Inferring Spatially-Variable Rock Uplift from Fluvially-Incised Landscapes: a Bayesian Inversion Framework in χ-space

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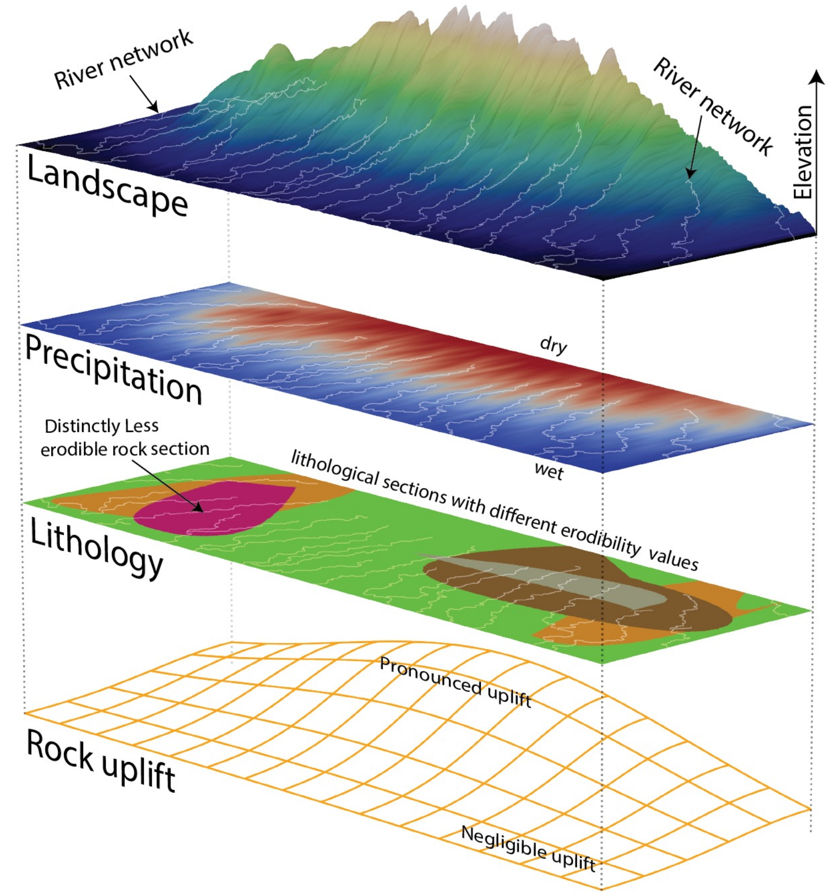
SHAPING FLUVIAL LANDSCAPES

- Landscapes encode the combined forcing of tectonics, climate and erodibility.
- Separating induvial contributions is challenging but essential for using landscapes as quantitative records of crustal deformation.



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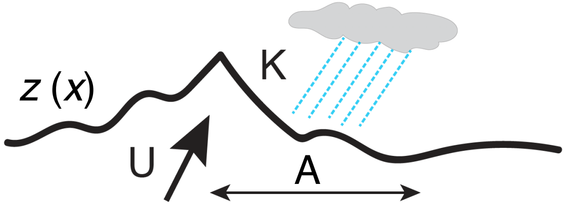
RIVER INCISION AT STEADY STATE



$$\boxed{U(X)} = \boxed{K(x)A^m(x)S^n(x)}$$

Tectonic uplift

Local incision rate

*(faster for steeper slope **S**, with more water flowing)*

Parameters:

- erodibility (**K**)
- drainage area (**A**)
- exponents (**m**, **n**)

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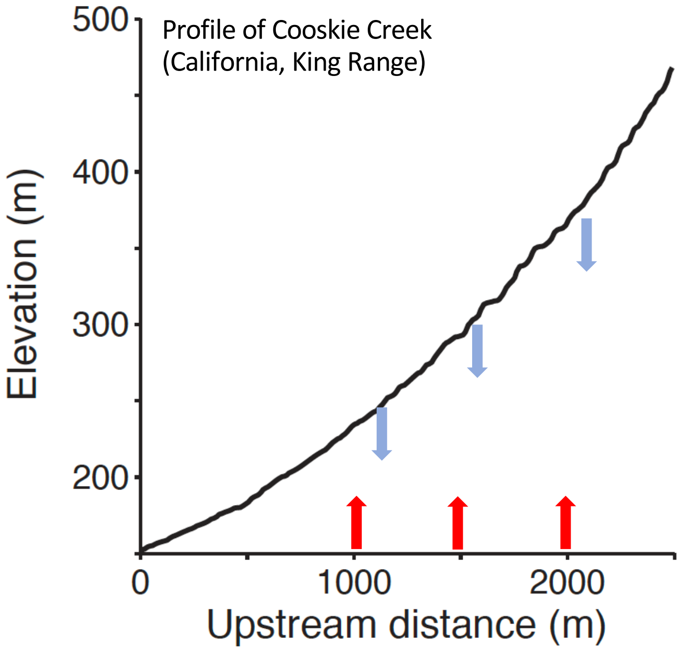

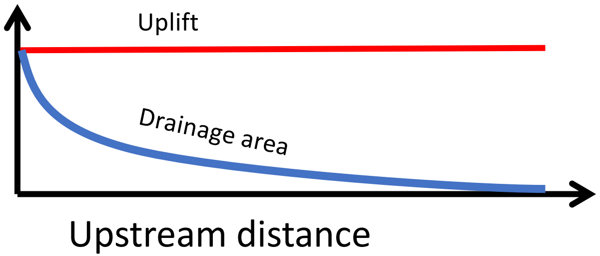

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River concavity reflects:

- Upstream decrease in drainage area
- Shape of uplift
- Spatially variable erodibility
- climate

[*Perron & Royden*, 2013]

