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A continuum model for snow and firn on the surface of ice sheets

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Meltwater is produced on the surface of glaciers and ice sheets when the seasonal energy forcing warms the snow or ice to its melting temperature. Meltwater may runoff immediately, or may percolate into the snow and subsequently either run off laterally beneath the surface, be stored as liquid water, or refreeze. These processes are crucial to understanding ice sheet mass loss, as well as determining the surface boundary conditions to be applied to ice-sheet models which typically neglect the near-surface dynamics.

We present a continuum model for the fluid- and thermo-dynamics of the surface snow layer that includes meltwater transport, refreezing, and mechanical compaction. The model is forced by surface mass and energy balances, and the percolation process is described using Darcy's law, allowing for both partially and fully saturated pore space. Water is allowed to run off from the surface if the snow is fully saturated or impermeable.

The one-dimensional version of the model predicts evolution of temperature, density, and water-content profiles, as well as the partitioning of surface melt between runoff, storage and refreezing. We use these results to examine the influence of the surface forcing on the mean deep firn temperature (which provides an effective surface boundary condition to the ice sheet below) and surface mass balance. We also examine the formation of ice lenses and of 'piping' features that enhance the effective vertical permeability of the snow, and discuss extensions of the model to account for macroscopic lateral flow.