Formation and interpretation of eskers beneath retreating ice sheets

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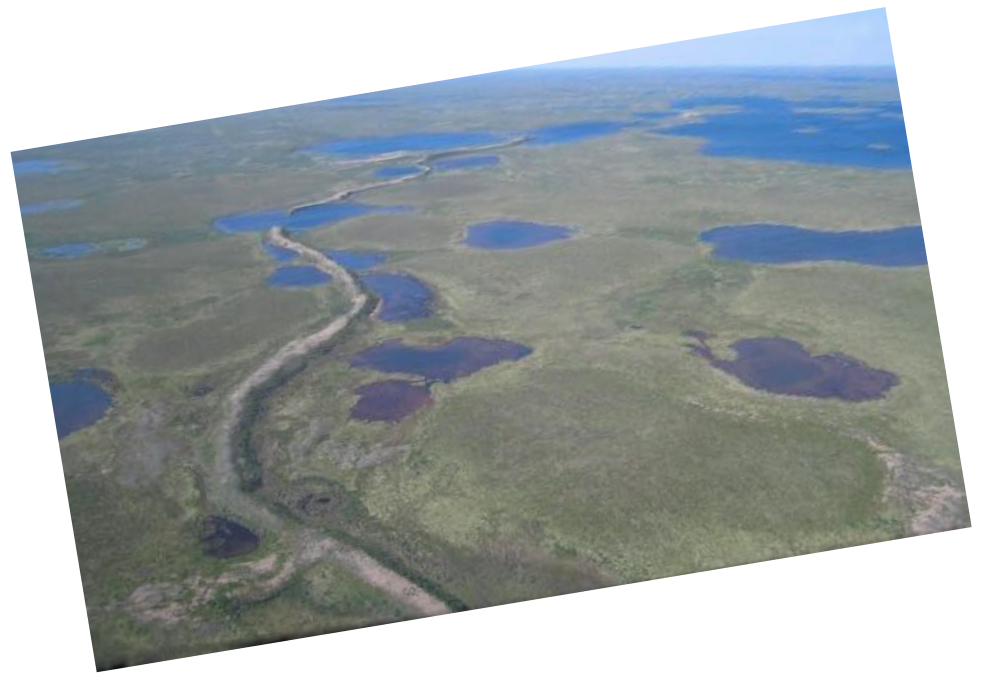
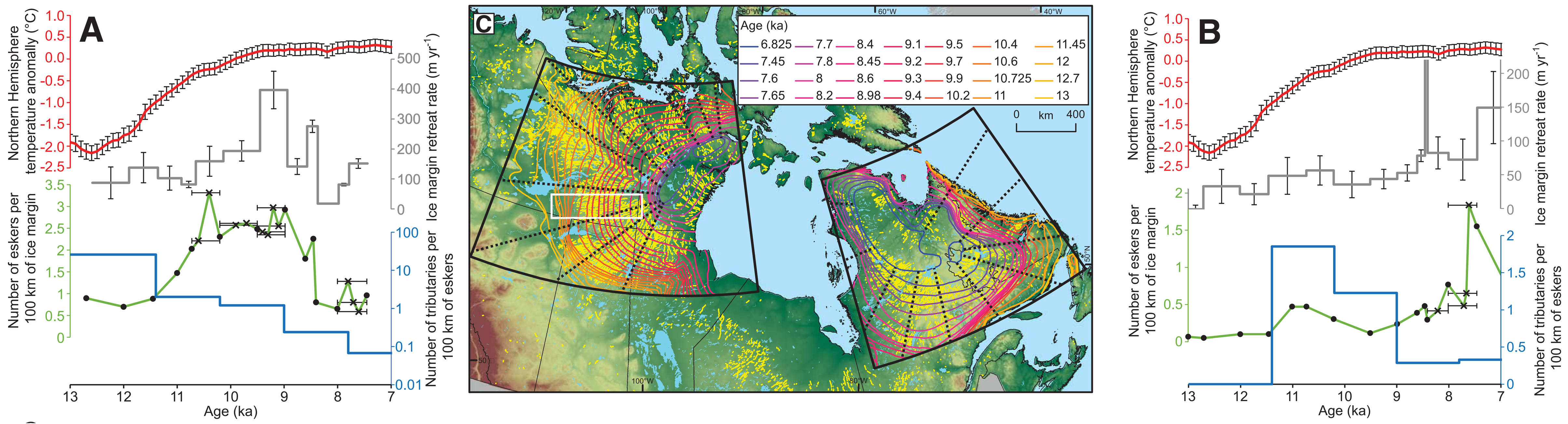
Summary

- Eskers are believed to form as meltwater deposits during the retreat of former ice sheets.
- We provide a quantitative model for the formation of eskers based on fluid mechanical descriptions of subglacial tunnel flow and sediment transport.
- The model yields predictions for how esker spacing and size vary with surface melt rate and margin retreat rate.



