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Modeling the evolution of crystal fabric and its link to climate and ice sheet history

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A perturbation in climate can induce a subtle change in the near-surface texture and fabric of ice. In the central regions of ice sheets, the basal planes of crystals tend to rotate over time, until they are horizontal, developing a preferred crystal-orientation fabric deep within the ice sheet. This rotation affects the bulk deformation of an ice sheet because ice crystals deform anisotropically; Ice crystals shear easily along the slip systems in their basal planes, while shear on the other slip systems are nearly two orders of magnitude harder. Further, a positive feedback mechanism exists between fabric development and ice deformation which may allow information about climate perturbations, recoded in the near-surface texture and fabric, to persist deep in the ice sheet.

We model the evolution of a climate-induced, subtle variation in the near-surface texture and fabric under different stress and recrystallization scenarios. Our model is based on that developed by Thorsteinsson (2002), which assumes homogeneous stress and includes crystal growth, polygonization, migration recrystallization, and the influence of neighboring crystals on the rotation of each crystal. We find that under constant stress experiments, a layer of initially stronger fabric evolves more rapidly, strengthening the initial fabric contrast. However, at large total strains, when the fabric is nearing perfect alignment of the basal planes, the fabric contrast will weaken. Because the stress state of an ice particle in an ice sheet changes through time, we suggest that this weakening of the fabric contrast is rare compared to the strengthening.

We also explore the fabric evolution through time within multiple ice sheets where an ice core has been drilled to bedrock including Taylor Dome and Dome C, East Antarctica. We model bulk fabric evolution driven by a stress history derived from the geometry, temperature and depth-age relation and study the sensitivity of the results to initialization of near-surface fabric. The results are validated by thin-section fabric data and our model successfully captures the large-scale fabric variations observed through thin section in the ice sheets.

We find that the influence of neighboring crystals has a negligible effects over millennial time scales and small effect over longer ice-sheet time scales. Our model successfully captures the evolution of fabric on both large (ice-sheet) and small (single climate perturbation) scales and suggests that a subtle changes in fabric caused by climate perturbations will be enhanced through time and depth in an ice sheet. These results offer the possibility of extracting information about past climate directly from the ice texture and fabric.