Fracture-induced softening for large-scale ice dynamics

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PIK

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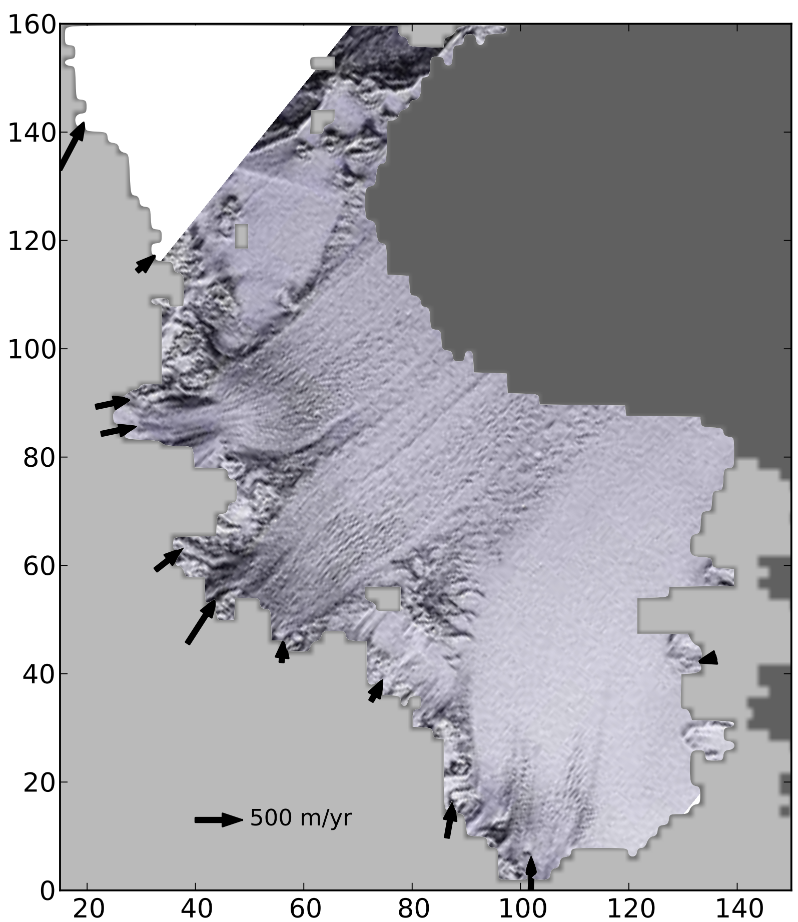
Motivation



RADARSAT SAR of Larsen B (1997)
Jezek & RAMP, 2002

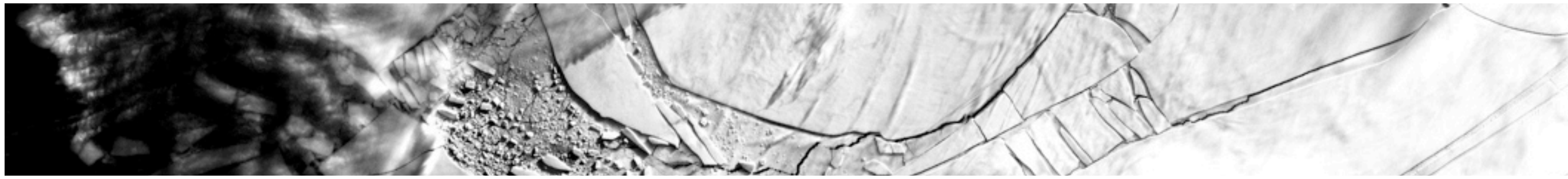
fractures → ice flow

- ice fractures have a significant effect on flow dynamics, iceberg calving and on stability

ice flow → fractures

- formation along shear margins, in the wake of topographic features and where flow units merge
- fractures elongated in band structures of certain frequency

- simple macroscopic parameterization needed for large-scale ice flow models (e.g. PISM) to evaluate location and feedback of fracture processes



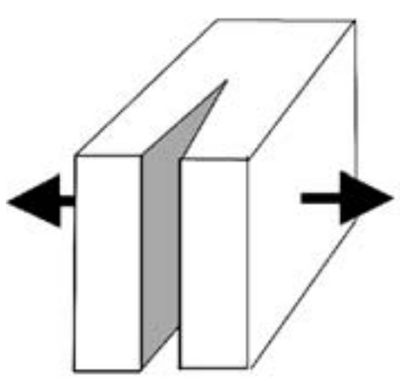
The concept of the fracture density field

- define $0 \leq \phi \leq 1$ as measure of fracture density
- advective transport $\frac{\partial \phi}{\partial t} + \boldsymbol{v} \cdot \nabla \phi = f_s$
- defining source $f_{\mathrm{s}} = \gamma \cdot \dot{\varepsilon}_1 \cdot (1 - \phi) \cdot \Theta(\sigma_{\mathrm{t}} - \sigma_{\mathrm{cr}})$

fracture growth rate (maximal spreading)

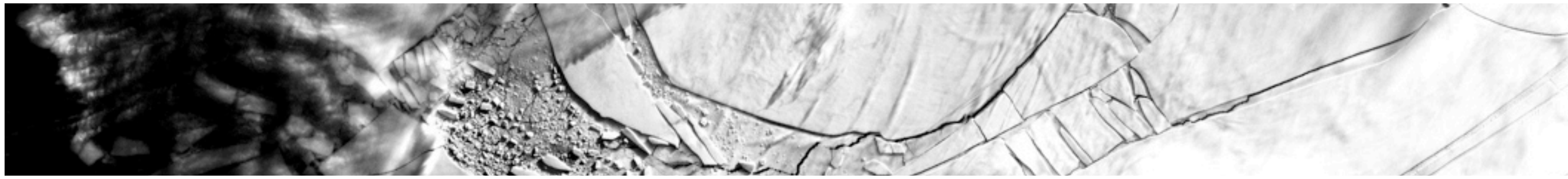
fracture interaction (upper bound)

von Mises criterion for fracture initiation (max. octahedral shear stress)



