



Constraining the relationship between velocity and basal traction over the grounded regions of Greenland

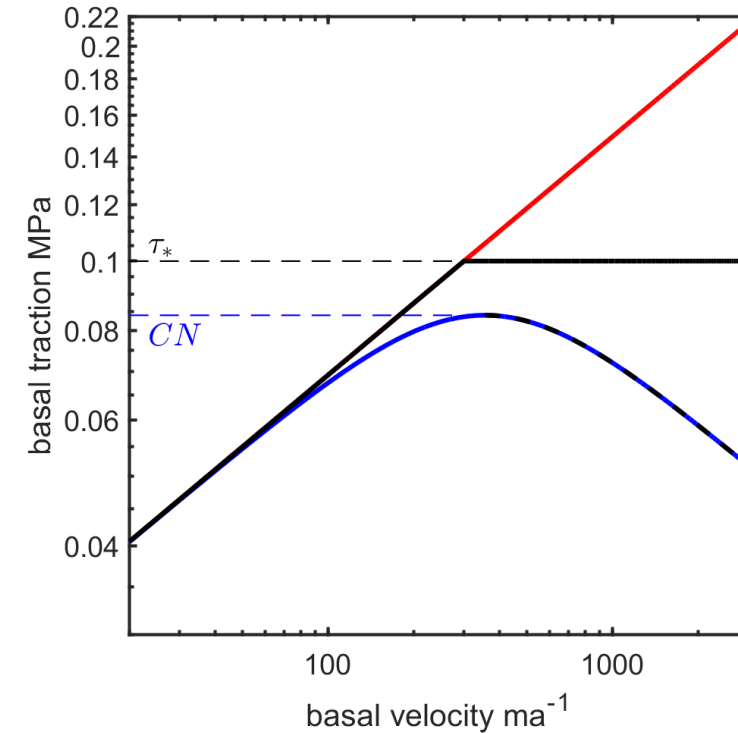
Nathan Maier, Florent Gimbert, Fabien Gillet-Chaulet, and Adrien Gilbert

Traction laws

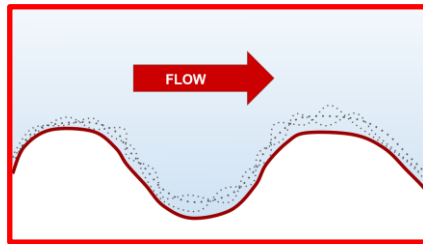
- Relationship between basal velocity and basal traction (friction, drag)

$$\tau_b = f(u_b, \dots)$$

- Physics highly dependent on the type of substrate and hydrologic conditions

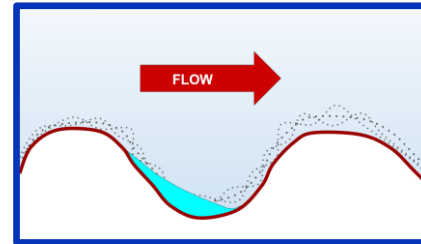


Hard bed (Weertman, 1964)



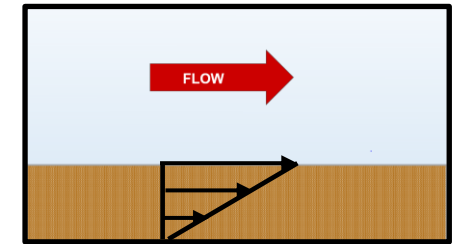
Rate strengthening

Hard bed, cavitation (Gagliardini, 2007)



Coulomb-like

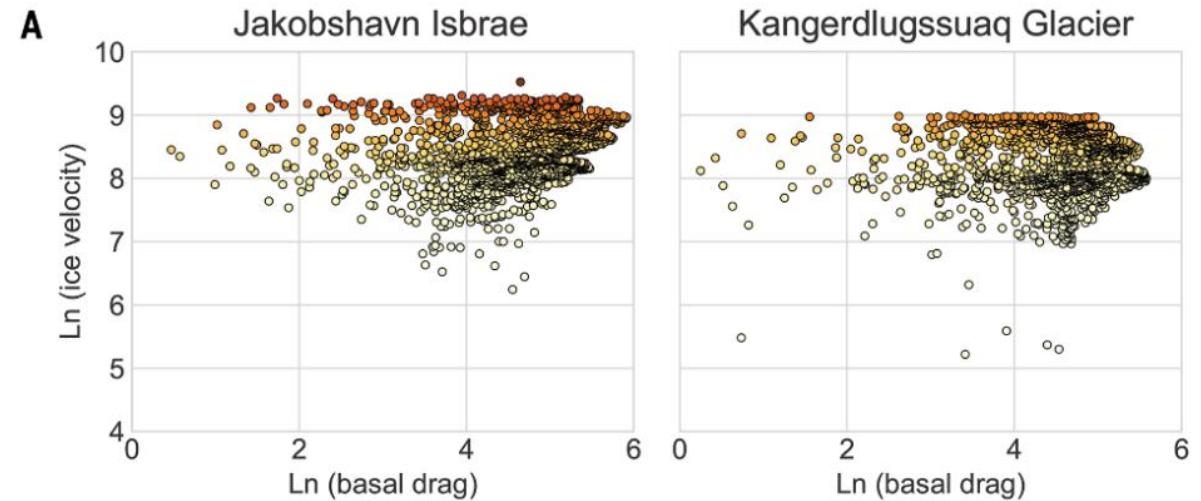
Deformable bed (Zoet, 2020)



