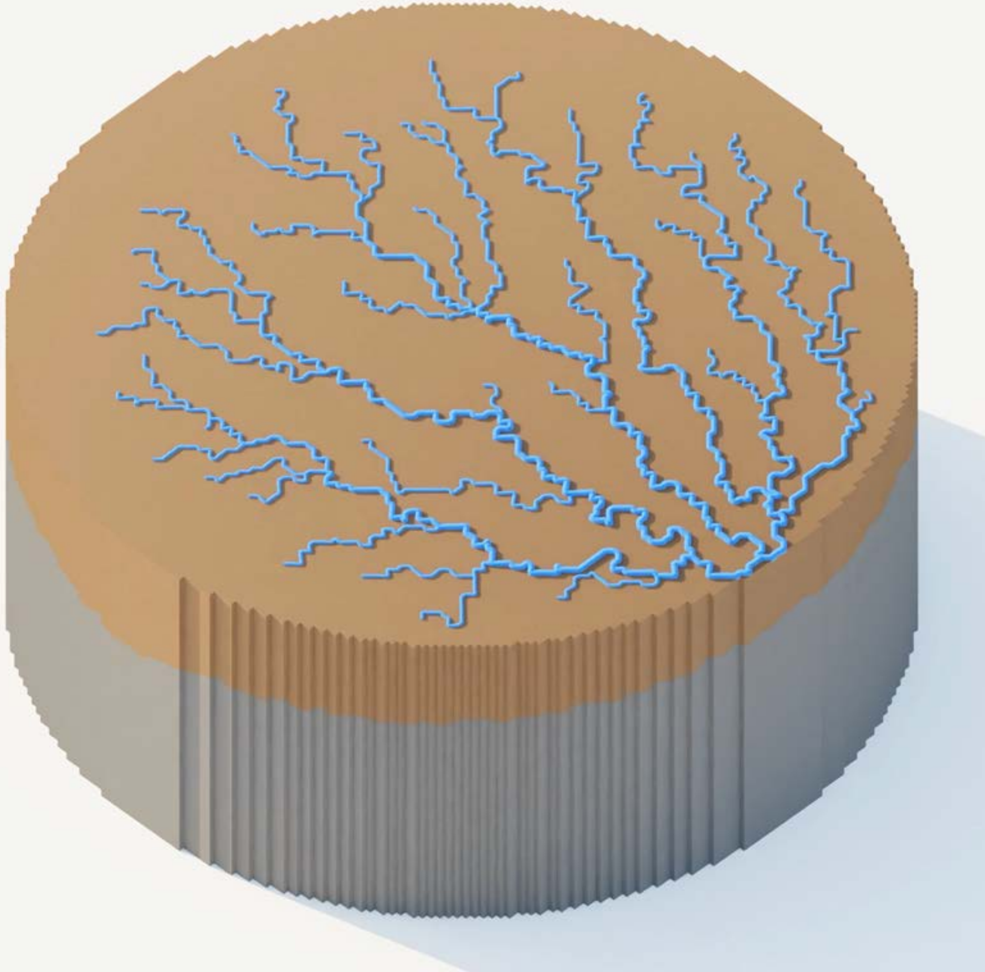
AGU Fall Meeting 2023: EP32A-07

Drainage network signatures of landscape reorganization in post-glacial landscapes



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12/13/23

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ST. ANTHONY FALLS LABORATORY

UNIVERSITY OF MINNESOTA

Driven to Discover℠

The Driftless Area

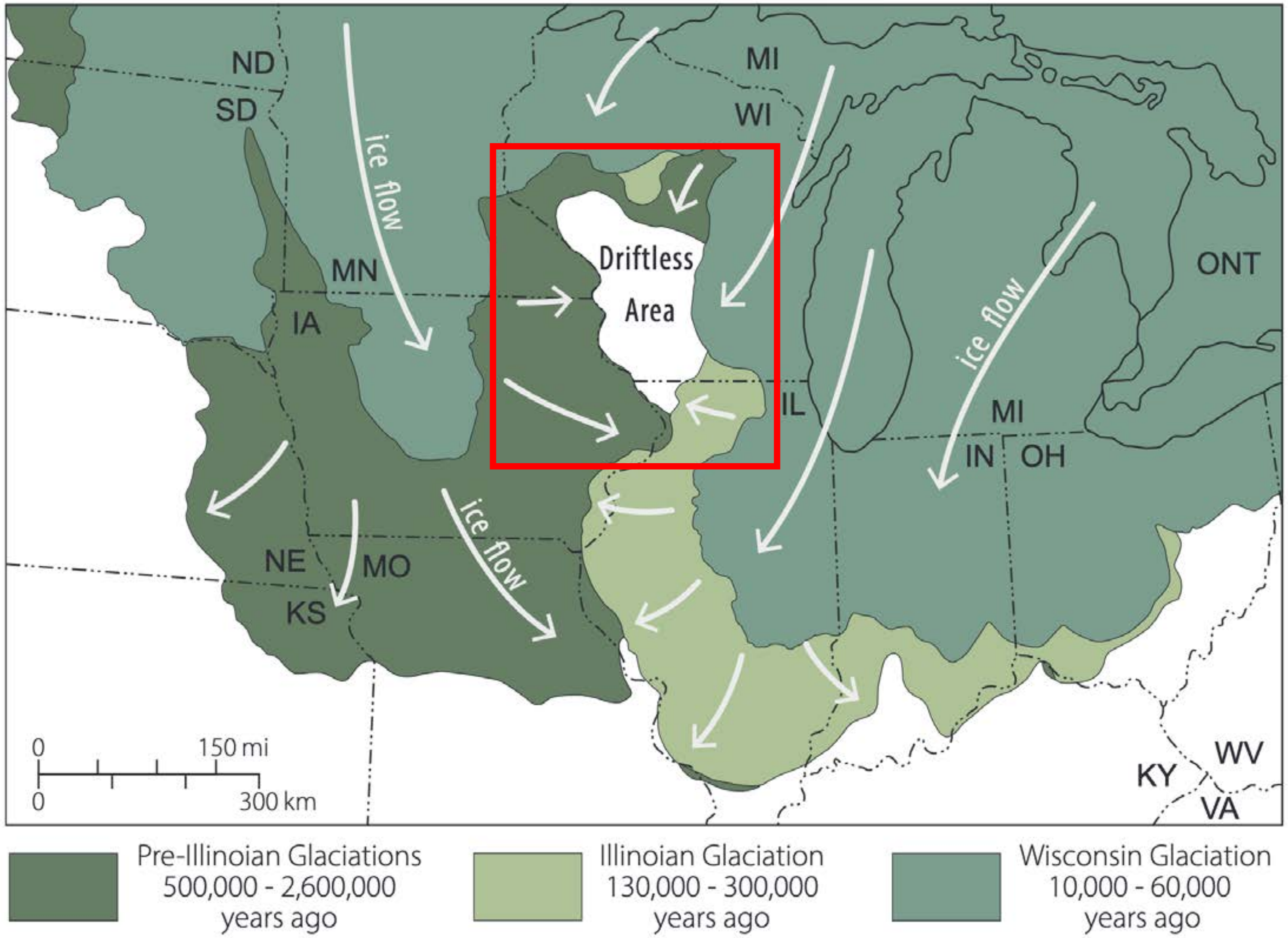


Figure 1. Age and distribution of glacial deposits surrounding the Driftless Area, showing general direction of ice flow for glaciers that bounded the Driftless Area.

