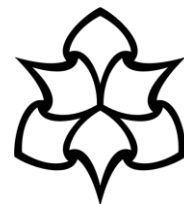


Subglacial meltwater conduit dimensions and processes at the ice sheet scale: 3D morphometry of a large sample of eskers

Storror, R.D., Jones, A.H., Butcher, F.E.G., Dewald, N., Clark, C.D., Delaney, C., Evans, D.J.A., Lewington, E., Livingstone, S.J. & Stokes, C.R.

**Sheffield
Hallam
University**



**Manchester
Metropolitan
University**



**Durham
University**

Outline

- Rationale
- Study areas
- Headline results
- Process models (seasonal records of ice sheet hydrology)
- If you are still interested:
 - Methods
 - Expanded results

Rationale

What does a channelised ice sheet drainage system look like?

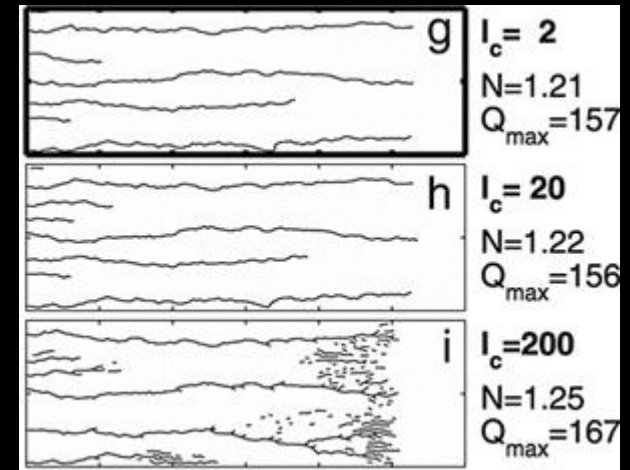
- Important for constraining models of subglacial hydrology
- Difficult to observe, particularly over >decadal timescales

What happens to the subglacial system when melting speeds up?

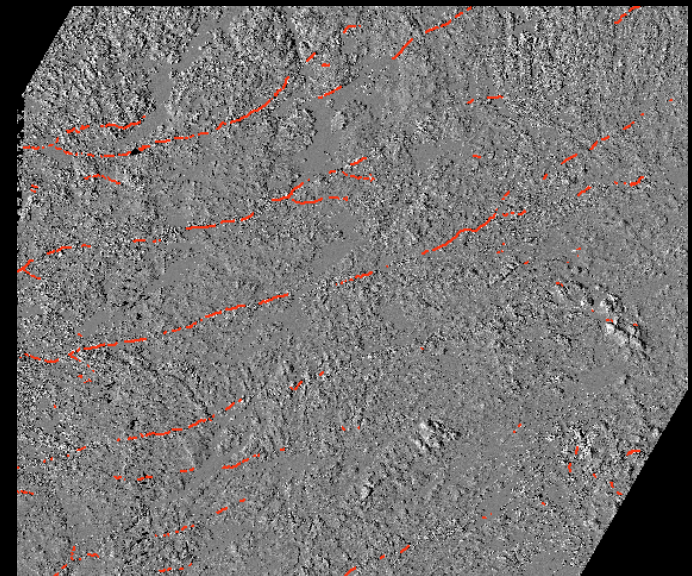
- Channelised vs. distributed flow
- Diurnal, seasonal variability
- Channel configuration/size
- Sediment flux

Eskers can provide constraints on key metrics/patterns

- Previous insights from 2D measurements
- Abundance of high-resolution DEMs (ArcticDEM, Lidar)
- Potential for significant new advances from high-resolution, 3D data



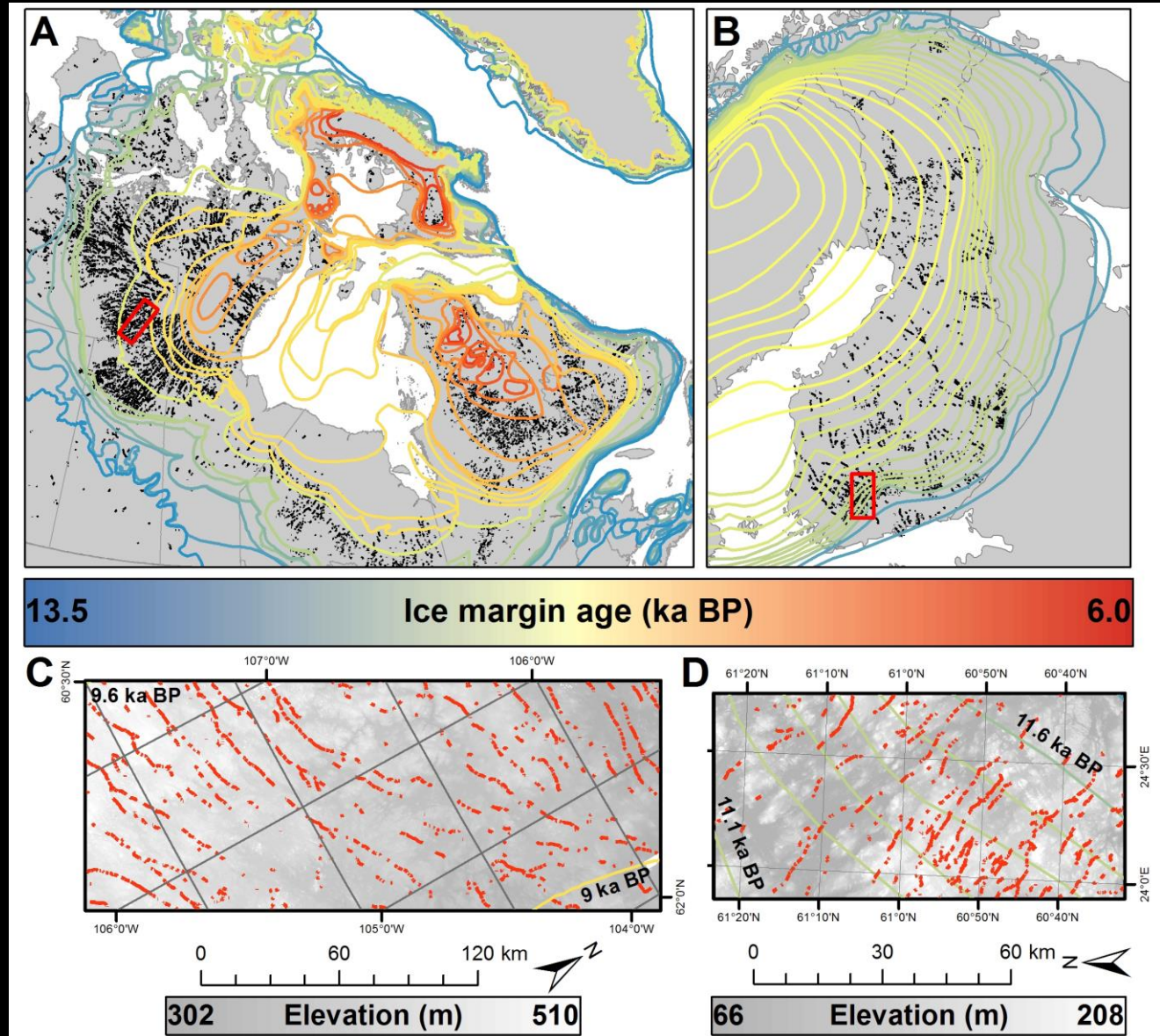
Model: Werder *et al.* (2013) JGR



Eskers from the Laurentide Ice Sheet

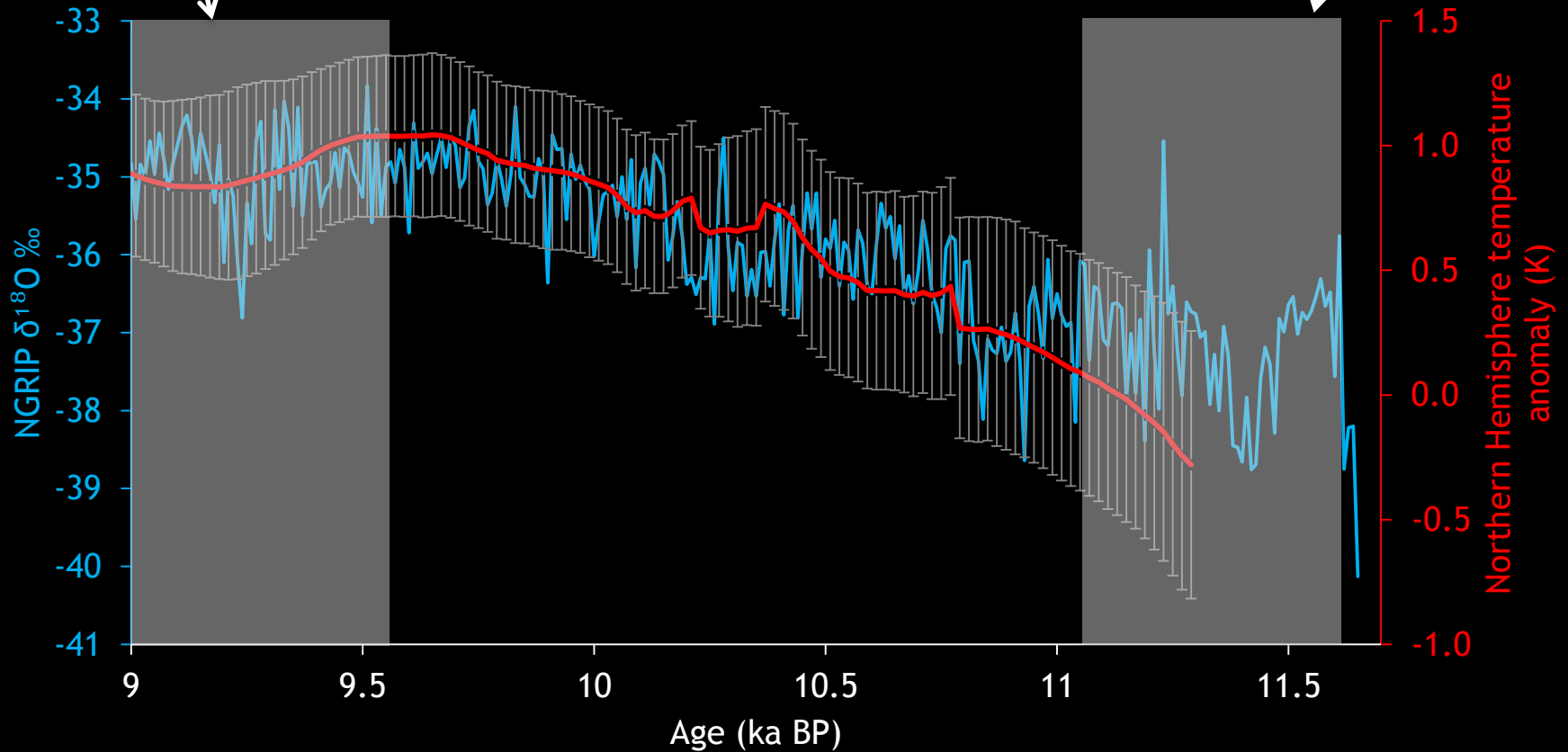
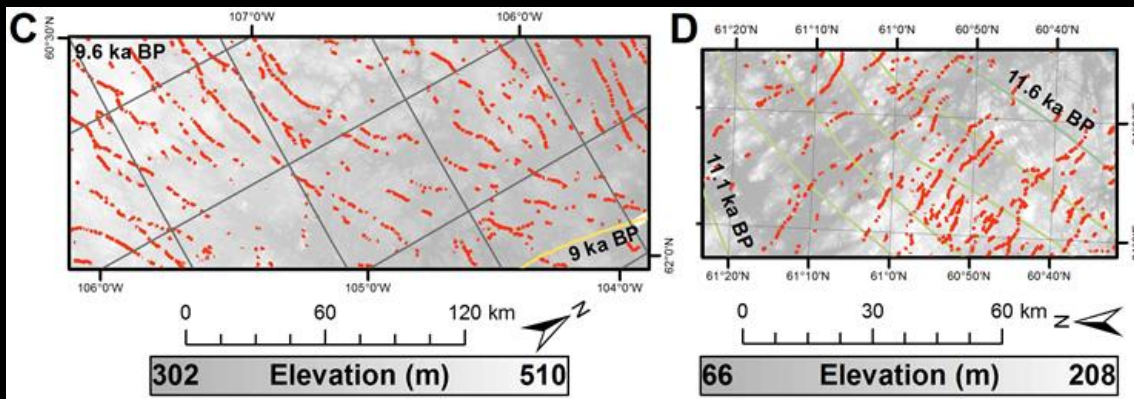
Study areas

- Study areas in Canada and Finland
- Sweden study area (work in progress)
- Aim: to capture ice sheet-scale metrics



