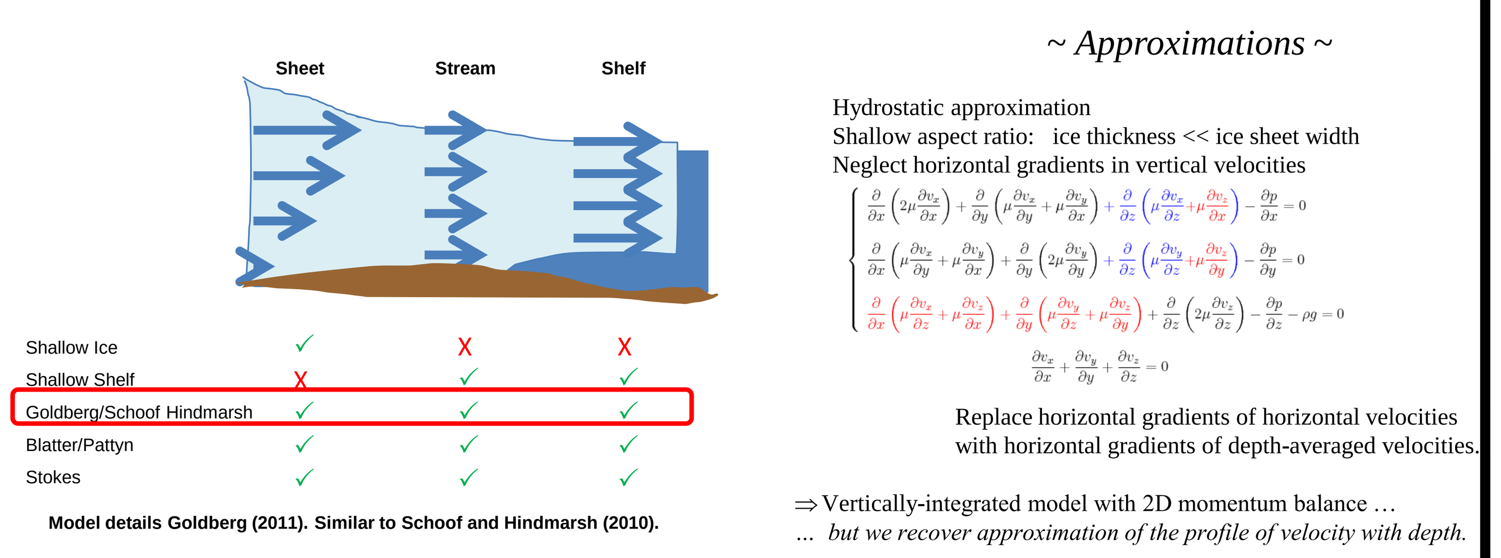
Inferring controls on basal drag in the Amundsen Sea sector of Antarctica

Robert Arthern, Rosie Williams, Kelly Hogan, Alex Brisbourne, Andrew Smith, and Tom Jordan
British Antarctic Survey

We consider a variety of ways that the basal drag that acts to resist the sliding of an ice sheet can be inferred from satellite observations, or from in situ observations. Three approaches are considered here. (1) use of inverse methods combined with large scale models of ice flow. (2) spectral analysis of basal topography combined with a theory of ice flow near small scale undulations, and (3) seismic methods that probe the physical characteristics of the subglacial sediment. Consideration is given to which sliding relationships are consistent with the available observations, and to identifying measurements that could help reduce ambiguity in sliding laws.