Coulomb

Limited Constraints in Greenland

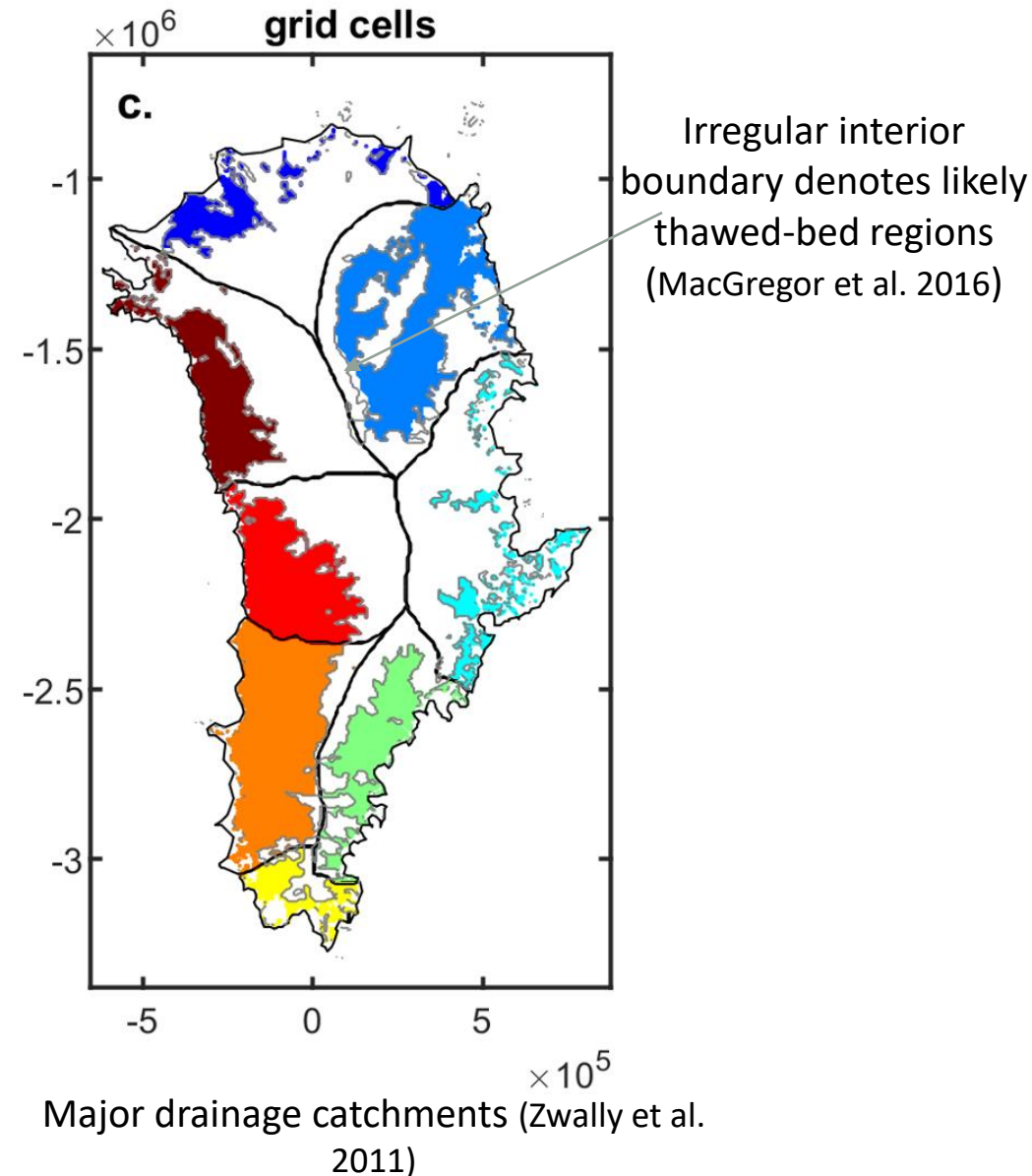
- Traction laws investigated for marine-terminating glaciers along periphery of ice sheet
 - Relationships consistent with Coulomb-type traction law
- **No constraints** on traction relationships for regions inland of the marine terminating outlets