Laurentide

Fennoscandian



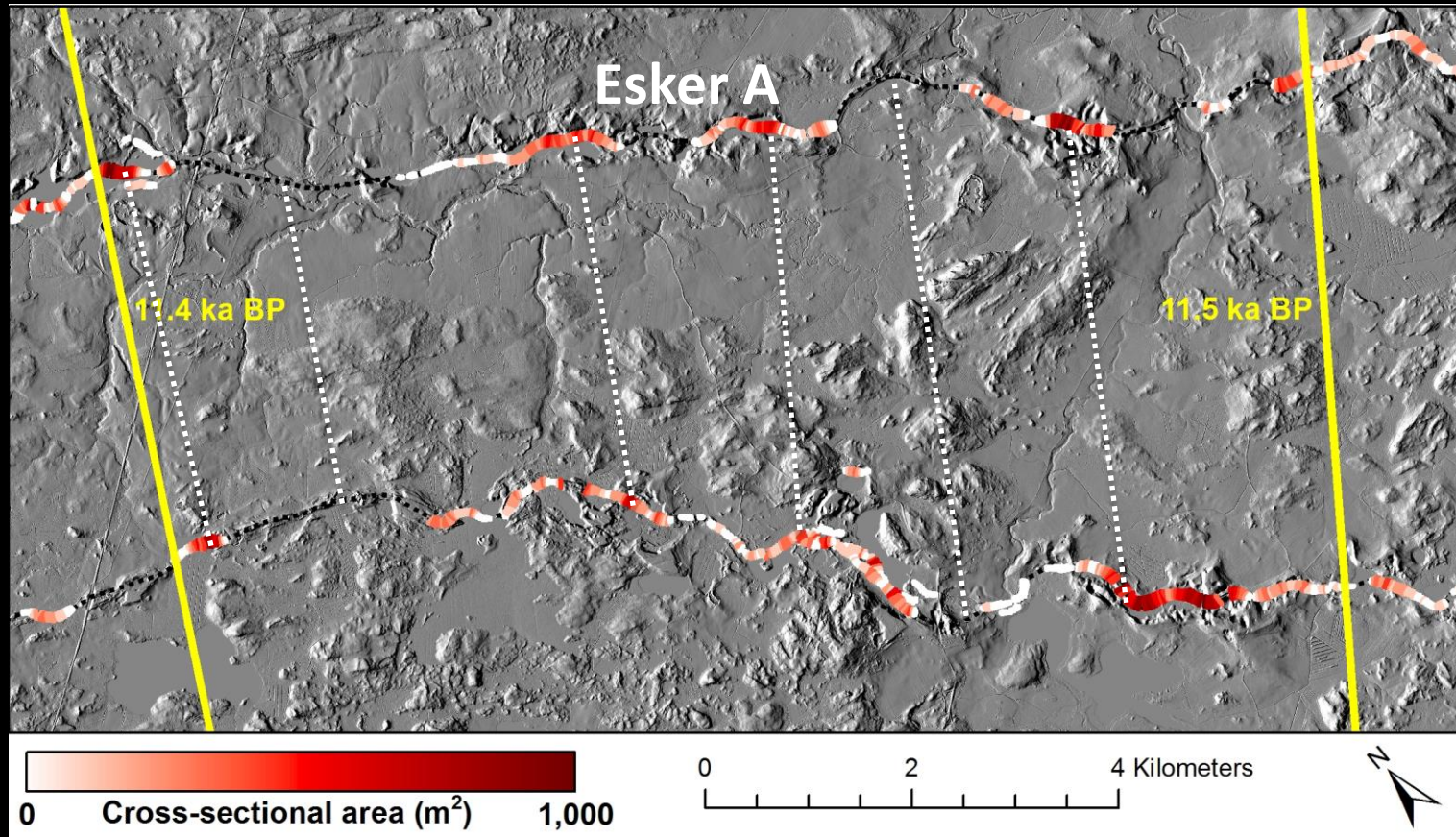
NGRIP data from Rasmussen *et al.* (2007) QSR

Northern Hemisphere temperature reconstruction from Marcott *et al.* (2013) *Science*

Headline results

- The following slides present some key insights from new metrics:
 - R-channel sediment flux (esker volume)
 - Synchronicity between conduits
 - Esker proxies for R-channel width & height

Sediment flux



Esker A	Surveyed	Unsurveyed	Total	Flux
Length (m)	7,286 m (56%)	5,818 m (44%)	13,104 m	131 m per year
Volume (m ³)	1,828,975	1,437,051	3,266,026 (est.)	32,660 m³ per year

Sediment flux

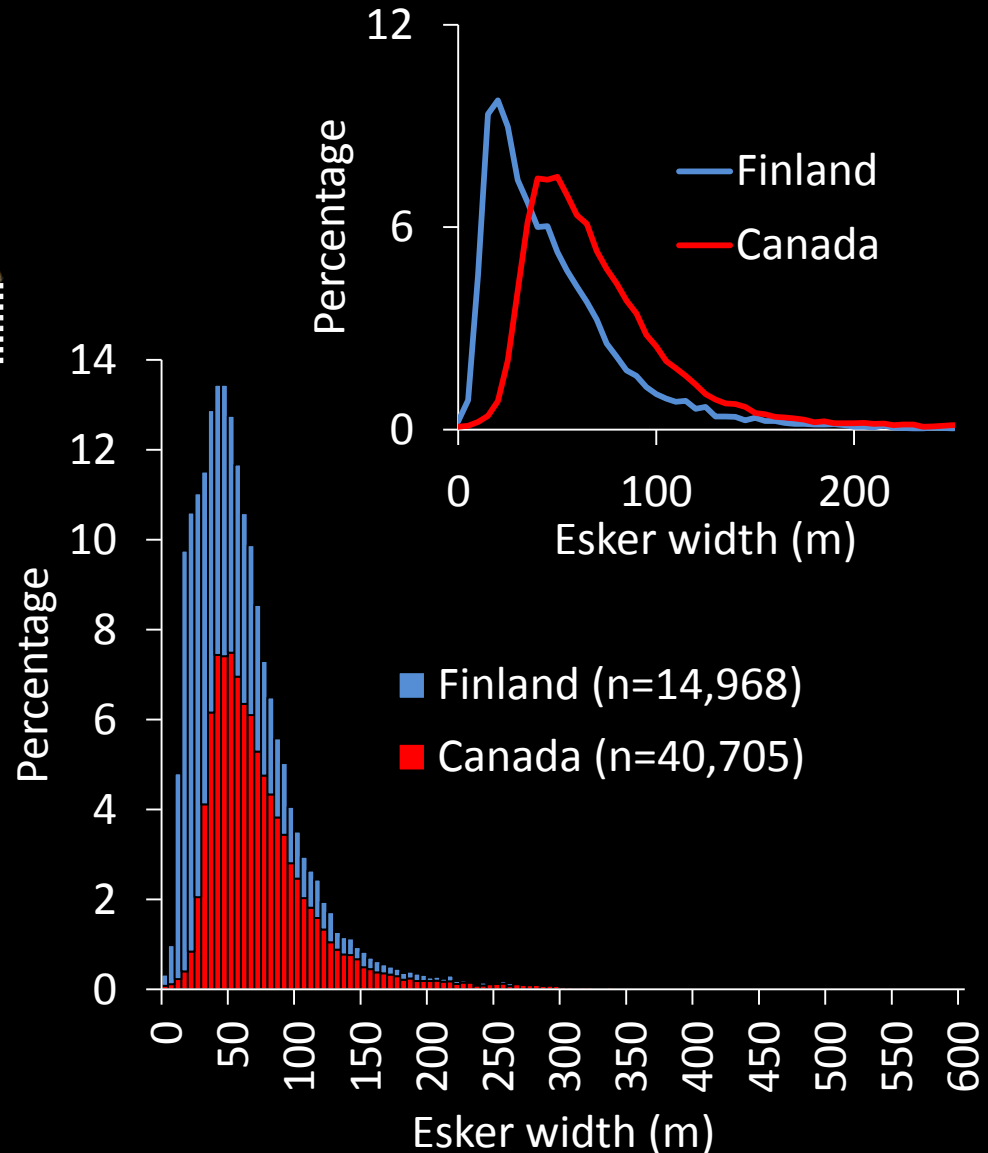
- Volume estimates allow quantification of sediment flux (covering 100s of years, 10s of km)
- *Minimum* estimate
 - Only captures sediment that remained in the R-channel (in some places, some may have spilled out to form fans)
 - May only measure surface of eskers
- Example from esker A: 32,660 m³ per year
- Fluctuations exhibit synchronicity between adjacent systems (annual-decadal seasonality)

Width



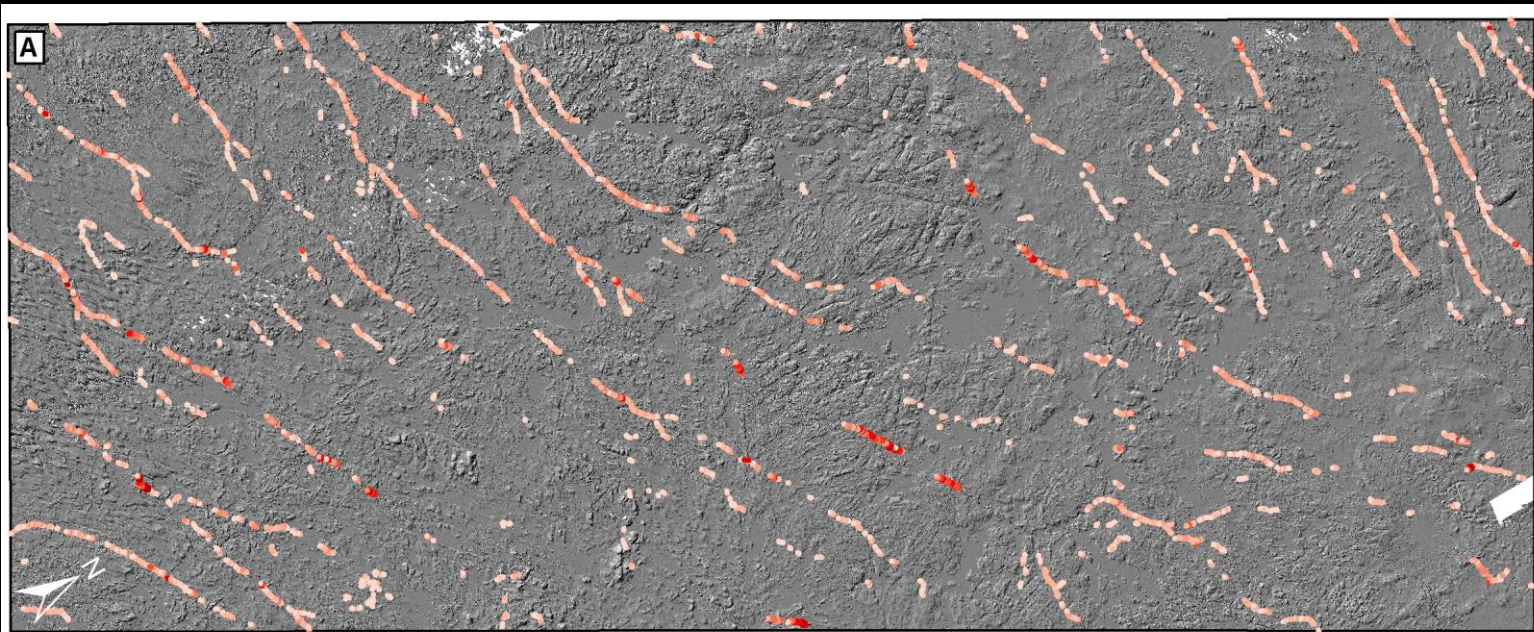
Relevance:

- Esker width provides an approximation of R-channel width
- Most R-channels ~20-50 m wide near terminus
- Extremes up to ~200 m