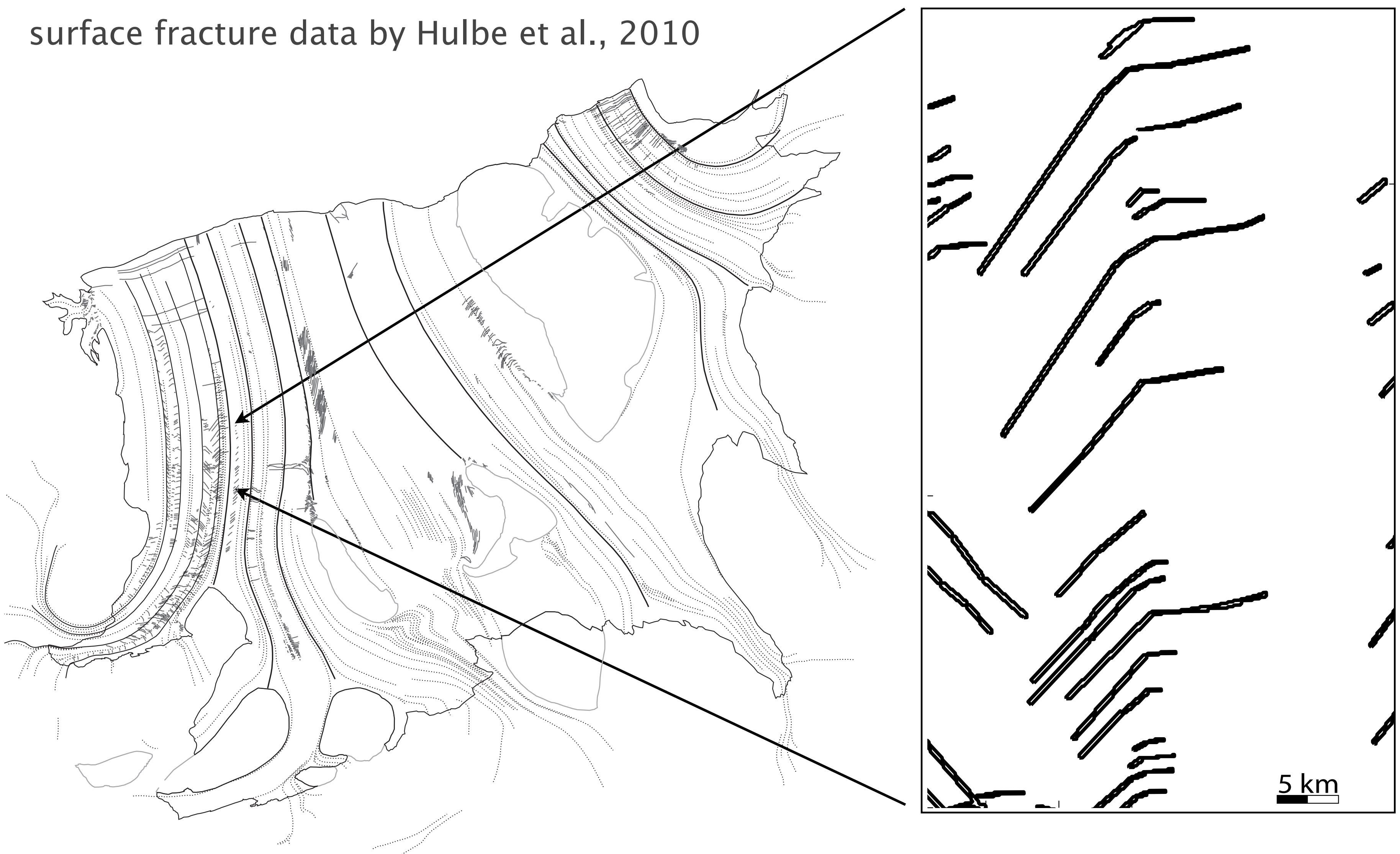
Vaughan, 1993

Pralong & Funk, 2005

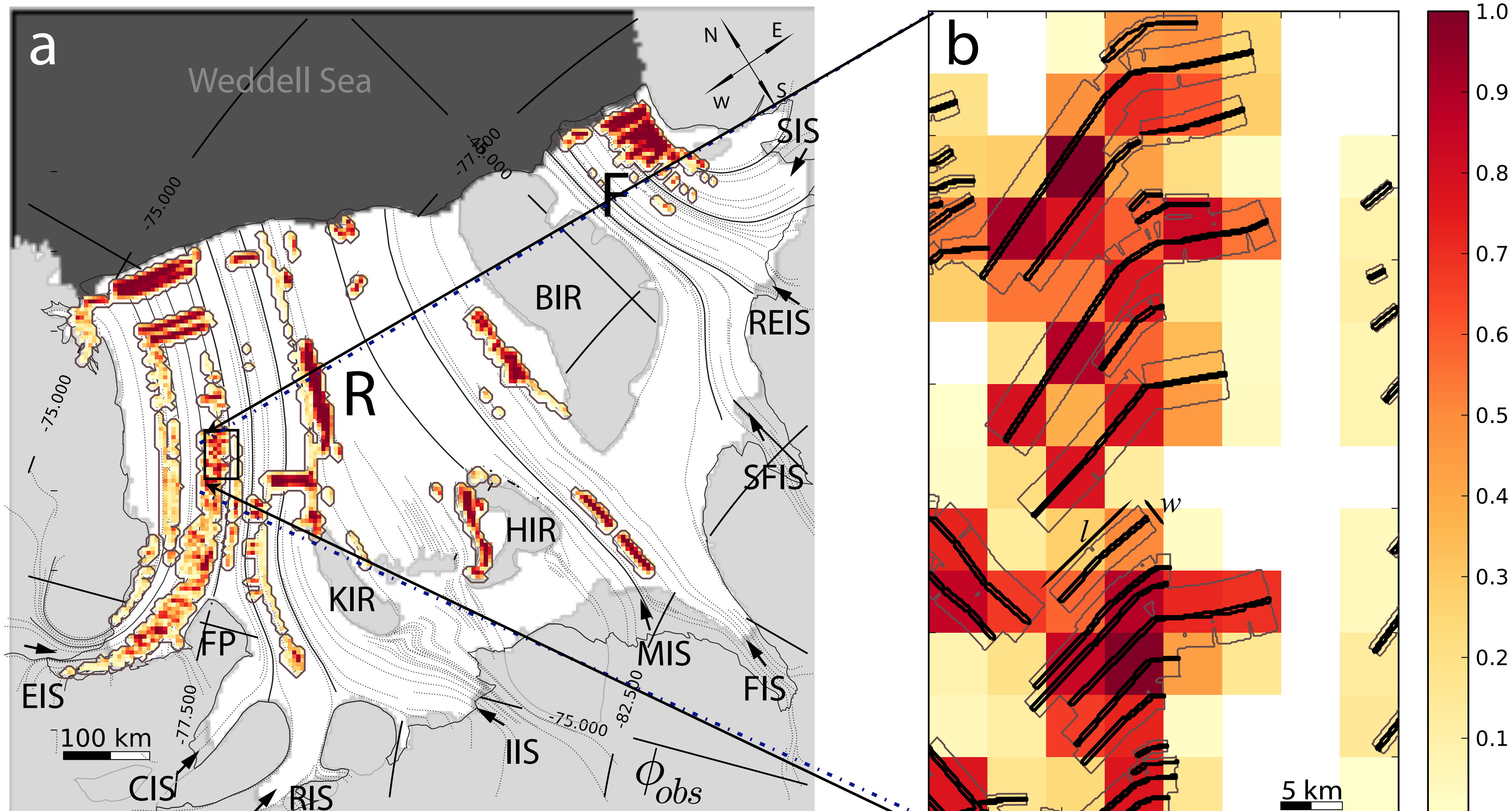


Observations of surface features
(Filchner-Ronne / Antarctica)

surface fracture data by Hulbe et al., 2010

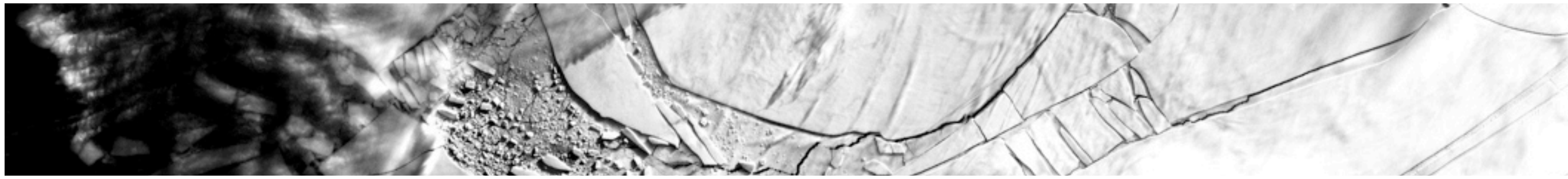


Validation against surface observations
(Filchner-Ronne)

