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Modelling ice lens and aquifer formation in firn

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The lower percolation zone of the Greenland Ice Sheet is characterized by a near balance between accumulation and melt, hence melt rates in dry lower percolation zones are lower than in high accumulation percolation zones. Observations reveal a distinct bimodal behavior in retention regime. If annual snowfall is below about 500-700 mm per year, ice lenses are formed, fully or partially blocking deep percolation of melt water into the firn column. If annual snowfall exceeds 500-700 mm per year, melt water aquifers are formed instead – unless crevasse formation due to ice flow inhibits permanent standing water above the glacial ice.
This bimodal behavior is not resembled by the so-called bucket method, which is generally employed in the firn models embedded in numerical weather forecast models. Here, I show that this bimodal behavior of melt water retention can be resembled by representing water percolation as Darcy flow through (partially) saturated snow. The simulations show that in low accumulation percolation zones, capillary pressure differences distribute melt water downwards even though liquid water concentrations are relatively low, until the melt water reaches higher-density layers. Here, refreezing can match downwards water transport, inducing a positive feedback loop leading to ice lens formation. In high accumulation percolation zones, abundant melt water availability heats the whole firn column quickly to the melting temperature, cancelling any positive feedback mechanisms by refreezing.
Concluding, vertical liquid water transport for concentrations below the irreducible water content is essential during the formation of ice lenses.