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How ice anisotropy contributes to fold and ice stream in large-scale ice-sheet models

Yu Zhang[1], Paul D. Bons[1], Till Sachau[1], and Steven Franke[1,2]
[1]Department of Geosciences, Tübingen University, Tübingen, Germany
[2]Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany

Satellite and airborne sensors have provided detailed data on ice surface flow velocities, englacial structures of ice sheets and bedrock elevations. These data give insight into the flow behaviour of ice sheets and glaciers. One significant phenomenon observed is large-scale folds (over 100 m in amplitude) in the englacial stratigraphy in the Greenland ice sheet. A large population of folds is located at ice streams, where the flow is distinctly faster than in the surroundings, such as the North-East Greenland Ice Stream (NEGIS). While there is no consensus regarding the formation of large-scale folds, unraveling the underlying mechanisms presents significant potential for enhancing our understanding of the formation and dynamics of ice streams.

Ice in ice sheets is a ductile material, i.e., it can flow as a thick viscous fluid with a power-law rheology. Furthermore, ice is significantly anisotropic in its flow properties due to its crystallographic preferred orientation (CPO). Here, we use the Full-Stokes code Underworld2 (Mansour et al.,2022) for 3D modelling of the power-law and transversely isotropic ice flow, also in comparison with the isotropic ice models.

Our simulated folds with anisotropic ice show complex patterns on a bumpy bedrock, and are classified into three types: large-scale folds (fold amplitudes >100 m), small-scale folds (fold amplitudes <<100 m, wavelength <<km) and recumbent basal-shear folds. Our results indicate that bedrock topography contributes to perturbations in ice layers, and that ice anisotropy due to the CPO amplifies these into large-scale folds in convergent flow by horizontal shortening. As for our ice stream model, we simulate convergent flow as initial condition, which subsequently initiates the development of shear margins due to the rotation of the ice crystal basal planes. As soon as the shear margins develop, the ice stream starts to propagate upstream in a short time and narrows in the upstream part. Our modeling shows that the anisotropic rheology of ice and CPO change play a significant role for large-scale folding and for the initiation of ice streams with distinct shear margins. Hence, we promote the implementation of ice anisotropy in large-scale ice-sheet evolution models as it holds the potential to introduce novel perspectives to the glaciological community on the dynamics of ice flow.

References

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