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Effect of fast dynamics on the centennial mass loss of the Greenland Ice Sheet

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Observations have revealed high-frequency fluctuations in outlet glacier discharge around the margin of the Greenland Ice Sheet (GIS). It has been estimated that the net effect of these fluctuations may have contributed up to half of the increased mass loss of the GIS during the last decade. If such marginal accelerations are to have an appreciable effect on total mass loss on a century time scale, a fast mechanism to transmit such perturbations inland is required. Almost instantaneous transmission of marginal perturbations is effectuated by gradients in longitudinal stresses and facilitated by high basal sliding. The effectiveness of these mechanisms on the transient response of the GIS however remains controversial because of potentially strong feedbacks from basal sliding (driving stress) and surface mass balance (hypsometry).
Here we use a three-dimensional thermo-mechanically coupled model of the Greenland ice sheet to assess the effects of marginal perturbations on volume changes on centennial time scales. The model is designed to allow for three different ice-dynamic cores using different approximations to the force balance. The reference model is based on the shallow ice approximation (SIA) for both ice deformation and basal sliding. A second version confines longitudinal stress gradients to the basal sliding layer using the shallow shelf approximation (SSA). The third model version relies on a higher-order Blatter/Pattyn type of core that includes longitudinal stress gradients and lateral drag throughout the entire ice column. In terms of complexity, the three models allow for gradually more dynamic feedbacks and together form a feasible tool to study the potential effect of fast stress transmission.

Idealised experiments were conducted to compare the time-dependent response of all three model versions forced by imposed accelerations at the marine calving front. In model versions allowing for longitudinal stress transmission, there is an instantaneous speedup of upstream ice some distance inland. However the total ice volume loss after 100 years differs only slightly from the SIA model as most of the response is due to common changes in driving stress that are moreover strongly dampened. If at all, the inclusion of fast dynamics in the full higher-order model even serves as a negative feedback mechanism, as it allows for a faster attenuation of the initial perturbation. These experimental results are robust starting from different initial conditions, using horizontal grid sizes between 5 and 20 km, and using different step changes in the ice discharge flux.