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Benefits of the Brinkman Volume Penalisation Method for the Ice-Shelf Melt Rates Produced by Z-coordinate Ocean Models

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Antarctic ice-shelf basal melting is a major source of uncertainty in sea level rise projections. A persistent challenge in simulating the ice-shelf-ocean interactions in z-coordinate ocean models is the introduction of artificial steps, leading to the generation of noise that impacts both melting and ocean currents. This study explores the potential of the Brinkman Volume Penalisation (BVP) method (Debreu et al. 2020, 2022) to address the recurrent issue of steps in ice-shelf-ocean models. While penalisation methods are typically applied to land topography, here, the method is generalised to ice-shelf interactions with oceans. This approach introduces porous cells that are half-ice, half-ocean, combined with a permeability parameter (friction within porous cells) to model the blocking effect of the ice draft. A unique aspect of this method is its ability to spread the penalisation region, thereby reducing model sensitivity to numerical level changes. We assess the potential benefits of the BVP approach within the idealised ice-shelf configuration ISOMIP+ as presented by Asay-Davis et al. (2016). First, a new calculation of the horizontal pressure gradient is formulated using the BVP approach, which eliminates residual biases in ocean currents down to zero machine precision. Second, the spreading of the penalised interface significantly reduces noise in the melt rates, enabling a smooth response of the ocean beneath the ice-shelf without the need for further mesh refinement. Other simulations are used to investigate the sensitivity of basal melting and freezing in the penalised configuration to changes in numerical parameters (e.g. spatial resolution). These results pave the way for a better numerical treatment of ice-shelves in earth system models.