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First steps for a 3d flexible, unstructured finite element ocean model for flow under ice shelf cavities: an ISOMIP+ case study

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Accurate modelling of basal melting beneath ice shelves is key to reducing the uncertainty in forecasts of ice-shelf stability and, thus, the Antarctic contribution to sea level rise. However, the lack of flexibility inherent to traditional ocean models can pose problems.

Obtaining accurate melt estimates requires capturing the turbulent exchange of momentum, heat and salt at the ice-ocean interface, which may be modulated by the competing effects of stratification and basal slope. There are still significant uncertainties surrounding the trade-off between the simplicity of the melt parameterisation and the processes that need to be resolved by the numerical ocean model near the boundary.

Real ice-shelf cavity geometries are complicated. Bathymetric valleys are common and provide pathways for warm circumpolar deep water. The ice base is marked by channels, crevasses and terraces. These features will affect the boundary flow, with an added complication that melting plays a role in their formation. It is very difficult to model such flow regimes using a traditional ocean model not only because of the resolution constraints imposed by inflexible grids, but also due to the inbuilt assumptions of large aspect ratio processes and domains that may be violated when flow occurs past these features.

Ice flow models are very sensitive to how they are forced by melting at the grounding line, where the ice starts to float. The grounding line is precisely the region where ocean models are most questionable due to insufficient resolution imposed by limitations on the grid. Subglacial outflow into the cavity will likely break the inherent physical assumptions of hydrostatic, non-negligible vertical accelerations in large aspect ratio domains.

To model these effects requires the use of an ocean model that contains a flexible, unstructured mesh, is applicable at a range of length scales and, crucially, is still valid when the vertical-to-horizontal grid aspect ratio approaches order one. We are developing such a model for simulating flow under ice shelf cavities using the Firedrake finite element framework, primarily because it

enables adjoint sensitivities to be calculated automatically. We present our 3d simulations of ISOMIP+ experiments alongside simulations using the MITgcm ocean model, a commonly used z-layer (constant vertical resolution) model. We have found that the ability to vary the mesh resolution flexibly in the horizontal and vertical, even in a relatively simple ISOMIP+ domain (i.e., no channels or crevasses) is very useful to investigate how melt rate depends on grid resolution, which ultimately must be the first aim of any study using a numerical model.