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Investigating the flow and stress regime at the front of a tidewater outlet glacier

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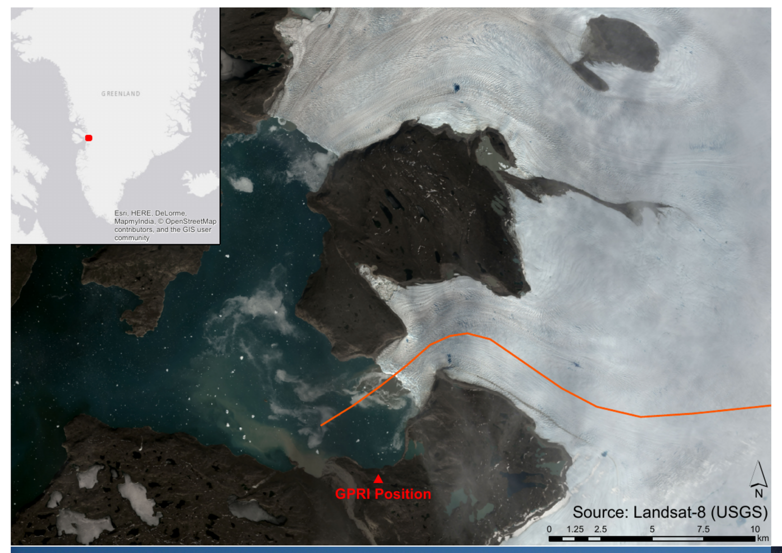
Introduction

- Dynamic changes in ocean-terminating glaciers account for ~ 50 % mass loss of the Greenland ice sheet.
- The related calving process occurs when stresses at the calving front exceed the fracture toughness of ice.
- This process is still not well understood and poorly represented in current generation ice-sheet models.
- Sensitivity analysis on idealized glacier → influence of water depth, slope of the calving front and basal sliding on ice failure → calving.

Study region



- Eqip Sermia, West Greenland
- Recent retreat of the terminus
- Different geometries induce different stress and flow regimes:
  - Northern part: 200m grounded front inclined 45°
  - Southern part: 50m vertical cliff close to floatation

View of Eqip Sermia from the East side

Calving front of Eqip Sermia on 30th June 2014

Data & methods

Data:

- Idealized geometry: 2000m x 200m block
- Real geometries and velocities:
  - Terrestrial radar interferometer (TRI) → surface topography and velocity
  - Operation IceBridge radar profile (Gogineni, 2012) + Bathymetry measurements (Rignot et al., 2015) → bed topography

Model

- 2-dimensional flow model, solving full Stokes flow equations, using Glen's flow law, implemented in the libMesh finite element library (Kirk et al., 2006)
- Basal sliding: $u_b = C\tau_b$
- Ice failure using the Hayhurst criterion (Hayhurst, 1972):