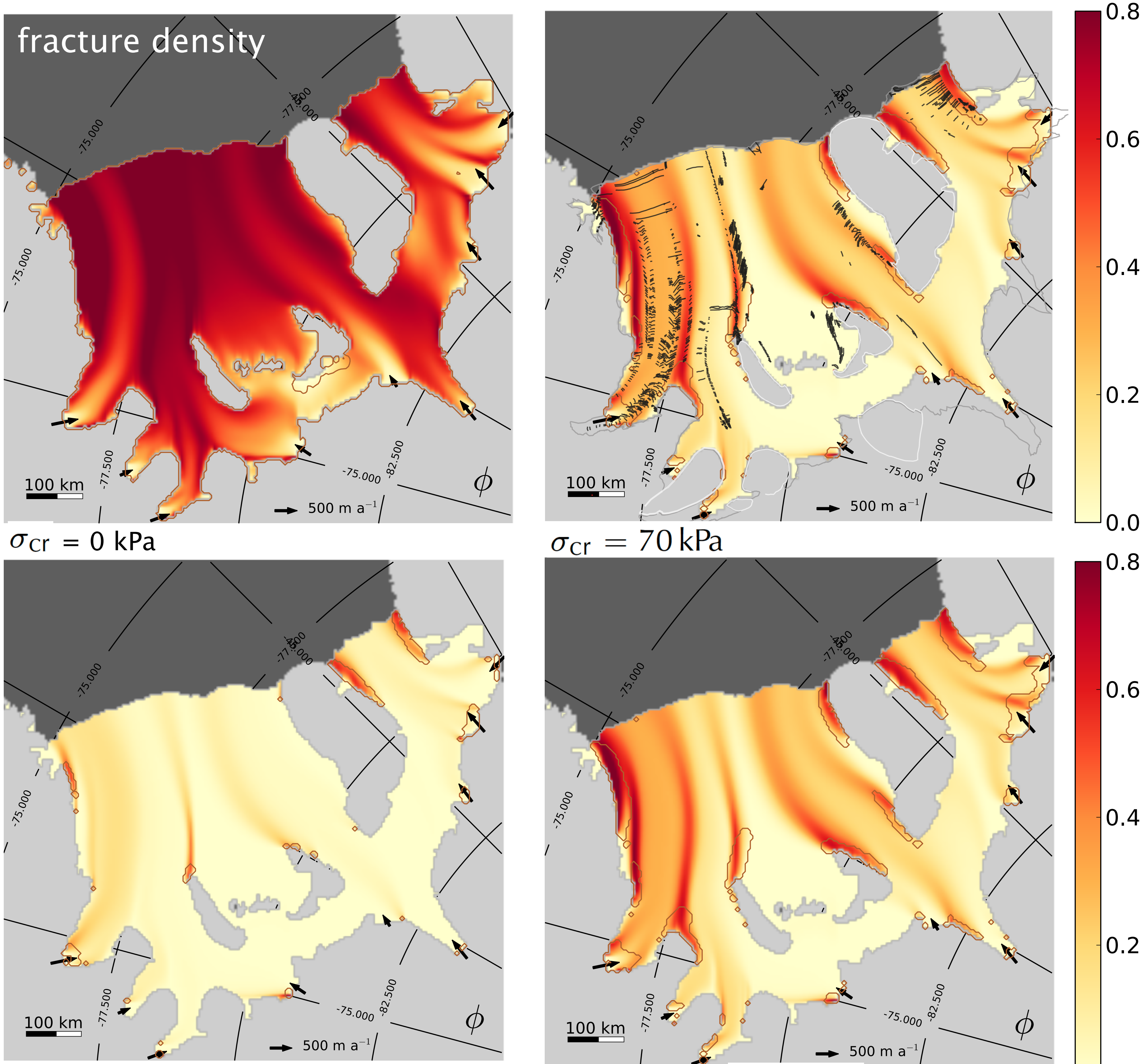


surface fracture data by Hulbe et al., 2010

- simplified zone of influence around (visible) surface fractures
- fraction of covered grid cell (here 5km) determines ϕ_{obs}



Application in diagnostic simulation of Filchner–Ronne



σ_{cr} = 0 kPa

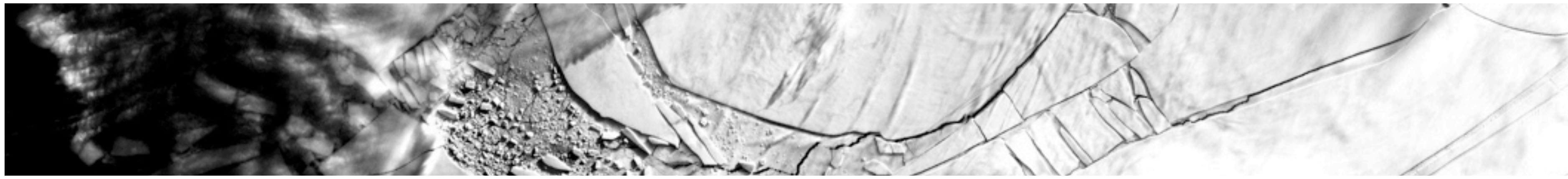
$\sigma_{cr} = 70\,\mathrm{kPa}$

σ_{cr} = 90 kPa

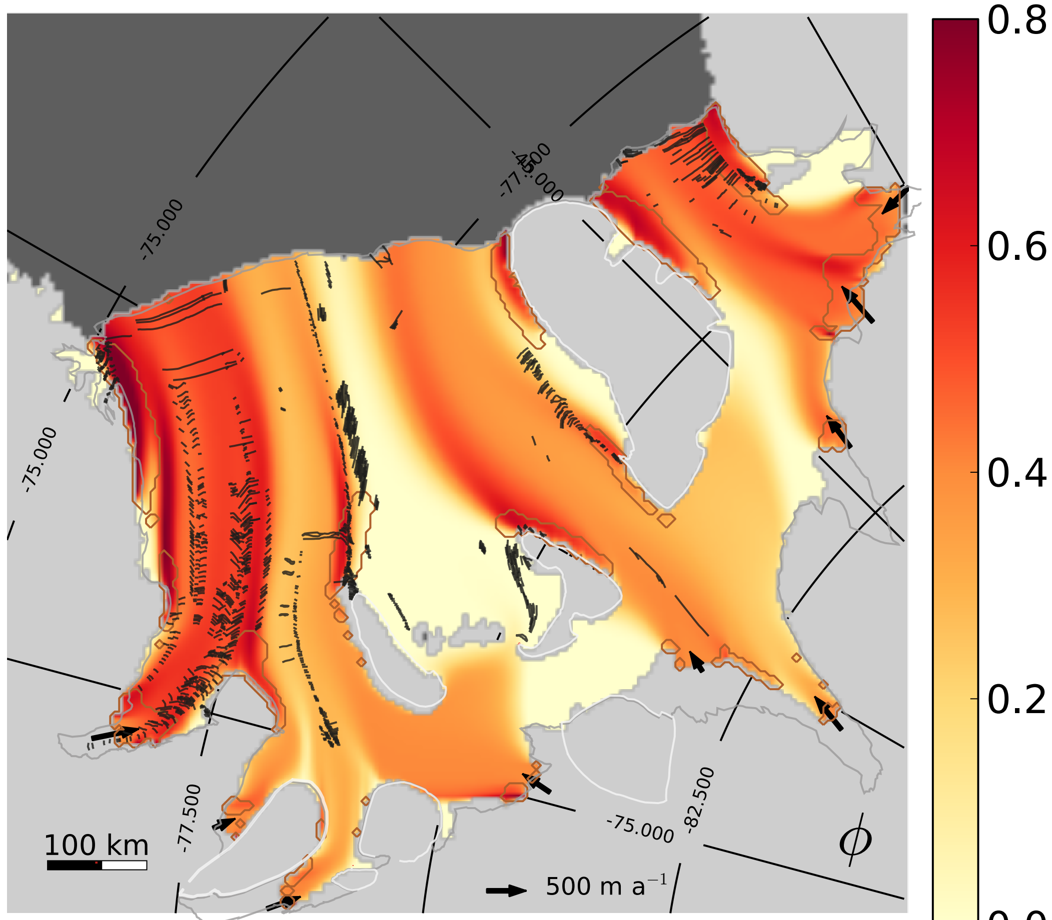
$\sigma_{cr} = 70\,\mathrm{kPa}$ $\psi = \gamma\,\bar{\dot{\varepsilon}}_1$