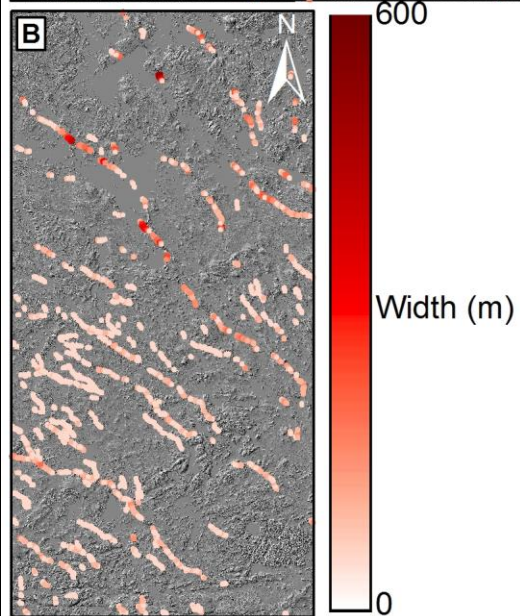


Width

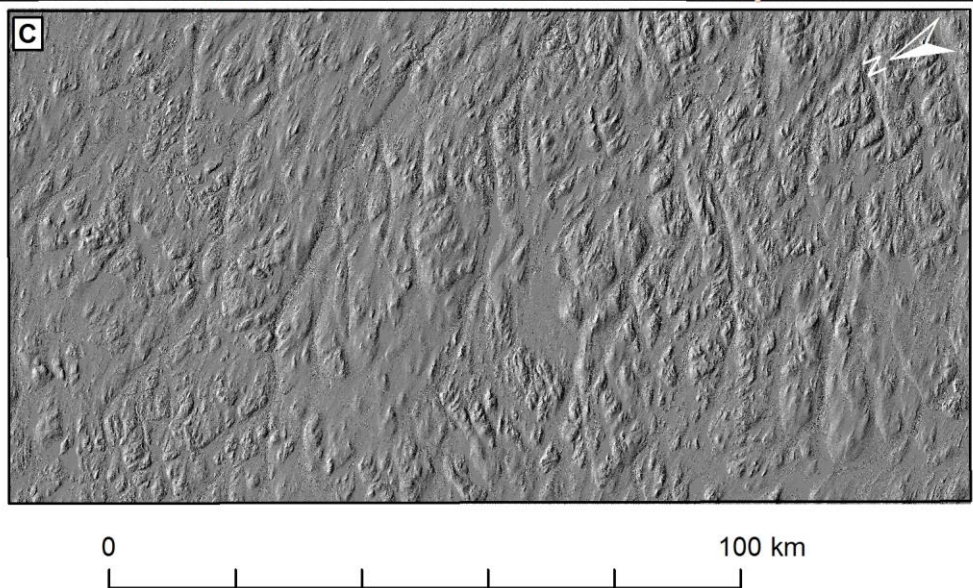
Canada



Finland



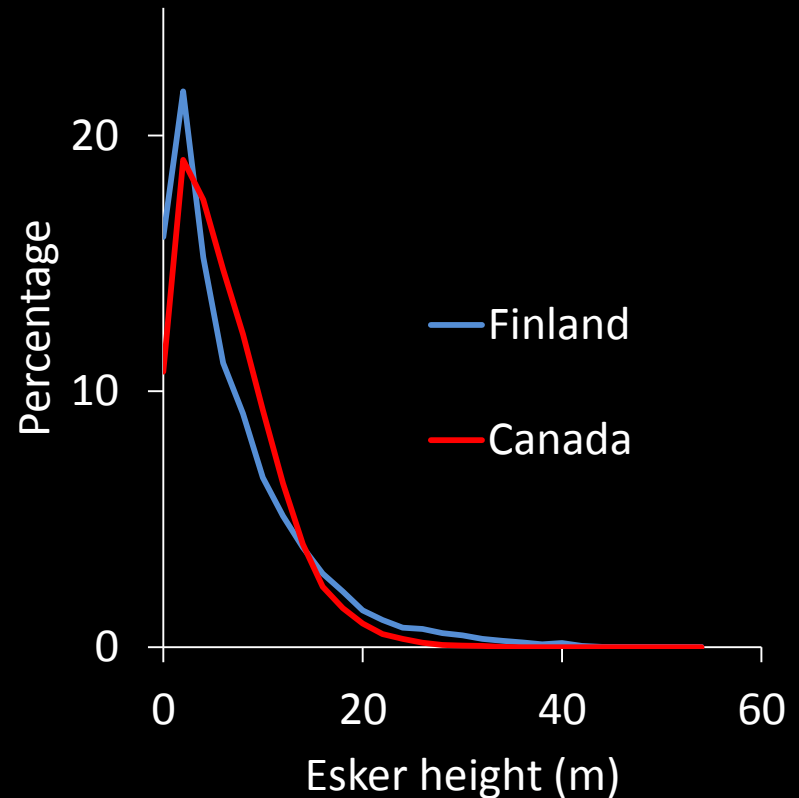
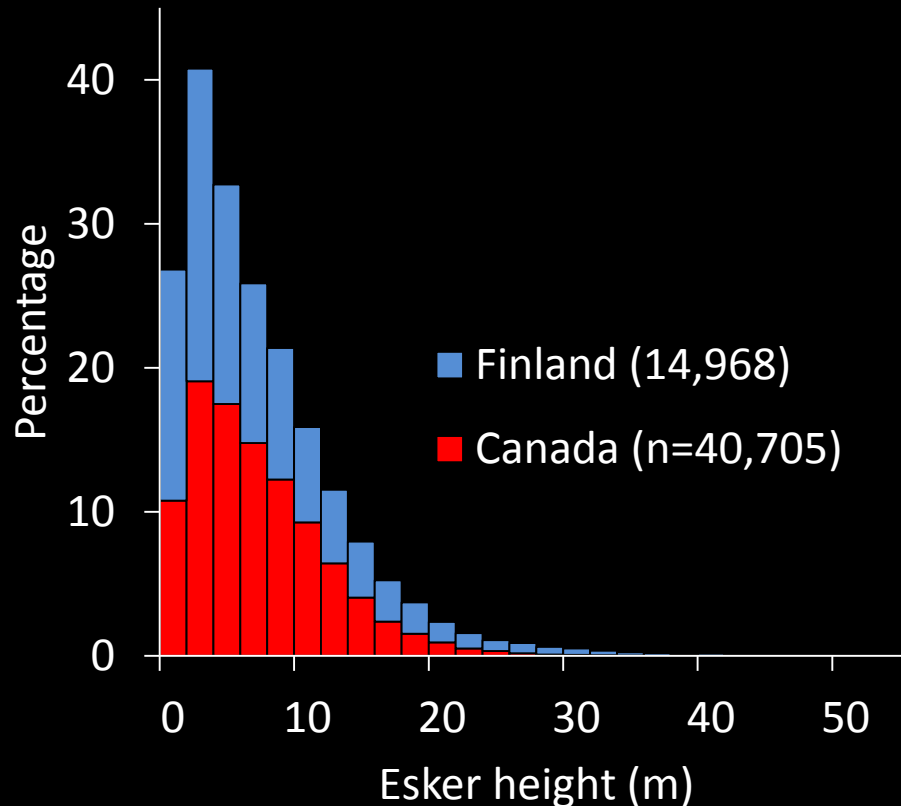
Sweden



Height

Relevance:

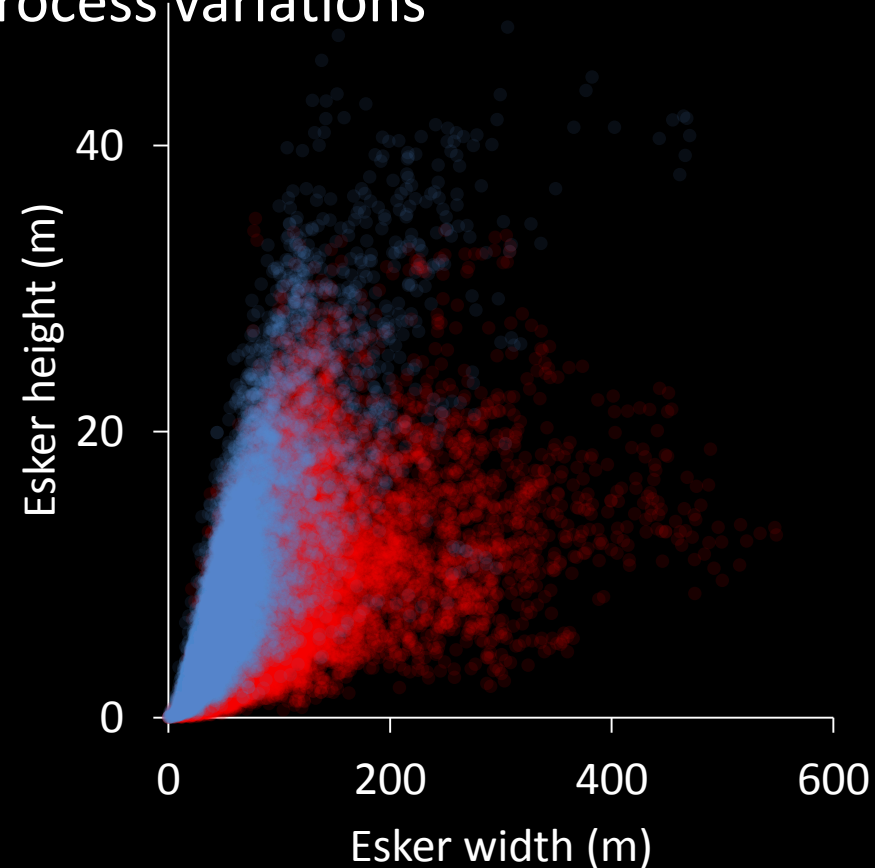
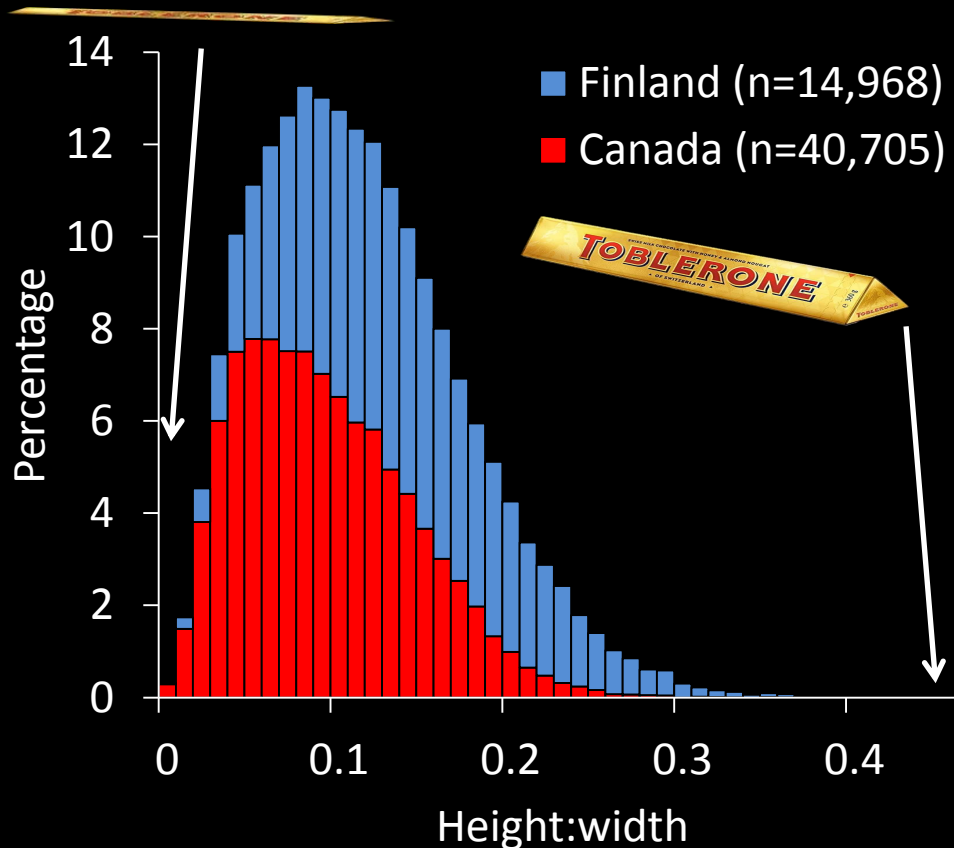
- Limited information on conduit height
- Esker height reflects amount and nature of sediment deposited



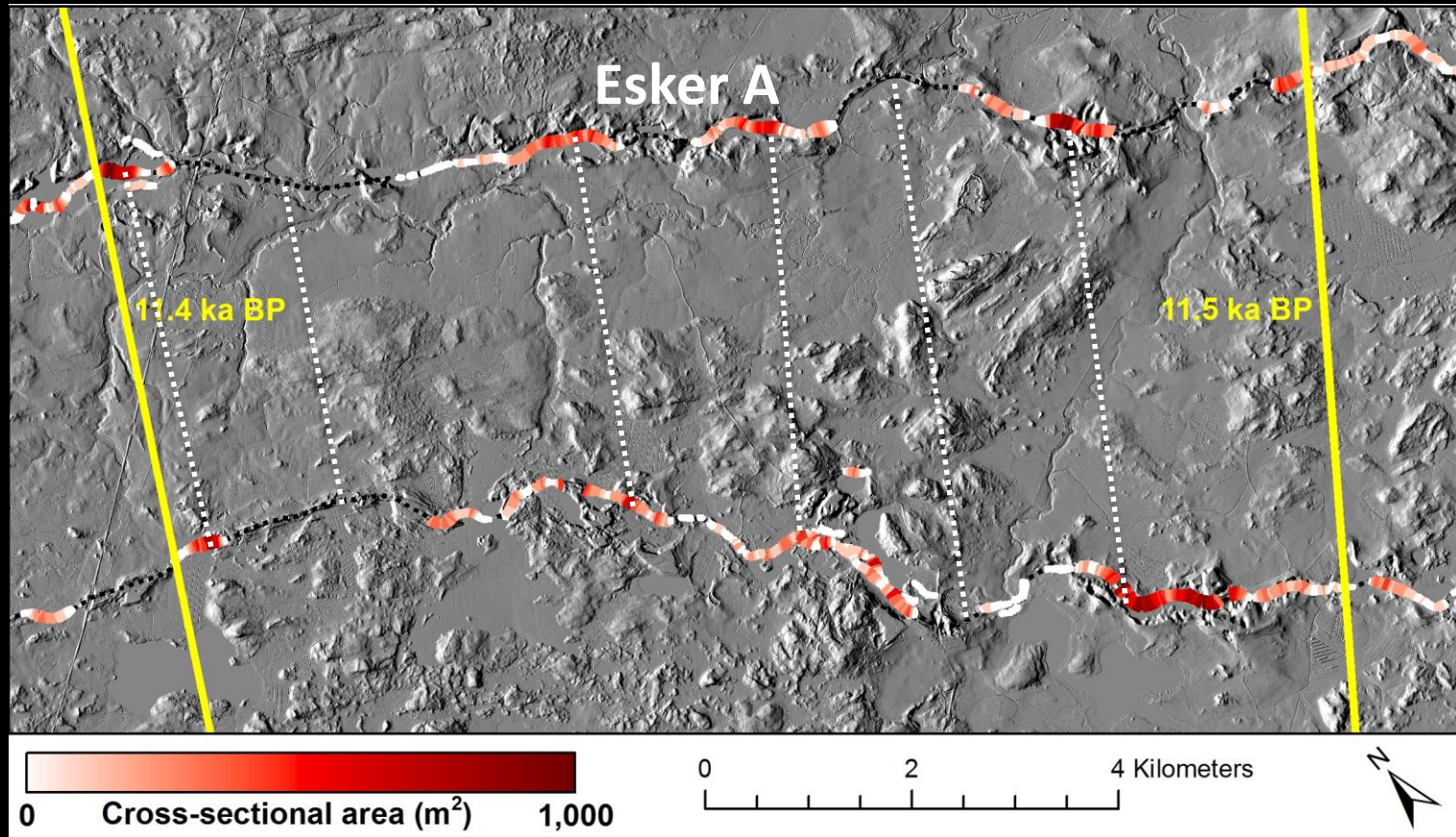
Height vs. width

Relevance:

- Fundamental control on slope stability
- Potential indicator of esker composition
- Spatial variability related to process variations



Process models



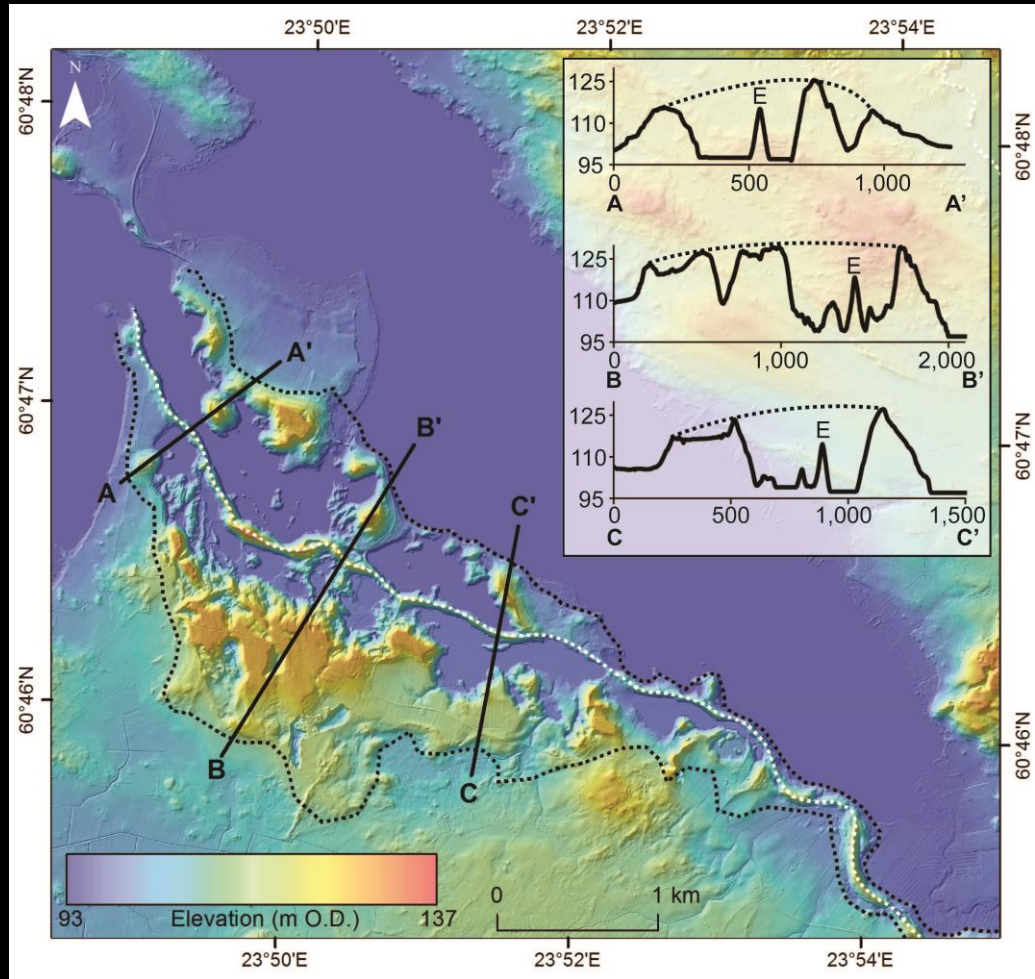
Observation 1:

Some adjacent esker systems demonstrate synchronicity, suggesting wider system response to seasonal/annual/decadal climate forcing

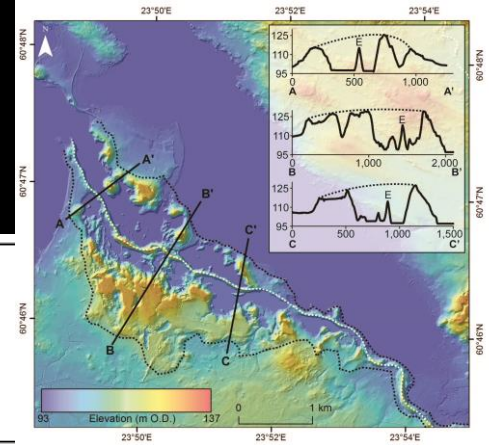
Process models

Observation 2:

Some Finnish eskers are part of an unusual wider system, with a central esker immediately surrounded by a large void, then with flanking deposits



Process models



Climate warms:

- Intense meltwater production
- R-channels develop

Summer:

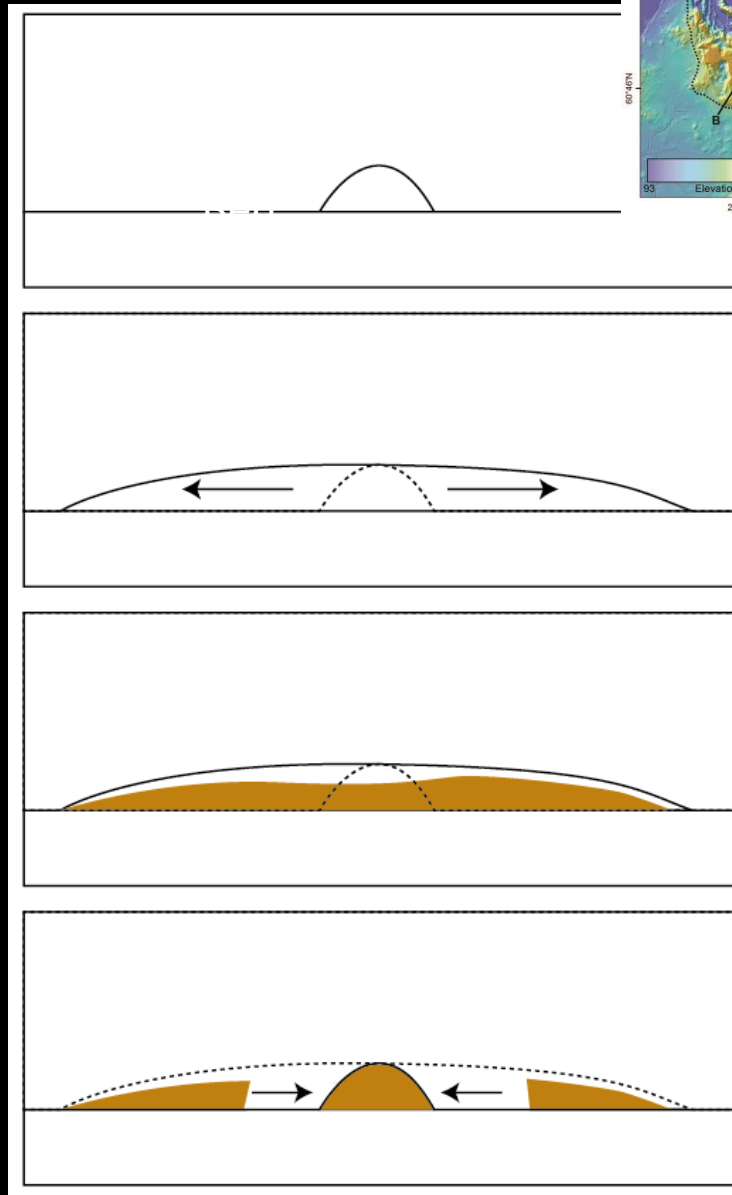
- Excessive melting
- R-channels overwhelmed
- Extends laterally (but not vertically)

End of melt season 1:

- Reduced discharge
- Decreased competence: fills with sediment

End of melt season 2:

- Decreased flow
- R-channel back to normal
- Low pressure draws in sediment



Process models

Other glaciofluvial landforms provide evidence for seasonal evolution of hydrological systems

The Cryosphere, 14, 2949–2976, 2020
<https://doi.org/10.5194/tc-14-2949-2020>
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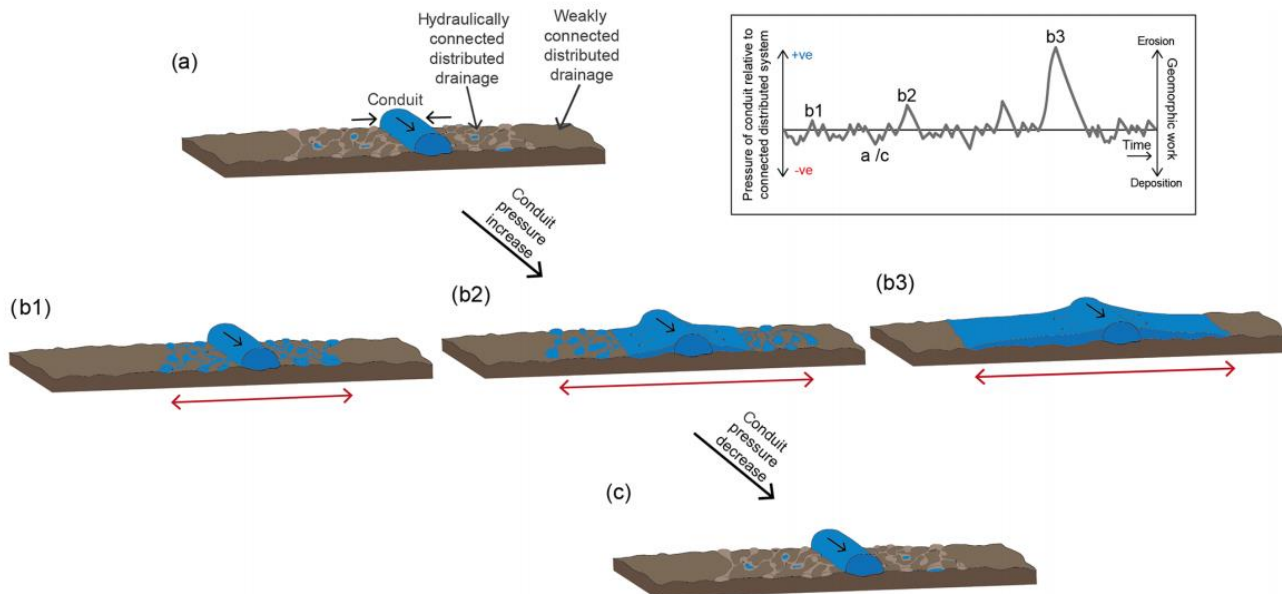
The Cryosphere  Open Access

A model for interaction between conduits and surrounding hydraulically connected distributed drainage based on geomorphological evidence from Keewatin, Canada

Emma L. M. Lewington¹, Stephen J. Livingstone¹, Chris D. Clark¹, Andrew J. Sole¹, and Robert D. Storrar²

¹Department of Geography, University of Sheffield, Sheffield, UK

²University of Sheffield, Sheffield, UK



Conclusions

- Eskers (and allied features) provide a centuries-millennia-long record of subglacial meltwater behaviour at ~seasonal/annual resolution
- Subglacial channel morphometry at the ice sheet scale can be inferred from the esker record
- Quantification of sediment flux
- Applications:
 1. Informing subglacial hydrology models
 2. Informing geomorphological models
 3. Teasing out spatial differences in process
 4. Dataset for future region (& interplanetary) comparisons

If you are still interested (methods and supplementary data)

The following slides provide some further detail on:

- Digitisation
- Approach to metrics
- More detailed results
 - Length
 - Sinuosity
 - Asymmetry
 - Cross-sectional area
 - Slope

Digitisation

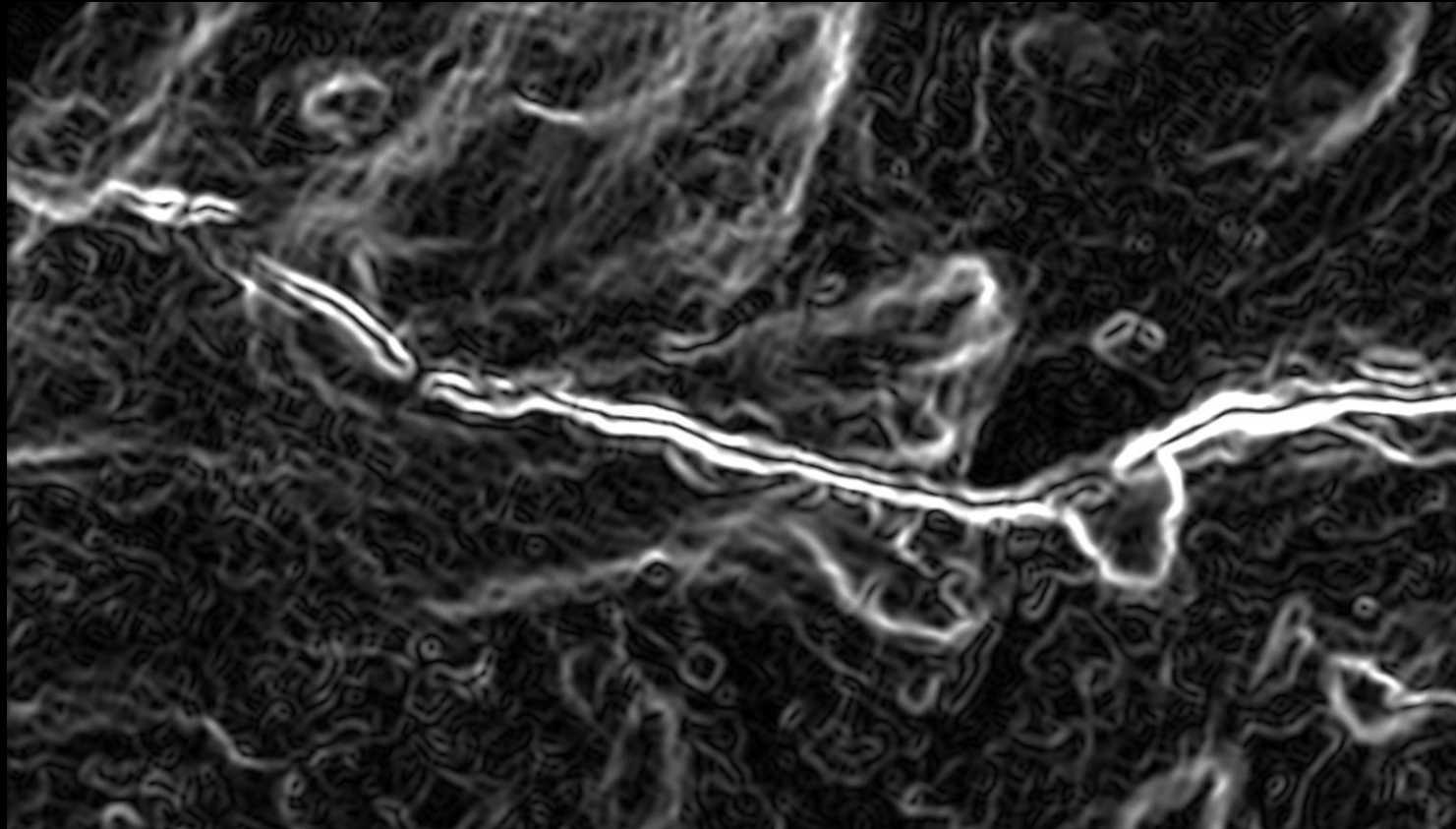
1. Identification in hillshaded DEM

- Canada: ArcticDEM
- Finland: Lidar



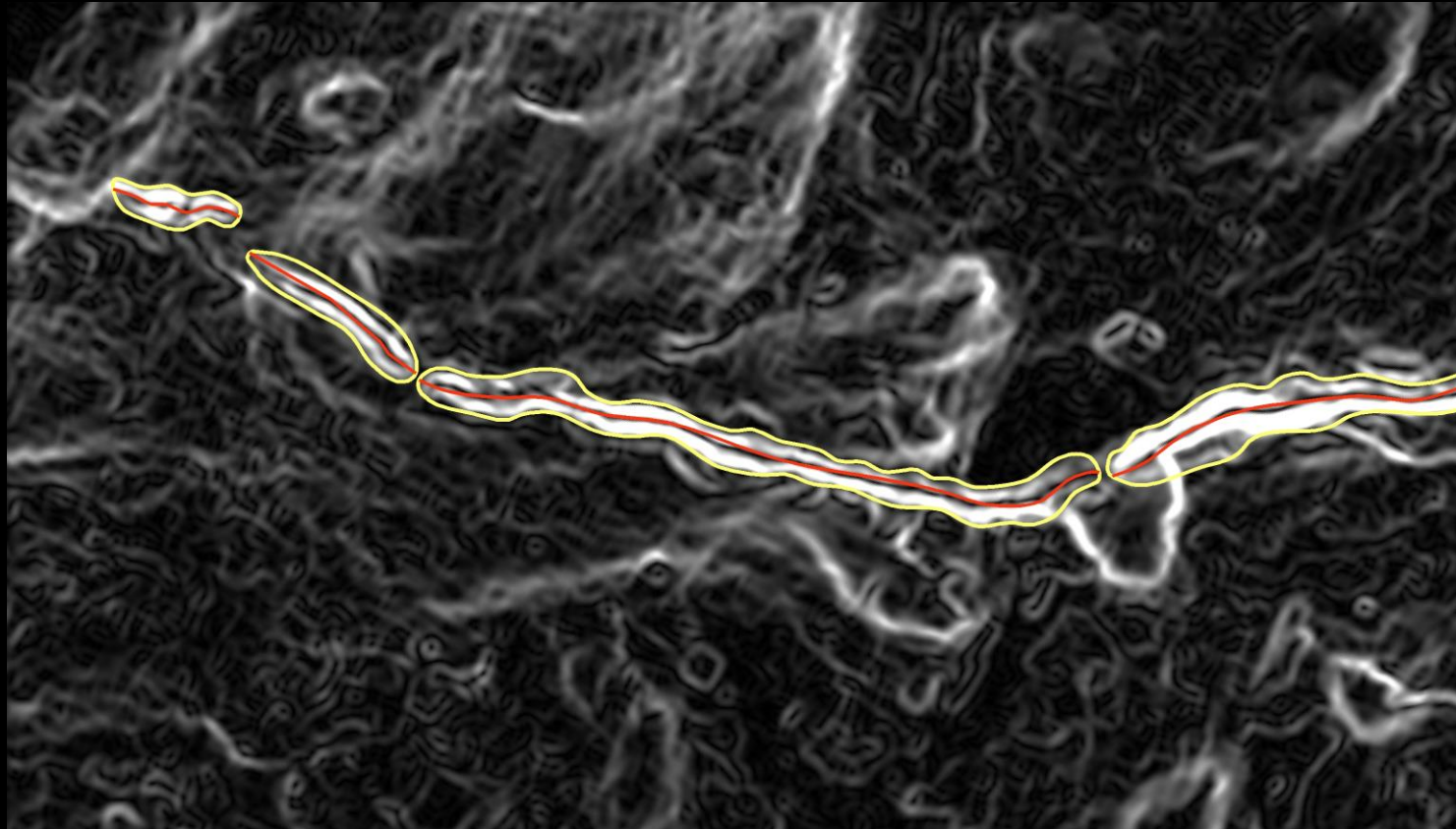
Digitisation

1. Identification in hillshaded DEM
 - Canada: ArcticDEM
 - Finland: Lidar
2. Digitisation in slope-shaded DEM



Digitisation

1. Identification in hillshaded DEM
 - Canada: ArcticDEM
 - Finland: Lidar
2. Digitisation in slope-shaded DEM
 - Crestline
 - Outline