Stearns and van der Veen, 2018

Research Objectives

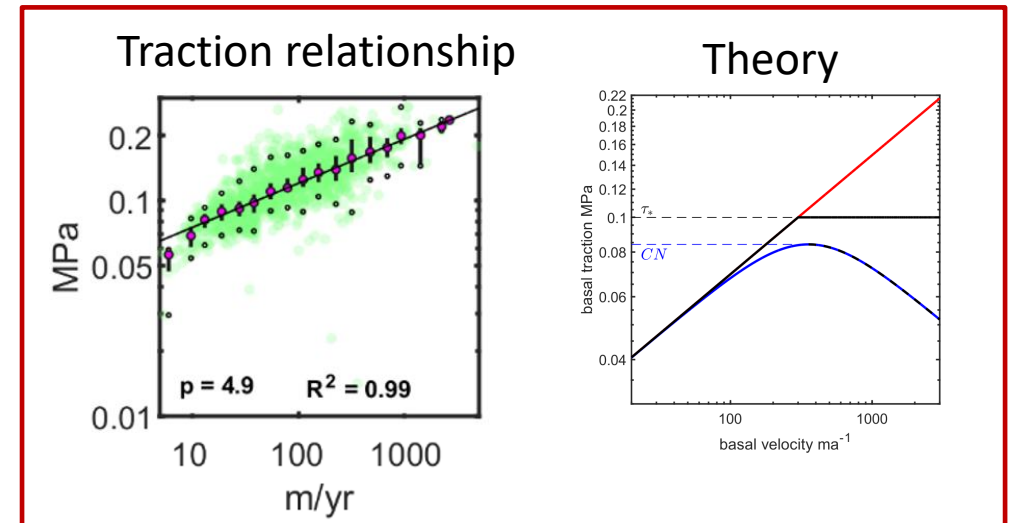
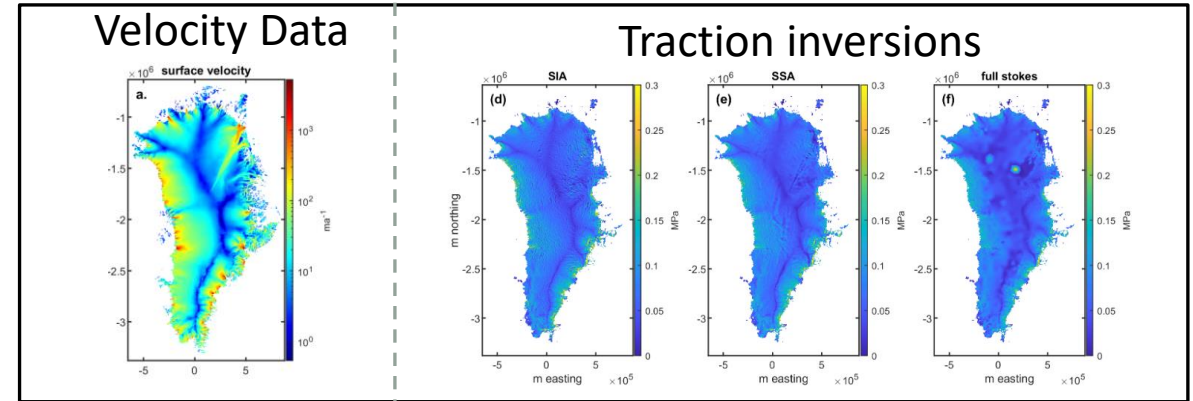
1. Determine the form of the traction relationship for all major drainage catchments by comparing velocity to modelled traction.
2. Characterize and interpret the traction relationships in terms of dominant basal physics within each catchment.



Methodology

- Compare spatial variations in velocity to inverted traction to derive catchment-scale traction relationships
 - Ice sheet scale datasets
 - Surface velocity field – Measures Velocity Mosaic (Joughin, 2016)
 - Surface elevation - GIMP surface dem (Howat, 2013)
 - Bed topography – Bed Machine v3 (Morlighem, 2016)
 - Inverted traction field (using three methods)
 - Shallow Ice Approximation (SIA) – local force balance
 - Shallow Stream Approximation (SSA) – 2D with higher-order stresses
 - Full Stokes (FS) – 3D flow with higher-order stresses
- Compare derived relationships to theoretical expectations given different bed substrate

