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Inferring ice rheology in Antarctic ice shelves from remotely sensed observations

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Glaciers and ice sheets flow as a consequence of ice rheology. At the temperatures and pressures found on Earth, several creep mechanisms allow glacier ice to flow as a non-Newtonian (shear-thinning) viscous fluid. The semi-empirical constitutive relation known as Glen's Flow Law is often used to describe ice flow and to provide a simple expression for an effective viscosity that decreases with increasing stress and deformation rate. Glen's Flow Law is a power-law relation between effective strain rate and deviatoric stress, with two parameters defining the rheology of ice: a rate factor, A, and stress exponent, n. The rate factor depends on features such as temperature and grain size, while the stress exponent is primarily representative of the creep mechanism. Neither A nor n are well constrained in natural ice, and the stress exponent is typically assumed to be $n = 3$ everywhere. Here, we take advantage of recent improvements in remotely sensed observations of surface velocity and ice shelf thickness to infer the values of A and n in Antarctic ice shelves. We focus on areas of ice shelves that flow in a purely extensional regime, where extensional stresses are proportional to observed ice thickness, drag at the base of the ice is negligible, and extensional strain-rates are calculated from the gradients of observed surface velocity fields. In this manner, we use independent observational data to derive spatially dependent constraints on the rate factor A and stress exponent n in Glen's Flow Law. The robust spatial variability provides insights into the creep mechanisms of ice, thereby capturing rheological properties from satellite observations. Our analysis indicates that $n \approx 4$ in most fast-flowing areas in an extensional regime, contrary to the prototypical value of $n = 3$. This finding implies higher non-linearity in ice flow than typically prescribed, influencing calculations of mass flux and the response of ice sheets to perturbations. Additionally, This result suggests that dislocation creep is the dominant creep mechanism in extensional regimes of Antarctic ice shelves, indicative of tertiary creep. This analysis unites theoretical work and synoptic-scale observations of ice flow, providing insights into the rheology and stress-states of ice shelves in Antarctica.