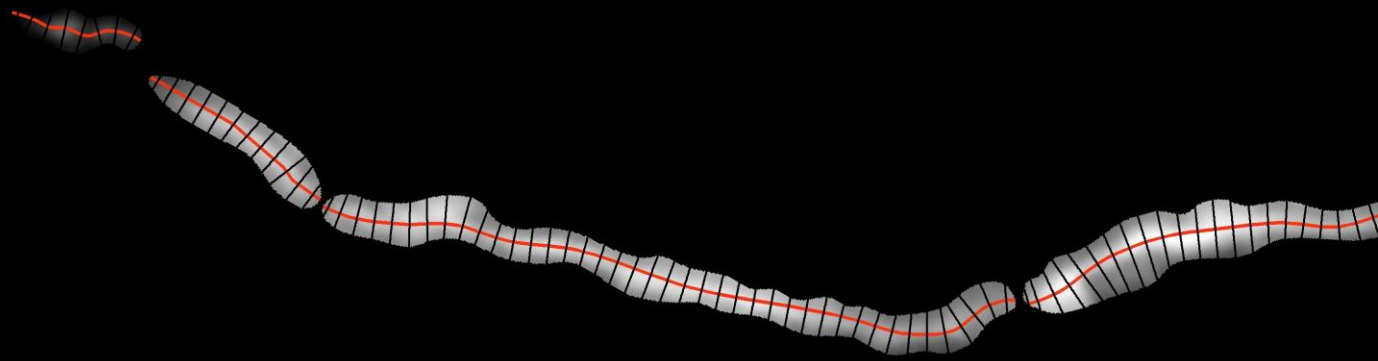
Digitisation

1. Identification in hillshaded DEM
 - Canada: ArcticDEM
 - Finland: Lidar
2. Digitisation in slope-shaded DEM
 - Crestline
 - Outline
3. Extraction of DEM



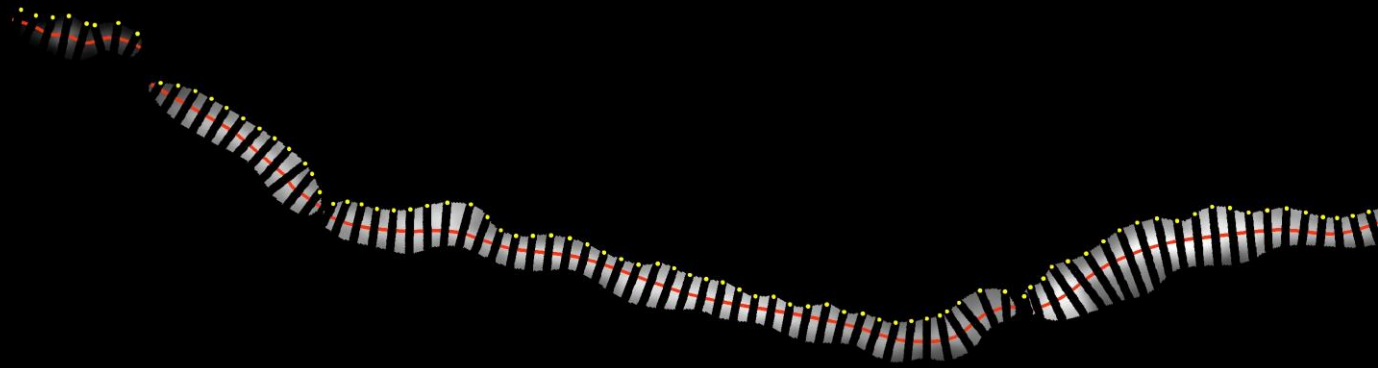
Digitisation

1. Identification in hillshaded DEM
 - Canada: ArcticDEM
 - Finland: Lidar
2. Digitisation in slope-shaded DEM
 - Crestline
 - Outline
3. Extraction of DEM
4. Transects at 90° to crestline
 - 25 m intervals (example shows 100 m)



Digitisation

1. Identification in hillshaded DEM
 - Canada: ArcticDEM
 - Finland: Lidar
2. Digitisation in slope-shaded DEM
 - Crestline
 - Outline
3. Extraction of DEM
4. Transects at 90° to crestline
 - 25 m intervals
(example shows 100 m)
5. Points every 2 m along transects

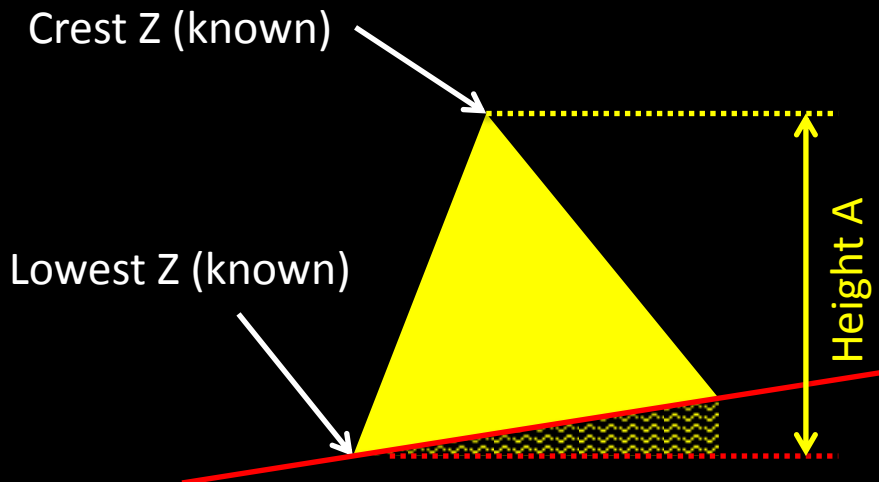


Height

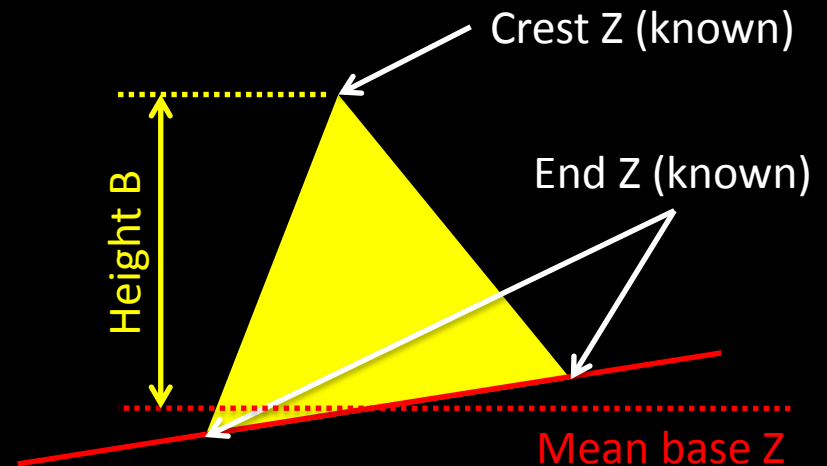


- Height measured using Z values of esker transects
- Base elevation is unknown, so estimated in two ways:

A: upper estimate



B: lower estimate

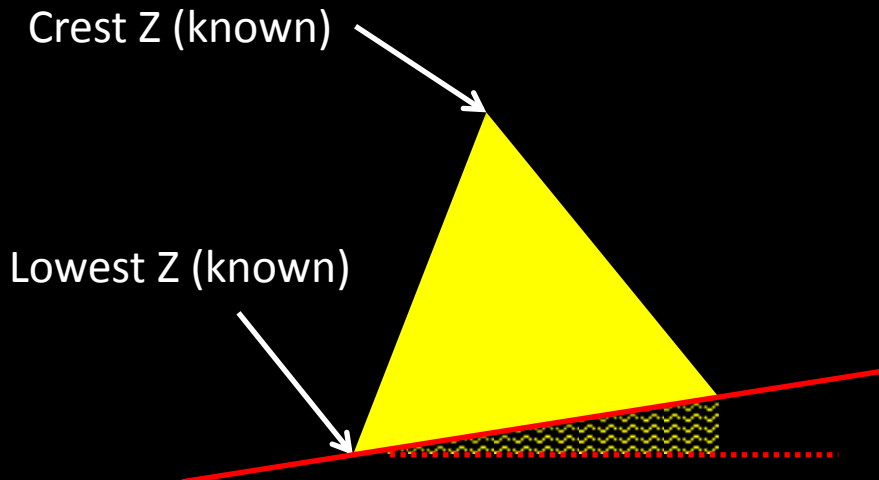


Cross-sectional area/volume

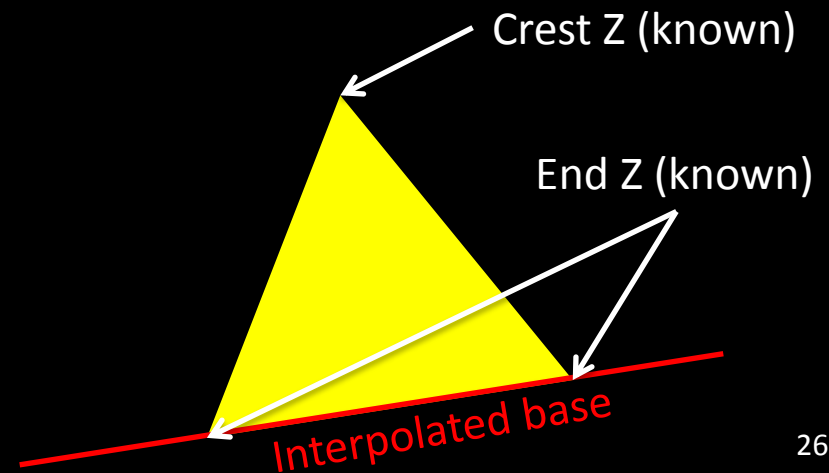
- Cross-sectional area calculated using similar methods to height
- Volume estimated by multiplying by 25 m spacing



A: upper estimate

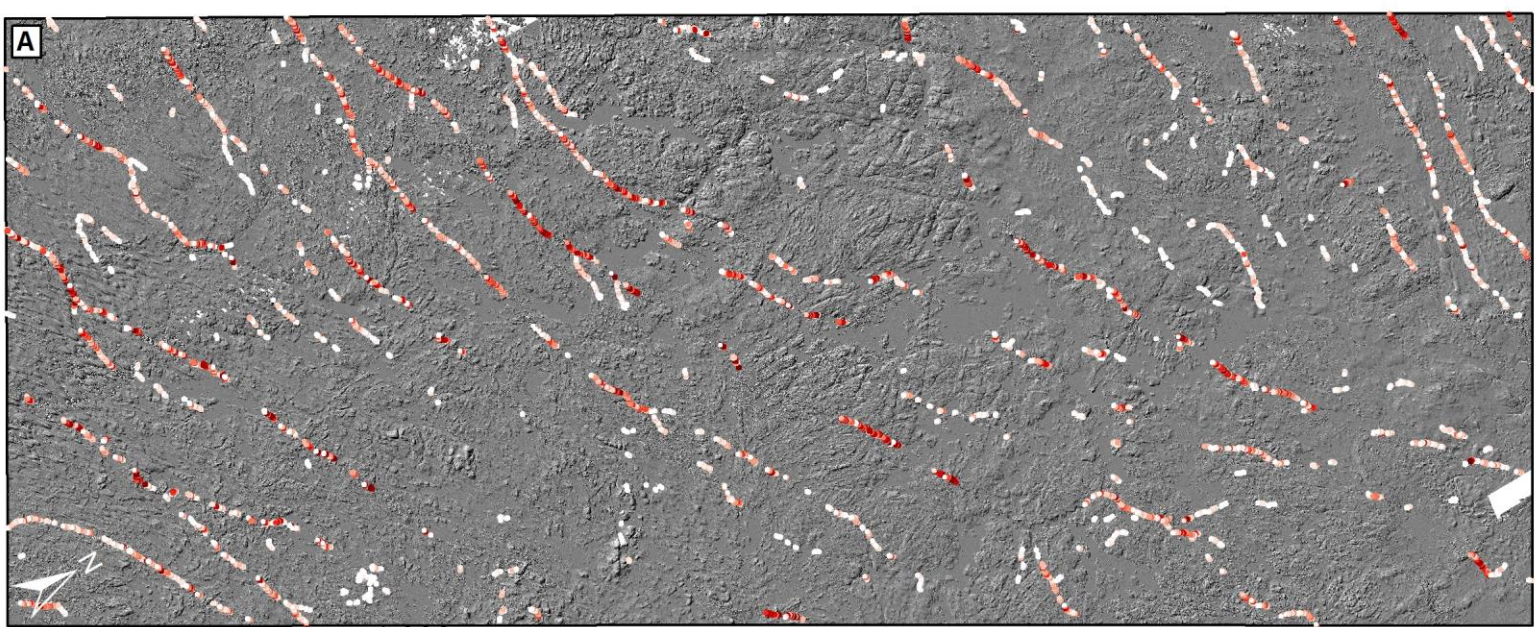


B: lower estimate

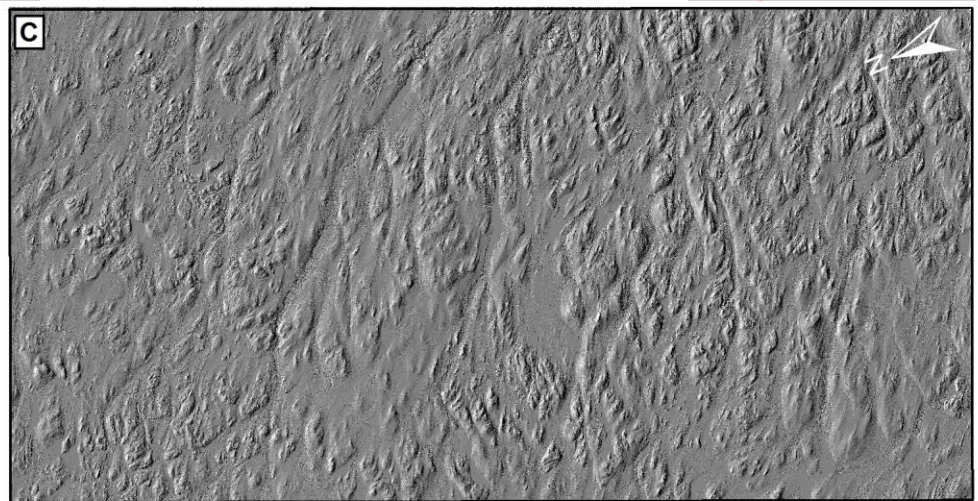
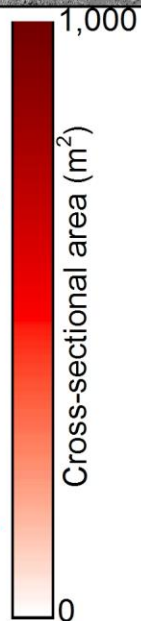
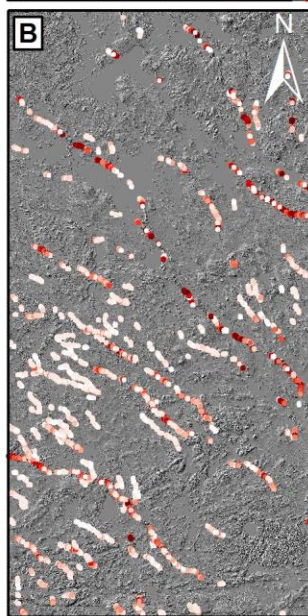