$$\chi(\sigma) = \alpha\sigma_1 + \beta\sigma_e + (1-\alpha-\beta)I_\sigma$$

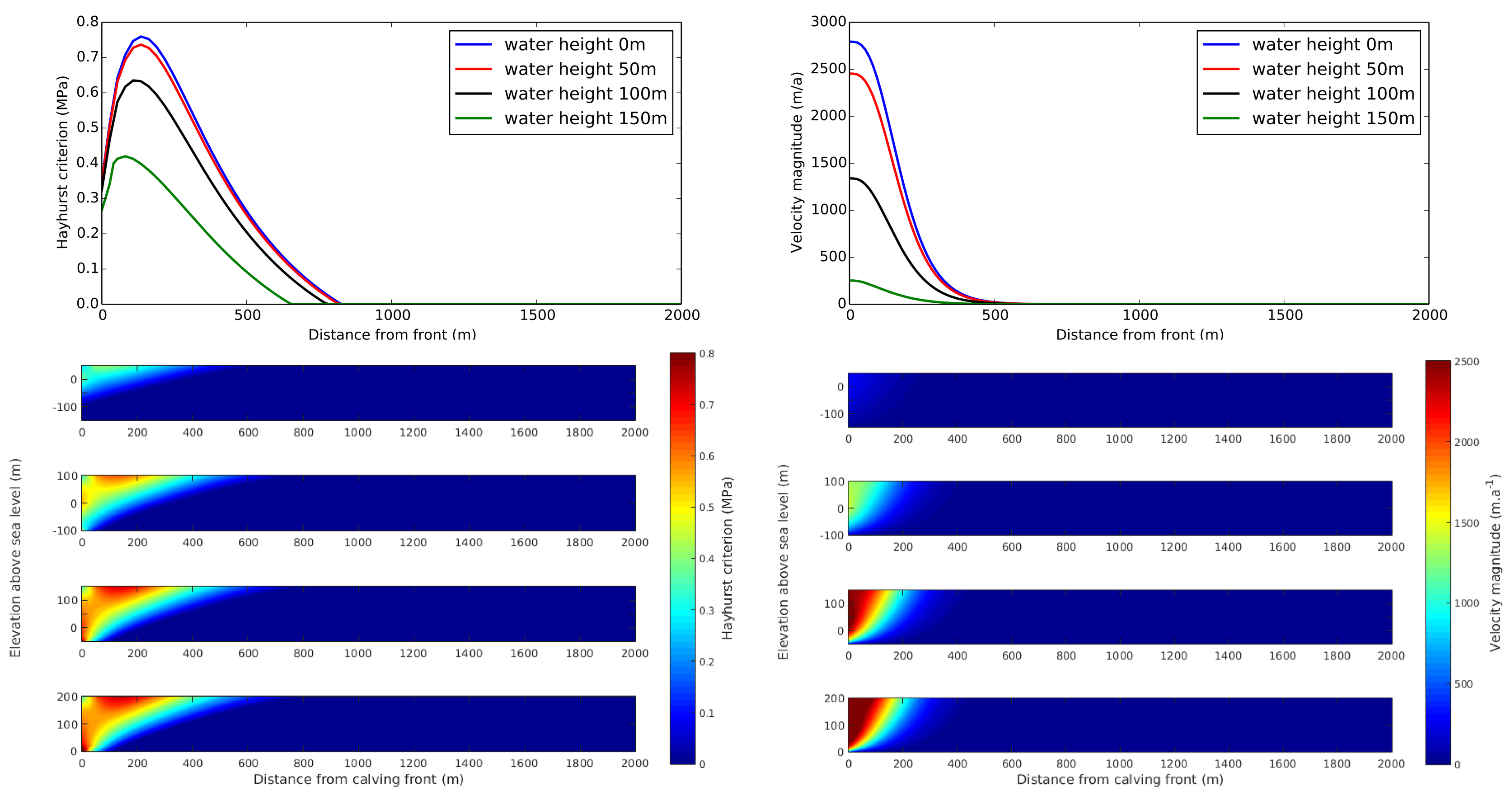
Combining the maximum principal stress σ_1, the von Mises yield criterion σ_e and the first invariant of the cauchy stress tensor I_σ and where α and β give the relative importance of the invariants and fulfill:

