Modelling the influence of air on the deformation and recrystallisation mechanisms in polar firn and ice

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Within their upper approximately thousand meters, ice sheets on Earth contain a significant amount of air and air hydrates below. In the permeable firn, this air is still exchanging with the atmosphere and is under atmospheric pressure, whereas the air bubbles are entrapped at the firn-ice transition 60 – 120 m depth. As recent research showed, 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). Understanding the dominant deformation mechanisms has essential implications on paleo-atmosphere research and allows more realistic modelling of ice sheet dynamics. Therefore, numerical models were set up and performed focussing on the implications of the presence of bubbles on recrystallisation and the mechanical properties of ice with air inclusions.
The 2D numerical microstructural modelling platform Elle was coupled to the full-field crystal plasticity code of Lebensohn (2001), which is using a Fast Fourier Transform (FFT) following the approach by Griera et al. (2013). Taking into account the mechanical anisotropy of ice, FFT calculates the viscoplastic response of polycrystalline and polyphase materials that deform by dislocation glide, predicts lattice re-orientation and using the local gradient of the strain-rate field, dislocation densities are calculated. FFT was used for the simulation of dynamic recrystallization of pure ice by Montagnat et al. (2013).
Polyphase grain boundary migration driven by surface energy and internal strain energy reduction was incorporated in the code and now also enables us to model deformation of ice with air bubbles. The approach is based on the methodology of Becker et al. (2008) and Roessiger et al. (2014).
During Deformation, spherical to elliptical bubble shapes are only maintained, when surface energy based recrystallisation is activated, whereas they quickly collapse at low strains in the absence of recrystallisation. The presence of bubbles leads to increased localization of stress, strain and dislocation densities, a reduction of the bulk strength of the bubbly ice is observed. Furthermore, strain-induced grain boundary migration already occuring in the uppermost levels of ice sheets (Kipfstuhl et al. 2009, Weikusat et al. 2009) is confirmed by our modelling.

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