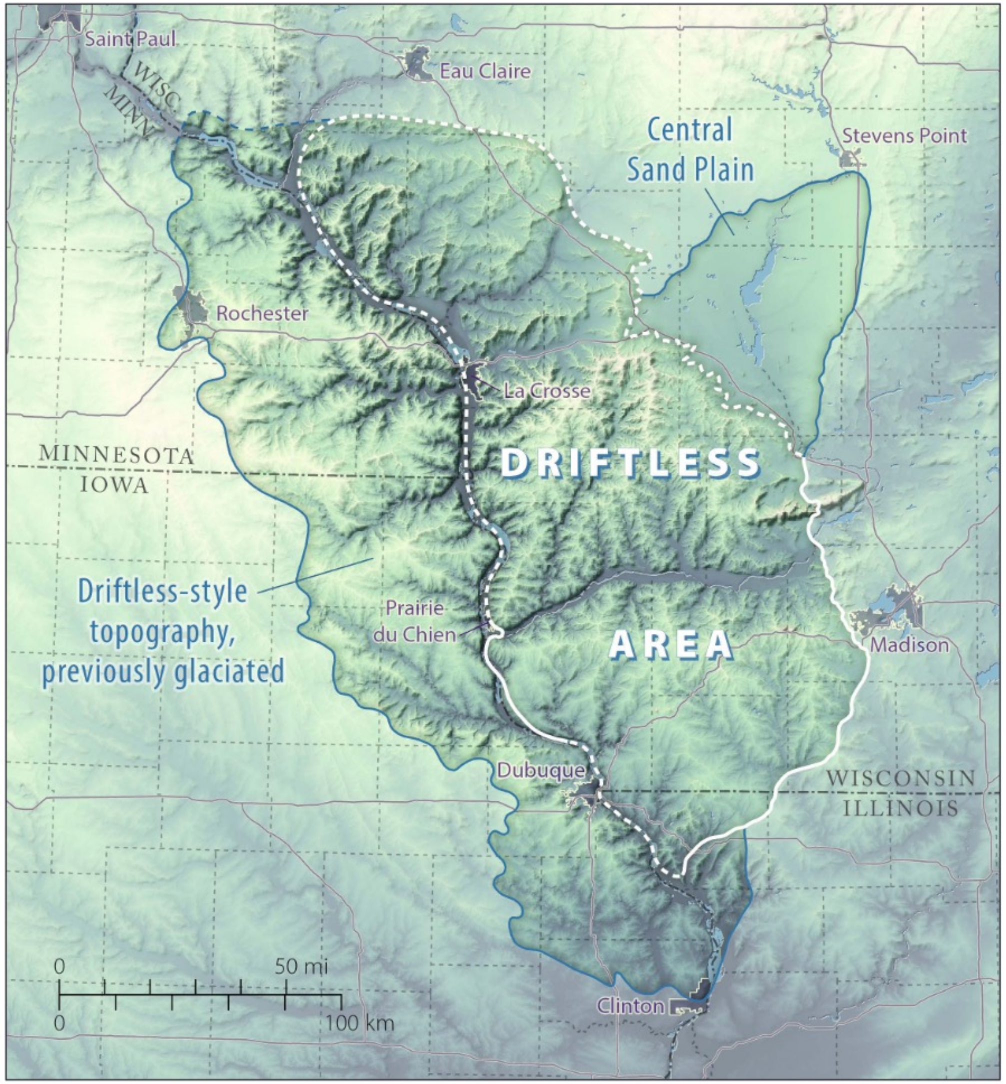
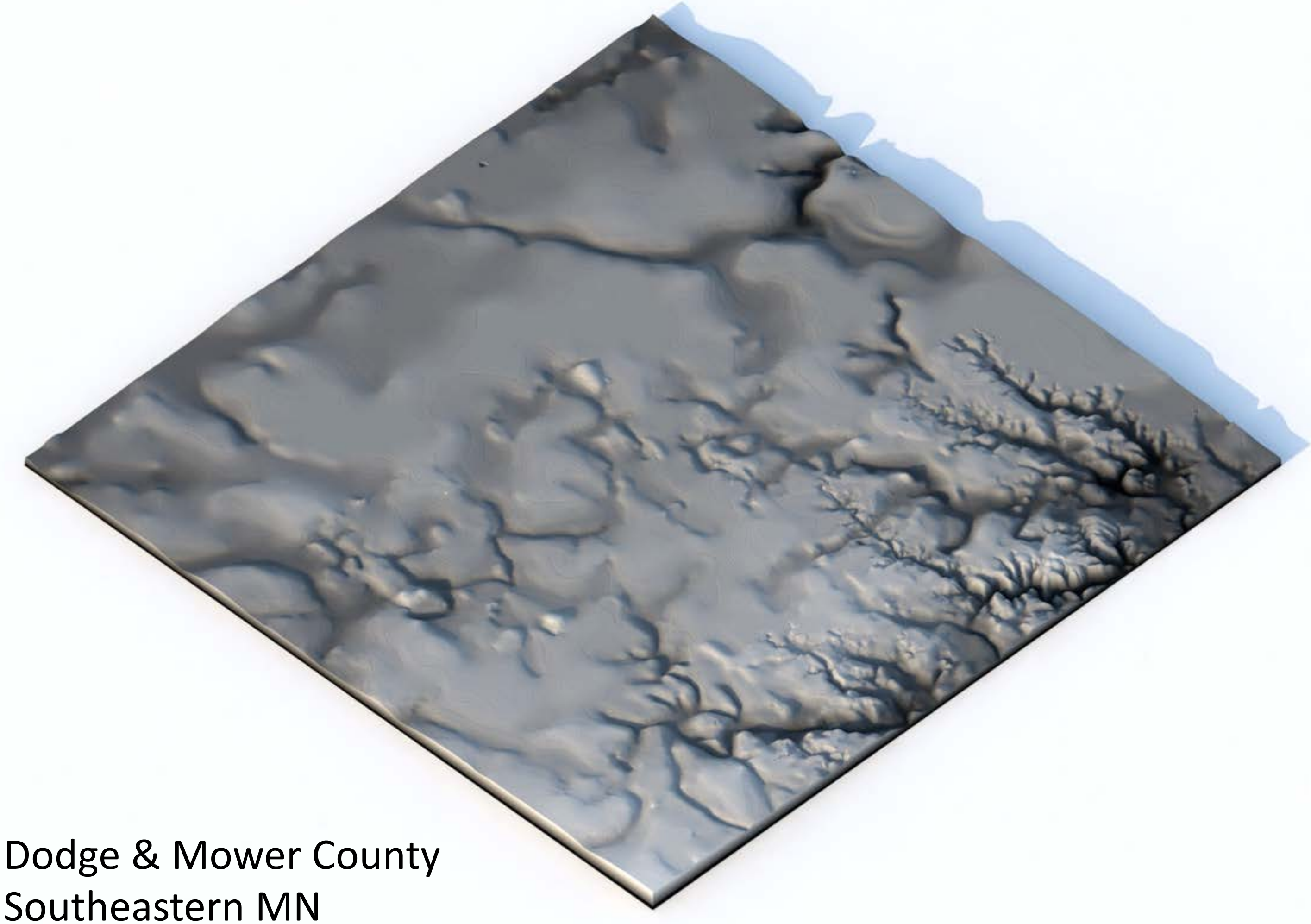


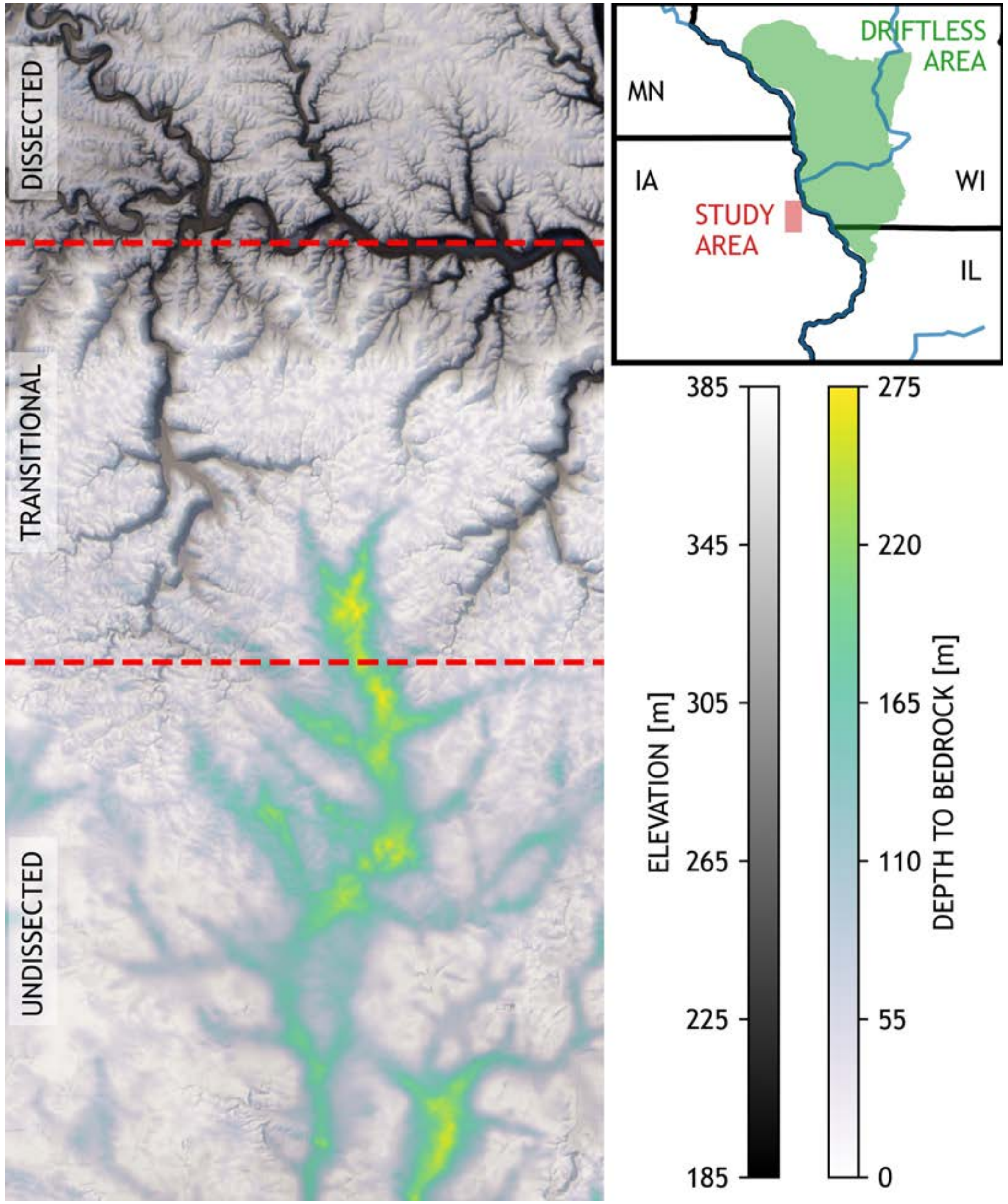
Figure 2. Extent of the Driftless Area in southwestern Wisconsin and northwestern Illinois, and similar landscapes in adjacent areas of Minnesota and Iowa that were glaciated in the relatively distant geologic past. Dashed lines indicate uncertain or inferred boundaries.

Wisconsin Geological and Natural History Survey

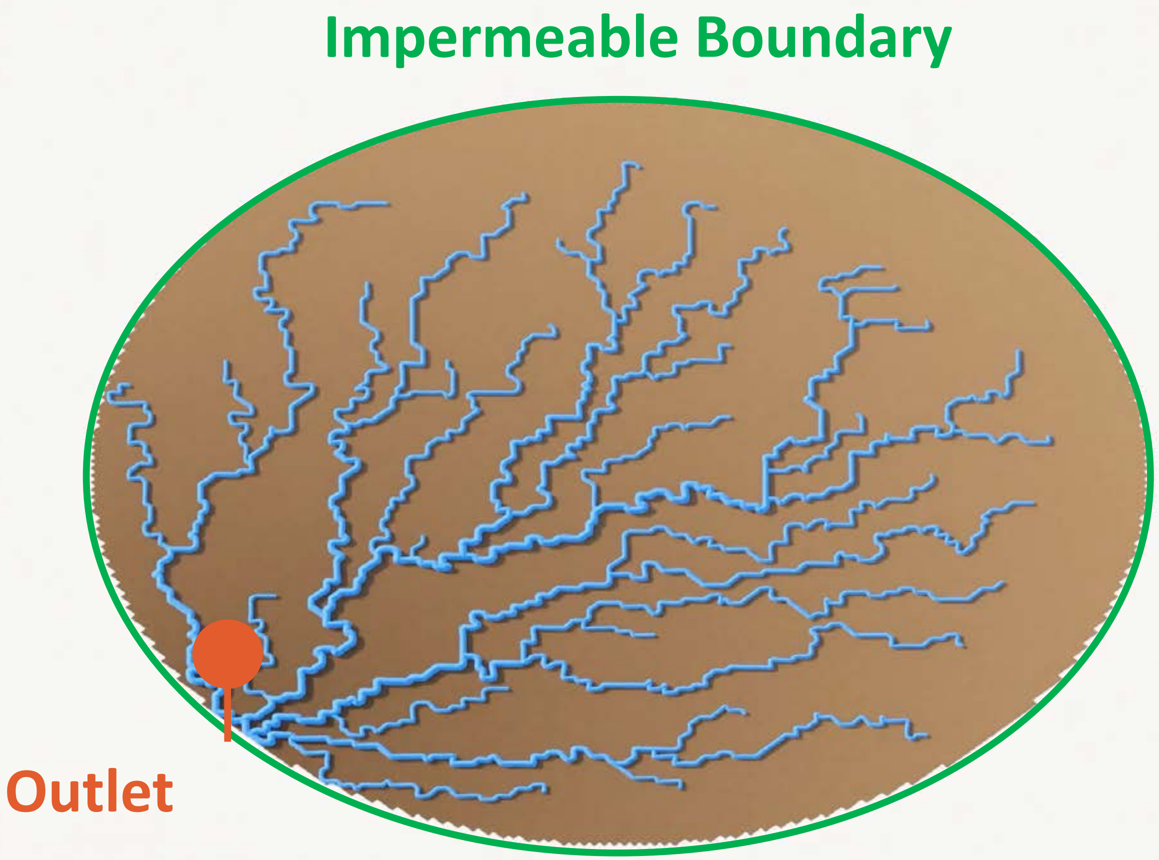
A natural experiment



Dodge & Mower County
Southeastern MN



Landscape evolution models (LEMs)