$$f_s = \gamma \cdot \dot{\varepsilon}_1 \cdot (1-\phi) \cdot \Theta(\sigma_t - \sigma_{cr})$$

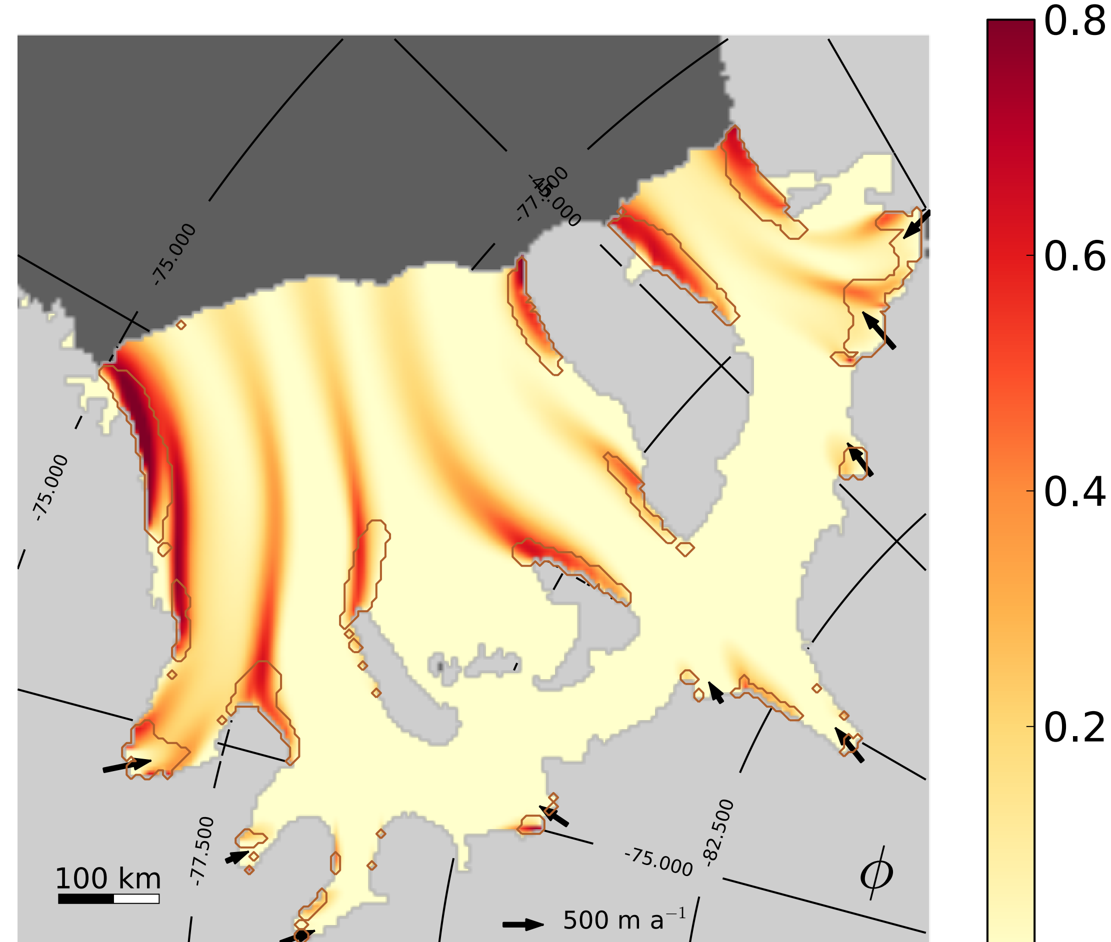
- fracture initiation regions at shear margins and suture zones
- crevasse bands agree with high values of ϕ