Relation to ice-sheet evolution

- Large mapped datasets (Storrar et al 2014) show varying esker density during ice-sheet retreat.



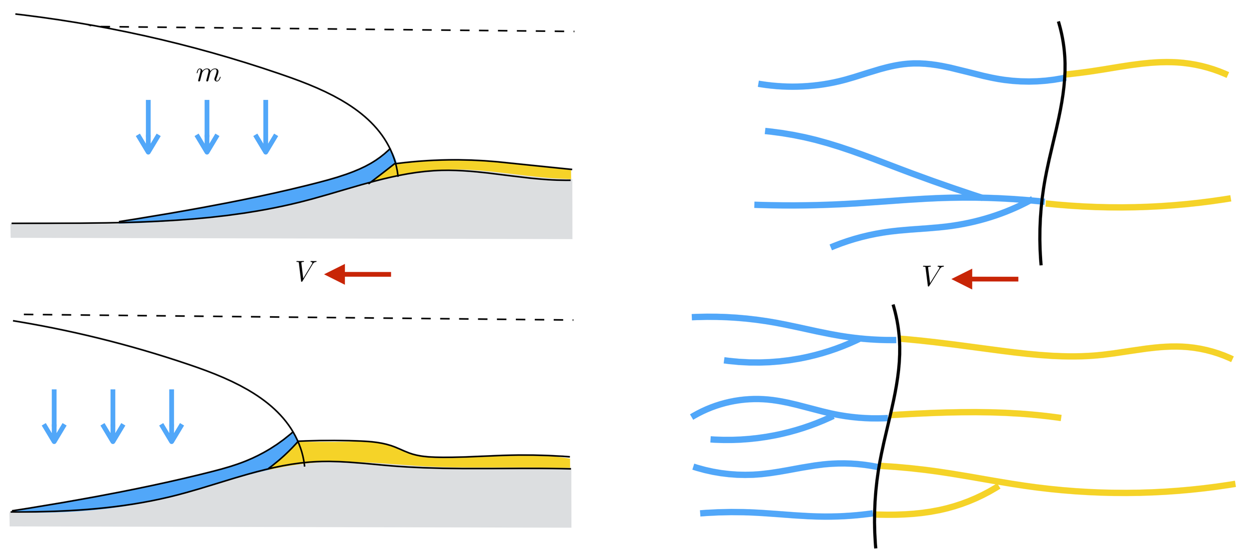
- Our model provides a suggestion as to how *spacing* and *size* relate to melt rates and retreat rates.

Spacing and size

- The model suggests esker *size* (cross-sectional area) is controlled by water flux and retreat rate

