EGU2020-4188
https://doi.org/10.5194/egusphere-egu2020-4188
EGU General Assembly 2020

Recent developments in modeling ice sheet deformation

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Viscous deformation is the main process controlling ice flow in ice shelves and in slow-moving regions of polar ice sheets where ice is frozen to the bed. However, the role of deformation in flow in ice streams and fast-flowing regions is typically poorly represented in ice sheet models due to a major limitation in the current standard flow relation used in most large-scale ice sheet models – the Glen flow relation – which does not capture the steady-state flow of anisotropic ice that prevails in polar ice sheets. Here, we highlight recent advances in modeling deformation in the Ice Sheet System Model using the ESTAR (empirical, scalar, tertiary, anisotropic regime) flow relation – a new description of deformation that takes into account the impact of different types of stresses on the deformation rate. We contrast the influence of the ESTAR and Glen flow relations on the role of deformation in the dynamics of Thwaites Glacier, West Antarctica, using diagnostic simulations. We find key differences in: (1) the slow-flowing interior of the catchment where the unenhanced Glen flow relation simulates unphysical basal sliding; (2) over the floating Thwaites Glacier Tongue where the ESTAR flow relation outperforms the Glen flow relation in accounting for tertiary creep and the spatial differences in deformation rates inherent to ice anisotropy; and (3) in the grounded region within 80km of the grounding line where the ESTAR flow relation locally predicts up to three times more vertical shear deformation than the unenhanced Glen flow relation, from a combination of enhanced vertical shear flow and differences in the distribution of basal shear stresses. More broadly on grounded ice, the membrane stresses are found to play a key role in the patterns in basal shear stresses and the balance between basal shear stresses and gravitational forces simulated by each of the ESTAR and Glen flow relations. Our results have implications for the suitability of ice flow relations used to constrain uncertainty in reconstructions and projections of global sea levels, warranting further investigation into using the ESTAR flow relation in transient simulations of glacier and ice sheet dynamics. We conclude by discussing how geophysical data might be used to provide insight into the relationship between ice flow processes as captured by the ESTAR flow relation and ice fabric anisotropy.