$$\frac{\partial \eta}{\partial t} = U - KA^m S^n + D\nabla^2 \eta$$

In words…

The change in elevation equals

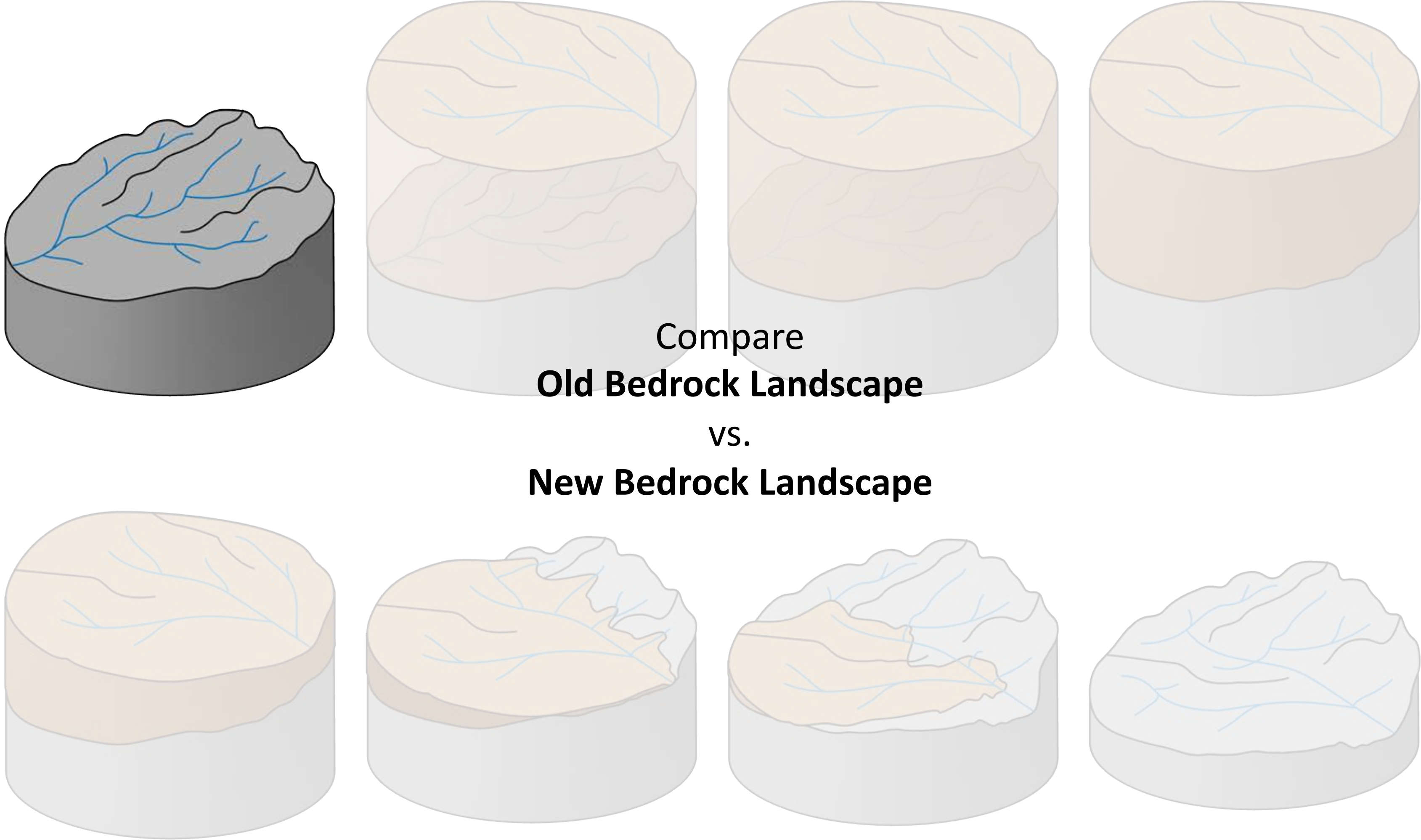
- + rock uplift/baselevel fall rate
- - fluvial erosion
- + hillslope diffusion