$$0 \leq \alpha, \beta, (1-\alpha-\beta) \leq 1$$

Stress and velocity sensitivity analysis

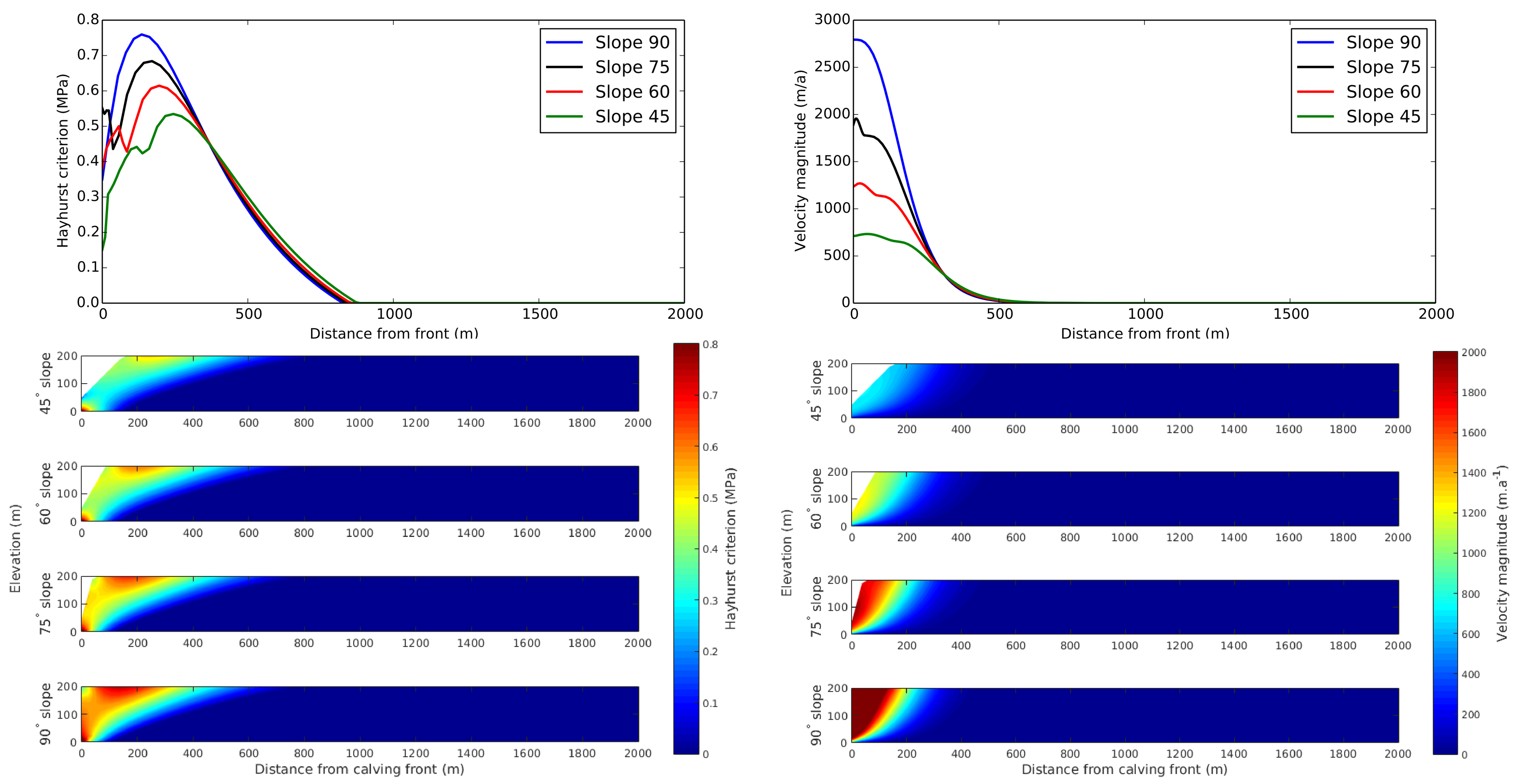
Water depth

Fixed conditions: No basal sliding, 90° calving front slope



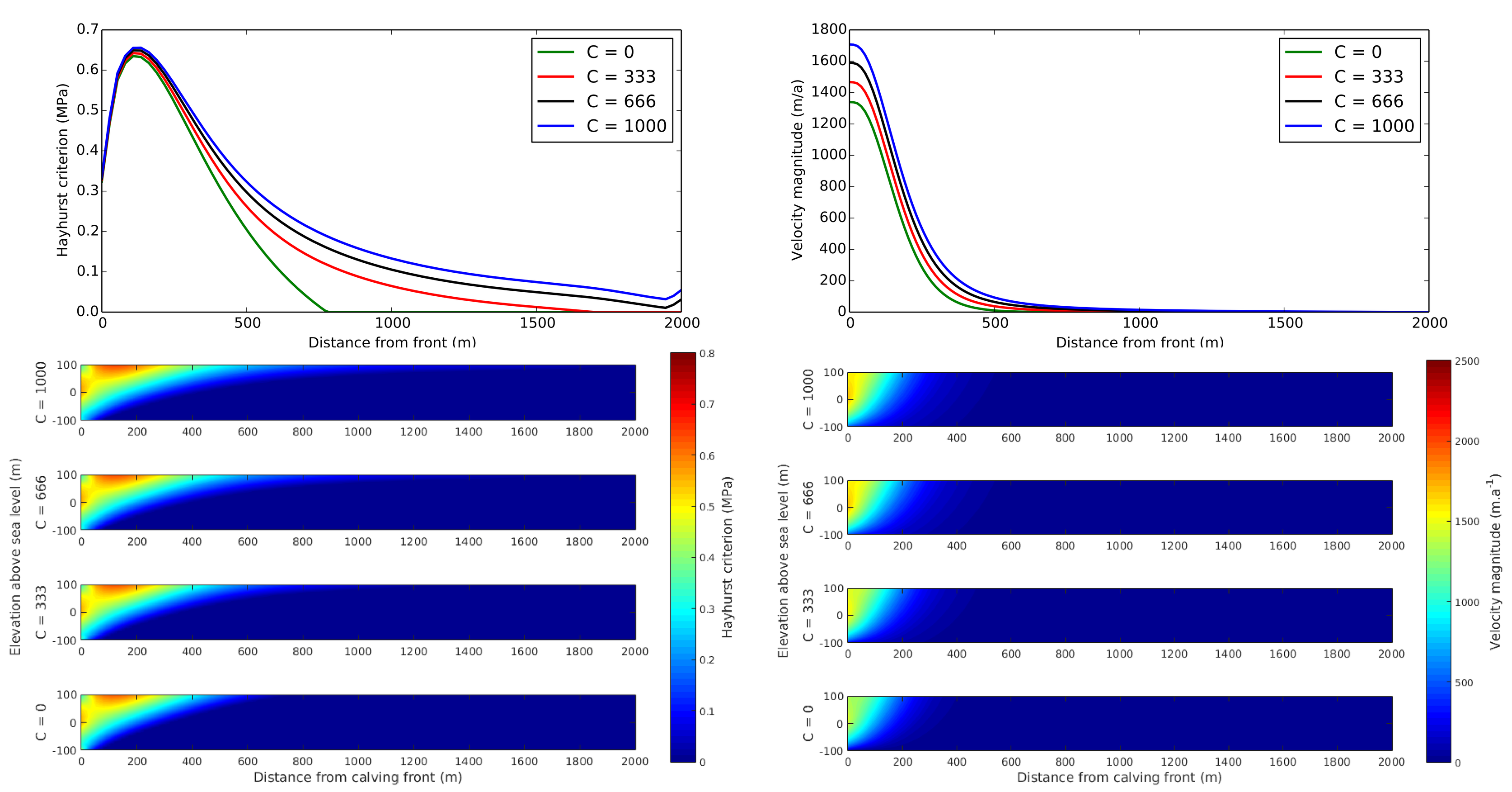
Calving front slope

Fixed conditions: No basal sliding, water depth = 0m

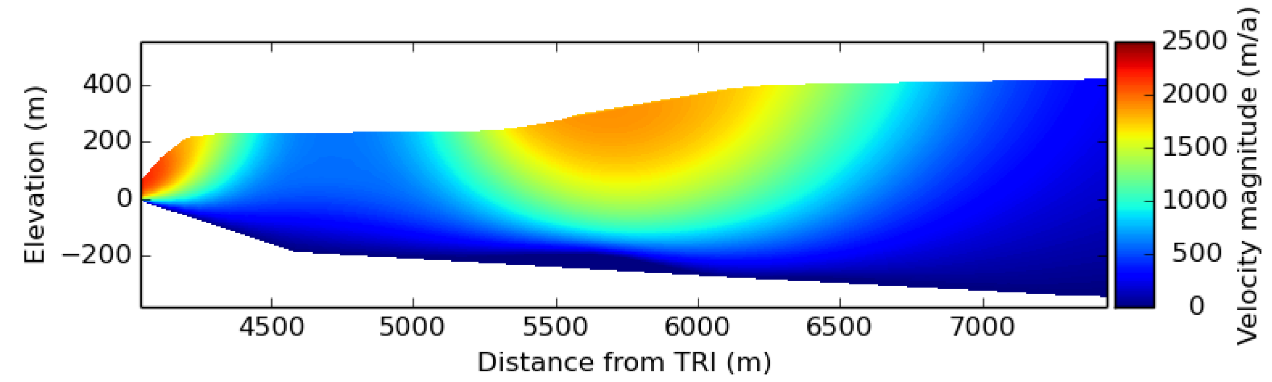


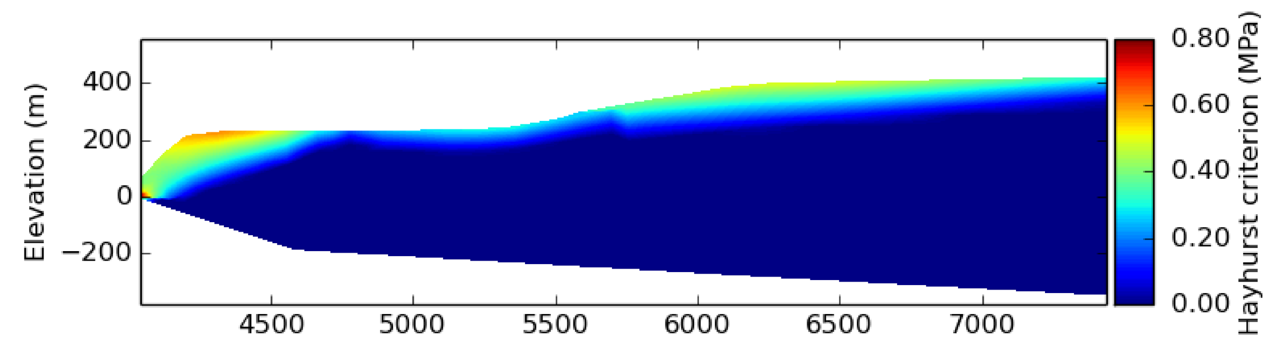
Basal sliding

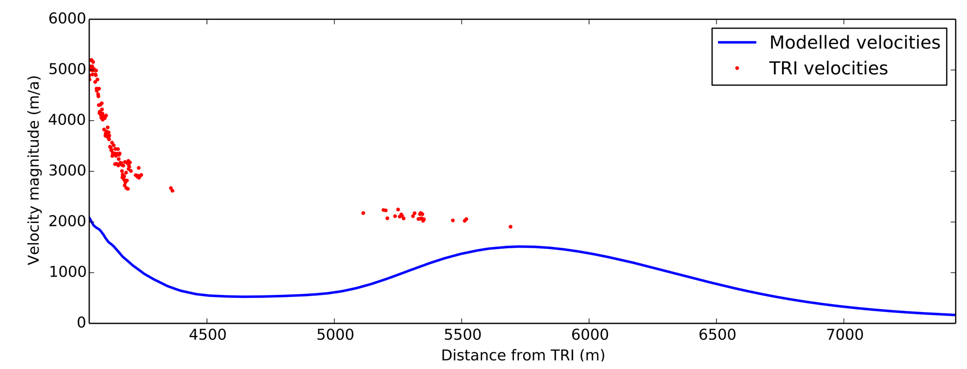
Fixed conditions: 90° calving front slope, water depth = 100m



Real geometry of Eqip Sermia







Conclusions

- This stress analysis improves our understanding of how and where the ice is susceptible to failure and crevasse formation:
  - Water depth and calving front slope significantly influence the stress and flow regimes
  - Increasing basal sliding leads to higher stresses at the surface upstream of the calving front
- Extrusion flow is observed by TRI measurements and repoduced by the flow model.
- Modelled velocities are smaller than observed by TRI, sliding needs to be included.
- Modelled ice failure ($\chi(\sigma) > 0$) patterns correspond to observed crevasse formation location.
- In further work, we aim to use this information as a constraint to investigate the short-term and long-term processes related to outlet glacier calving.

Acknowledgments

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