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Ice stream modelling results from a higher-order ice sheet model with plastic bed and simplified hydrology

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Current predictions of ice sheet mass balance and sea-level rise are based on ice-flow models with limited representation of subglacial processes. One of the most challenging aspects of ice sheet modelling is the ability to realistically simulate the fast and transient flow of ice streams that drain the interior of ice sheets and discharge large volumes of ice into the polar ocean. We present results from experiments using a 3D higher order ice sheet model, which we have coupled to a subglacial processes model that include hydrologically-controlled shear strength evolution in a till layer with Coulomb plastic rheology. The basal processes model was originally developed for simulations of the Siple Coast ice streams with a two-dimensional flowband model, but its coupling to a 3D higher-order ice sheet model enables us to assess the response of three-dimensional ice-stream flow to hydrological and geological settings as well as variable basal shear strength.

The model is run for 20ka on a simplified domain. In the first experiment setup, the basal resistance to flow reduces (increases) as basal melting (freezing) weakens (strengthens) the till layer. For this experiment, the ice stream oscillates between active and stagnant phases as a result of thermodynamic feedbacks occurring at the ice-till interface. However, the velocity amplitude gradually decreases, as insufficient provision of basal meltwater causes the ice stream to gradually thicken and enter a slow flowing "ice sheet mode". In a second experiment, we assume that vertical mixing in the till layer is efficient enough at high velocity for the till to be able to assimilate extra water from a hypothetical hydrology system. The added water volume is scaled with the ice velocity, and remains small in comparison to the basal melt water volume. For this experiment, a stable oscillating "ice-stream mode" is maintained because the extra water delivered to the bed leads to higher velocity achieved (due to weaker till). This triggers stronger thermodynamic feedback between the ice and till layer, in particular widespread basal melt rate as the ice stream thickens during stagnant phases.

Our model results also suggest that flow of ice streams are influenced by till conditions that are partly defined by the duration and magnitude of freezing in the preceding stagnant phase. The latter is in turn influenced by the pattern of fast ice flow in the preceding active cycle. We infer that in Nature, till conditions may also be affected by water transport from a regional hydrology system.

Additional modelling developments will include the generalization of the subglacial processes model by coupling pore water pressure in the till layer to a more physically-based hydrology model.