Numerical Modeling of Glacier Sliding with cavitation

Initial “results” and challenges

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Project/ underlying scientific question

To investigate whether, or to what degree, a rate-weakening effect persist for realistic glacier beds using the assumptions of free-slip and clean ice. To this end we attempt to combine field data, experimental data and numerical simulations.

Dynamical processes: boundary conditions at the bed

- Sliding can amount to a substantial part of the total velocity, and is therefore important when considering the dynamics of glaciers and ice sheets.

Towards process oriented sliding

- Data from sliding experiments performed with clean, temperate ice (ice at the pressure melting point) against bedrock, indicate that a thin *water-film* that develops at the ice-bed interface causes a near *free-slip* condition, i.e. $\mathbf{T}_{nt}\mathbf{t} = \mathbf{0}$.

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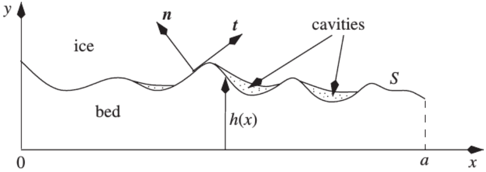
- This suggest that the local *drag*, defined as the average component of upstream stress is a function of the local bed topography h.

Towards process oriented sliding

- Using the assumption of free-slip and that forces are in balance, one can show that local drag over the domain, satisfies

$$\tau_b \leq (p_i - p_w)h'(x),$$

where p_i is the ice pressure over the domain and p_w is the water pressure in the cavities.



Schoof2005.

Towards process oriented sliding

- Both semi-analytical results, numerical results for simple 2D domains, and experimental results have indicated that this limit exists, and that glaciers can exhibit a *double-valued* drag to velocity relation, showing *rate-weakening* characteristics.

Schoof2005.

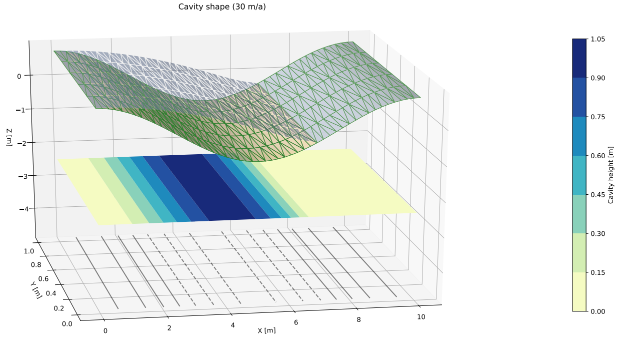
Gagliardini2007.

IversonZoet2015.

ZoetIverson2016.

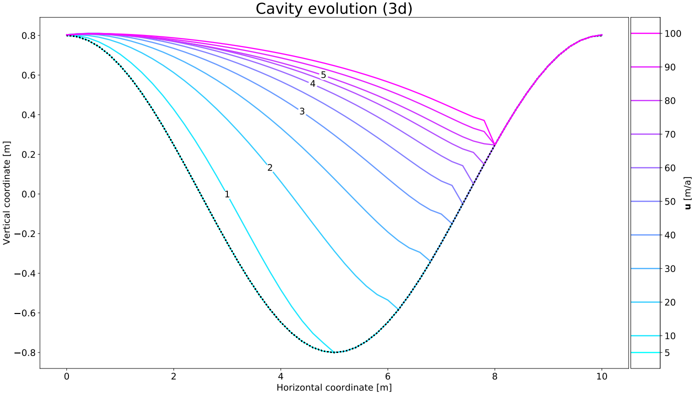
Results 3D

Sinusoid type bed of roughness 0.08, horizontal domain is $x = 10m; y = 10m$. Velocity is $u_0 = 30m/a$.



Results 3D

Sinusoid type bed of roughness 0.08, horizontal domain is $x = 10m; y = 10m$. Slice is at $y = 0.5m$.