Boundary conditions and Healing

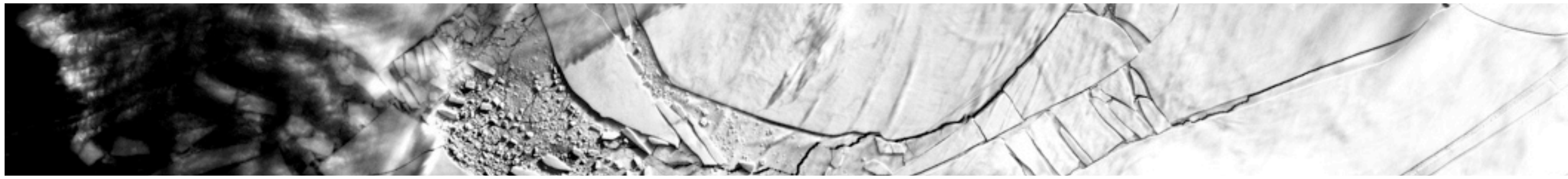


$\phi_0 = 0.4$

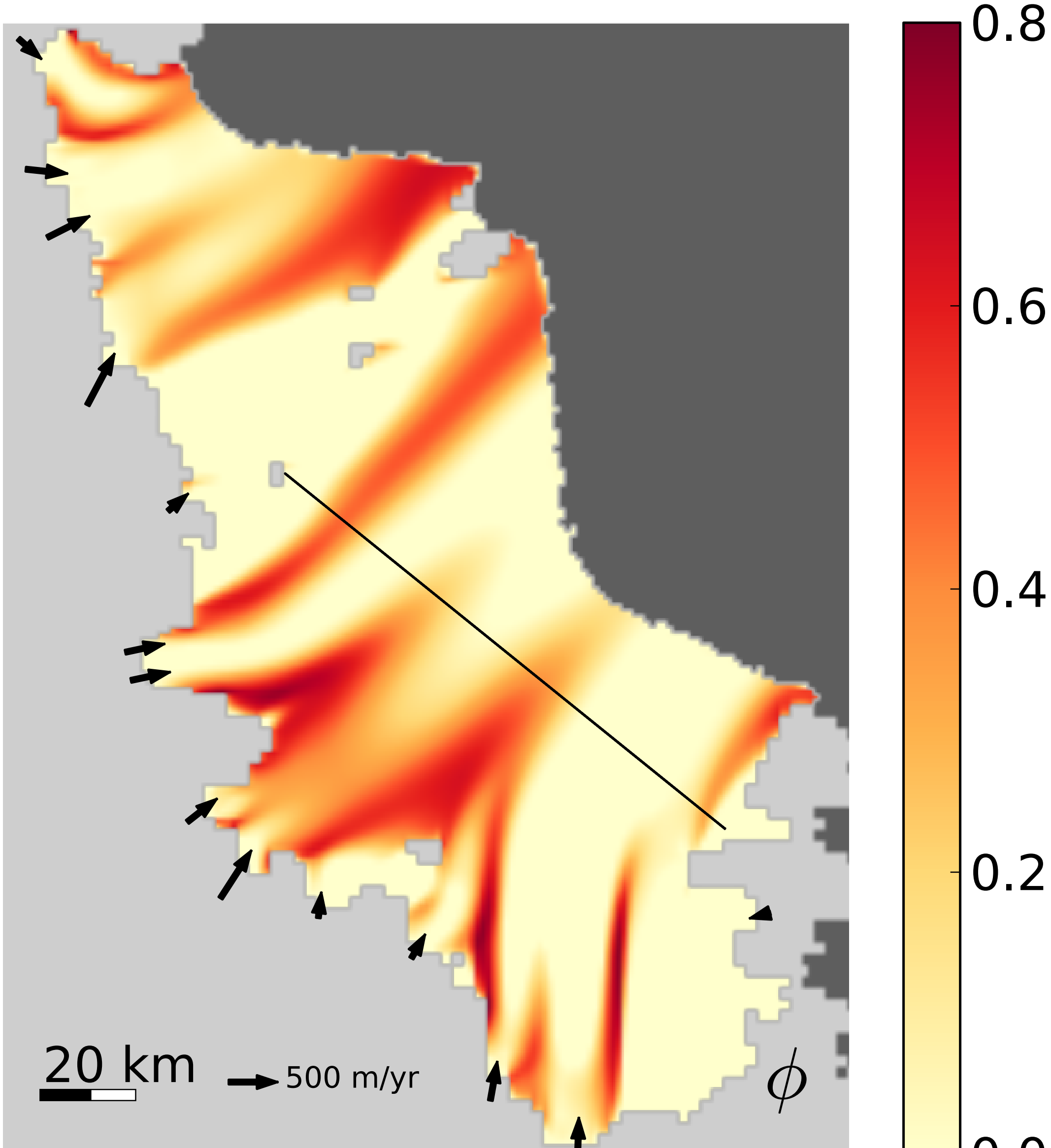


$\gamma_h = 0.1 \quad \dot{\varepsilon}_h = 2 \times 10^{-10}\,\mathrm{s}^{-1}$

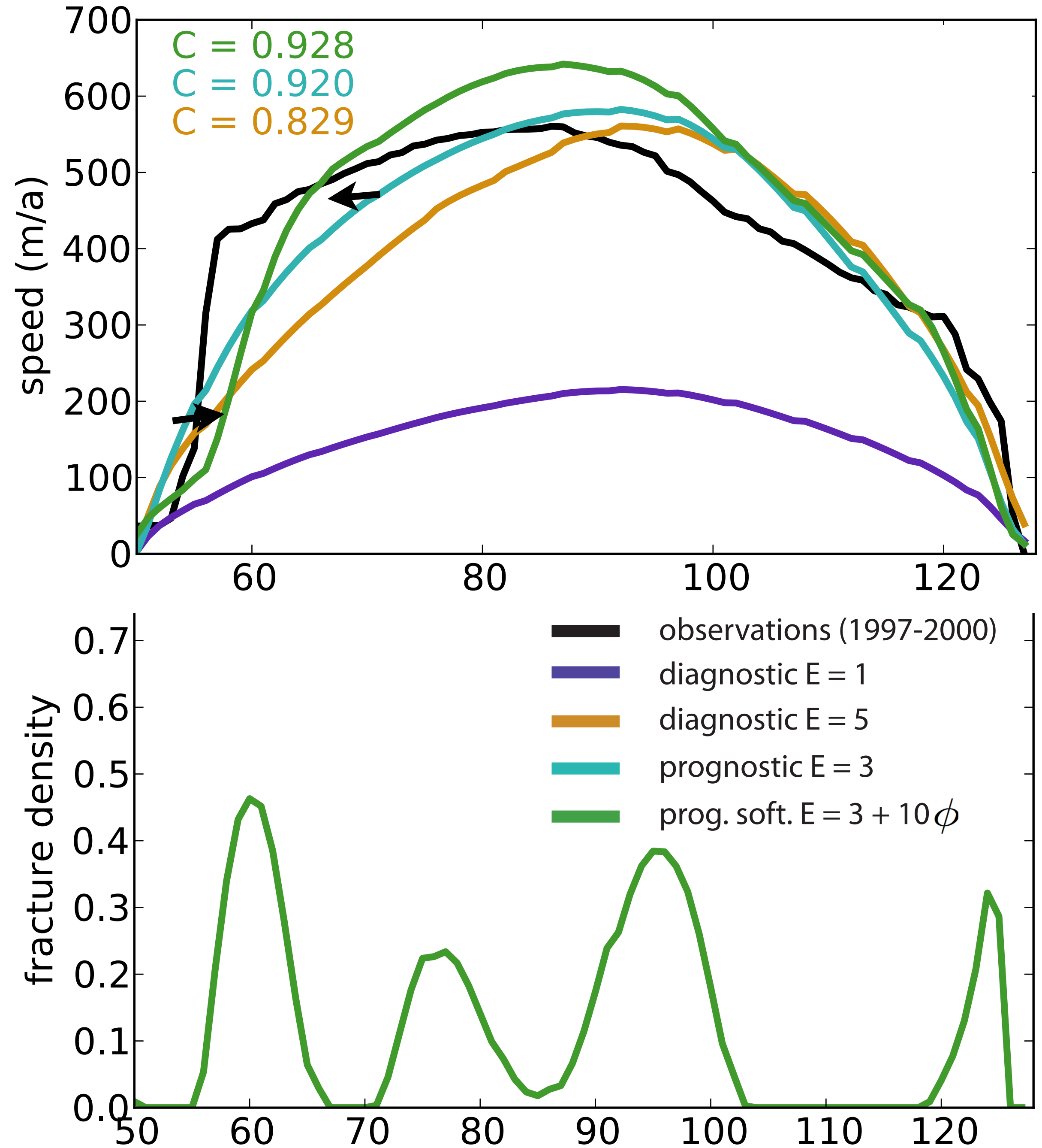
- Boundary conditions (fractures from inlets, tidal tilt data Green et al.) ϕ_0
- Healing rate $f_h = \Theta(-\psi_h) \cdot \psi_h$, with $\psi_h = \gamma_h (\dot{\varepsilon}_1 - \dot{\varepsilon}_h)$



Fracture-induced softening
(Larsen A + B)



$\sigma_{cr} = 50$ kPa $\gamma_h = 0.5$ $\dot{\varepsilon}_h = 6 \times 10^{-10}\,s^{-1}$

