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Development of physically based liquid water schemes for firn densification models

Vincent Verjans
Lancaster University, United Kingdom (v.verjans@lancaster.ac.uk)

As surface melt is increasing on the Greenland ice sheet, quantifying the retention and refreezing capacities of the firn layer is critical to link meltwater production to meltwater runoff. Refreezing of liquid water in firn has both an impact on mass balance and affects heat fluxes from the surface to the ice sheet. As such, understanding firn related processes, and in particular the interactions with liquid water, is becoming increasingly important to predict, and to accurately constrain, the mass balance of the Greenland ice sheet. Firn densification models have so far relied on simplified approaches to account for the percolation-refreezing process. However, observations have shown that liquid water transport in firn is characterised by complex flow patterns, and more physically based representations of liquid water flow might therefore bring improvements to model performance. Vertical water transport through snow is achieved by homogeneous (matrix) flow and rapid flow through discrete 'pipes' (preferential flow). Such water flow has been documented extensively in field observations, and preferential flow is an effective mechanism for transporting water from the surface into deep, potentially subfreezing, layers.

Here we implement three types of water percolation schemes into the Community Firn Model. We evaluate their impact on firn densification at four locations on the Greenland ice sheet and compare model results with firn core observations. The water schemes vary in their degree of physical details: a simple parameterized tipping bucket approach, the Richards Equation in a single domain and the Richards Equation in a dual domain accounting for the duality of water flow. The divergence in model results demonstrate that much progress towards an accurate description of water flow in firn is still to be made and we show that the most physically detailed schemes do not necessarily reach best agreement with observed density data. We investigate the sensitivity of these schemes to various parameters and we highlight the deficiencies of firn models in capturing the effects of liquid water on the densification process. The numerous uncertainties surrounding firn micro- and macro-structure and its hydraulic properties as well as the one dimensionality of firn models render the implementation of physically based percolation schemes difficult. An improved understanding of firn models' sensitivity to their various parameters, to the climatic forcing and to the treatment of liquid water would benefit further developments.