Modeling Procedure

$$\frac{\partial \eta}{\partial t} = U - KA^{m}S^{n} + D\nabla^{2}\eta$$

Bury Bedrock with Glacial Till

Steady State Bedrock Landscape



K_T – Erodibility of Glacial Till

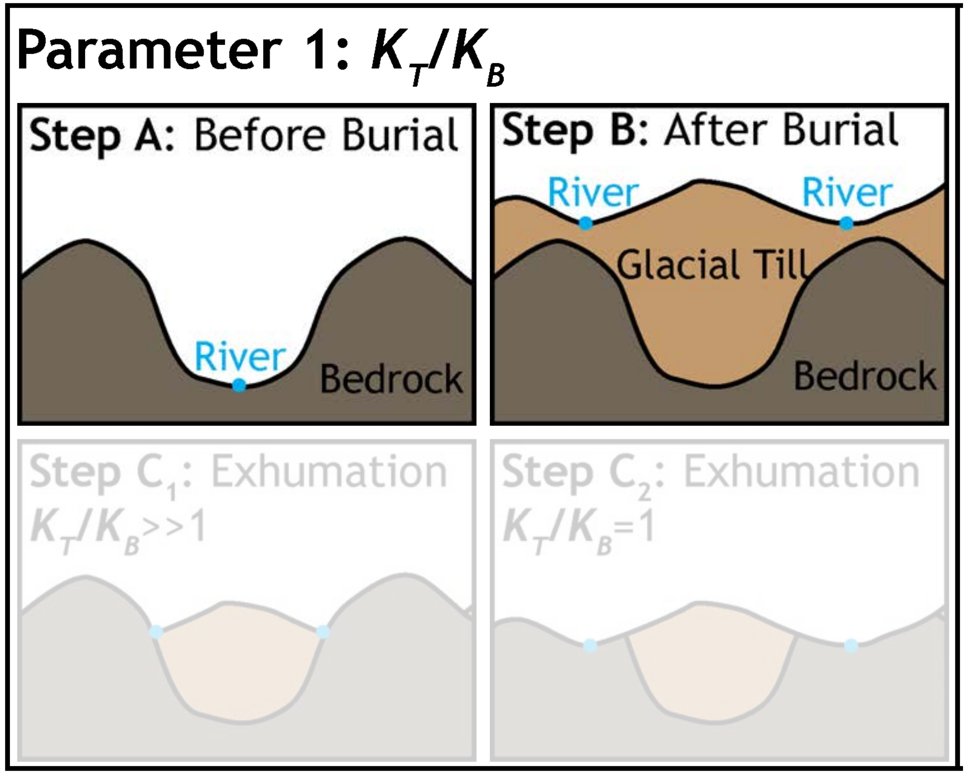
K_B – Erodibility of Bedrock

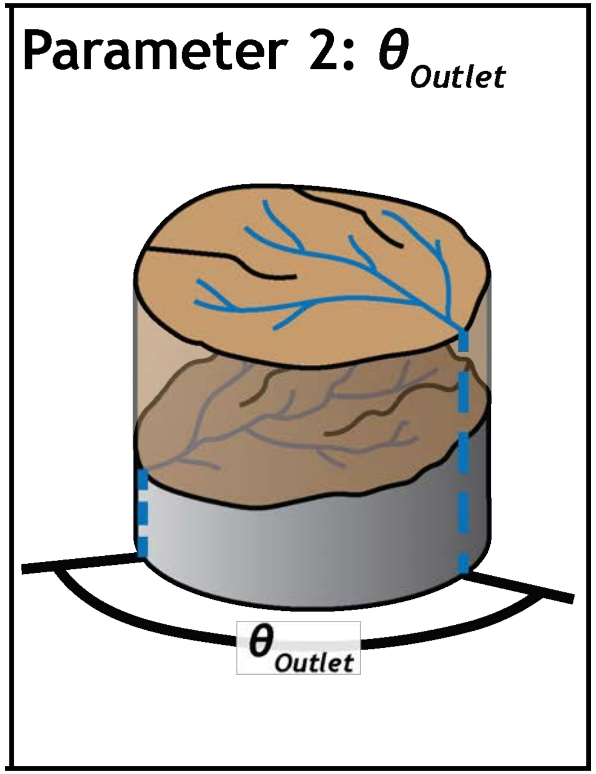
Erode Landscape and Exhume Bedrock

Parameters of Interest

Contrast in rock erodibility, $\frac{K_T}{K_B}$

Deviation angle between bedrock and surface outlet, θ_{Outlet}





$0° < \theta_{Outlet} < 180°$

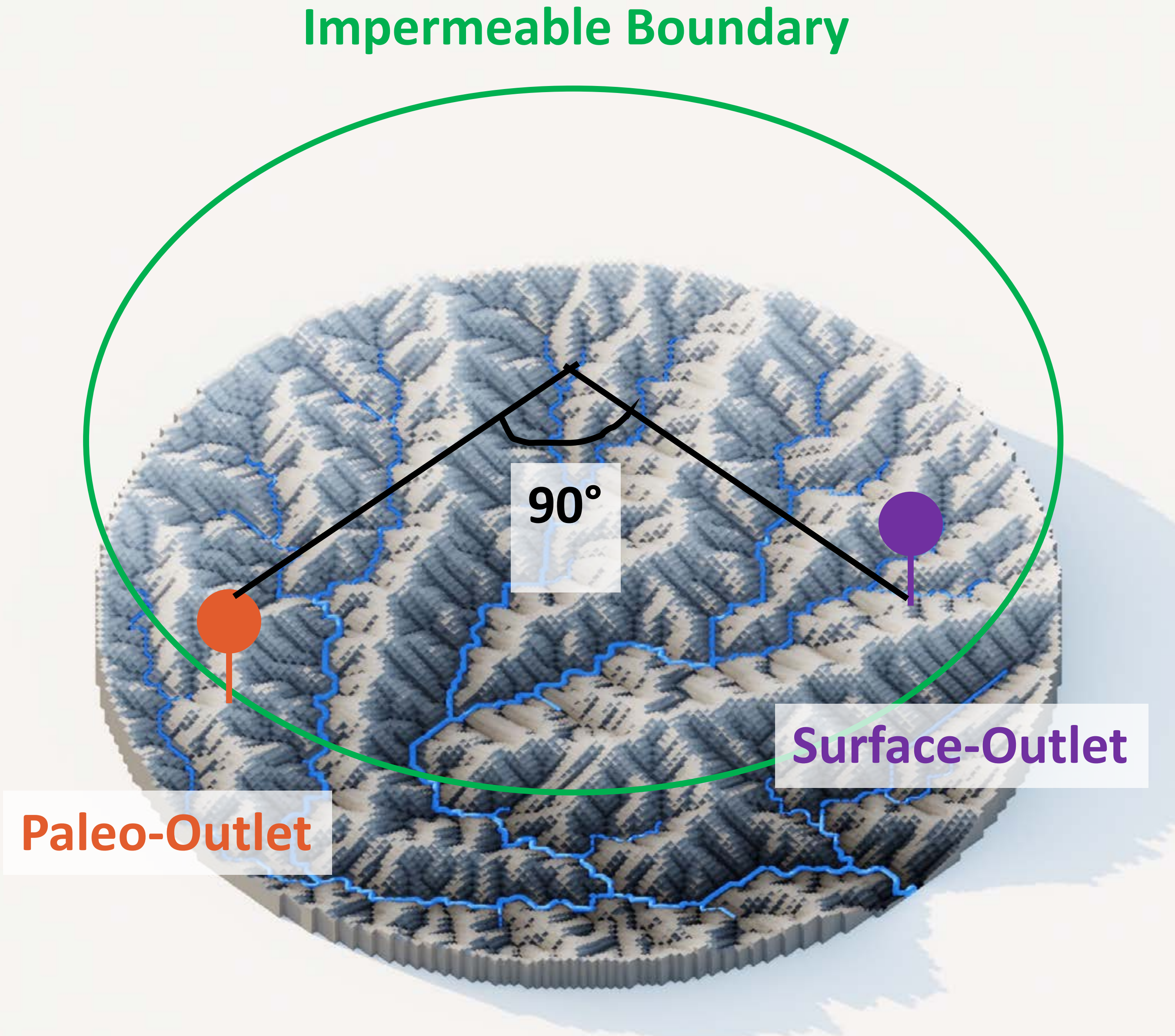
