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Modeling Firn Compaction in Dynamic Regions

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Firn compaction remains the largest source of uncertainty in assessments of ice-sheet mass balance from repeat altimetry measurements due to our limited understanding of the physical processes responsible for the transformation of snow into ice. In addition to the lack of a comprehensive, physically-based constitutive relationship that describes firn compaction, dynamic thinning is an important process in some regions, but is generally neglected in firn-compaction models due to their one-dimensional nature. Here, we report on preliminary results incorporating dynamic strain thinning into firn compaction models. Using a Lagrangian (material-following) reference frame, we first compact each firn element using a standard 1-D firn-compaction model without longitudinal strain. Then, we stretch each firn parcel at each time step by applying a prescribed longitudinal strain rate in the absence of further density changes; this produces additional vertical thinning. To assess variations among firn models, we compare results from eight firn densification models currently included in the UW Community Firn Model. We focus on the Northeast Greenland Ice Stream due to the high extensile strain rates ($10^{-3}\ yr^{-1}$ or higher) in the ice stream's shear margins and the extensive firn-density data in this area from seismic measurements and shallow firn/ice cores. For temperatures and accumulation rates typical for northeast Greenland, our preliminary results indicate up to an 18-meter decrease in bubble close-off depth in the shear margins compared to nearby areas either inside or outside the ice stream, which compares favorably to field data. Further work includes incorporating physically-based constitutive relations and applying these improved models to other dynamic regions, such as the Amundsen Sea Embayment, where dynamic strain thinning has accelerated in recent decades.