Elmer/ice



Main Challenge

- Inverted traction (SSA and FS) field dependent on ice rheology
- Ice rheology at a given location in Greenland is uncertain
 - Greenland has a complex polythermal structure (Harrington et al. 2015, Lüthi et al., 2015)
 - Wide range of deformation exponent estimates $n = 2 - 4.5$ (Bons et al., 2018; Dahl-Jensen and Gundestrup, 1987; Gillet-Chaulet et al., 2011; Lüthi et al., 2002; Ryser et al., 2014)
 - Crevassing not accounted with viscous rheology
- Solution: Average the traction field and velocity over large grid cells (6km)
 - Minimizes the effect of higher order stresses on traction field and need to correctly prescribe rheology (i.e. force balance becomes more local)
 - Also minimizes the effect of parameters used to avoid data overfit on traction solution (i.e. regularization)

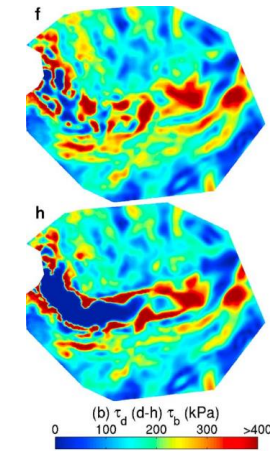
Glen's Rheology

$$\dot{\epsilon}_{ij} = A(T)(\tau_{II})^{n-1}\tau_{ij}$$

temperature dependent rate factor

Nonlinear deformation exponent

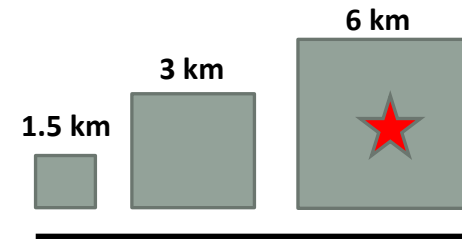
Traction field



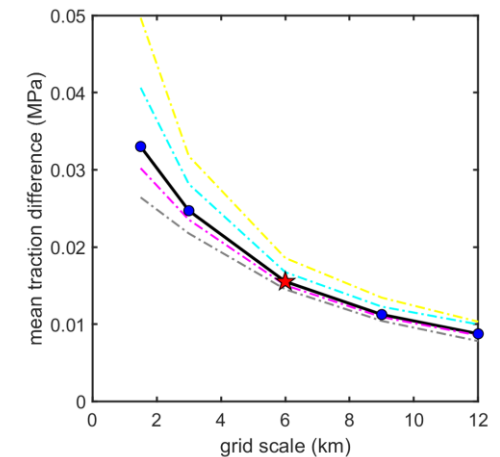
soft ice

hard ice

Joughin et al. 2012

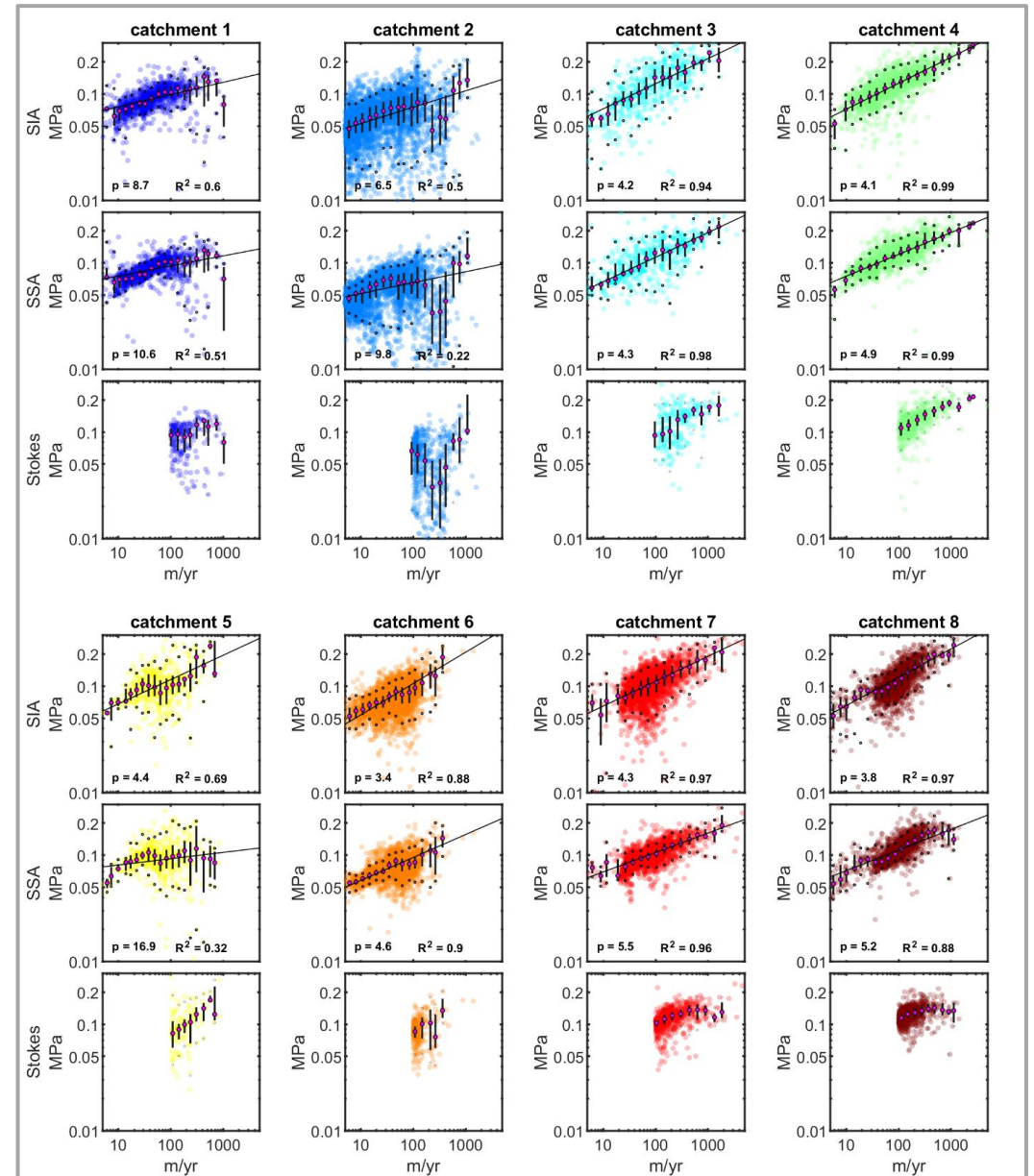
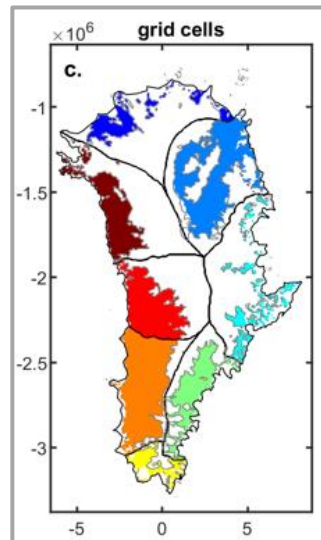