An Example Simulation

Parameters: $\frac{K_T}{K_B}$ **= 20 and** θ_{Outlet} **= 90°**

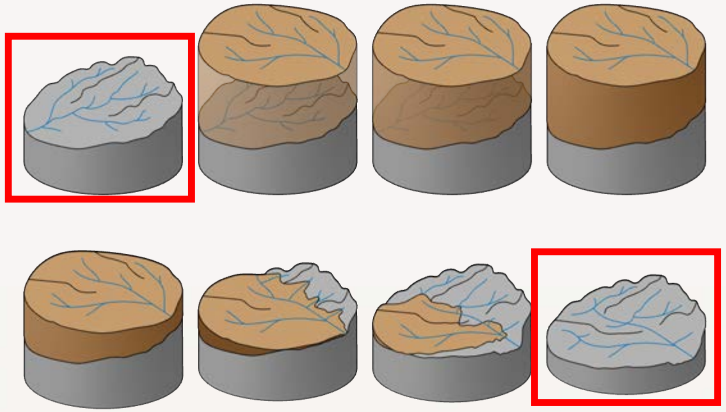
1. Create the paleo-topography

2. Bury bedrock topography with glacial till ($K_T/K_B = 20$)

3. Re-erode landscape to a new steady state



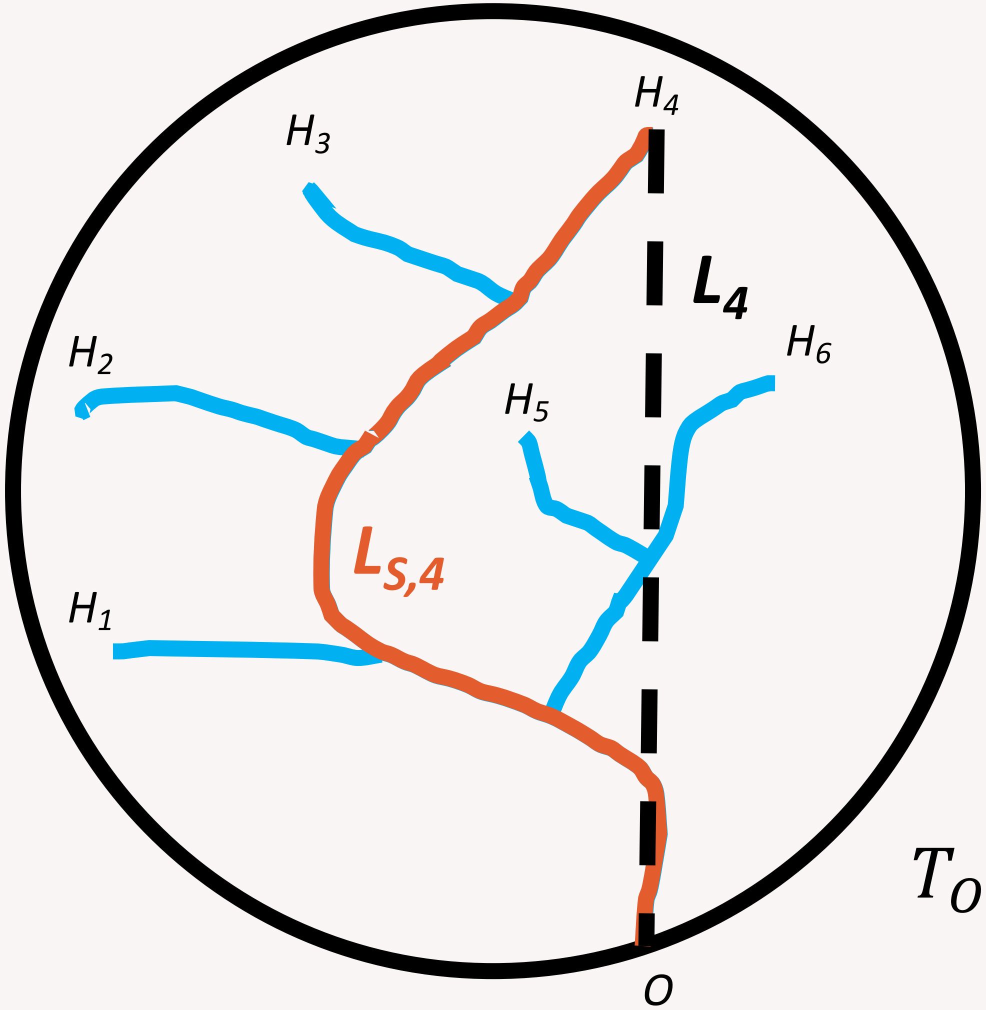
Antecedent (Paleo-) Drainage Legacy



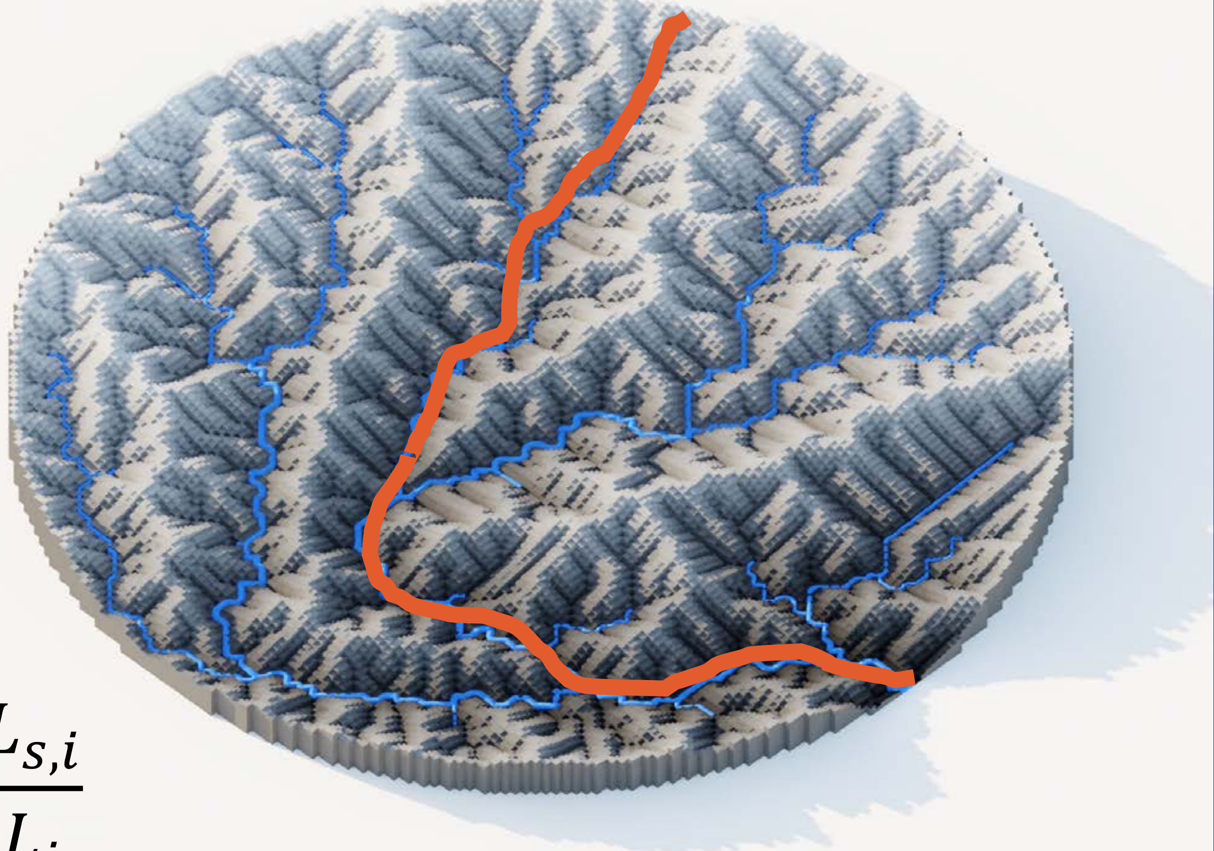
Paleo-Topography

Reworked Topography

Tortuosity – Quantifying Network Weirdness

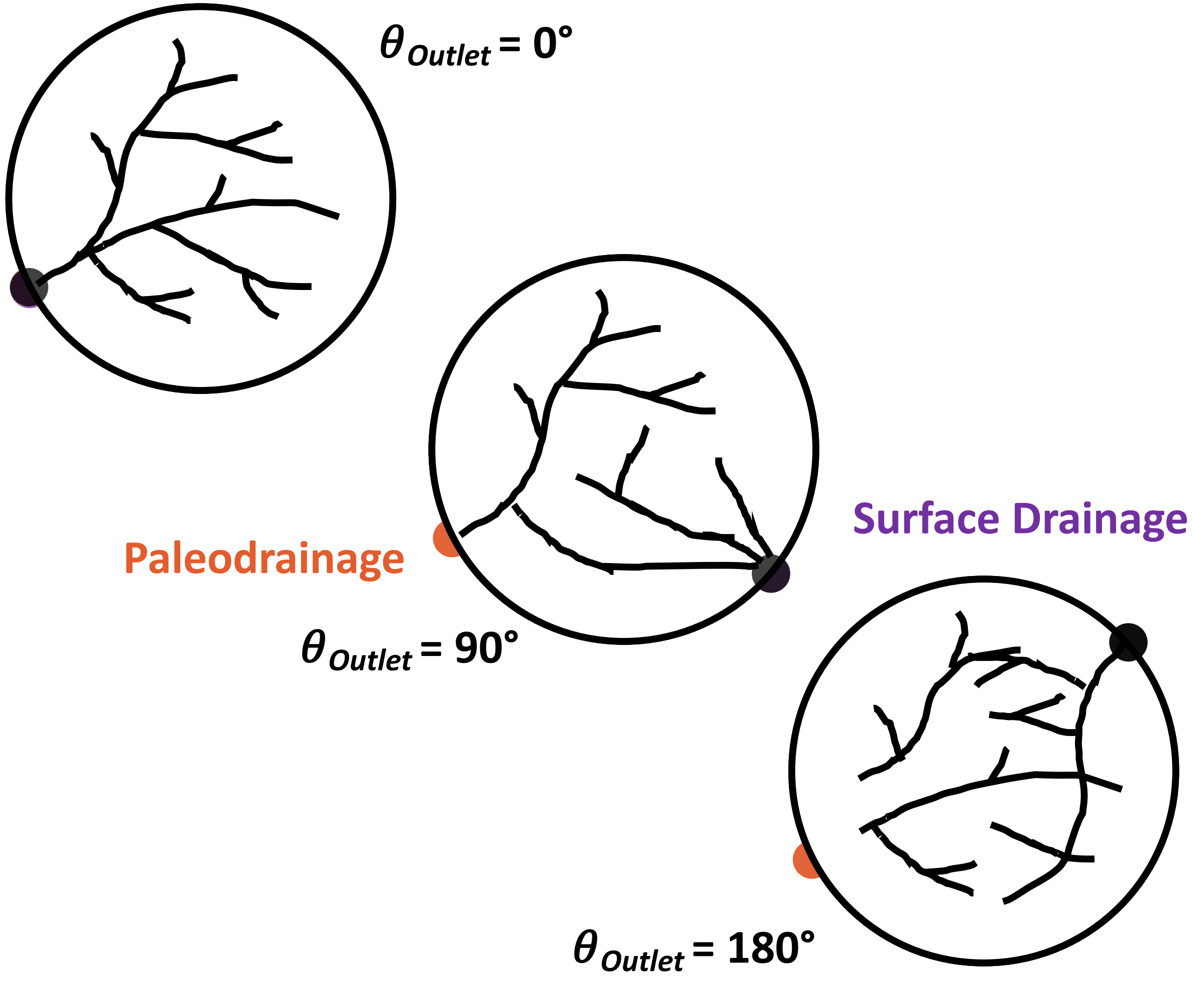


