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Upcaling microscopic crystal growth dynamics in snow

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While the growth of single ice-crystals in the atmosphere is reasonably well understood, the microstructure dynamics of snow on the ground as the collective growth of aggregated crystals, is still lacking a unified treatment based on first principles of ice crystal growth. One of the key-challenges is the lack of models for the microstructure evolution of the bicontinuous ice matrix. To this end, we developed a rigorous microstructure upscaling scheme which takes common pore-scale (diffusion) principles of crystal growth to predict the volume-averaged evolution of the interface morphology. We derived a coupled set of evolution equations for the (volume averaged) ice volume fraction, specific surface area, Gaussian curvature and first and second moment of the mean curvature distribution, and demonstrate their correctness by a comparison to the evolution of different non-spherical grains under a prescribed growth law. In a second step, we use the model as a benchmark tool without a-priori assumptions for a comparison to experiments of snow microstructure evolution via interface tracking on 4D X-ray tomography data. The benchmarking allows us to quantify uncertainties in local estimates of crystal growth velocities. Finally, we demonstrate how the rigorous model facilitates a statistical assessment of common growth laws by combining 4D microstructure data with finite element numerics for heat transfer. The results e.g. show that a decay of the specific surface area cannot be explained by diffusion-limited growth models for the interface velocity. In addition, the evolution of microstructural parameters confirm a morphological asymmetry between growth and sublimation sites. Further conceptual insight is therefore needed to improve the link between volume averaged microstructural evolution in snow and ice crystal growth mechanisms.

Significance statement

Most scientific problems involving physical properties of snow, depends highly on its microstructure. Given the range of scales of interest, there is a clear demand for a rigorous upscaling approach of objective and relevant microstructural parameters that connects recent advances in 4D X-ray tomography experiments and crystal growth theories.

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