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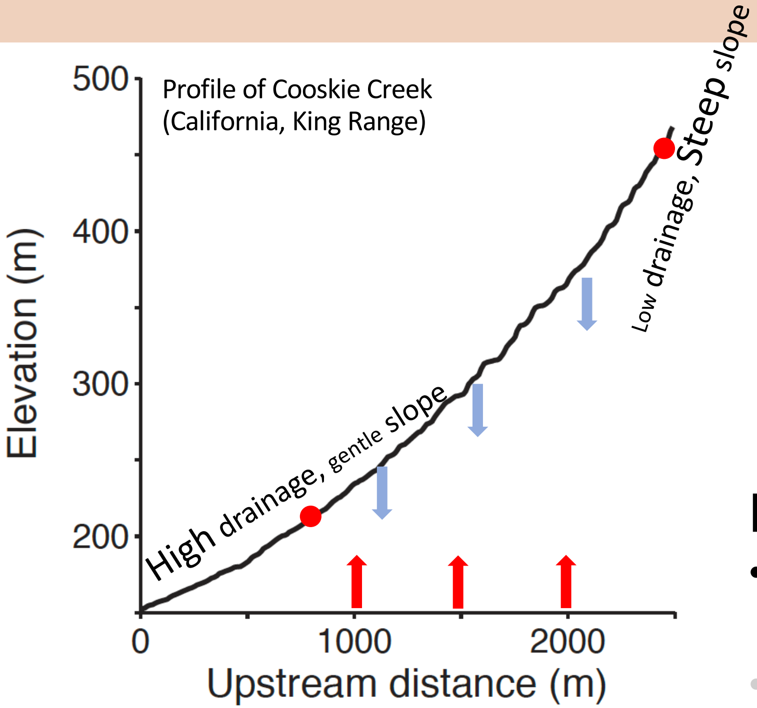

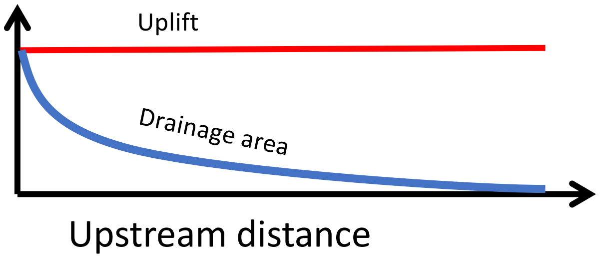

$$U(X) = K(x)A^m(x)S^n(x)$$

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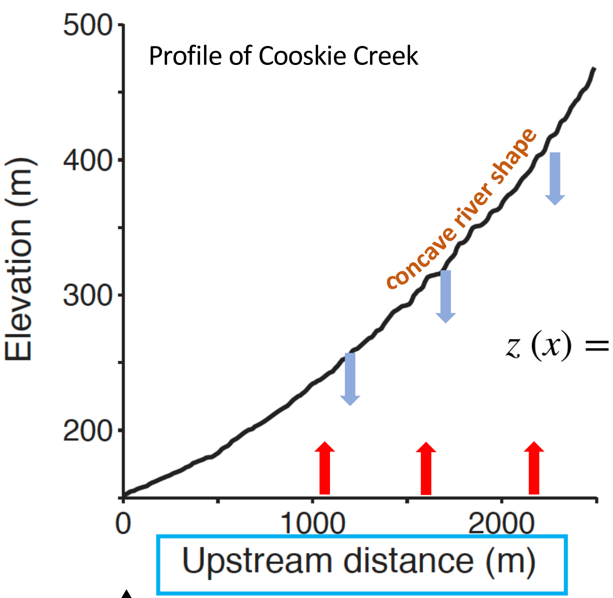
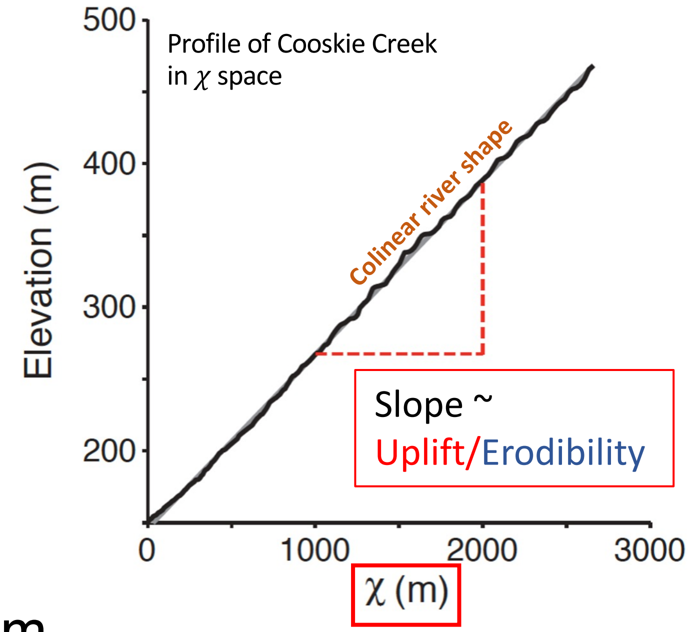
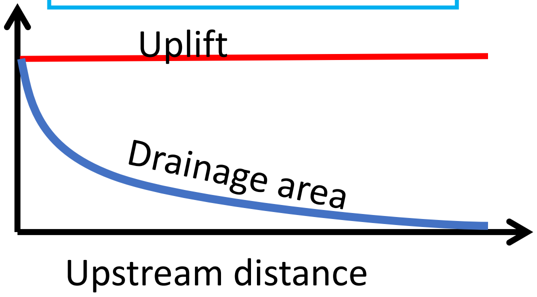
χ – TRANSFORMATION OF RIVERS



$$z(x) = z_b + \left(\frac{U_0}{K_0 A_0}\right)^{\frac{1}{n}} \underbrace{\int_{x_b}^{x} \left(\frac{A_0}{A^*(x)}\right)^{\frac{m}{n}} dx}_{\chi}$$

χ – TRANSFORMATION





Corrects for upstream decrease in drainage area while assuming uniform spatial uplift

[*Perron & Royden*, 2013]