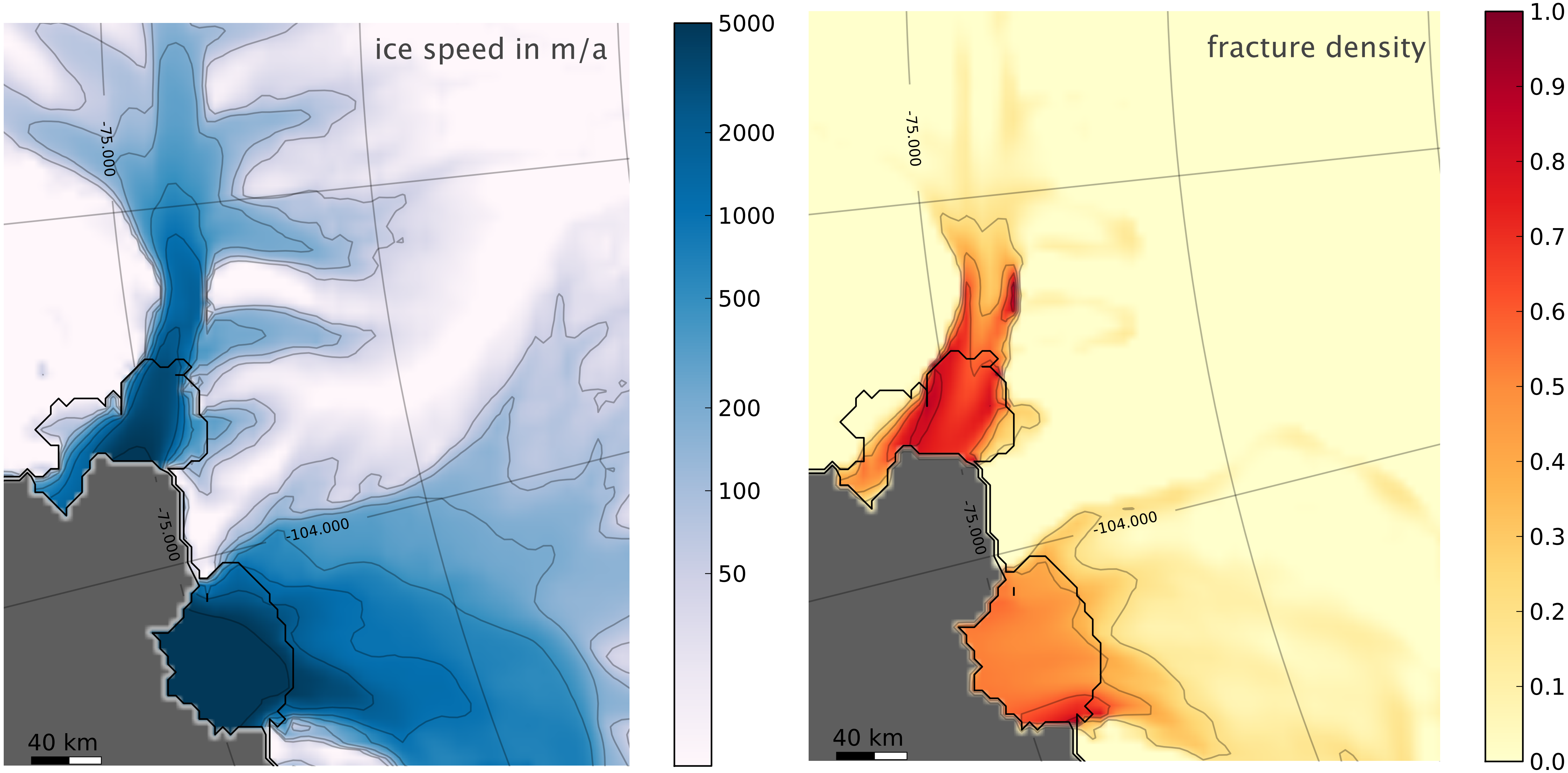


- macroscopic softening as enhancement factor E in Glen's law $\dot{\boldsymbol{\varepsilon}} = EA\tau_e^{n-1}\boldsymbol{\tau}$

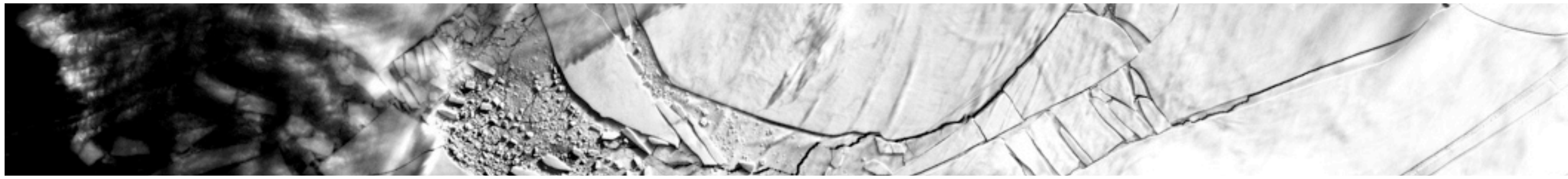
Ying Ma et al. 2010, Sandhäger et al. 2005, Humbert et al. 2009

Application to grounded ice streams

(Pine Island, Thwaites)



- softening and larger gradients along shearing margins



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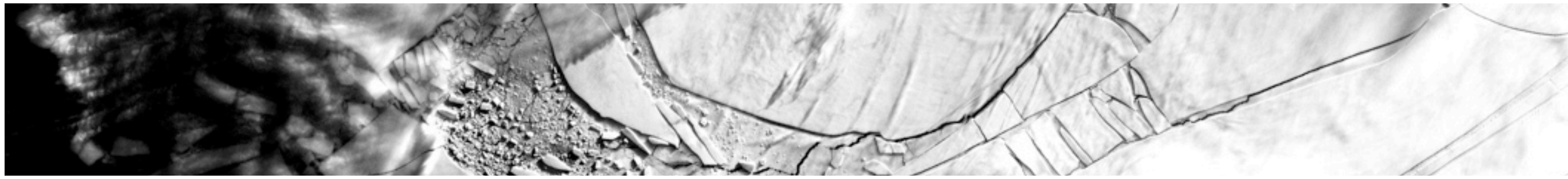
Conclusions

- first-order parameterization of fracture formation and its softening effect for coarse-scale ice sheet/shelf simulations
- reproduces observed surface-fracture pattern in ice shelves
- more realistic representation of flow dynamics

next steps

- consider fracture depth (parameterize hydro fracturing and refreezing processes)
- expand "eigencalving" parameterization (material dependent $C = K(\phi) \cdot \det(\dot{\boldsymbol{\epsilon}})$)
- need fracture-data for validation!



Thank you!

T. Albrecht, A. Levermann; Fracture Field for Large-Scale Ice Dynamics; (2012), Journal of Glaciology, Vol. 58, No. 207, 165-176, DOI: 10.3189/2012JoG11J191

A. Levermann, T. Albrecht, R. Winkelmann, M. A. Martin, M. Haseloff, I. Joughin Kinematic first-order calving law implies potential for abrupt ice-shelf retreat; (2012), The Cryosphere 6, 273-286, DOI:10.5194/tc-6-273-2012

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