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Numerical modelling of polyphase deformation and recrystallisation in polar firn and ice

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The ice sheets in Greenland and Antarctica contain a significant amount of air within their upper approximately thousand meters and air hydrates below. While this air is still in exchange with the atmosphere in the permeable firn, the gas is entrapped at the firn-ice transition at 60 – 120 m depth. Understanding the dominant deformation mechanisms is essential to interpret paleo-atmosphere records and to allow a more realistic model of ice sheet dynamics. Recent research shows how the presence of air bubbles can significantly influence microdynamical processes such as grain growth and grain boundary migration (Azuma et al., 2012, Roessiger et al., 2014). Therefore, numerical modelling was performed focussing on the mechanical properties of ice with air inclusions and the implications of the presence of bubbles on recrystallisation.
The full-field crystal plasticity code of Lebensohn (2001), using a Fast Fourier Transform (FFT), was coupled to the 2D numerical microstructural modelling platform Elle, following the approach by Griera et al. (2013), and used to simulate dynamic recrystallization of pure ice (Montagnat et al., 2013). FFT calculates the viscoplastic response of polycrystalline and polyphase materials that deform by dislocation glide, takes into account the mechanical anisotropy of ice and calculates dislocation densities using the local gradient of the strain-rate field.
Incorporating a code for polyphase grain boundary migration driven by surface and internal strain energy reduction, based on the methodology of Becker et al. (2008) and Roessiger et al. (2014), now also enables us to model deformation of ice with air bubbles. The presence of bubbles leads to an increase in strain localization, which reduces the bulk strength of the bubbly ice. In the absence of dynamic recrystallisation, air bubbles quickly collapse at low strains and spherical to elliptical bubble shapes are only maintained when recrystallisation is activated. Our modelling confirms that strain-induced grain boundary migration already occurs in the uppermost levels of ice sheets (Kipfstuhl et al. 2009, Weikusat et al. 2009).

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