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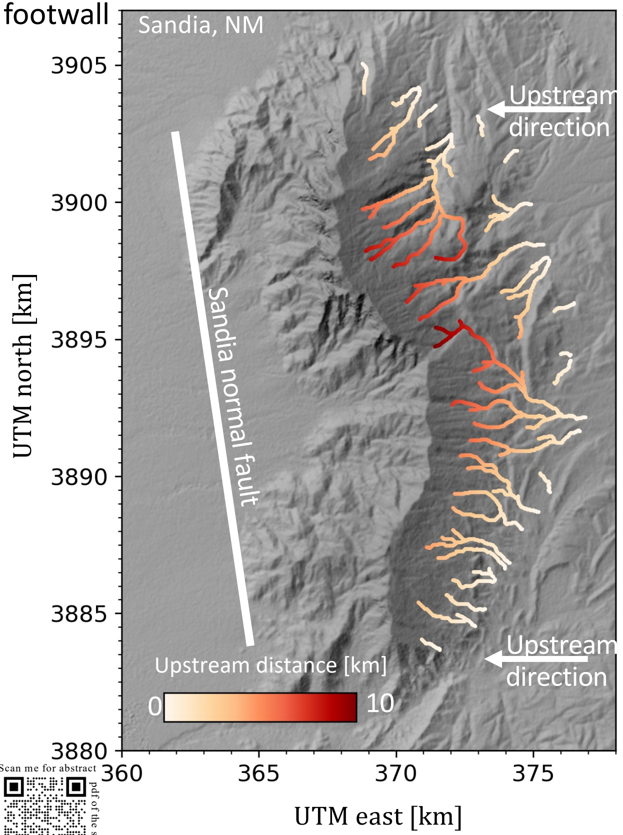
χ – TRANSFORMATION OF RIVER PROFILES IN SANDIA

Application to simple tectonic settings - normal fault footwall



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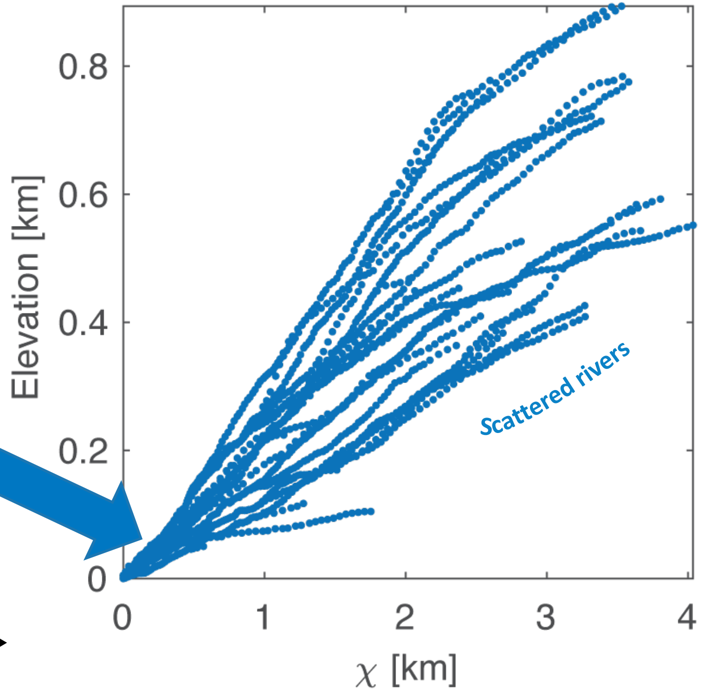
River concavity reflects:

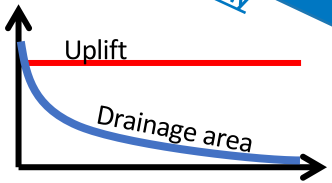
- Upstream decrease in drainage area
- Shape of uplift
- Spatially variable erodibility and climate

χ *space* —Sandia rivers



χ – TRANSFORMATION

Corrected for area only



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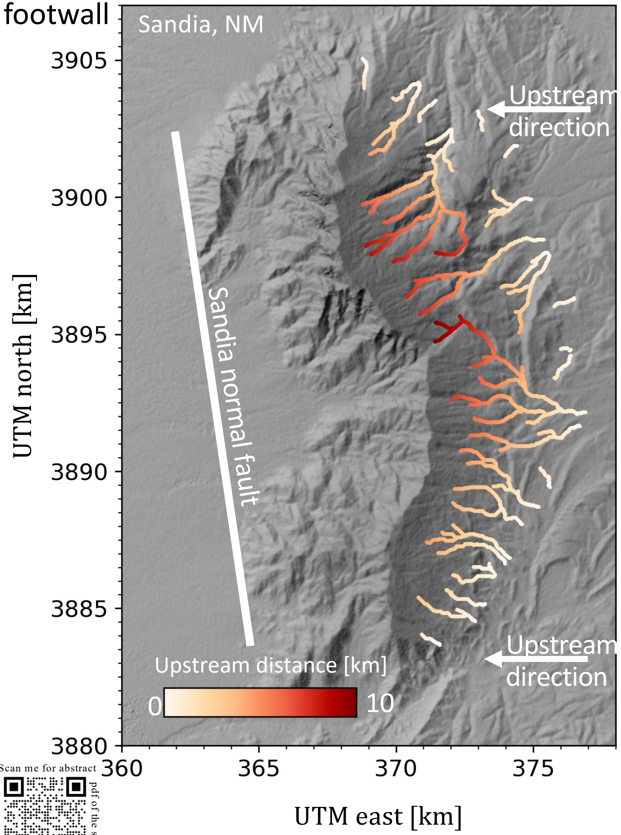

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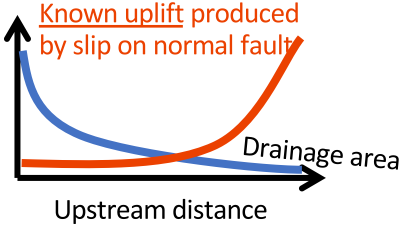