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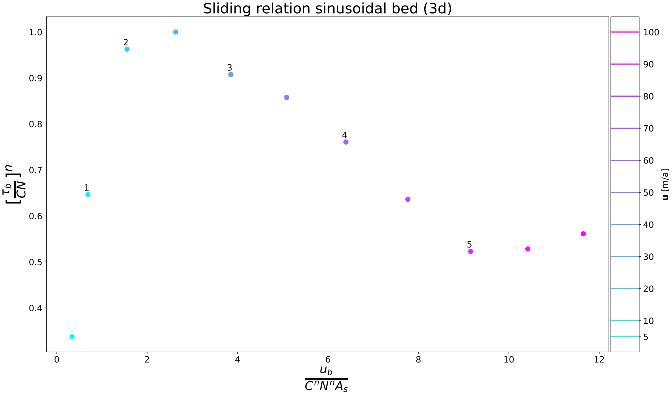
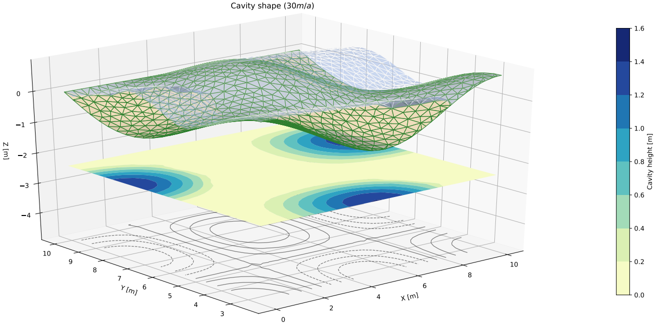


Results 3D

Cross-sinusoid type bed of “roughness” 0.08, horizontal domain is $x = 10m; y = 10m$. Slice at $y = 2.5m$, for $u_0 = 30m/a$.



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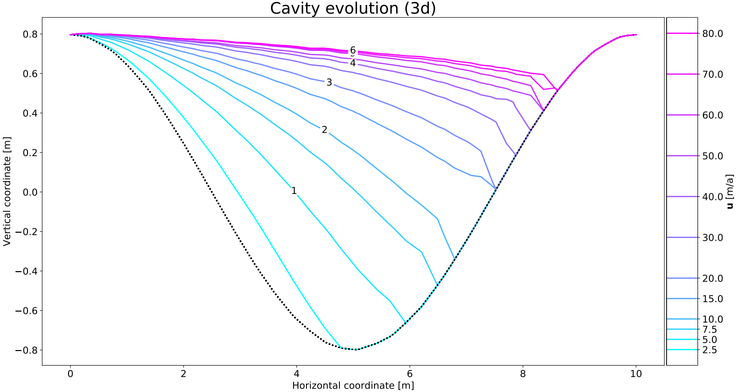

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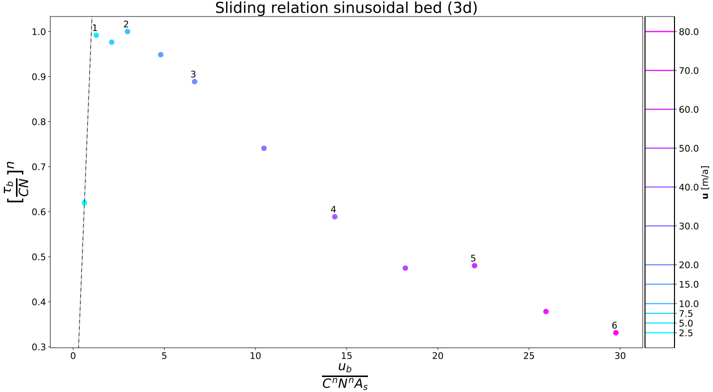

Numerical challenges

1. Steep cavity fronts, in particular in 3D.
   - Mesh resolution. But seems to be more, since same resolution in horizontal (x) and vertical for the 3d case produces steeper fronts than fro the 2D case.