Length scale optimized to minimize difference between SIA (local force balance) and SSA (includes higher order stresses) while still maintaining reasonable resolution to capture complex margin regions.



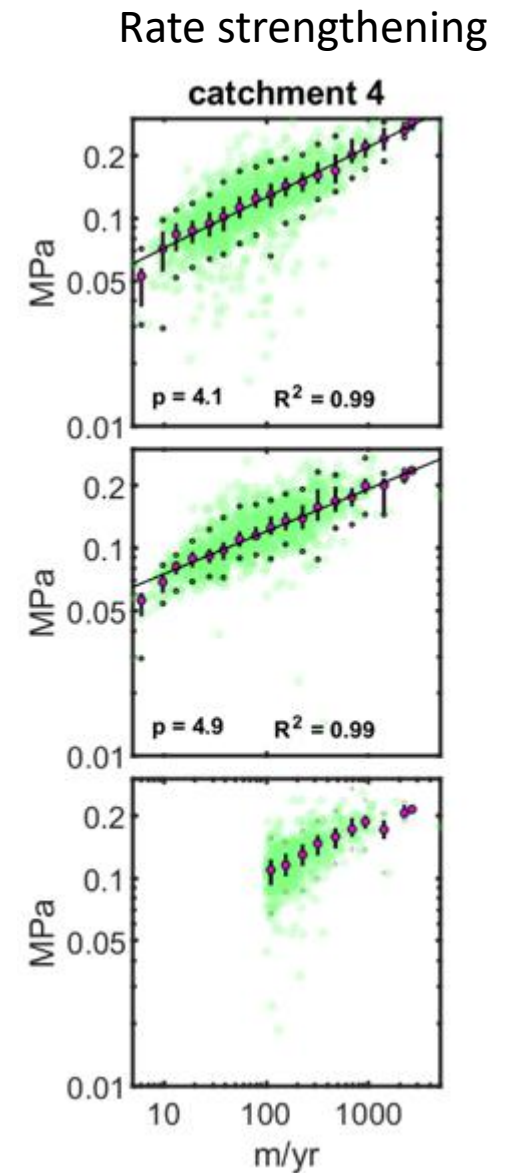
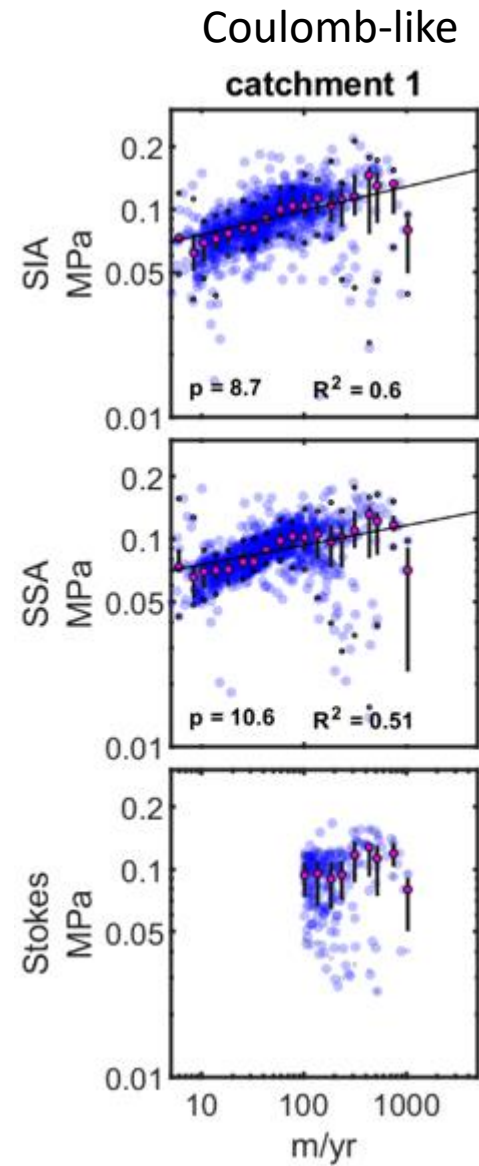
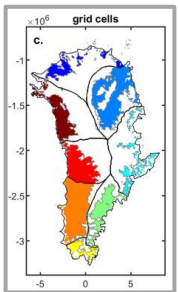
Results: Data and binned relationships