Cross-sectional area

Canada



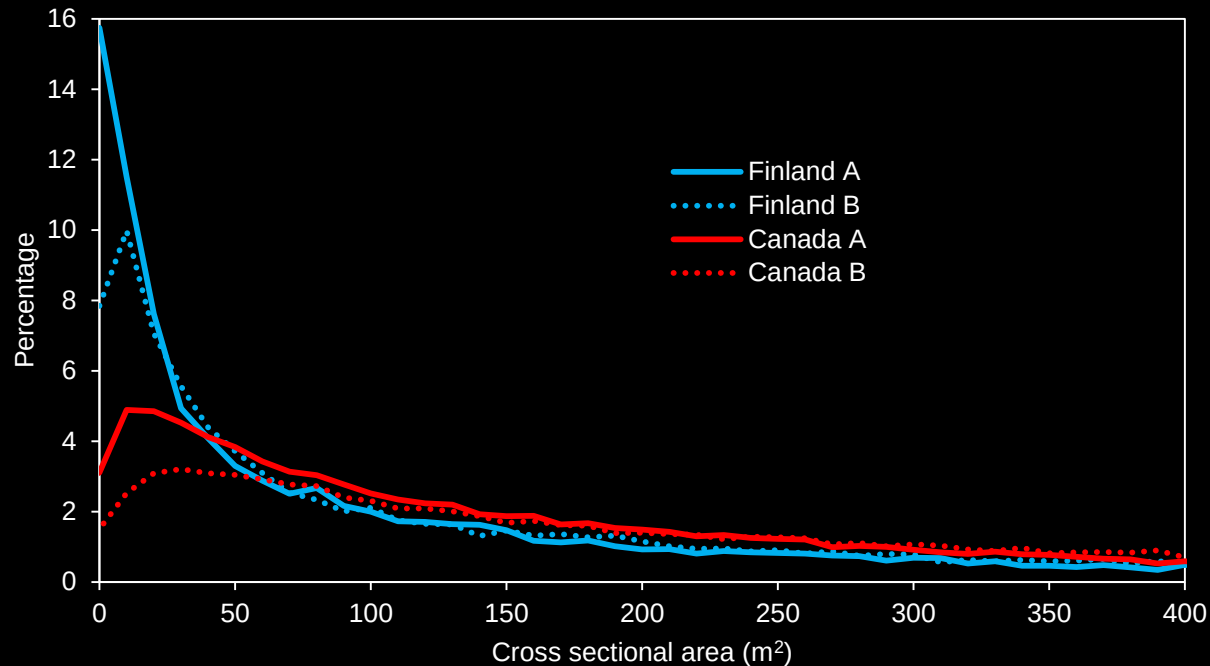
Finland



Sweden



Cross-sectional area

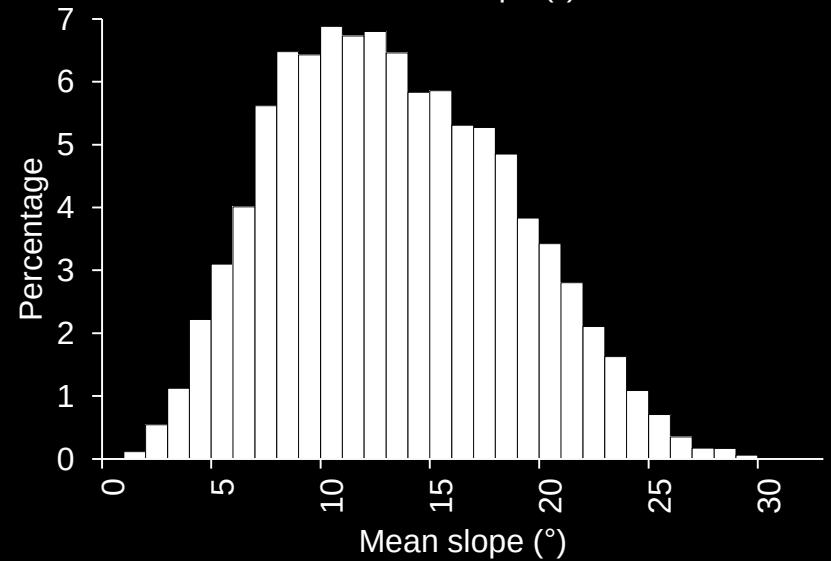
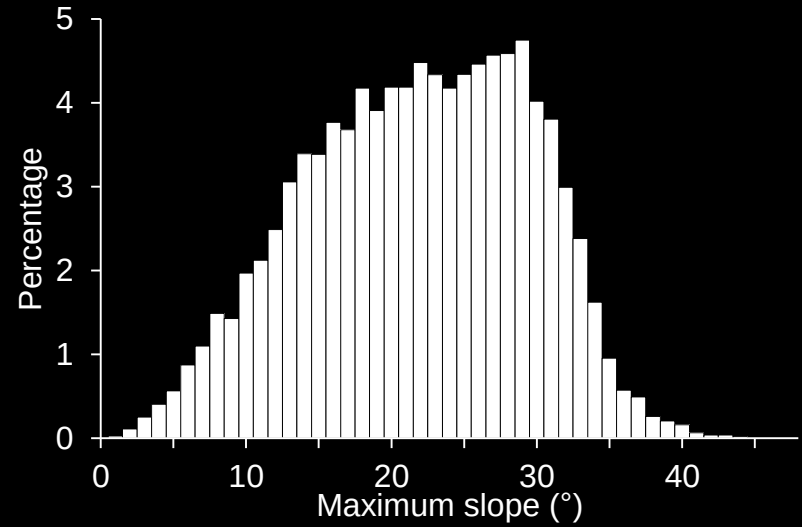


- Most eskers have a cross sectional area of 10s to 100s m²
- Finland has more smaller eskers, and fewer larger eskers than Canada (corresponding to width results presented above)

Slope



Slope values extracted every 2 m along transects.



Slope

Relevance:

Flat-topped:

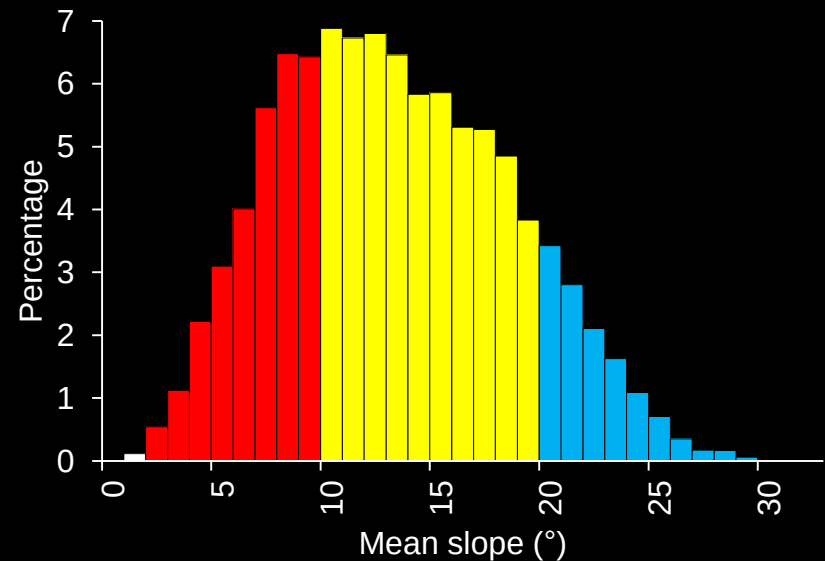
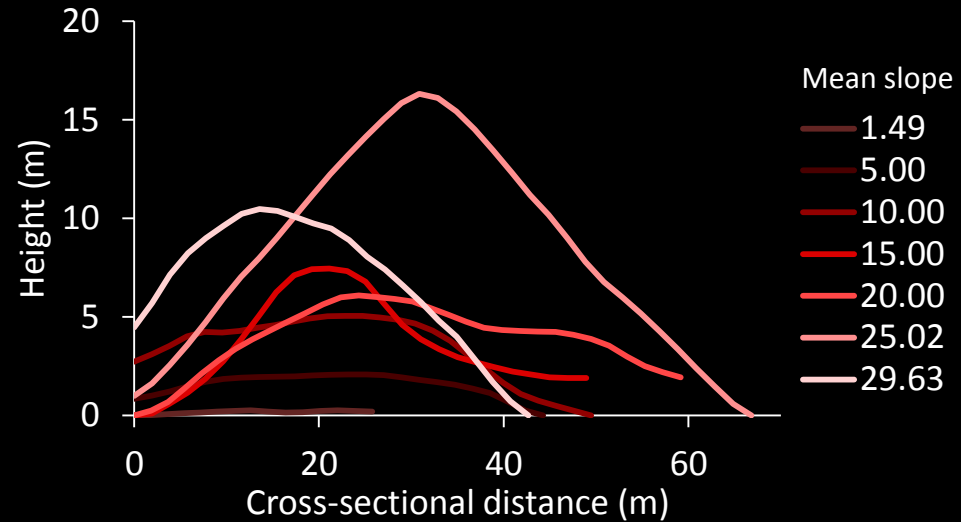
- Deposition in ice-walled canyons, or in tunnels under atmospheric pressure (Perkins *et al.*, 2016, QSR)
- Deposition in ascending reaches undergoing tunnel freezing (Shreve, 1985 *GSA Bull*)
- Mean slope $< \sim 10^\circ$

Round-crested

- Subglacial conduits (Perkins *et al.* 2016 QSR)
- Mean slope $\sim 10 - 20^\circ$

Sharp-crested:

- Flat/descending reaches, tunnel melting (Shreve, 1985)
- Forming near/at the ice surface (Perkins *et al.*, 2016 QSR)
- Meltout of englacial/supraglacial eskers (Price, 1966)
- Mean slope $> \sim 20^\circ$



Slope

Relevance:

Flat-topped:

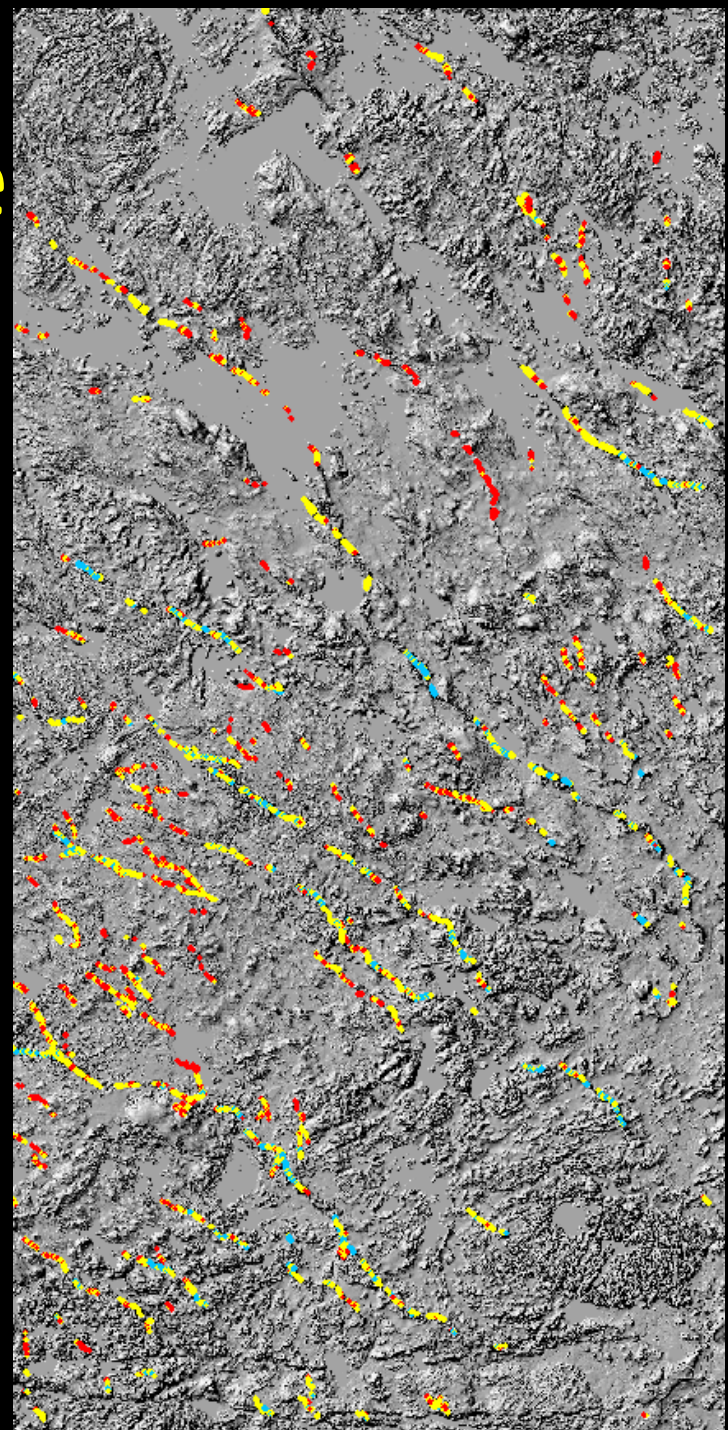
- Deposition in ice-walled canyons, or in tunnels under atmospheric pressure (Perkins *et al.*, 2016, QSR)
- Deposition in ascending reaches undergoing tunnel freezing (Shreve, 1985 *GSA Bull*)
- Mean slope $< \sim 10^\circ$

