EGU2020-17864
https://doi.org/10.5194/egusphere-egu2020-17864
EGU General Assembly 2020

Stress and strain rate variations and strain localisation in ice: Another complexity to be considered apart from a simple enhancement factor

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To describe the rheology of ice, it is customary to employ a flow law that relates the (differential) stress to the strain rate, typically as a function of temperature. The flow law thus predicts a single strain rate for a given stress and temperature. However, ice 1h is highly anisotropic when deforming by dislocation creep as is usually assumed to be the case in glaciers and polar ice sheets. Ice is effectively much softer in shearing parallel to the basal plane compared to deformation that requires activation of the non-basal crystallographic slip planes. Numerical simulation of ice deformation with the full-field crystal plasticity code (VPFFT, Lebensohn & Rollett, 2020) coupled with the numerical simulation platform Elle (Llorens et al., 2016) show that deformation in aggregates of ice grains is highly heterogeneous and typically shows strong strain heterogeneity and strain localisation in shear zones. This localisation remains when lattice rotation has resulted in a strong crystallographic preferred orientation (CPO) with basal planes all oriented approximately parallel to the shear plane in simple-shear deformation.

Plots of the differential stress versus strain rate of all points of the full field model at one point in time show a wide scatter within the polycrystal. Although most basal planes have an orientation close to optimal for slip along this plane, few, if any material points actually show a stress-strain rate state close to the one predicted by the flow law for basal glide. On the contrary, the hard non-basal slip planes contribute significantly to the overall deformation. Shear zones show a stronger alignment of basal planes than the surrounding material. However, differential stress tends to be highest inside these shear zones, suggesting that shear zones are not simply the result of the presence of "soft" ice.

The results give insight in the highly complex behaviour of the strongly anisotropic material ice.

This complexity is insufficiently described with a simple enhancement factor. We discuss how this complexity may help explain variations in grain size and apparent strength found in deep drill cores in the polar ice sheets.

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How to cite: Bons, P. D., de Riese, T., Gomez-Rivas, E., Griera, A., Llorens, M.-G., and Weikusat, I.: Stress and strain rate variations and strain localisation in ice: Another complexity to be considered apart from a simple enhancement factor, EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-17864, https://doi.org/10.5194/egusphere-egu2020-17864, 2020