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The Cryosphere Discussions

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Interactive comment

Interactive comment on "Strain localisation and dynamic recrystallisation in the ice-air aggregate: A numerical study" *by* Florian Steinbach et al.

Anonymous Referee #1

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General Comments:

This paper presents micro-dynamical simulations of polycrystalline hcp ice containing air bubbles using a numerical approach based on the coupling of the numerical platform Elle, a front-tracking formulation that accounts for microstructure evolution due to different dynamic recrystallization processes (normal grain growth, strain-induced grain boundary migration, recovery, polygonization) and a viscoplastic model based on Fast Fourier Transform (VPFFT) to calculate the micromechanical fields (stress, strain-rate, velocity, etc.) due to deformation of the constituent ice crystals by dislocation creep. In particular, the stored energy field calculated with VPFFT provides the driving force for the aforementioned recrystallization processes. Details of the integration between Elle and VPFFT and applications to different geomaterial systems have been reported in previous papers by the same team, including studies of the micro-dynamics

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Discussion paper

of fully-dense ice polycrystals. This paper presents a new application of Elle/VPFFT, to study the ice-air system, aiming at a better understanding of the onset of dynamic recrystallization in, e.g. firn. One of the main conclusions with glaciological relevance of this study is that the presence of air bubbles induces a "composite material" behavior, which contributes to: a) higher strain localization in the ice crystals, and therefore faster onset of dynamic recrystallization compared with fully-dense ice, and b) weaker CPO–not caused by grain-boundary sliding–, as the volume fraction of air increases.

Specific Comments:

While the proposed approach is sound and the main conclusions are reasonable, the specific treatment of the air inclusion phase, as far as its constitutive behavior and the treatment of the ice-air interfaces are concerned, needs to be better explained, including a better disclosure of the approximations involved. It is reported (section 2.6) that air bubbles are represented by an incompressible crystalline material with the same crystallography and slip systems as for ice, and that tau_s-air is set 5000 times smaller than tau_basal of ice. This seems to imply (more clarity is needed here) that the air is represented by hcp crystals deforming by basal, prismatic and pyramidal slip with equal critical resolved stresses. In turn, this implies the somehow unrealistic assumptions of: a) "anisotropic" bubbles (although the anisotropy remains small) and b) a unit cell unable to accommodate any volume change. The first approximation could have been avoided by adopting an isotropic viscoplastic behavior, or, even better, imposing zero stiffness (i.e. vanishing stress) to the unodes belonging to the air phase. With this said, I suspect (but I'd like to hear this from the authors!) that the predictions would not be dramatically affected.

The second approximation is more delicate. The air phase/unit cell incompressibility implies the inability of the present approach to consider volume changes that are inherent to ice flowing under its own weight. Moreover, the incorporation of a constitutive description admitting compressibility would have also allowed improving the convoluted treatment of the behavior of the ice-air interfaces described in section 2.4.1, accounting explicitly for the effect of the bubbles' internal pressure, both in terms of mechanical behavior and as a controlling factor of the recrystallization process. Furthermore, the shortcomings associated with the simplified treatment of the air bubbles as an incompressible phase may be responsible for the somehow puzzling results, in the cases of the F05 and F20 microstructures, showing the overall porosity almost unaltered after ∼50% vertical shortening. This makes the comparison with the EDML ice core at 80m depth presented in Fig. 8 questionable. This needs to be acknowledged and further model improvements to mitigate these limitations be discussed, before this paper is accepted for publication in The Cryosphere.

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