Round-crested

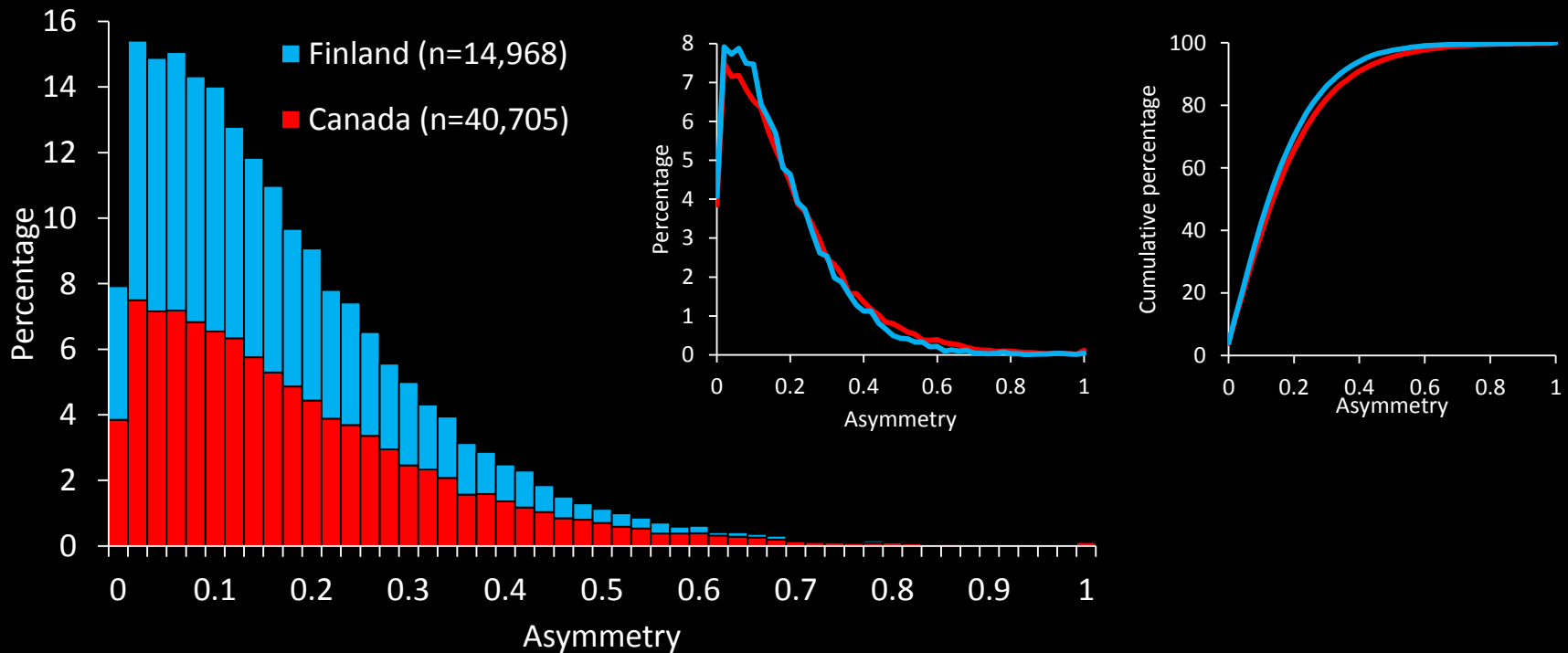
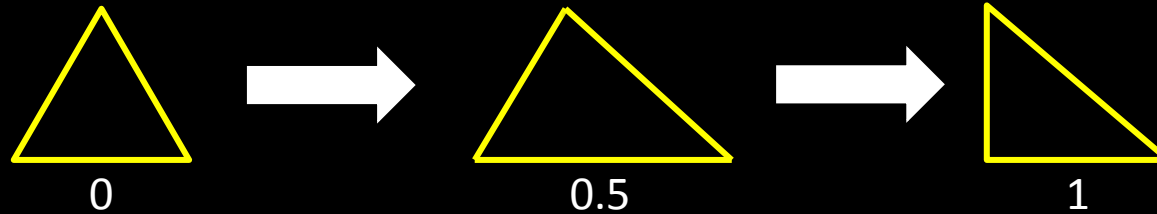
- Subglacial conduits (Perkins *et al.* 2016 QSR)
- Mean slope $\sim 10 - 20^\circ$

Sharp-crested:

- Flat/descending reaches, tunnel melting (Shreve, 1985)
- Forming near/at the ice surface (Perkins *et al.*, 2016 QSR)
- Meltout of englacial/supraglacial eskers (Price, 1966)
- Mean slope $> \sim 20^\circ$



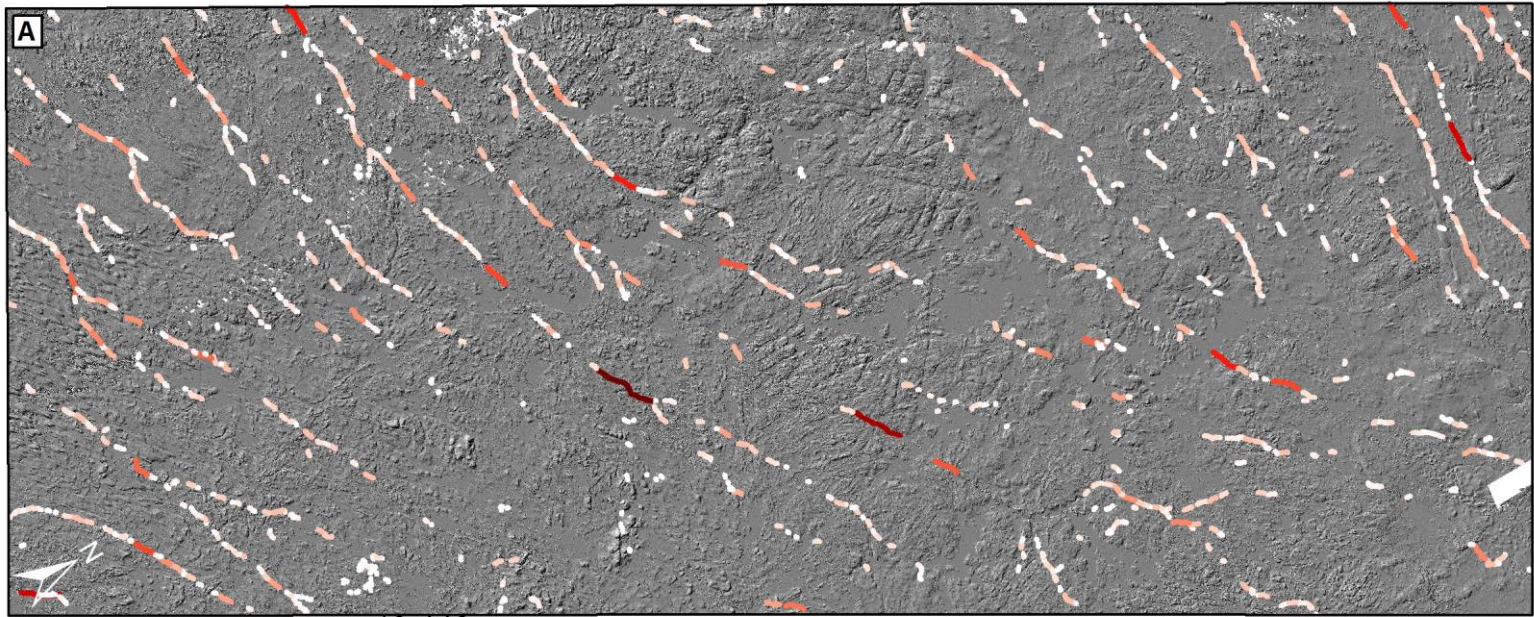
Cross-sectional asymmetry



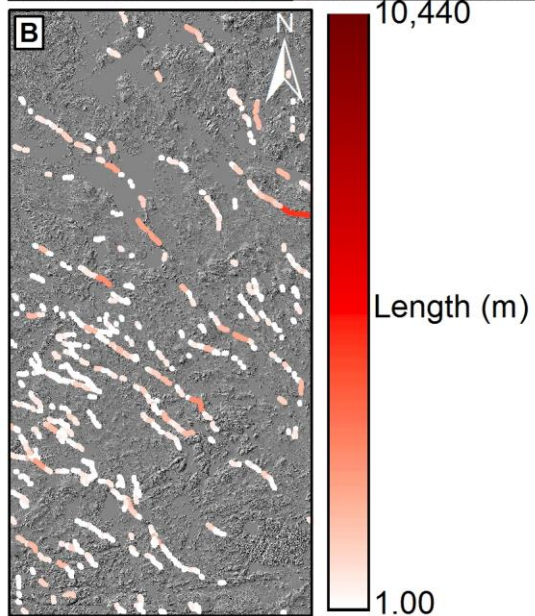
- Eskers are usually somewhat symmetrical (the crestline is usually near the centre line)
- Close distributions between datasets provide support for robustness of methods

Segment length

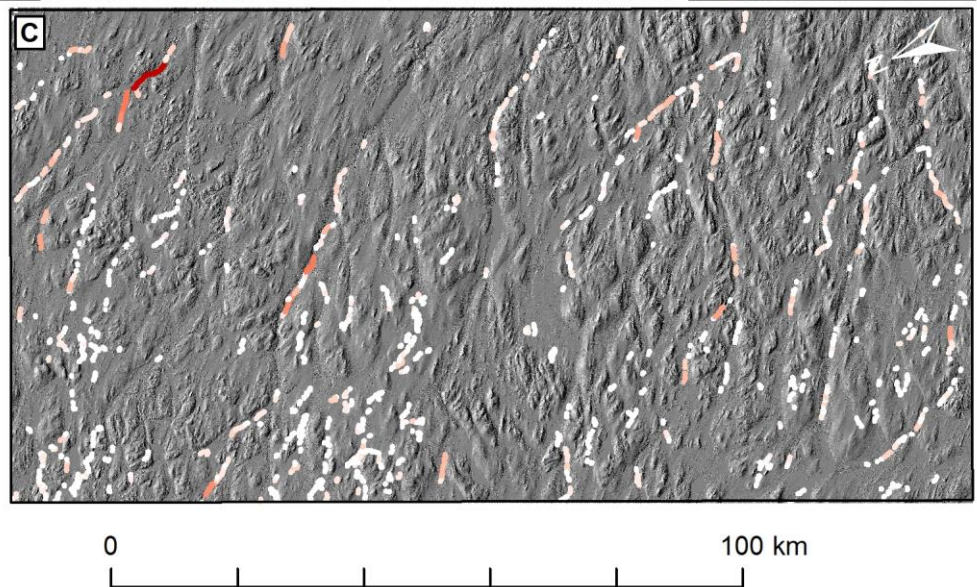
Canada



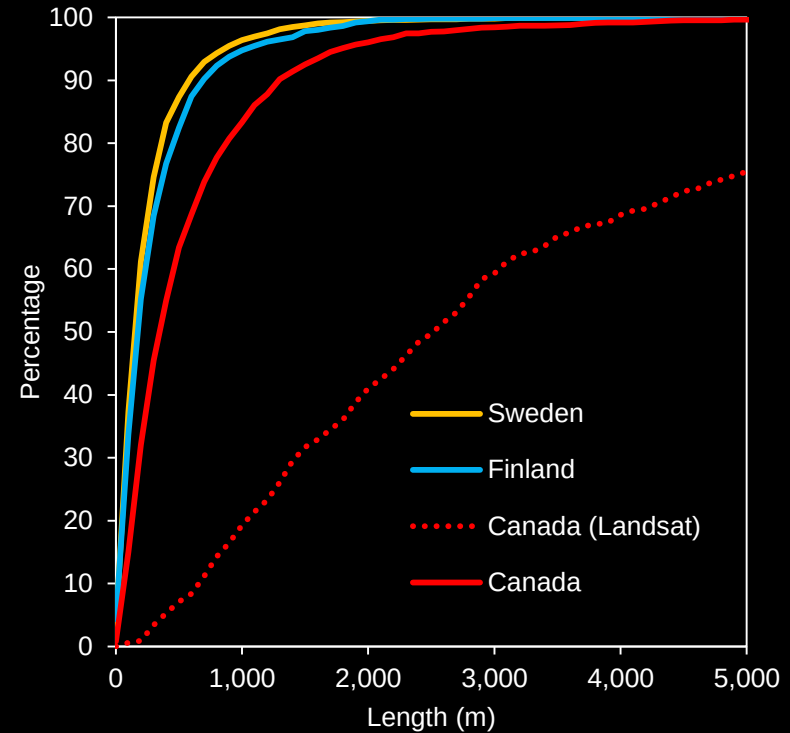
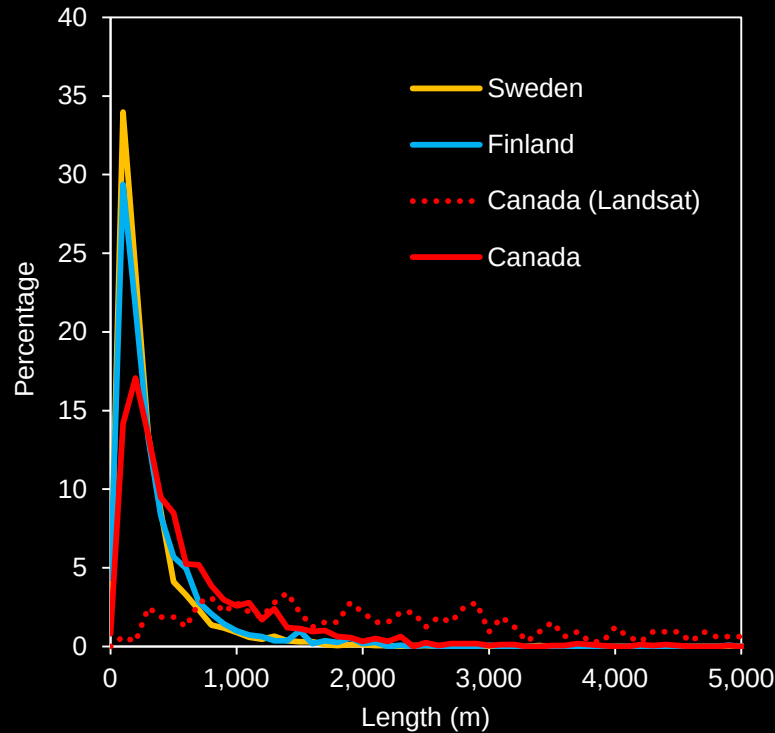
Finland



