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Phaseflow for the monolithic simulation of convection-coupled phase-change: Potential for application to ice-shelf/ocean interaction

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The most significant loss of mass from the Antarctic ice shelves is from melting at the base. Directly measuring this sub-surface process is challenging, necessitating numerical simulation using physics-based models. Accurately simulating the process requires capturing the physics of the sub-ice boundary layer, including water circulation, heat transport, and mass transport in the cavities below the ice shelves. This is all discussed in detail by Dinniman et al. (2016).

The state-of-the-art in numerical modeling of ice shelf/ocean interaction was reviewed by Williams et al. (1998). Subsequent advances and promising future research directions are described by Dinniman et al. (2016). Current state-of-the-art models typically consider a static ice shelf. An emerging research direction involves coupling dynamic ice shelves, which allow the ice to react to ocean changes; but, typically, these models are coupled asynchronously. There are several ongoing activities to synchronously couple these models via an operator-splitting approach. No model can practically capture all relevant spatio-temporal scales. This necessarily leads to significant uncertainties in parameterized models. To complement models with resolutions feasible for Earth system science simulations, a promising research direction involves the local application of “ultra-high-resolution” models to resolve sub-grid scale processes of the ice/ocean boundary layer. While computationally expensive, such models are needed for model validation, parameter uncertainty reduction, and scientific discovery.

Our goal is to simulate the unsteady evolution of coupled ice/ocean interaction at high resolution, which is relevant both for Earth sciences and other planetary science, e.g. ocean worlds such as Enceladus in our solar system. As a first step, we consider laminar flow and an idealized phase-change material with constant material properties, and focus on the evolution of the melting interface in the presence of convection. For this we have developed Phaseflow (Zimmerman, 2018), a monolithic (i.e. without operator-splitting) simulation tool for convection-coupled phase-change. Phaseflow leverages research regarding the convection-coupled melting and solidification of phase-change materials in general, which has already been applied to water-ice systems. Particularly, we have implemented an adaptive finite element method based on the numerical approach from Danaila et al. (2014). In this contribution, we present and discuss a series of reference cases computed with Phaseflow.

References

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