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 facilitated 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 (SSA) 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/Pattny 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.

Idealized 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 SSA model as most of the response is due to common changes in driving stresses 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.

**Can fast stress transmission alter the centennial response of large ice sheets?**

### In General
- Marginal flow acceleration increases GIS mass loss
- Dynamic discharge for speed-up of all outlet glaciers limited by inland drainage
- Centimeter scale sea level contribution by extensive outlet speed-up

### Dynamic Influence
- Fast stress transmission reduces dynamic discharge by ~10%
- Both models with enhanced dynamics give comparable centennial mass loss
- Cross-over indicates different response in SSA and HO model

**Spatial Pattern in Inland Transmission of Peripheric Forcing**

- Radial inland propagation of dynamic thinning mainly coincides in all models
- Along flow inland transmission via changes in driving stress dominates
- Propagation perpendicular to flow direction amplified by lateral shearing
- Gradients in longitudinal stresses enhance drainage of upsheet areas

**Experimental Setup**

**Shallow Ice Approximation**
- Local solution to force balance
- Immediate stress transmission is not accounted for

**Higher-order Approximation**
- Velocity field affected by surrounding areas
- Lateral shear and longitudinal stress gradients allow fast signal transmission

**Initial Response**
- Immediate effect for an identical ice geometry

**Setup**
- Initial acceleration confined to periphery
- Marginal acceleration affects surroundings for extended drainage of interior

**Mass Loss Contributions**

<table>
<thead>
<tr>
<th>Mass Loss Contributions</th>
<th>SSA</th>
<th>SIA</th>
<th>HO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meltwater Runoff</td>
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<tr>
<td>Negative feedback from enhanced dynamics</td>
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<tr>
<td>Positive feedback on meltwater runoff</td>
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<td>Main process for total discharge difference</td>
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</tbody>
</table>

**Outlook**

- Fast signal transmission by gradients in longitudinal stress or lateral shear does not significantly alter centennial response of ice sheet interior.

**Take Away**

- Integrated ice discharge from a HO and a SSA model resemble one another but spatial pattern of signal transmission differs.