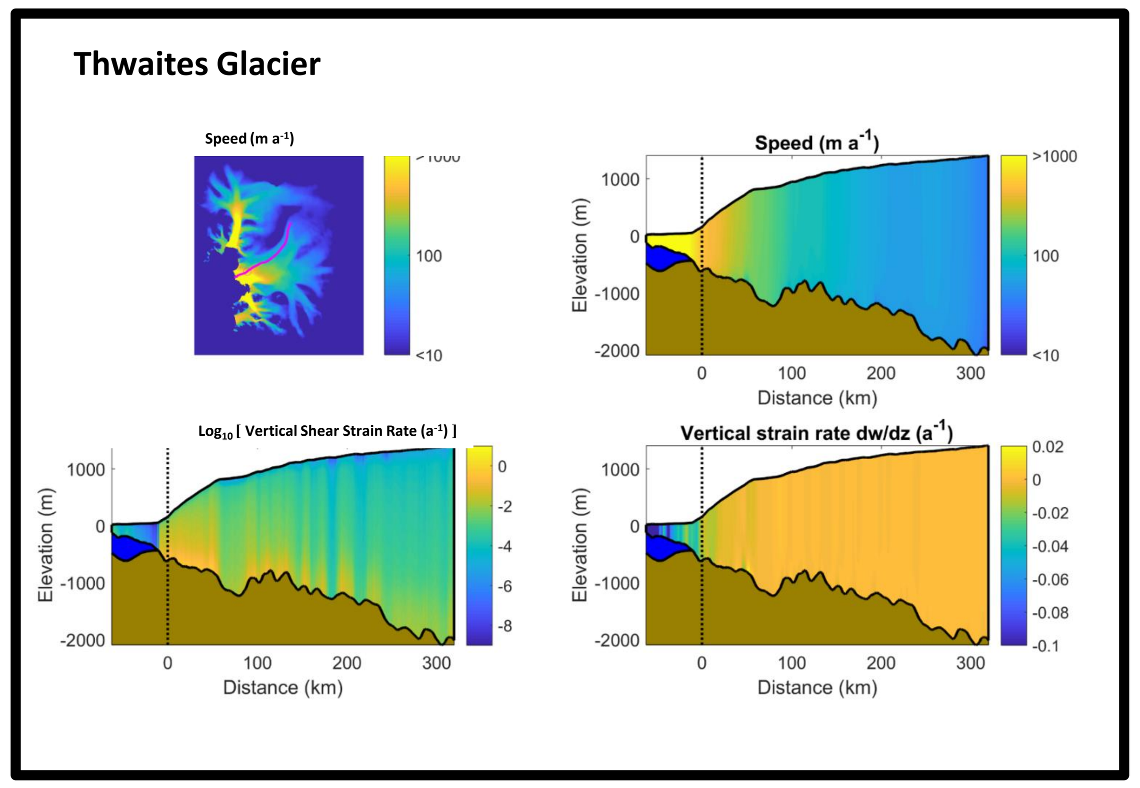
1. Using ice sheet models to infer basal drag



Inverse methods

- Adjust ice stiffness and basal drag coefficient to get best agreement between model velocities and satellite observations
- Use gradient-based optimisation method so that each iteration improves agreement between model velocities and observations.
- Plot cross-section through ice sheet showing vertical profiles of velocity, vertical shear strain rate (du/dz) and vertical strain rate (dw/dz).

Results



Consider the basal slip length: $L = u_{bed} \,/\, (du/dz)_{bed}$.

Thwaites Glacier: u_{bed} ~ 1000 m a^{-1}, $(du/dz)_{bed}$ ~ 1 a^{-1}

=> L ~ 1000 m.

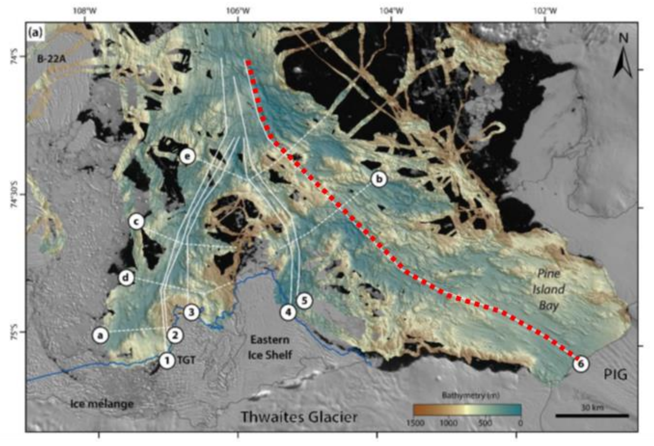
Thickness H ~ 1000 m => L/H ~ 1. Shearing flow.