- Velocity traction relationship for each catchment and inversion method
- 8 catchments x 3 methods = 24 relationships



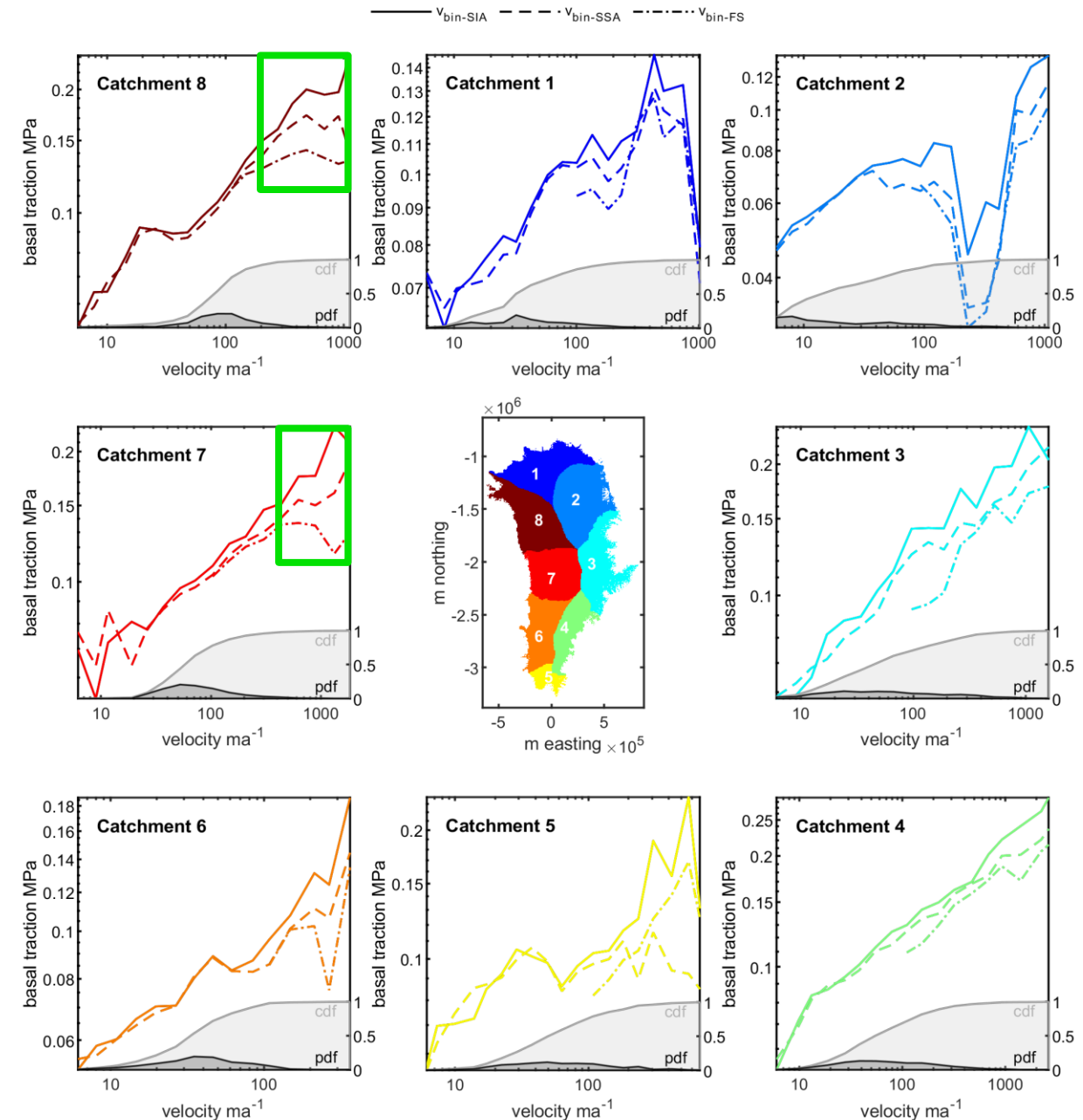
Results: Two types of relationships identified

