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Development of a snow-firn-ice surface mass balance treatment for ice sheet models

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The treatment of surface melt, runoff, and the snow-firn-ice transition in ice-sheet models (ISMs) is becoming increasingly important, as mobile liquid on Greenland and Antarctic flanks increases due to climate warming in the next century and beyond. Simple Positive Degree Day (PDD)-based box models used in some ISMs crudely capture liquid storage and refreezing, but need to be extended to include vertical structure through the whole firn-ice column, as in some regional climate models (RCMs). This is a necessary prelude to modeling the flow of mobile meltwater in channel-river-moulin systems, and routing to the base and/or margins of the ice sheet.

More detailed column models of snow and firn exist, that include compaction, grain size, and other processes. Some focus on dry-snow zones, and have fine vertical resolution spanning the entire firn column with Lagrangian tracking of annual snow layers (e.g., FirnMICE: Lundin et al., J. Glac., 2017). However, they are mostly too computationally expensive for ISM applications, and are not designed for ablation zones with meltwater and bare ice in summer. More general models are used in some RCMs that include similar physics but with fewer layers, and are applicable both to accumulation and ablation zones.

Here we formulate a new snow-firn model, similar to those in RCMs, for use within an ice-sheet model. A limited number of vertical layers is used ($\sim$10), with Lagrangian tracking of layers, grain size evolution, compaction, ice lenses, liquid melting, storage, percolation and runoff. Surface melting is computed from linearized net atmospheric energy fluxes, not from PDDs. The model is tested using the FirnMICE experiments, and using gridded $RACMO_2$ modern climate input over Greenland, seeking to balance model performance with computational efficiency.