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Superposition of velocity for ice sheet modeling

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A significant challenge in ice sheet modeling is coupling inland flow which is well approximated by the shallow ice approximation (SIA) to fast flow in ice streams and shelves where the shallow shelf approximation (SSA) is more appropriate. Until recently, the location of this transition was either prescribed a-priori or computed in an ad-hoc manner. Schoof (2006) showed that a plastic model for basal sliding gives rise to a free boundary problem for the SSA equations where the domain of sliding is part of the solution. We extend this approach, introducing shear in planes parallel to the geoid, by a superposition of SIA-predicted velocity with the SSA velocity. While we present no formal shallowness argument justifying this superposition, we find that it is practical to compute and yields a better approximation than either shallow model alone. This method has been implemented as part of PISM, an open source parallel ice sheet model capable of running simulations with 1 billion degrees of freedom. We assess the quality of the method by comparing it to a full Stokes model for simplified geometry. As a case-study, we model the development of an ice stream in a circular ice cap with perturbed bed.