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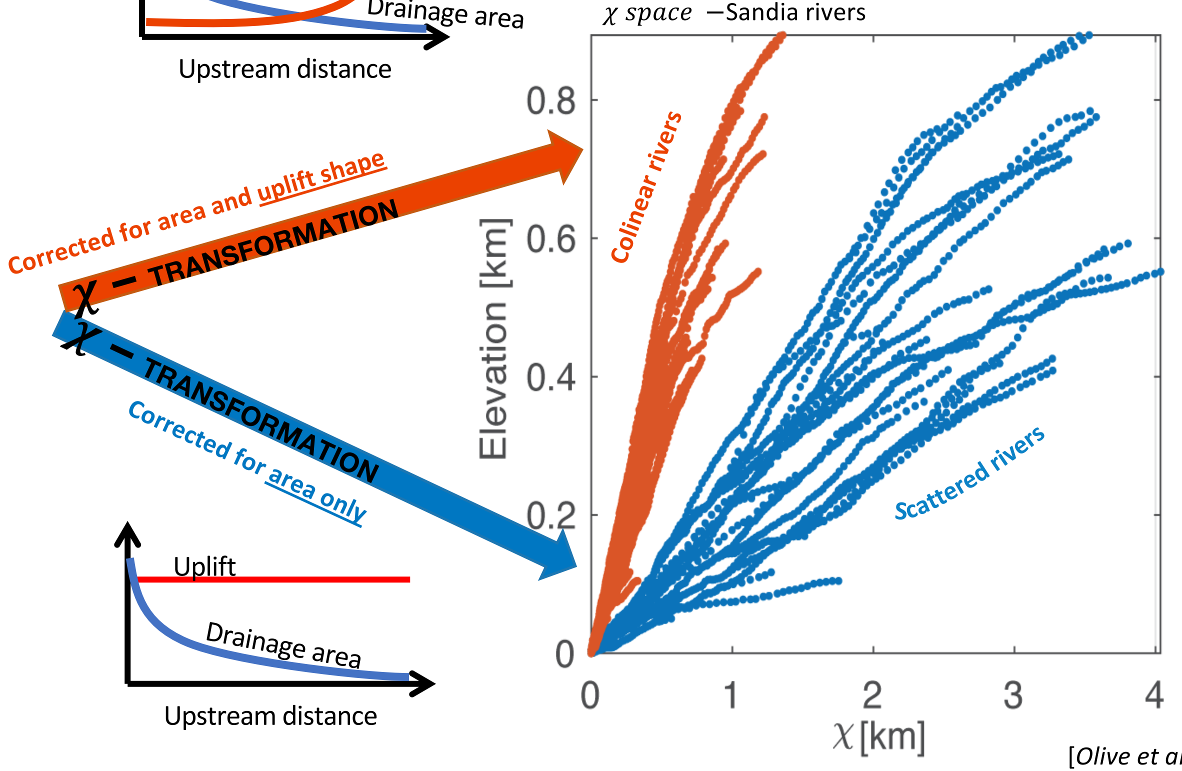

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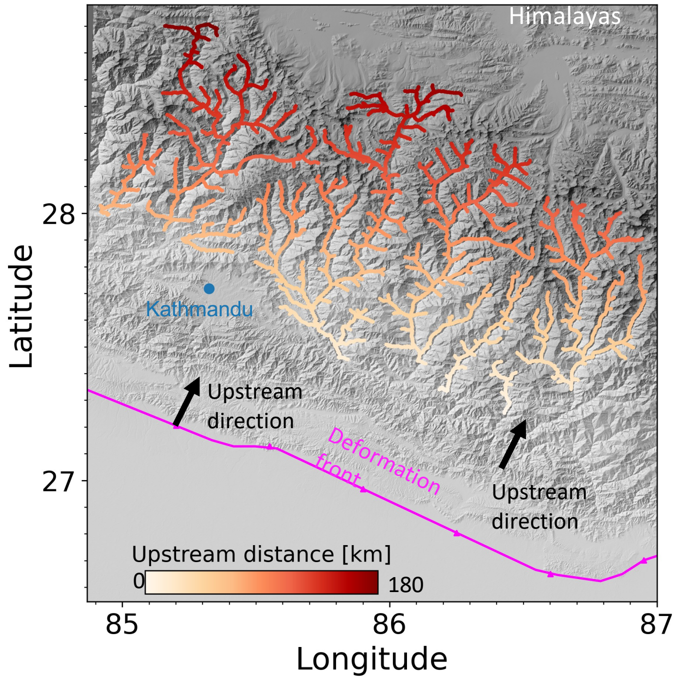

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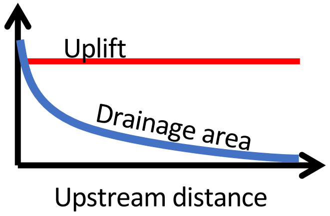