$$A = \frac{Q_{s\,\max}}{V(1-n_s)} \qquad Q_{s\,\max} \propto Q^{15/14}$$

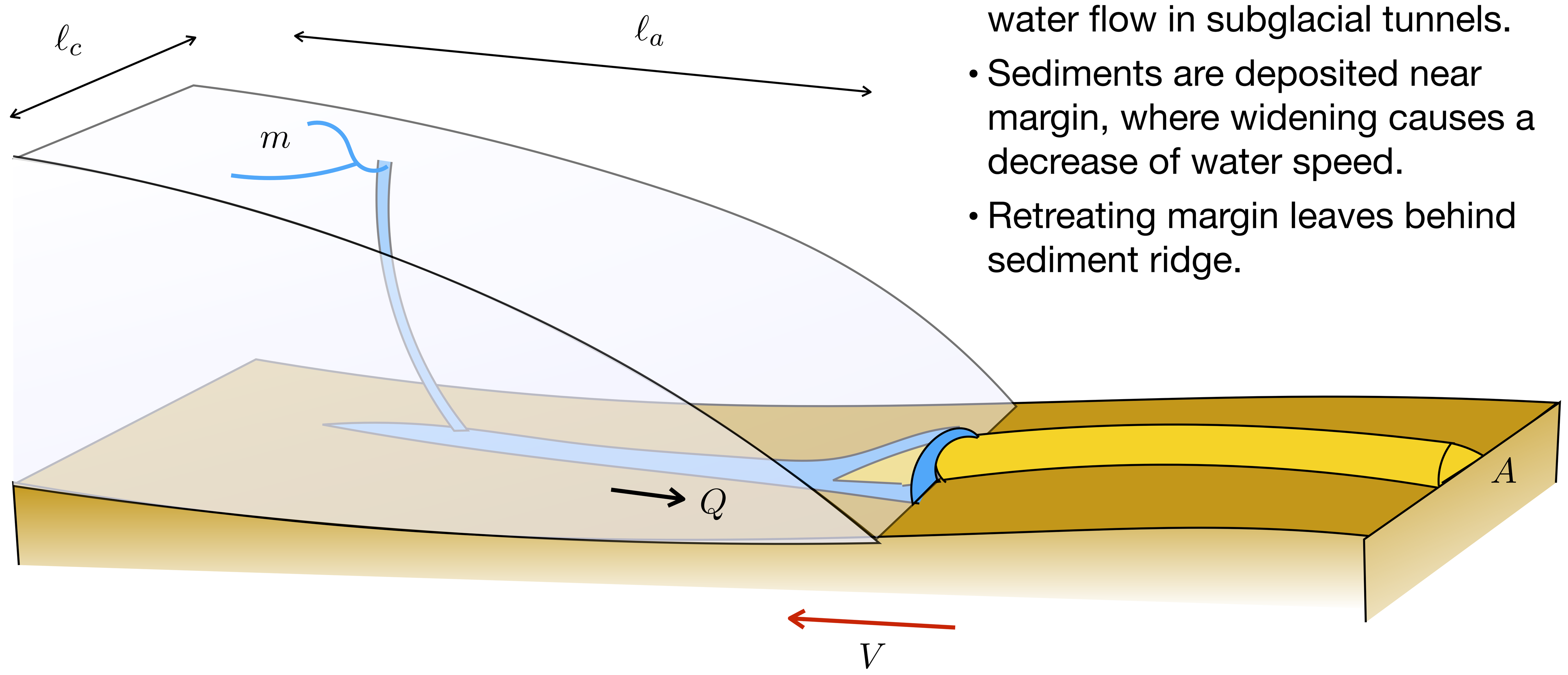
- **Faster retreat rates** produce **smaller eskers** because there is less time to deposit sediments.



- Esker *spacing* reflects major subglacial channel spacing at the time of retreat.
- **Larger melt rates** produce **more closely spaced** channels, each having **larger water flux**

$$\ell_c \propto m^{-11/23} \ell_a^{1/23} \qquad Q = m\ell_a\ell_c \propto m^{12/23}\ell_a^{24/23}$$