- Coulomb-like (cavitation, deforming till)
 - “Kink” in binned relationship not captured by power law model
 - High p (apparent flow exponent of model fit)
 - High velocity with low traction grid cells
- Rate strengthening (hard bed, non deforming till)
 - Good fit between power law and binned data
 - p is similar to n
 - High velocities = high traction

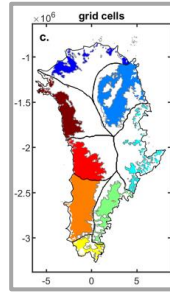


Results: Comparison of relationships using different inversion methods

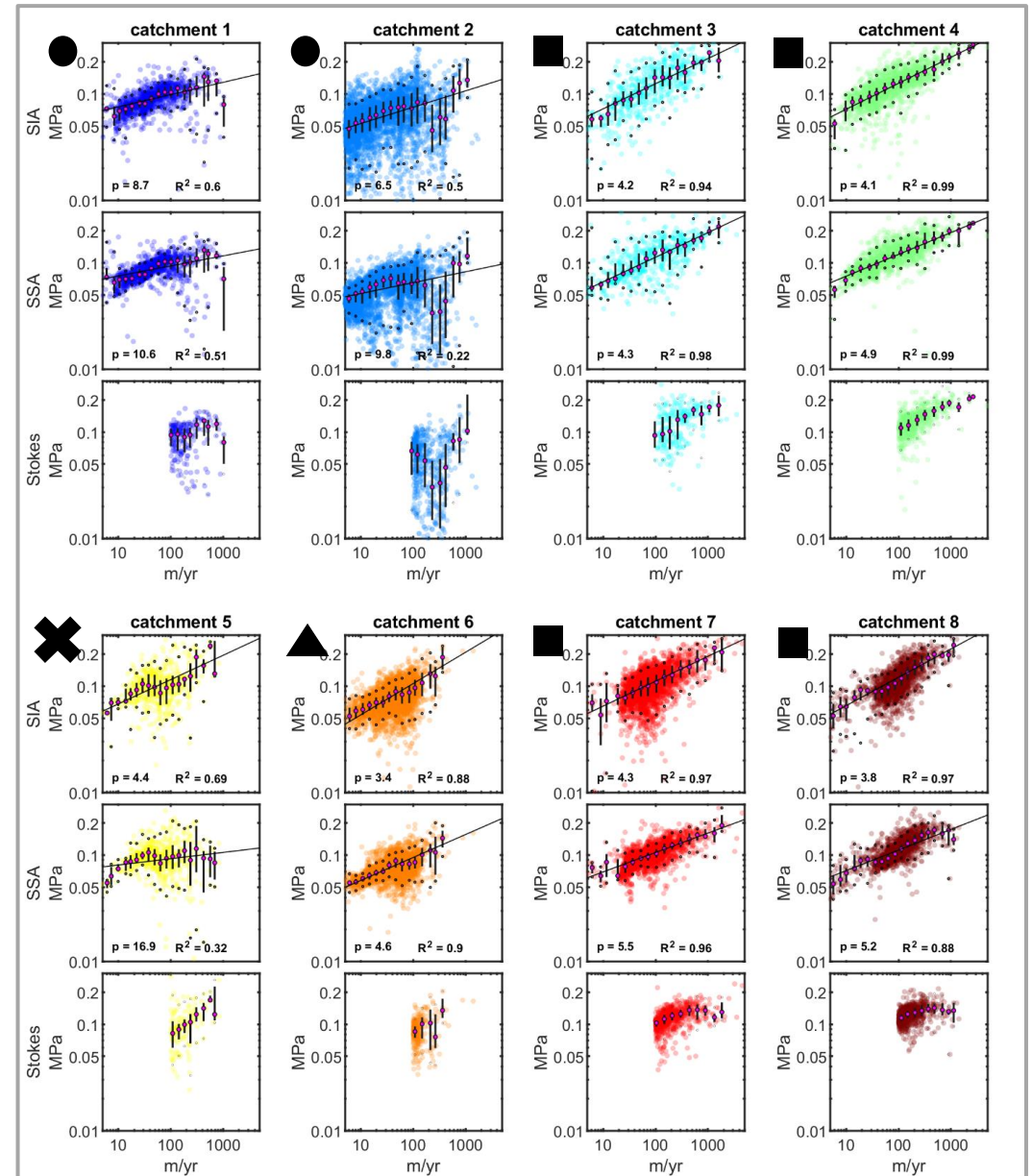
- Comparison between three inversion methods
 - SIA: local force balance, SSA: higher order stresses, FS: three-dimensional flow
 - Same interpretation – high confidence in traction relationship
 - Different interpretation – low confidence, higher order stresses not fully minimized or topographic form drag important
- Most catchments show good agreement between methods through velocity range
- Exception: Catchments 7 and 8
 - Traction relationship not confidently resolved at high velocities with our methodology (green boxes)