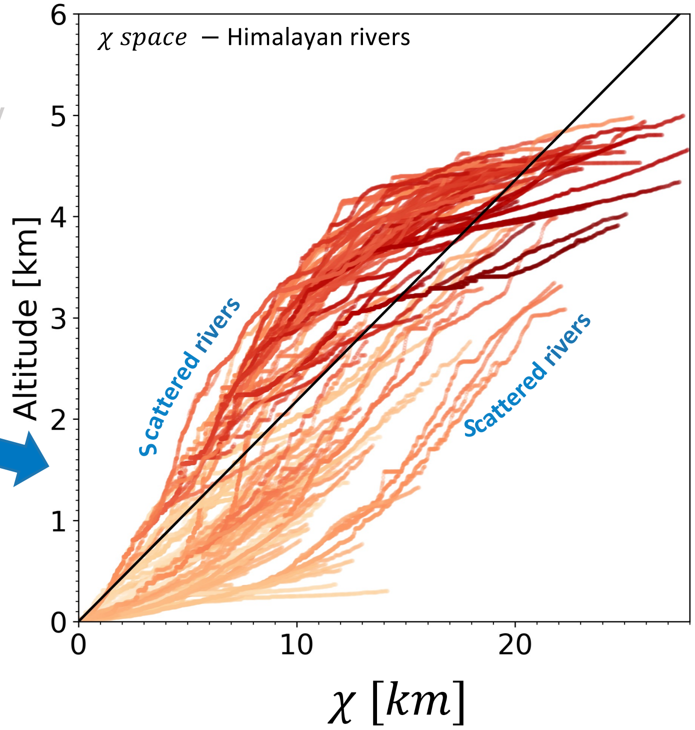

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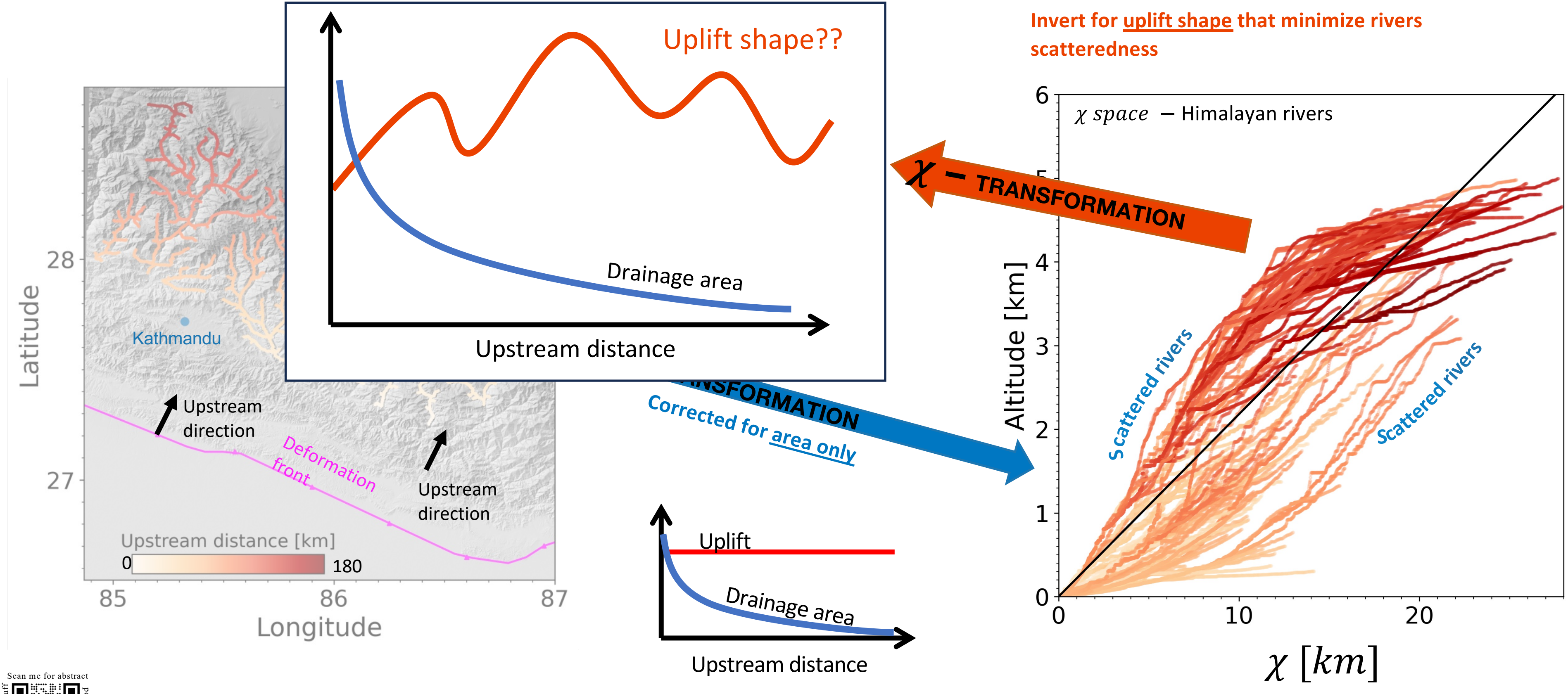

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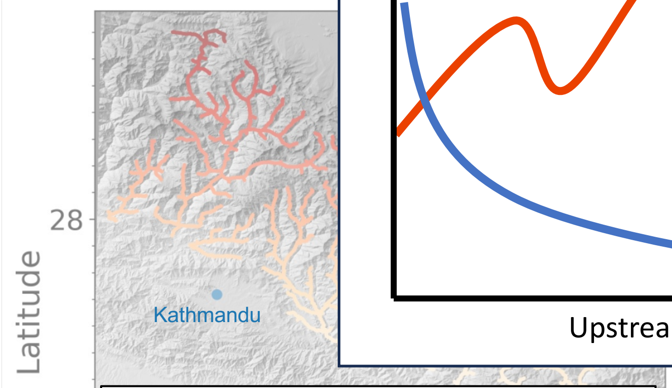

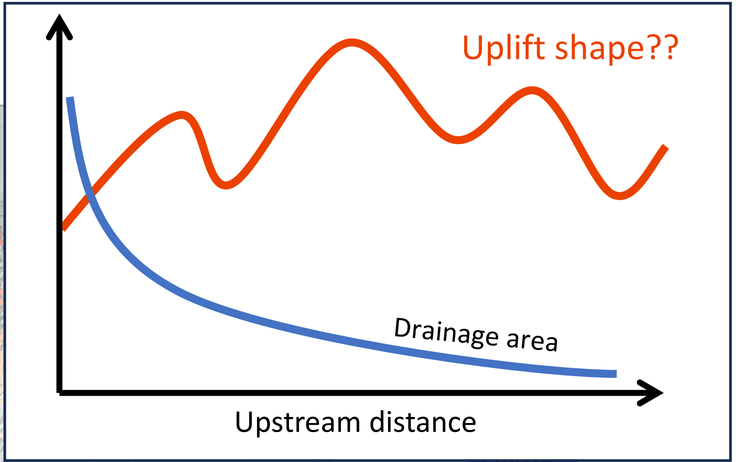

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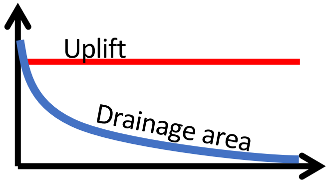
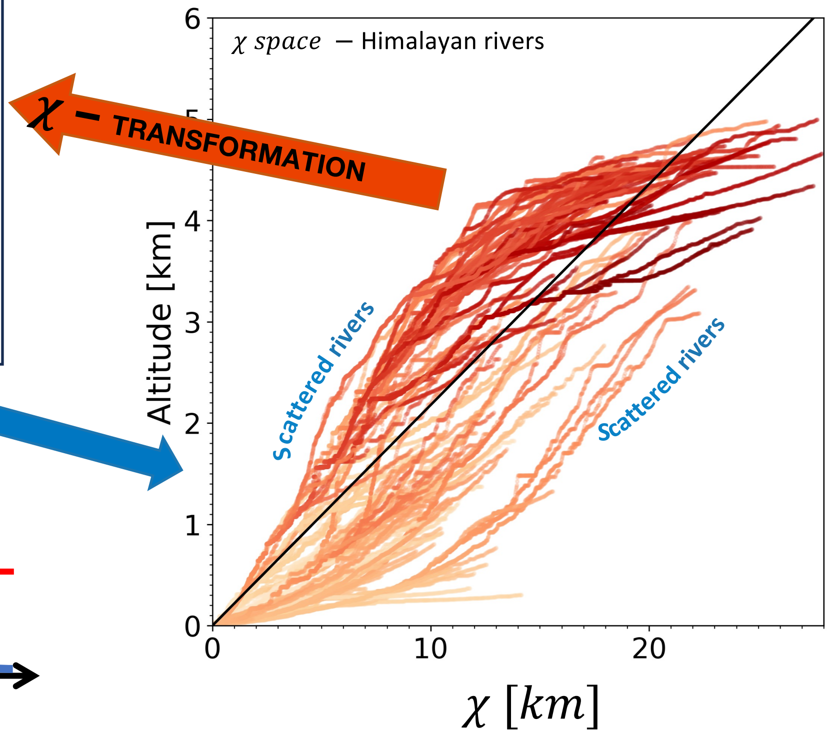


