Upscaling ice crystal growth dynamics in snow: Rigorous modeling and comparison to 4D X-ray tomography data

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Presently a unified treatment of microstructure dynamics in terrestrial snow from principles of ice crystal growth is hindered by the lack of models for the evolution of the bicontinuous ice matrix. To this end we developed a rigorous microstructure upscaling scheme which is based on common pore-scale (vapor diffusion) principles of crystal growth to predict the averaged evolution of the interface morphology. We derived a coupled set of evolution equations for the (volume averaged) ice volume fraction, surface area per unit volume, Gaussian curvature and first and second moment of the mean curvature distribution and demonstrate their correctness by a comparison to interface tracking of idealized grains. 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 image analysis on 4D X-ray tomography data. The benchmarking allows quantifying uncertainties from 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. The results show that the prediction of the surface area evolution from first principles demands further conceptual insight from ice crystal growth.

Stokes resistance of snowflakes

The equations of motion of snow particles suspended in air are governed by the gravitational force and the complex interaction between the geometry of the particle and the viscous forces of the surrounding air. For particles immersed in relatively low Reynolds number flow, the problem reduces to a linear equation that depends solely on the geometry of the particle and is described by the Stokes resistance. We use numerical simulations to obtain the particle resistance matrix of distinct snow particle shapes. For the geometrical representation, we extract individual snow particles from micro-computed tomography data. In addition, we used snowflake geometries generated by phase field models. After rescaling the particles to equal volume, we found that the resistance to translation depends on the square root of the interface area with a correlation coefficient of 0.80. Similarly we found that the average resistance to rotation is given by the interface area to the power two-third with a correlation coefficient of 0.75.