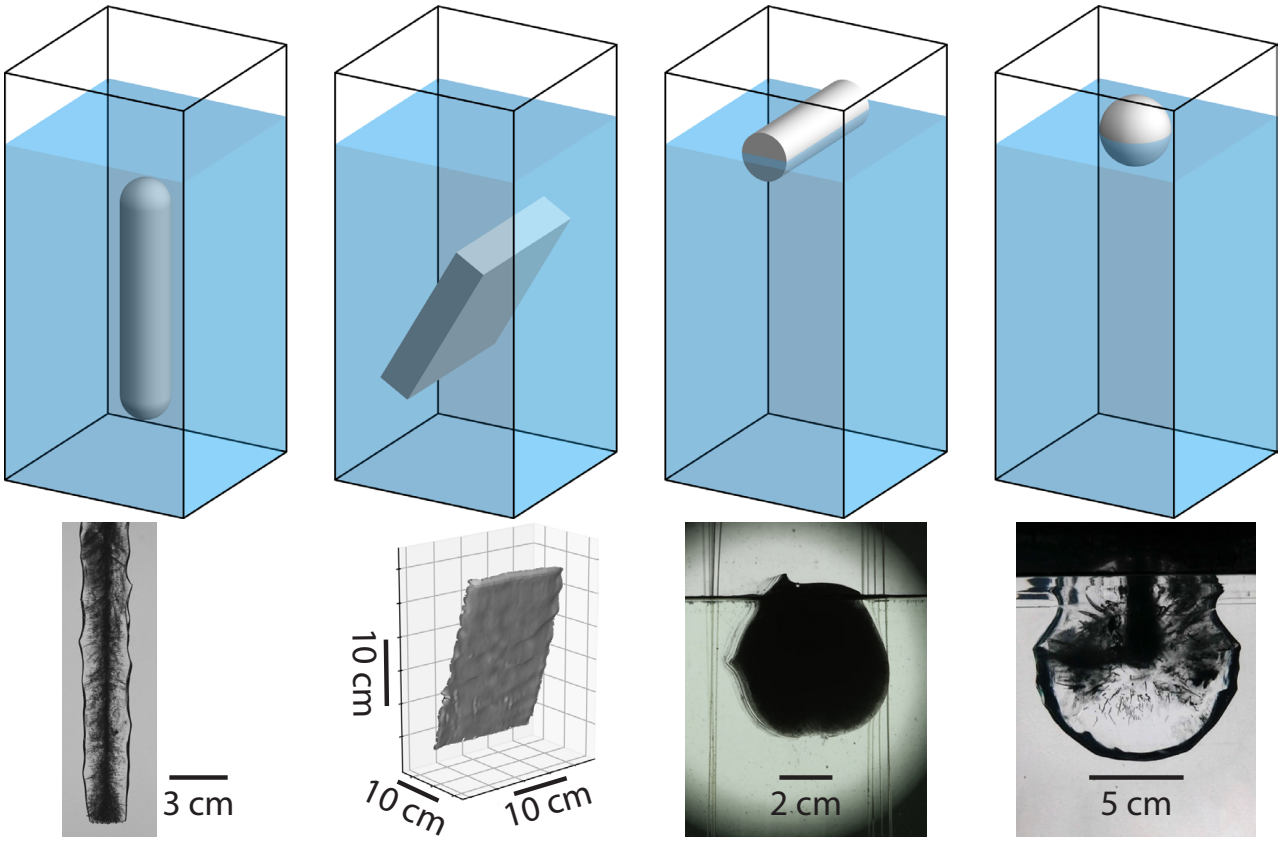

Figure 1: We explore the effect of salinity in four canonical geometries, top from left to right: fully submerged vertical ice cylinder, fully submerged tilted ice slab, freely-floating ice cylinder, and freely-floating ice ball. Bottom: Experimental photos of the experiments, and a 3D reconstruction of an ice surface.

naturally-occurring instances of melting are generally not directly attainable in the laboratory nor accessible using simulations, due to their grand scale and added complexities. The best one can do is to either study select naturally-occurring instances—with its concomitants imperfections and uncontrollabilities—or to do the largest-attainable well-controlled experiments in the laboratory and to use the latest direct numerical simulations, to understand the underlying mechanisms and then to extrapolate using the dimensionless numbers. We will follow this bottom-up approach, where the problem is simplified and perfectly controlled in high precision canonical geometries, yielding valuable information and tremendous predictive power, even for much larger systems, by fundamentally understanding the underlying physical mechanisms and their interactions.

Experimental setup and Numerical Methods:

In the experiments we make use of aquaria in which we vary the salinity while keeping the temperature around room temperature $T \approx 20\ ^\circ\mathrm{C}$, and we either fully submerge ice objects or have ice objects freely-floating on the water surface. We look at 4 canonical geometries, see figure 1. For the case of the vertical ice-cylinder we also compare with 2D and 3D direct numerical simulations.

Results and discussion:

For each of the different geometries we see a fundamental change in the flow when the salinity is sufficiently high ($S = \mathcal{O}(10\ \mathrm{g/kg})$), as the meltwater will then ascend rather than descend. For the submerged objects a reversal in flow direction does not matter as long as the problem is symmetric. However, for a tilted slab the dynamics is changed once the salinity is high, and also quantitatively different from fresh water as the problem is not symmetric. For intermediate salinity cases ($S \approx 5\ \mathrm{g/kg}$) the positive buoyancy (of the meltwater) due to salinity is close to the negative buoyancy due to temperature. In this regime we generally see an undulated morphology form at the ice-water interface, similar to fresh water cases [3]. For the cases of freely-floating objects the change is also fundamental in another way as the melting objects are now floating in their own (cold) meltwater, drastically decreasing the melt rate. We also observe that their rotational dynamics depends on the salinity.

Conclusion:

We will show that the inclusion of salinity will fundamentally change the melting rate, the morphology, and, for the case of freely-floating, the rotational dynamics, of a melting object.

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References

[1] I. J. Hewitt, *Subglacial plumes*, Annu. Rev. Fluid Mech. **52**, 145 (2020).

[2] C. Cenedese and F. Straneo, *Icebergs melting*, Annu. Rev. Fluid Mech. **55**, 377 (2023).

[3] S. Weady, J. Tong, A. Zidovska, and L. Ristroph, *Anomalous convective flows carve pinnacles and scallops in melting ice*, Phys. Rev. Lett. **128**, 044502 (2022).