T_o = 1.75



$$T_O = \frac{\sum_{i=0}^{6} L_{s,i}}{\sum_{i=0}^{6} L_i}$$

Must be ≥ unity

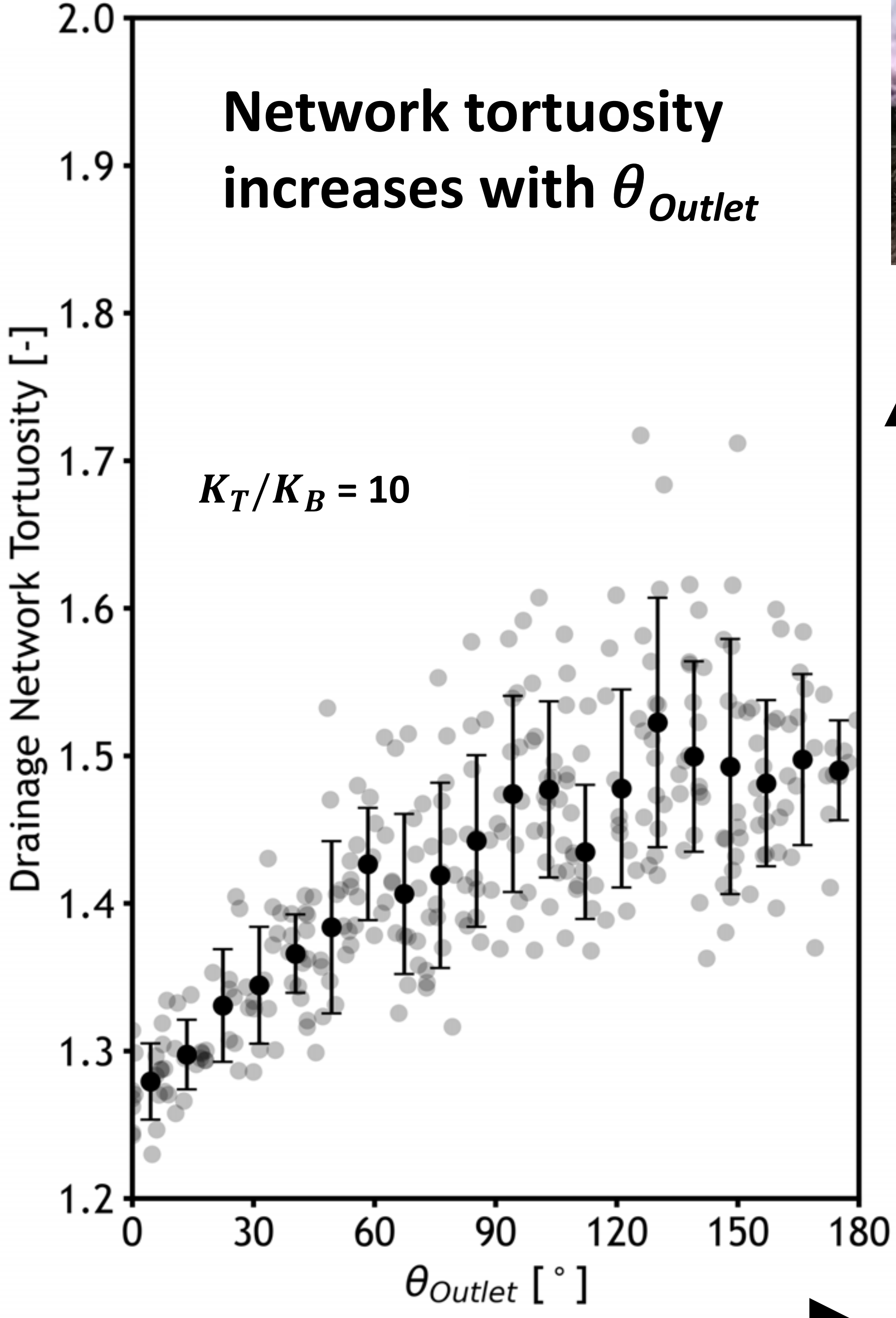


Value from Single Simulation

+1 Standard Deviation

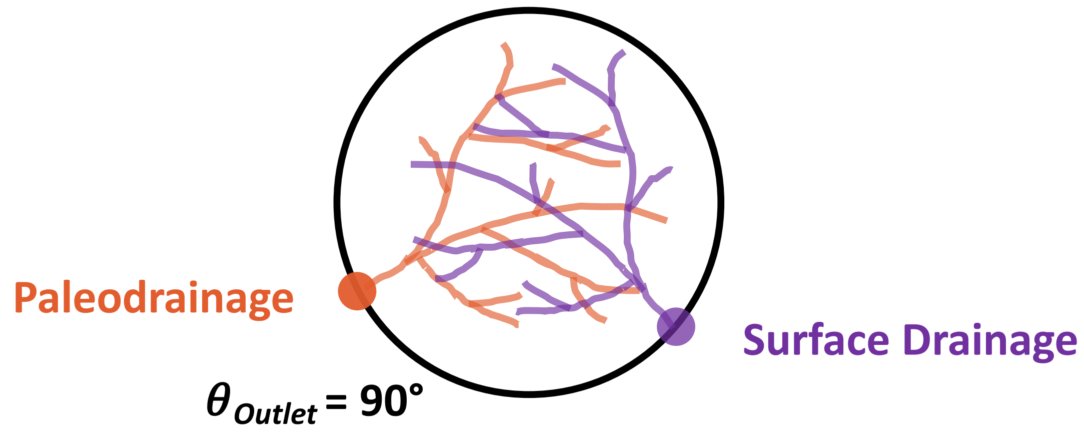
Mean Value

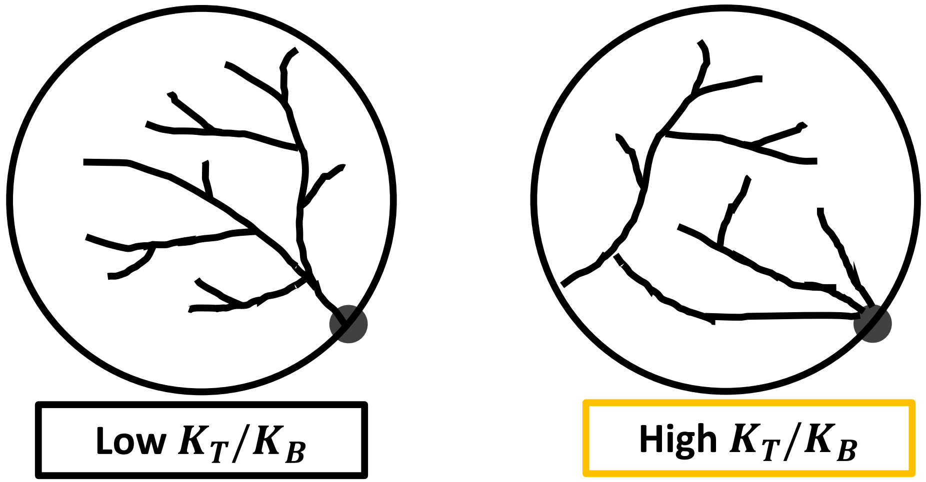
-1 Standard Deviation

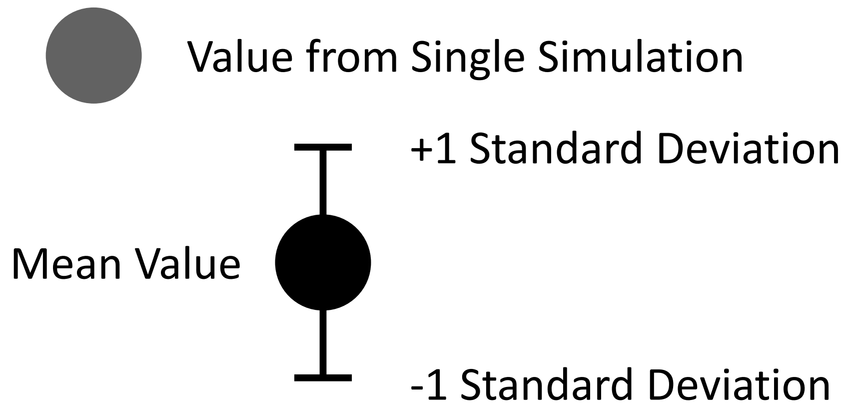


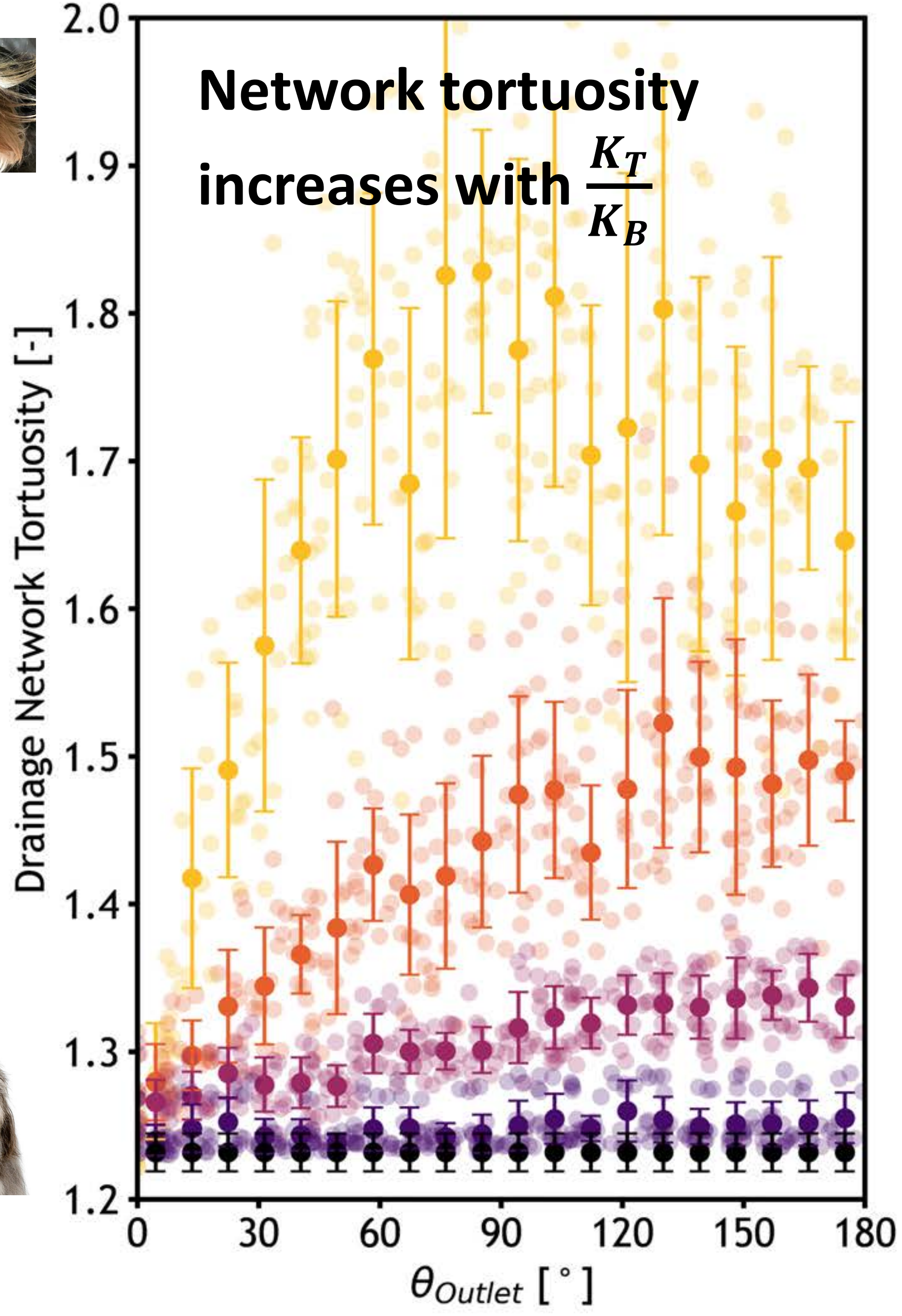
Weirder drainage networks

More Deviation









K_T/K_B = 20

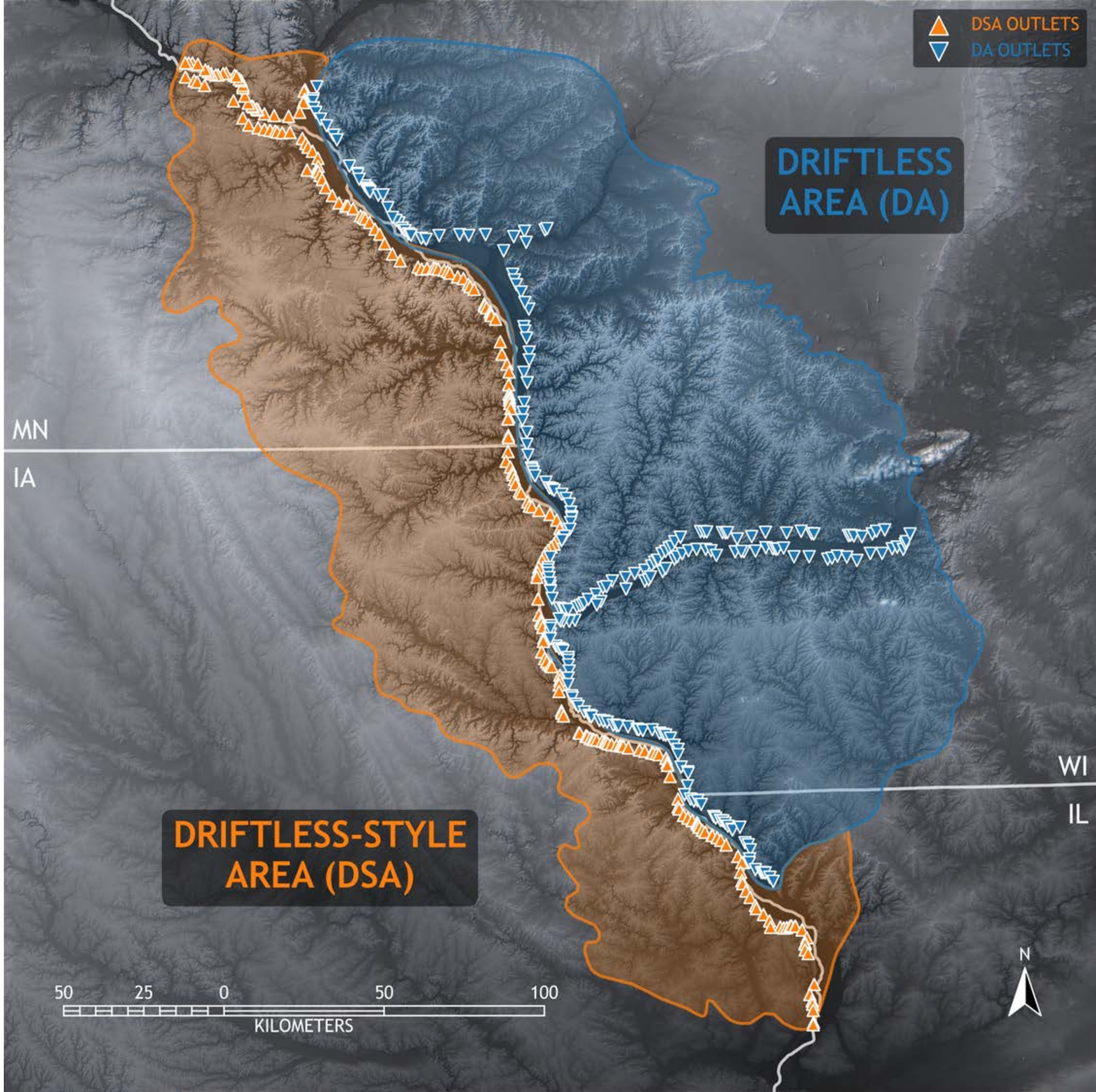
K_T/K_B = 10

K_T/K_B = 5