Numerical challenges

2. Non-smooth bed topography
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   - Convergence to a steady-state is sensitive to initial condition of cavity.
   - Wave propagation of the cavity free-surface at higher velocities.
   - Must be solved if a more realistic bed topography is to be used.

Future aspects

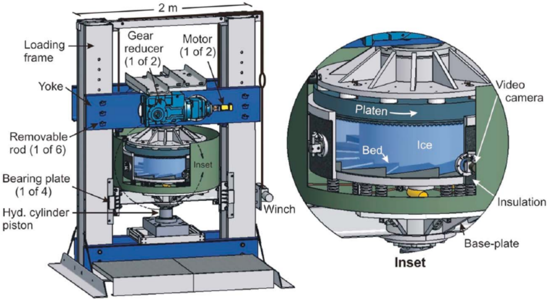
- Incorporate the effects of "dirty"/non-clean ice. This would contribute with proper friction at the base, indirectly dependent on $\mathbf{T}_{nn}$, as:

$$\mathbf{u}_\mu \cdot \mathbf{n} = \mu \mathbf{T}_{nt}\mathbf{t}$$

  Here μ is a friction coefficient and $\mathbf{u}_\mu$ is the velocity taken at some distance from the bed representative of the grain debris size in the ice. This relation is being measured in laboratory experiments at ISU.

Future aspects

- Incorporate sediments/debris at the glacier/bed interface. This would have a conceptually similar effect as that of dirty ice.



Future aspects

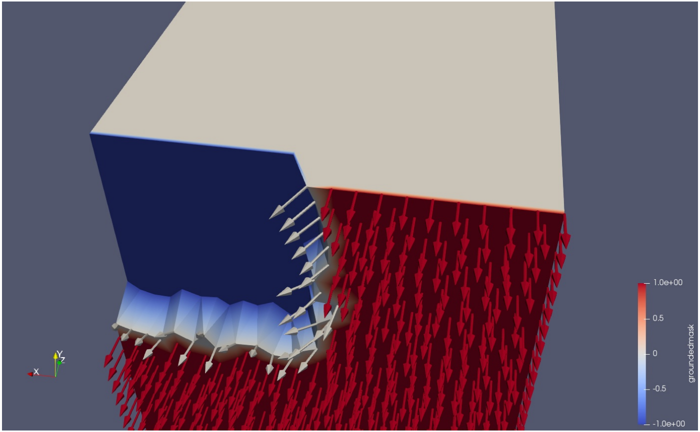
- Incorporate realistic bed topography for different characteristical glacier bed (a statistically determined representative bed area element)

Elmer Ice Workshop

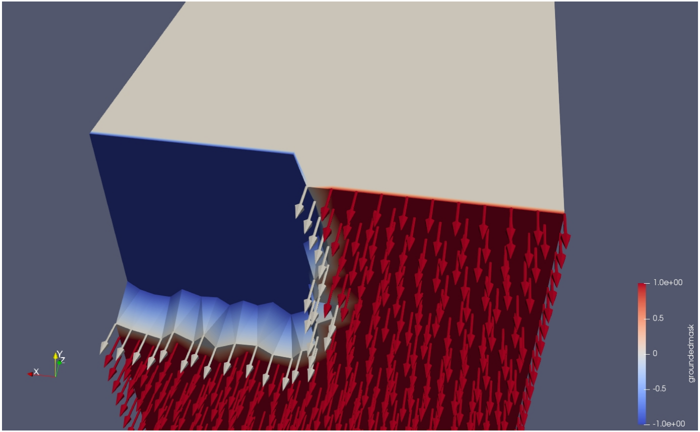
Things that I would *really* like to know a bit more about are:

- **Adaptive/dynamical mesh refinement/remeshing.** Seems like there has been a lot of progress regarding this recently. Tried to do this with `gmsh`, but had a hard time making `ElmerGrid` produce contiguous periodic meshes.
- Adapt the normal/tangential condition, so that it takes into account only the grounded part?

Elmer Ice Workshop



Elmer Ice Workshop



Thanks!