Sweden



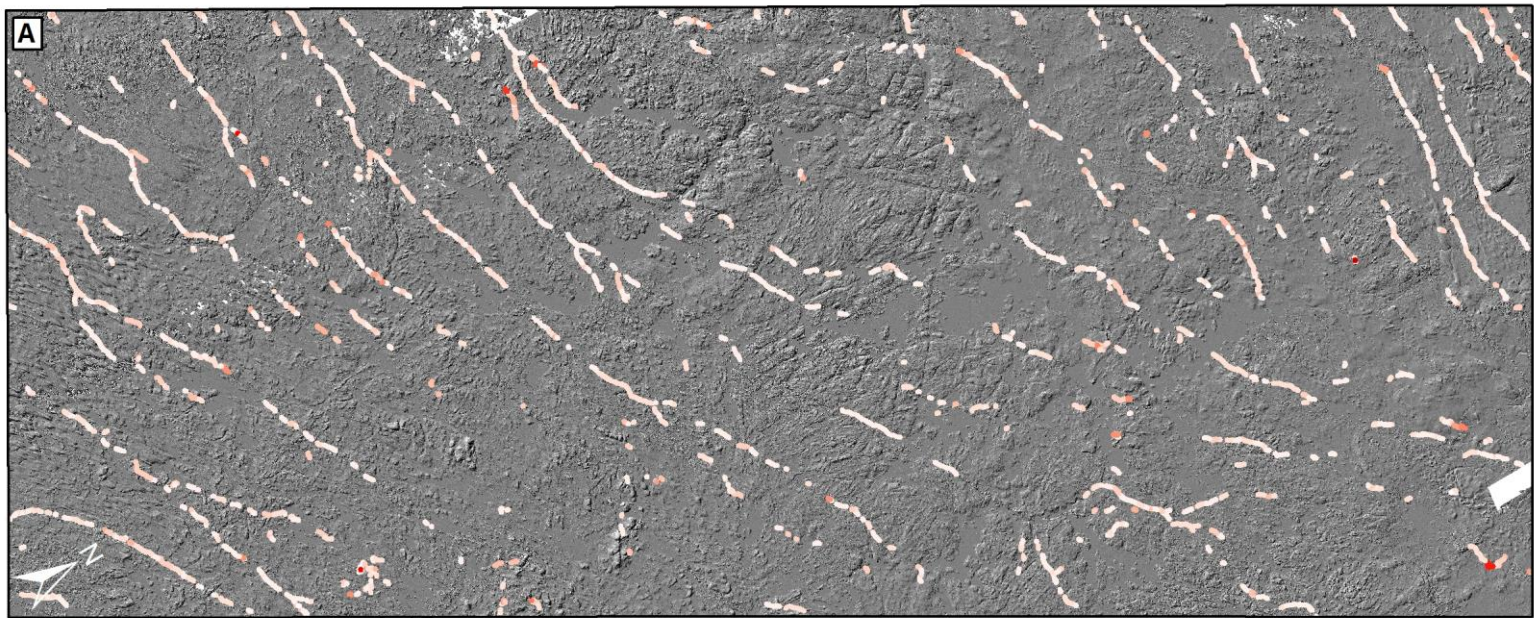
Segment length



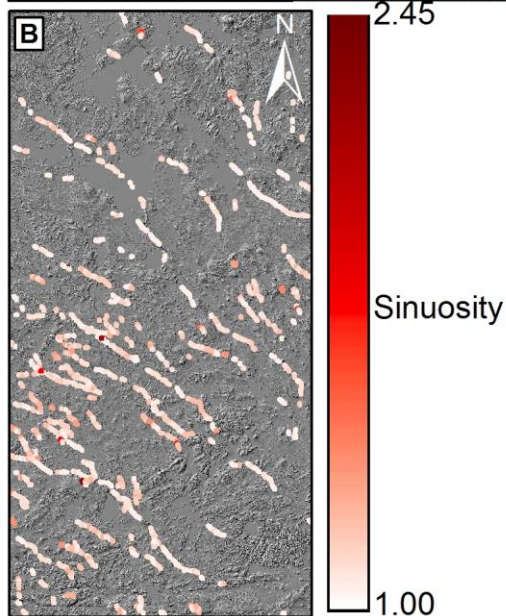
- Anthropogenic disturbance of Scandinavian eskers (e.g. quarrying, road building) likely accounts for differences with Canada (significantly less inhabited)
- Resolution difference of 2 m DEMs vs. 30 m Landsat (Storrar *et al.*, 2014 QSR) produces very different segment length measurements

Segment sinuosity

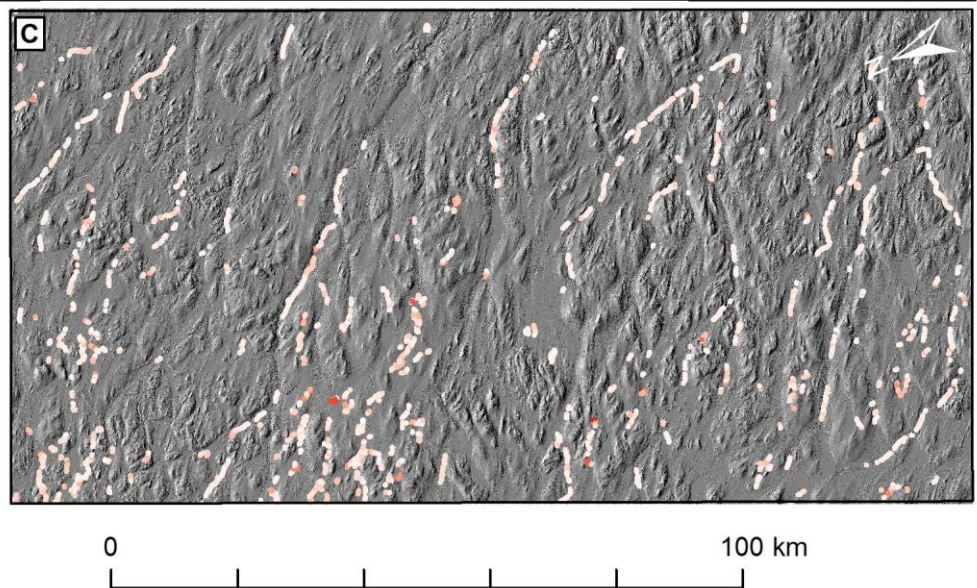
Canada



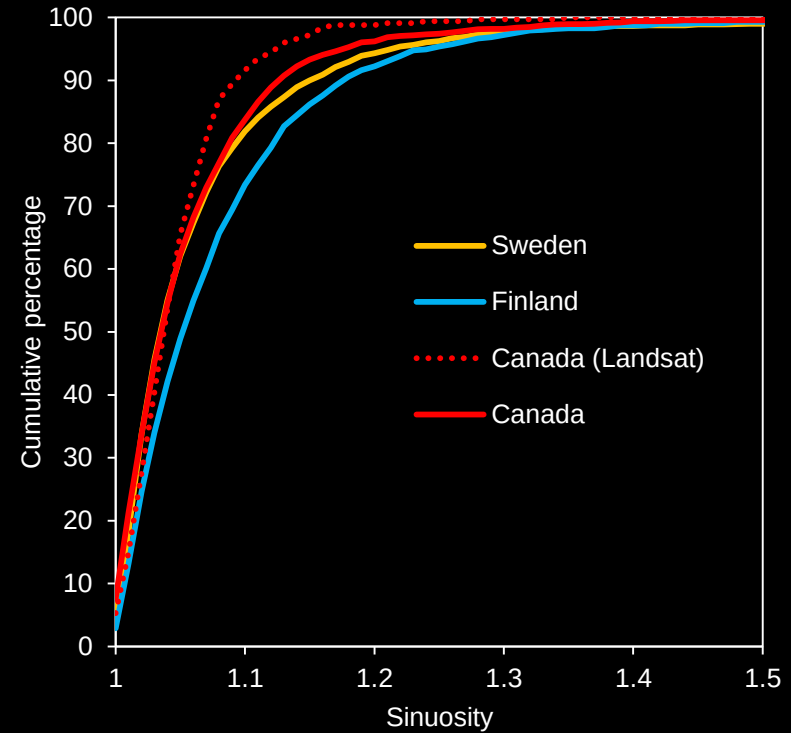
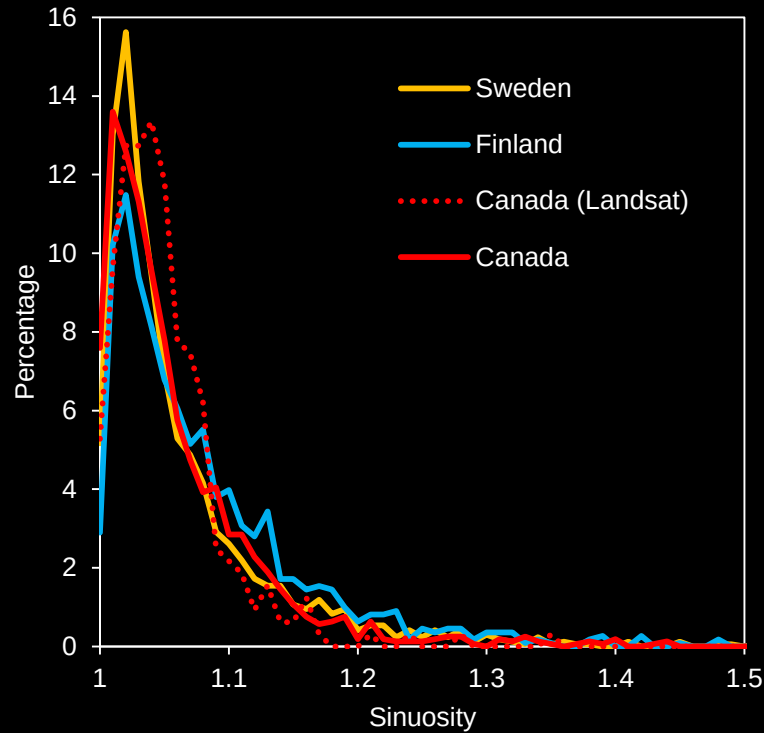
Finland



Sweden



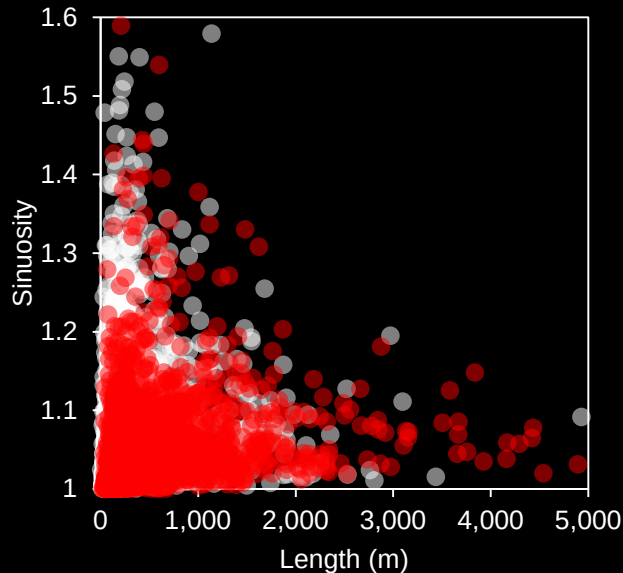
Sinuosity



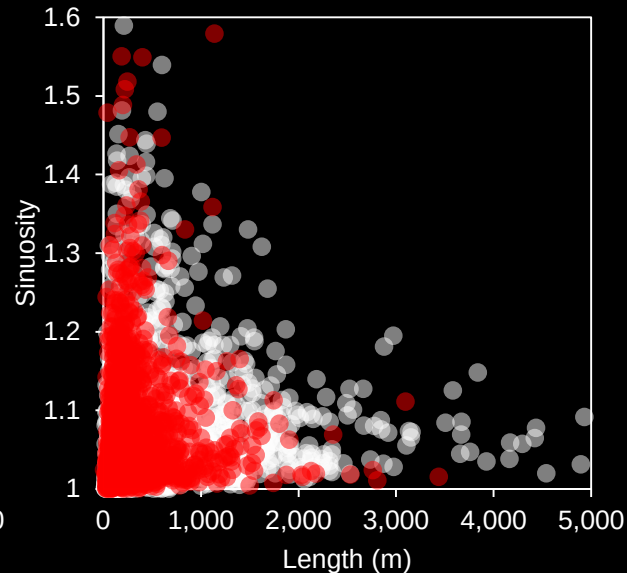
- Sinuosity very similar across all sites (and even between data sources)
- Reinforces that eskers (and so R-channels) are somewhat straight

Length vs. Sinuosity

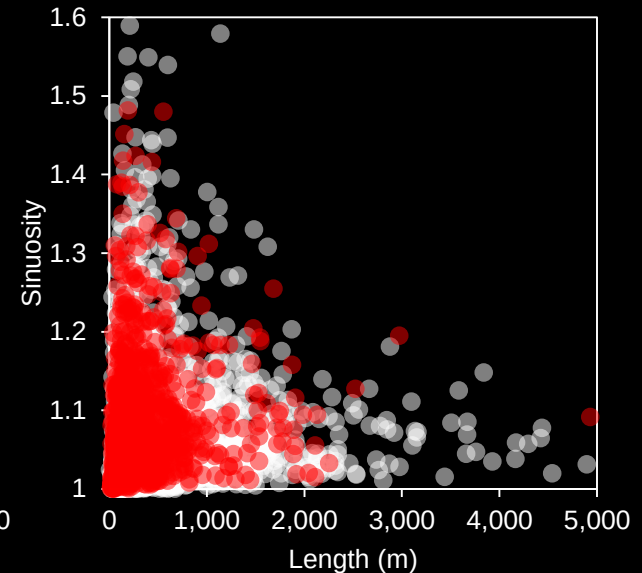
Canada



Sweden



Finland



- Sinuous eskers are preferentially short
- Long eskers are preferentially straight
- Smaller, transient, lower energy, sinuous channels
- Larger, more stable, higher energy, straight channels
- Similar relationships between sites (longer, less disturbed Canadian eskers)