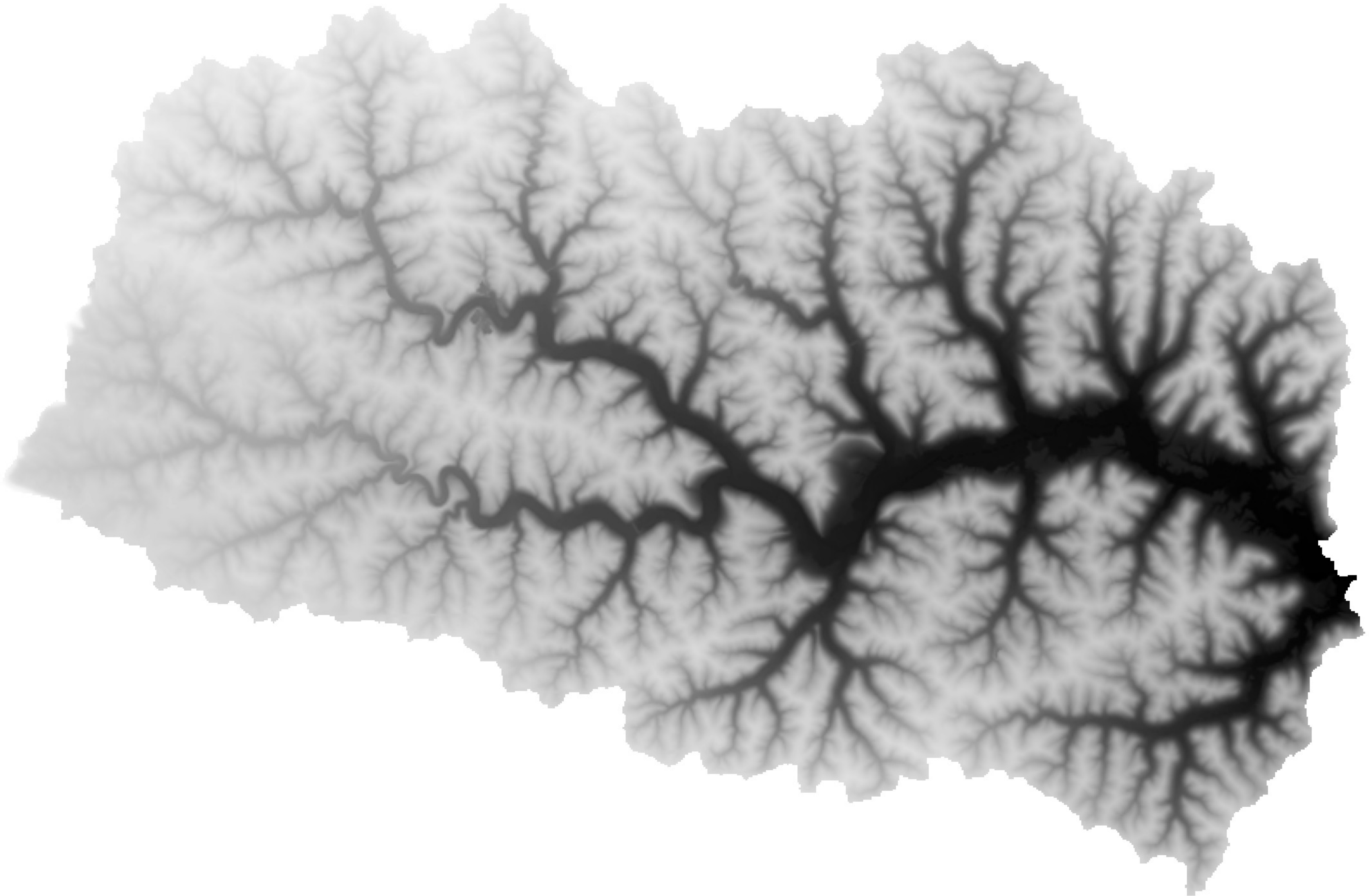
Tortuosity - A Signature of Reorganization

- The **Driftless Area** has never been buried.

- The **Driftless-Style Area** was buried been has since been uncovered.



~250 Subbasins mapped on each side of the MS river

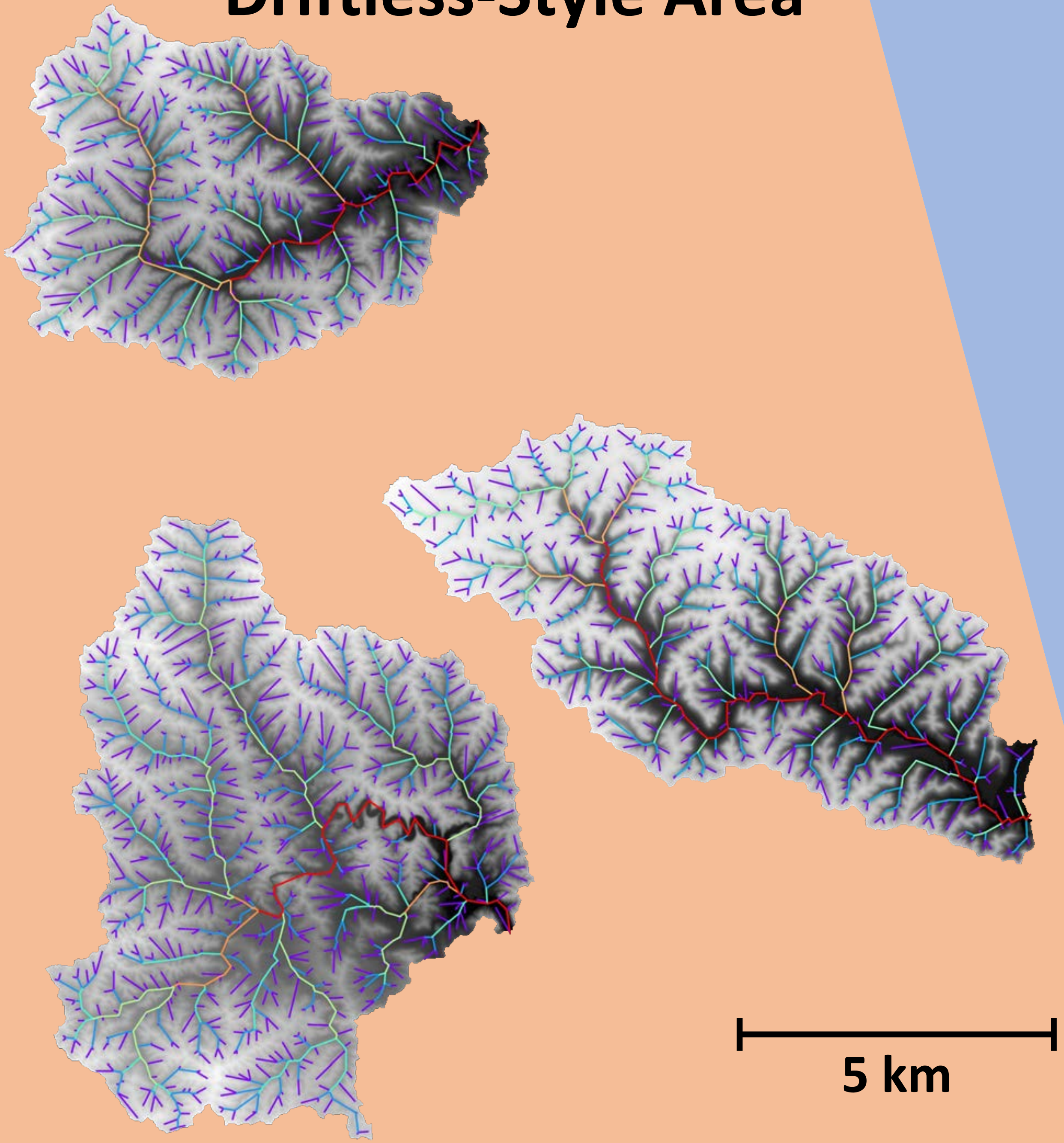


6th Order Basin in the Driftless-Style Area

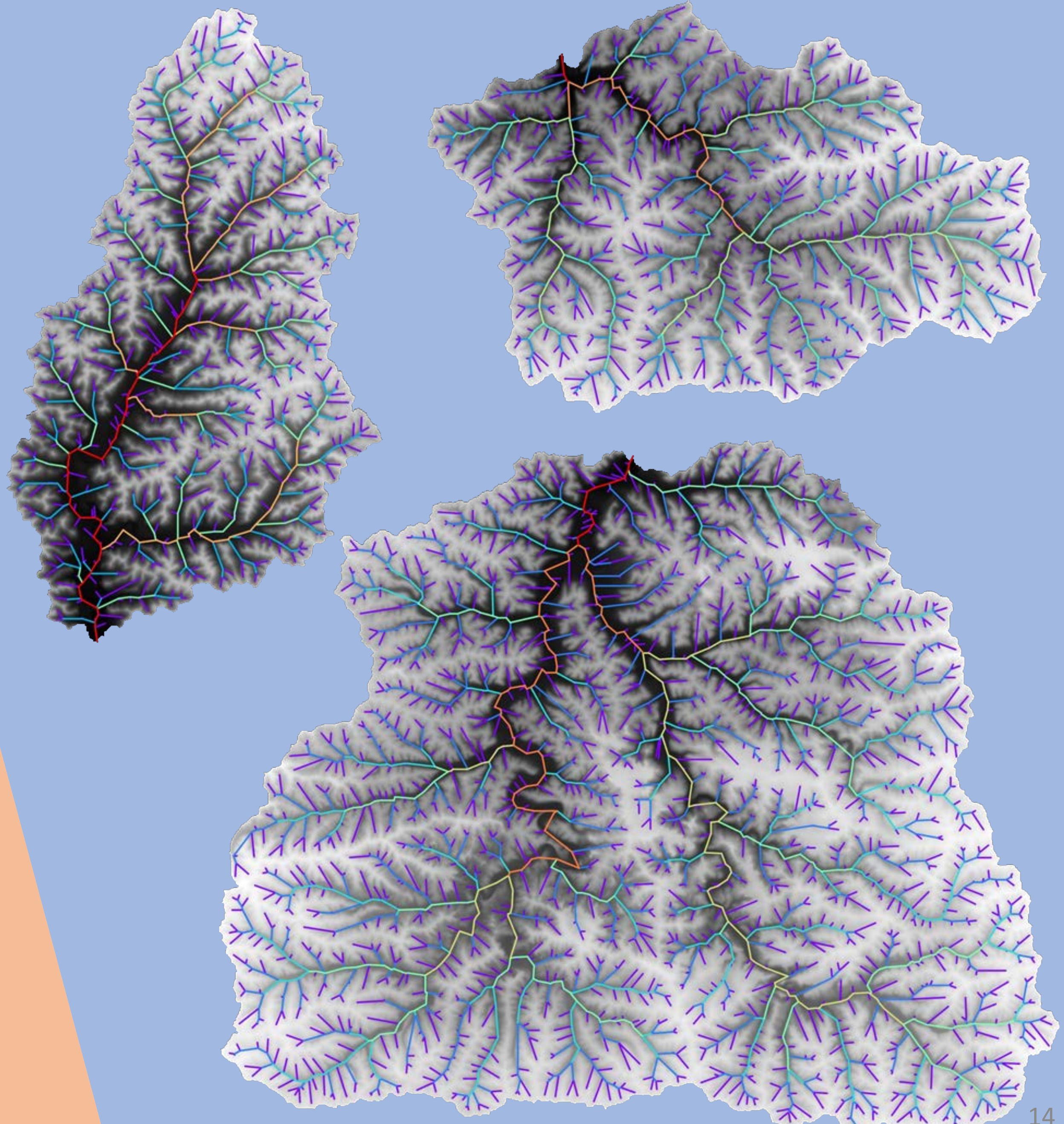
Measuring Tortuosity in Nature

1. Isolate the subbasin by its watershed
2. Delineate the drainage network and stream order
3. Segment sub-subbasins by stream order