Invert for uplift shape that minimize rivers scatteredness



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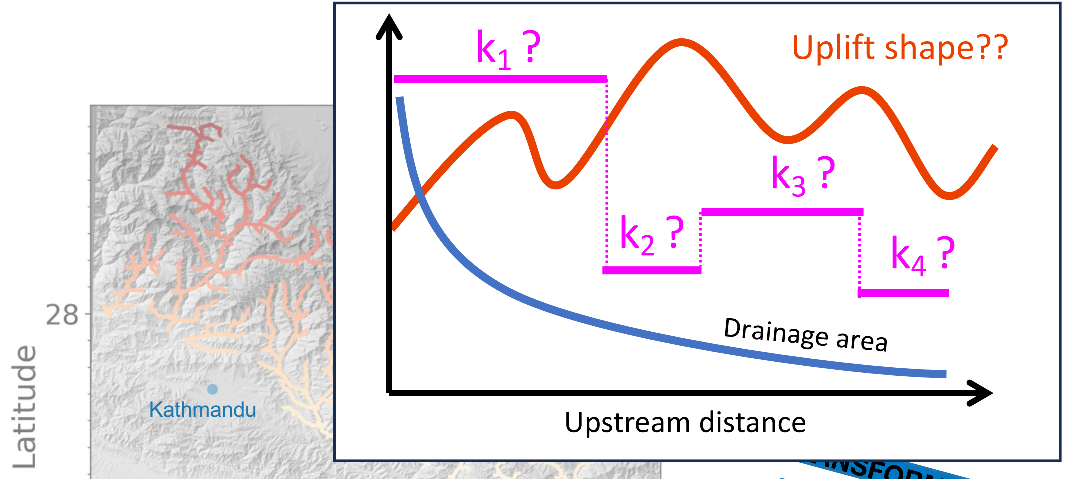

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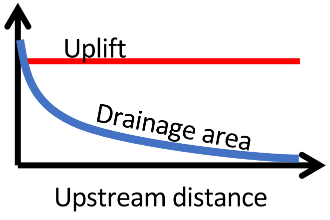

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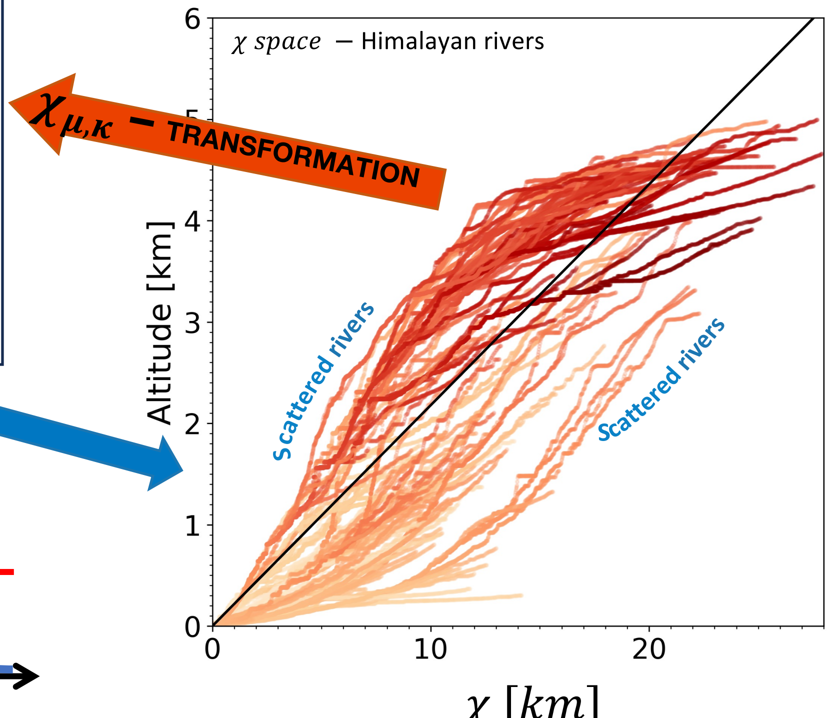

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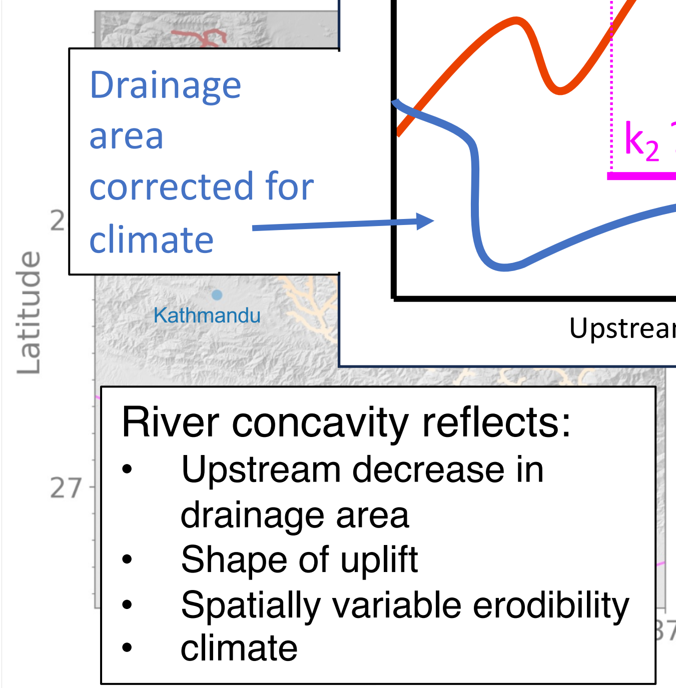