For example, low-shear SSA approximation MacAyeal (1989) assumes L/H >> 1.

This indicates strongly shearing basal ice underlies Thwaites glacier.

2. Using offshore swath bathymetry to infer form drag

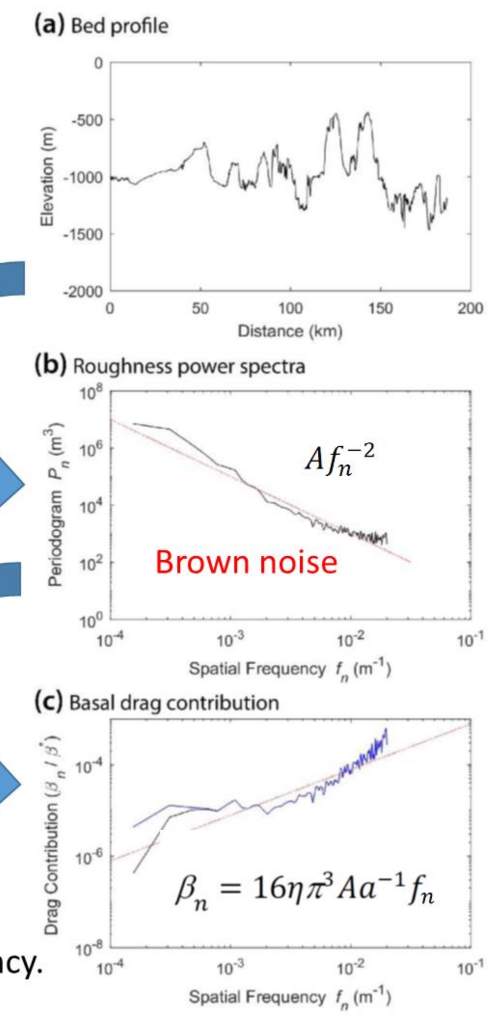
Swath bathymetry along flowline



Spectral analysis

$A = 0.1$ m

Linearised theory of form drag Schoof (2002)

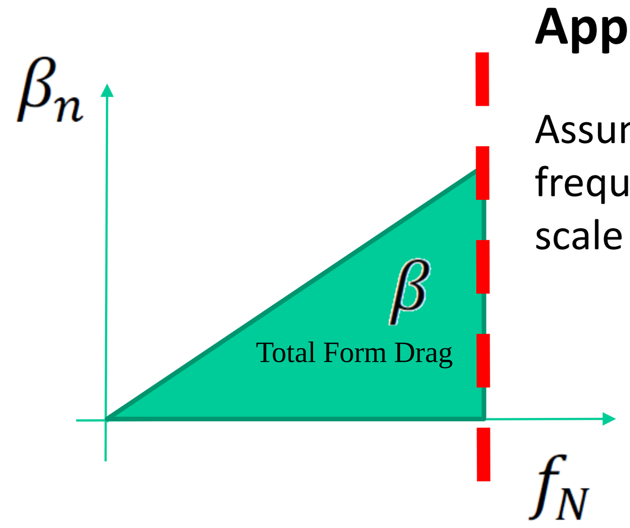


$$\tau = \beta U$$

$$\beta = \sum_{n=1}^{\infty} \beta_n$$

The drag coefficient is the sum of contributions from each frequency.