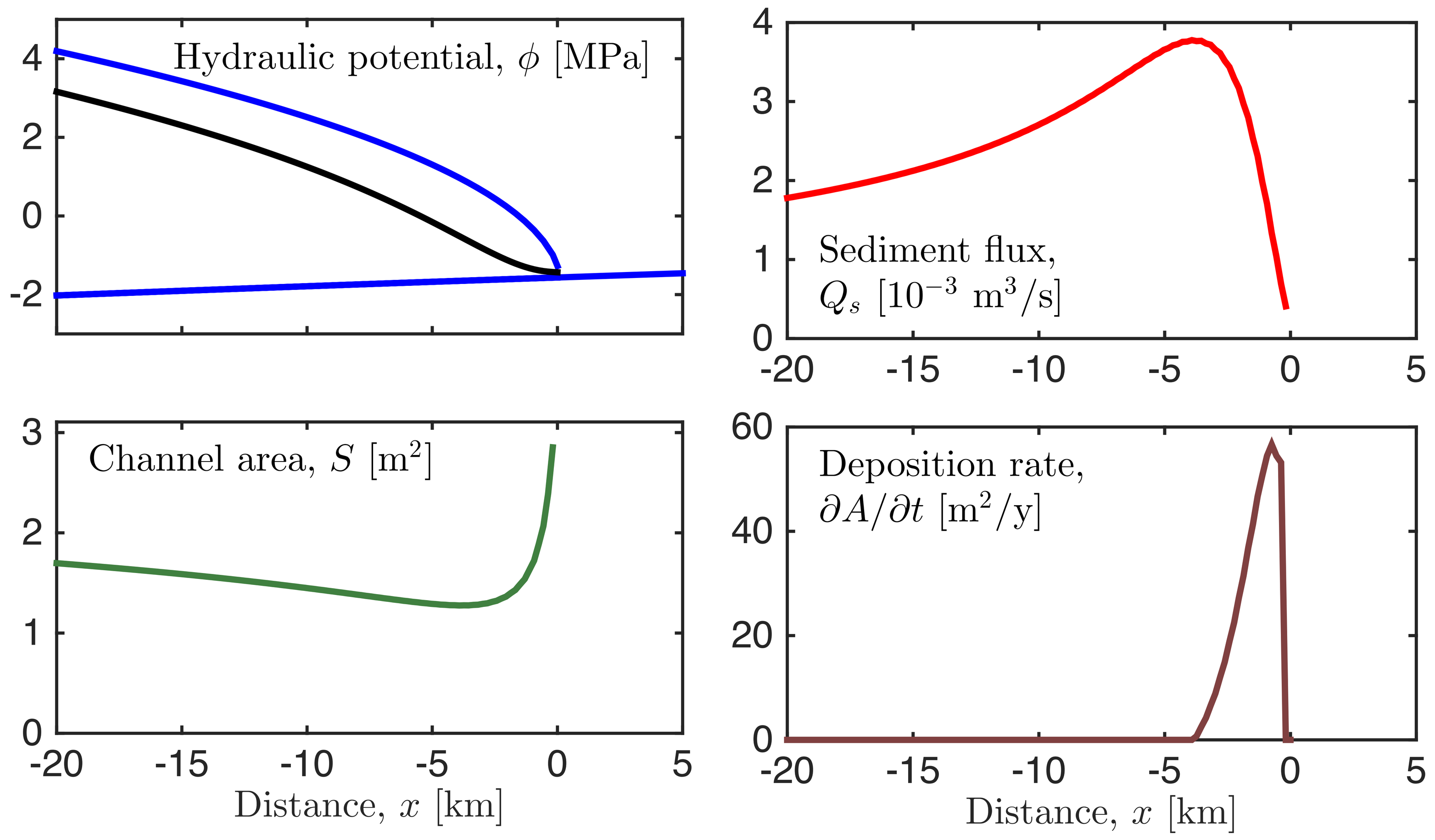
Formation mechanism



- Sediments are mobilised by rapid water flow in subglacial tunnels.
- Sediments are deposited near margin, where widening causes a decrease of water speed.
- Retreating margin leaves behind sediment ridge.

Model

- We assume a steadily translating shape of the ice-sheet margin during retreat (a plastic-ice profile).
- Equations for a steady-state **Röthlisberger channel** are solved to calculate water speed; these are used to estimate **sediment flux**, which is coupled to an **Exner equation** for bed evolution.



Water flow

$$\frac{\partial Q}{\partial x} = m\ell_c$$

$$Q = SU = KS^{4/3}\Psi^{1/2}$$

$$\Psi = -\rho_i g\frac{\partial s}{\partial x} - (\rho_w - \rho_i)g\frac{\partial b}{\partial x} + \frac{\partial N}{\partial x}$$

$$\frac{\Psi Q}{\rho_i L} = \frac{2A}{n^n} S|N|^{n-1}N$$

Sediment flux

$$Q_s = K_s S^{1/2}(f\rho_w U^2 - \tau_c)^{3/2}$$

Exner equation

$$(1-n_s)\frac{\partial A}{\partial t} + \frac{\partial Q_s}{\partial x} = q_s$$

References: Boulton, G.S., Hagdorn, M., Maillot, P.B. & Zatsepin, S. 2009 Drainage beneath ice sheets: groundwater-channel coupling and the origin of eskers systems from former ice sheets. Quaternary Science Reviews.; Schoof, C. 2010 Ice sheet acceleration driven by melt supply variability. Nature.; Hewitt, I.J. 2011 Modelling distributed and channelised subglacial drainage: the spacing of channels. J Glaciol.; Storrar, R.D., Stokes, C.R., Evans, D.J.A. 2014 Increased channelization of subglacial drainage during deglaciation of the Laurentide Ice Sheet. Geology. **Acknowledgements:** IJH was supported by a Marie Curie FP7 Career Integration Grant PCIG13-GA-2013-618007 ImPISM.