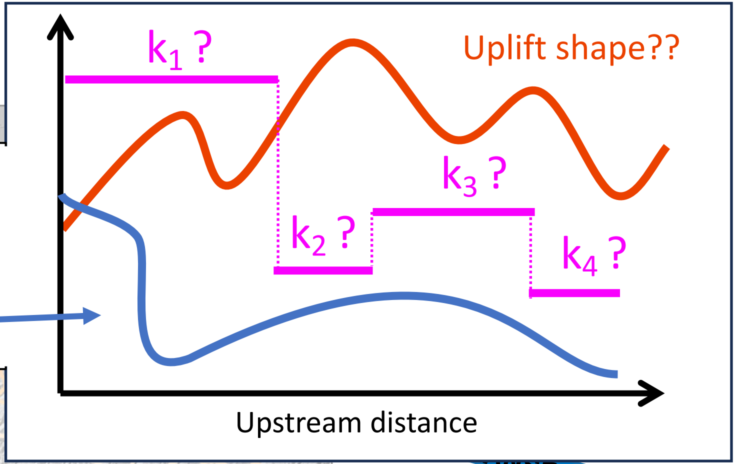

Drainage area corrected for climate

River concavity reflects:

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- Shape of uplift
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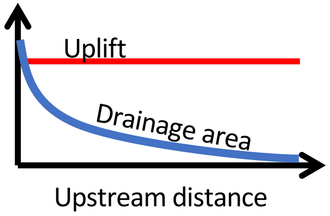
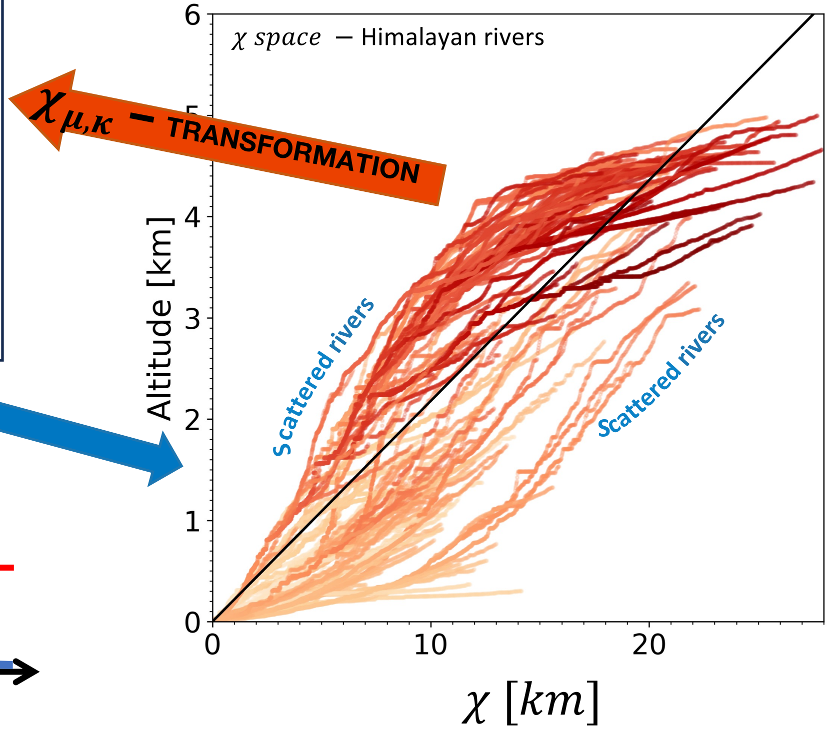
- climate



Invert for <u>uplift shape</u> that minimize rivers scatteredness



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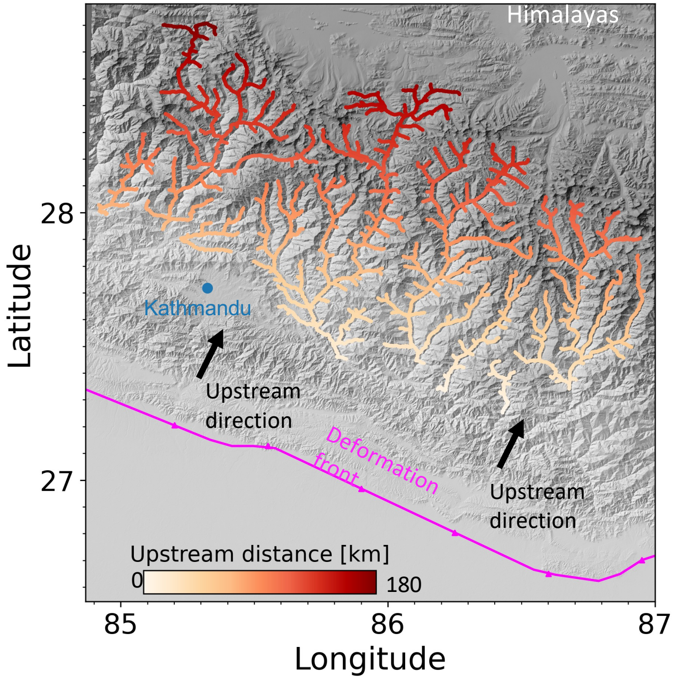

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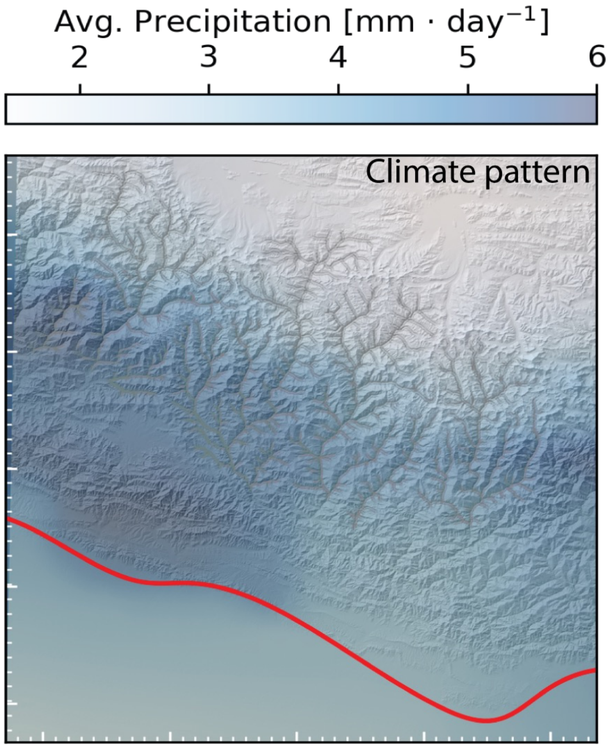