Details: Hogan et al. 2020 (Cryosphere Discussions, https://doi.org/10.5194/tc-2020-25)



Approximation of basal slip length

Assume Brown noise spectrum is cut off at some spatial frequency, corresponding to smallest effective spatial scale λ_N

$$f_N = \lambda_N^{-1} \qquad \eta = \text{Ice viscosity}$$

$$\beta = \sum_{n=1}^{N} \beta_n = 8\eta\pi^3 A \lambda_N^{-2}$$

Basal slip length $\quad L = \eta/\beta = \lambda^2_N \,/\, 8\pi^3 A$

$$A = 0.1 \text{ m} \qquad L \sim 1000 \text{ m} \Rightarrow \quad \lambda_N \sim 150 \text{ m}$$

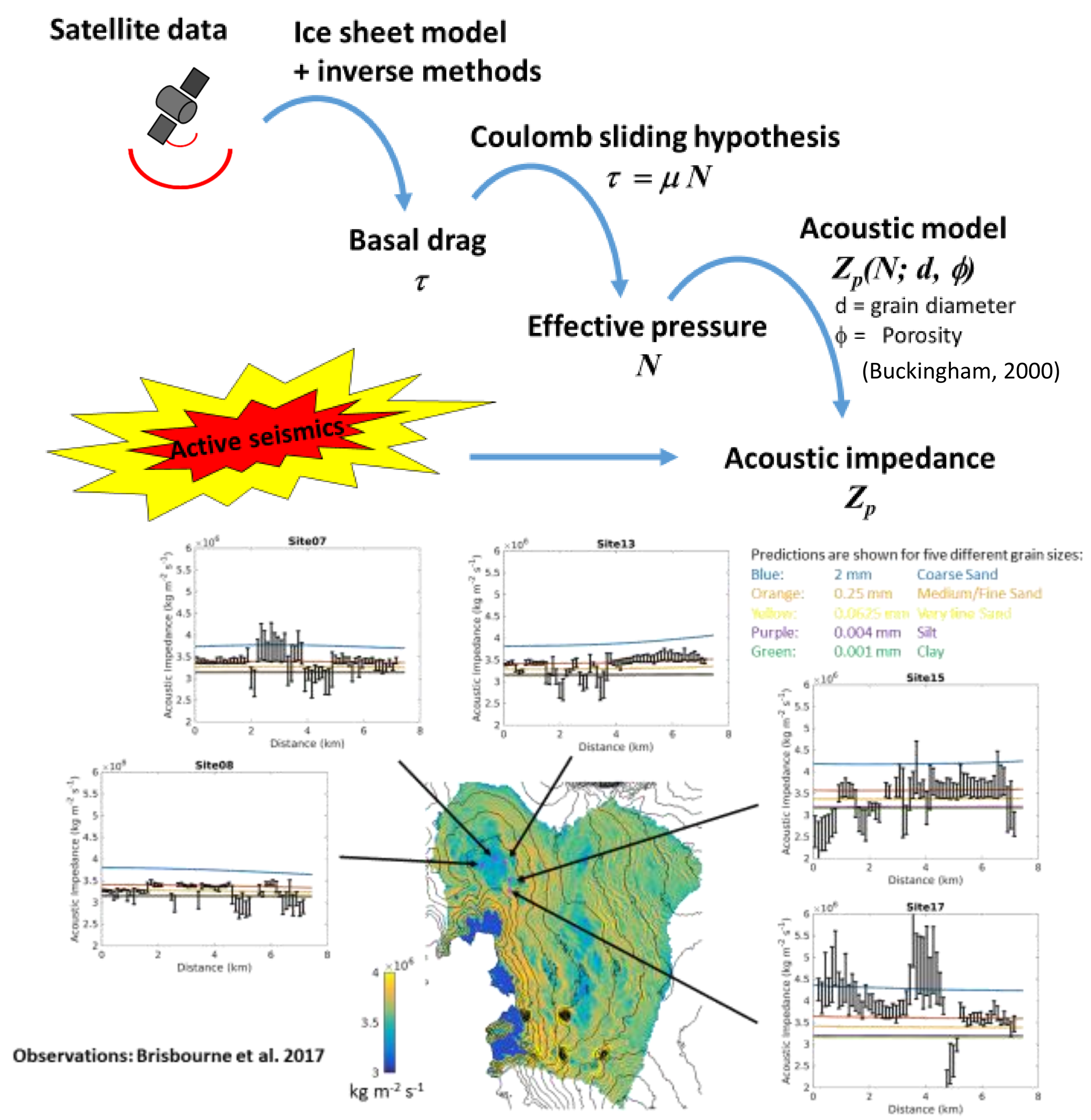
The Brown noise spectrum from swath bathymetry extends to scales smaller than 150 m, so this terrain could produce basal slip lengths L < 1000 m, implying strong shearing.