Interpretations

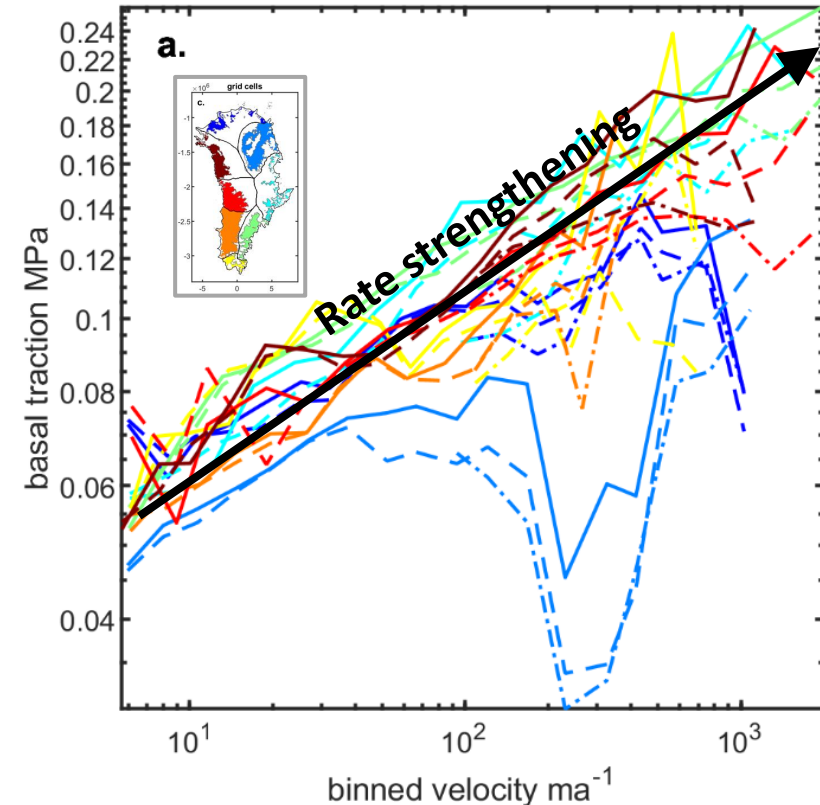


- Predominantly Coulomb-like ●
 - Catchments 1 and 2
 - Consistent with either cavitation or deforming till
 - Weak beds underly NEGIS and marine terminating areas with high flotation fraction
- Predominantly Rate Strengthening ■
 - Catchments 3 and 4
 - Most of the data in Catchment 7 and 8 → up to 450 m/yr
 - Weertman-type physics: hard bed, non deforming till
- Mixed Bed ▲
 - Catchment 6
- Unclassified ✕
 - Catchment 5
 - Large divergence between different inversion → possible data quality issues?



Conclusions

- We identify both rate strengthening and Coulomb-like behavior at the catchment scale
- Outside of NEGIS and regions with high flotation fractions, areas < 450 m/yr generally adhere to rate strengthening
- Fastest flowing ice (> 450 m/yr) either continues to exhibit rate strengthening, shows Coulomb-like behavior, or is not confidently resolved with our methodology
- Overall, Weertman-type hard-bed physics mainly dictates the traction field over the grounded regions of Greenland





Published in: The Cryosphere – click [HERE](#)

Maier, N., Gimbert, F., Gillet-Chaulet, F., & Gilbert, A. (2021). Basal traction mainly dictated by hard-bed physics over grounded regions of Greenland. The Cryosphere, 15(3), 1435-1451