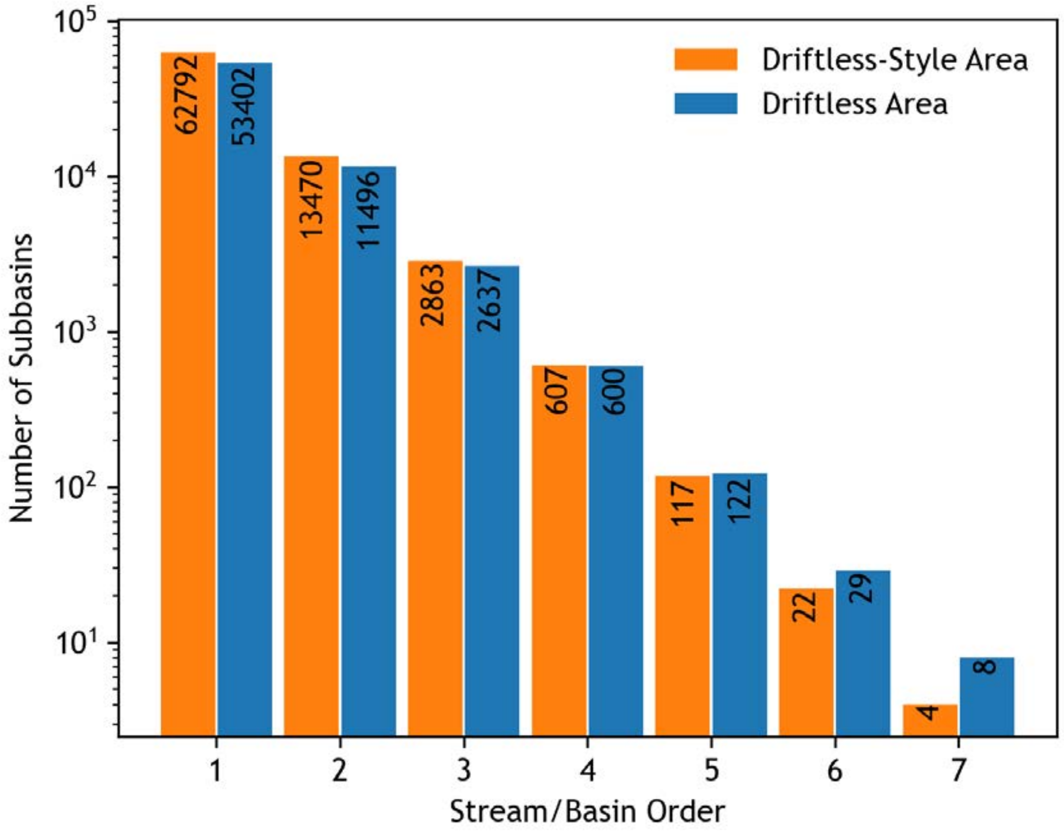
Driftless-Style Area

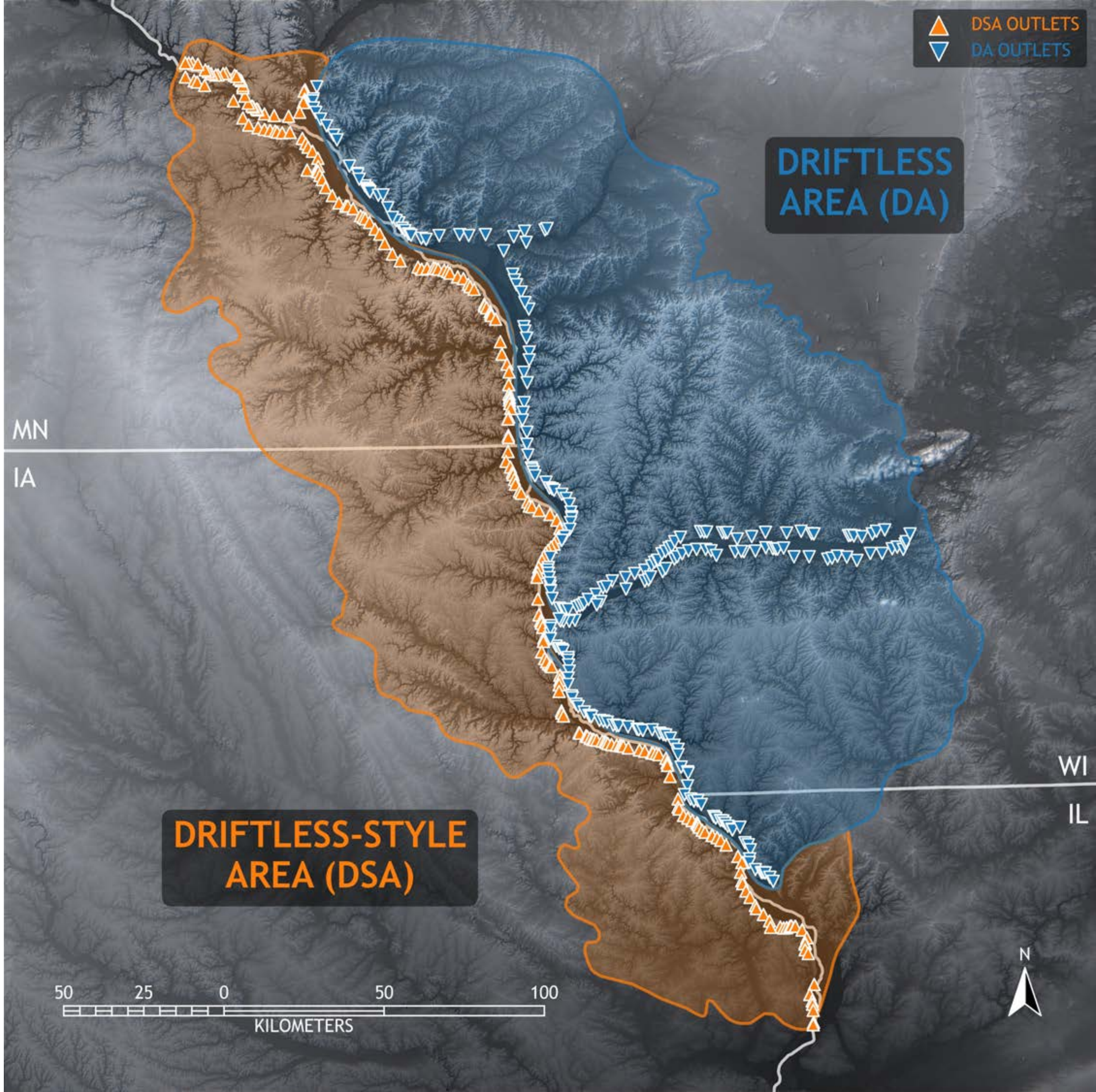


Driftless Area



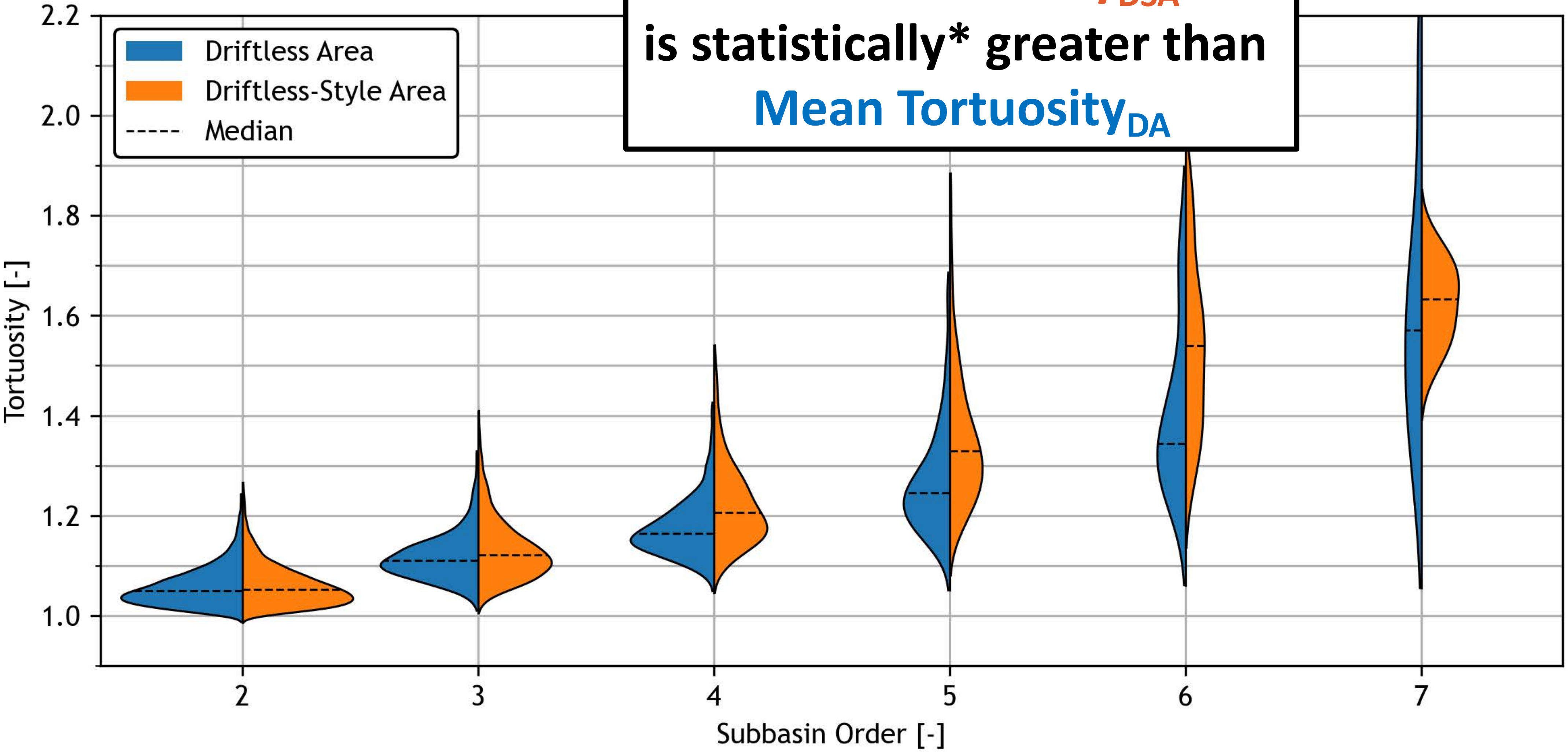
Measuring Tortuosity in Nature





Mean Tortuosity$_{DSA}$
is statistically* greater than
Mean Tortuosity$_{DA}$

Weirder drainage networks



Indicates that lithologic-induced drainage reorganization occurred in the Driftless-Style Area

*Orders 2-6 and $\alpha = 0.05$; Wilcoxon Rank Sum Test

Conclusions

- According to the LEMs, lithologic heterogeneity can have a **first-order control** on drainage reorganization.

- **Integration of antecedent drainage** results in **higher network tortuosity**.

- When lithologic induced drainage reorganization occurs, it **leaves a distinct and quantifiable drainage network signature**.