Form drag caused by roughness similar to that observed offshore can explain strong shearing of the basal ice of Thwaites Glacier. This is consistent with drag inferred using inverse methods (left).

A few caveats

- Only a simple flowline model, not 3D.
- Undulations are treated as small perturbations.
- Extension to a non-linear flow law would be useful.
- What controls cut-off scale λ_N? Possibly cavitation (e.g. Fowler, 1986; Schoof, 2005). Possibly shear localisation (e.g. Liu, this meeting).

3. Using seismic surveys and acoustic models to infer skin drag



The map show acoustic impedance predicted from the physical model using basal drag and the Coulomb hypothesis.

The plots to the right show the mismatch to the seismic observations for two different assumptions.

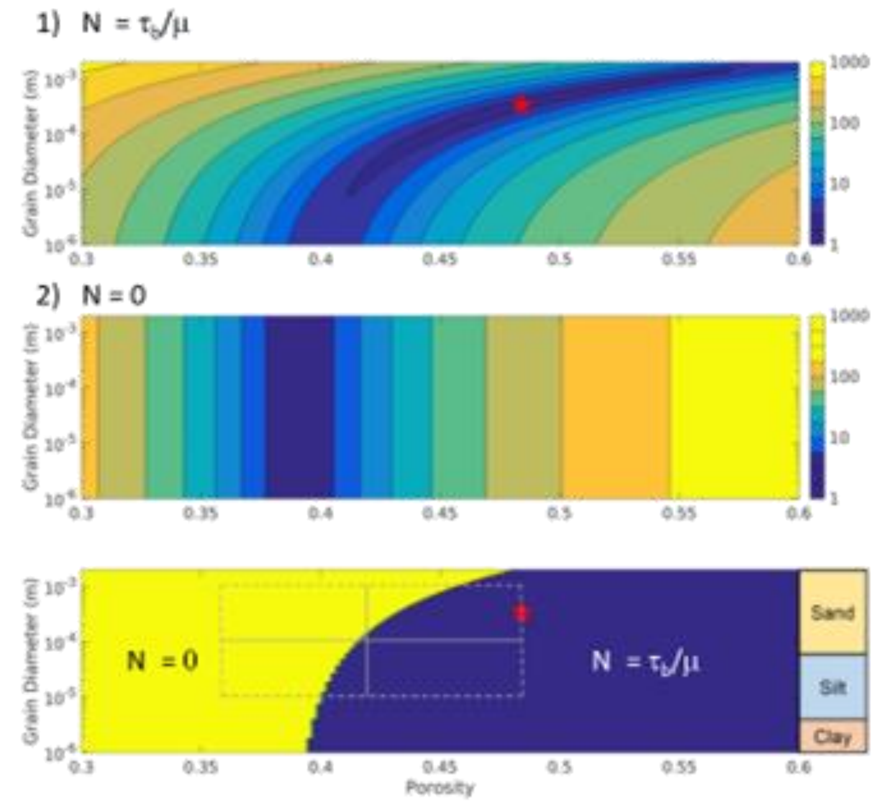
1) Effective pressure inferred using the Coulomb sliding law.

2) Dilated till with effective pressure set to zero.

Searching through the parameter space (grain diameter and till porosity), the best match to data is found for the Coulomb sliding hypothesis (red star).

The parameters that produce the best match are in a realistic range compared to observations from boreholes (dashed rectangle).

Yellow and blue regions show the parameteter values where each hypothesis fits the seismic data best.



Seismic surveys provide evidence that Coulomb friction, not form drag, is controlling the fast-flowing tributaries of Pine Island Glacier.

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