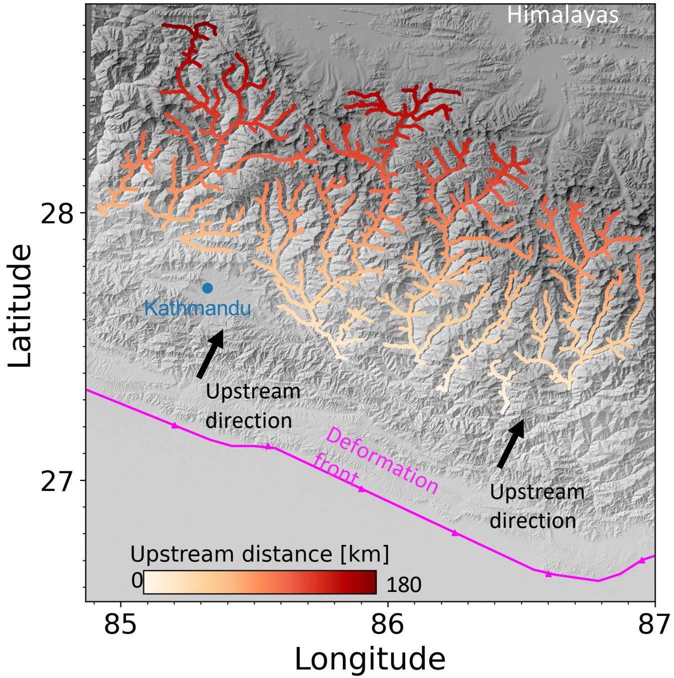

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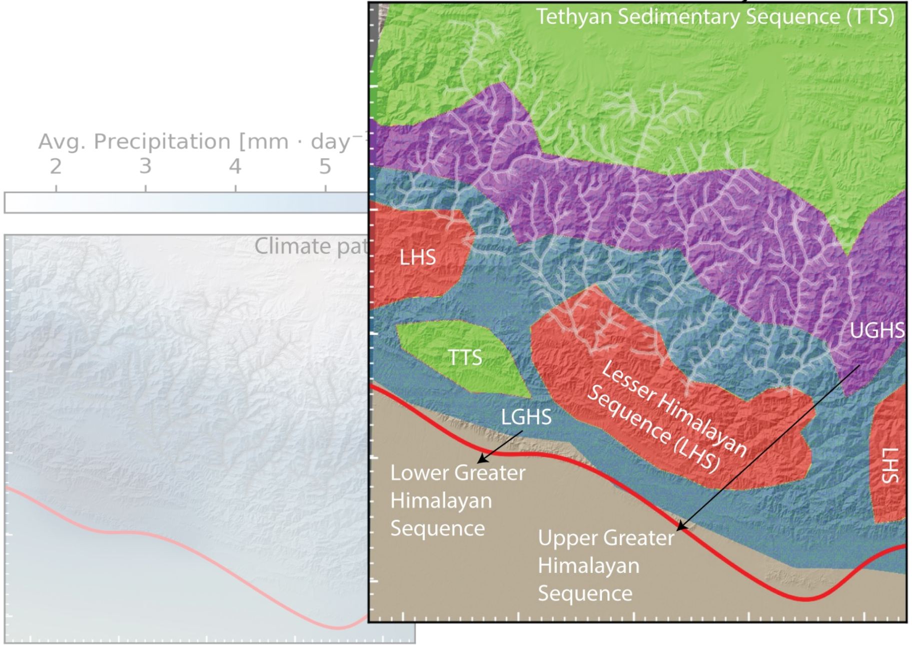
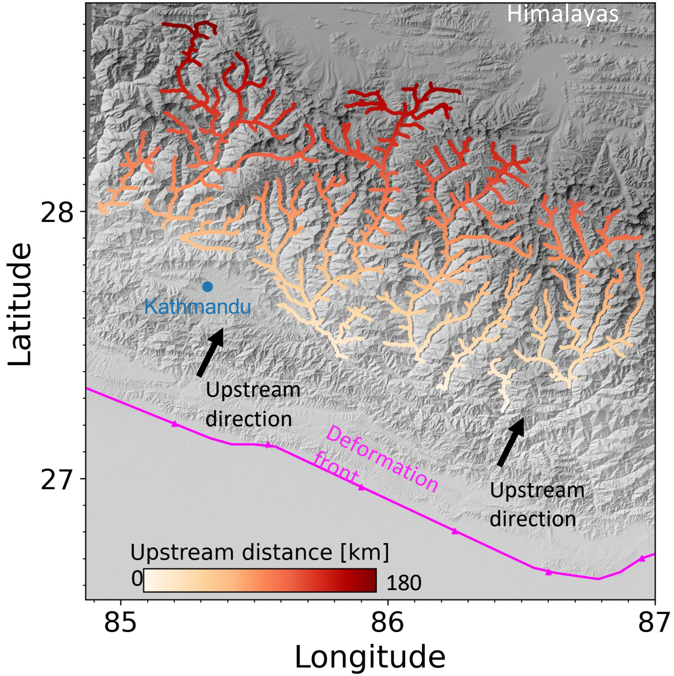
INVERTING HIMALAYAS USING $\chi_{\mu,\kappa}$ TRANSFORMATION

1. Compute drainage area corrected for climate [e.g., Leonard & Whipple, 2021; Leonard 2023].
2. Map the spatial distribution of major lithological sections for piecewise erodibility values.

Four inverted erodibility sections





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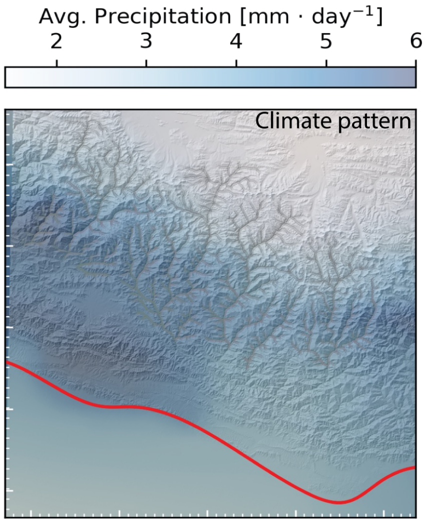

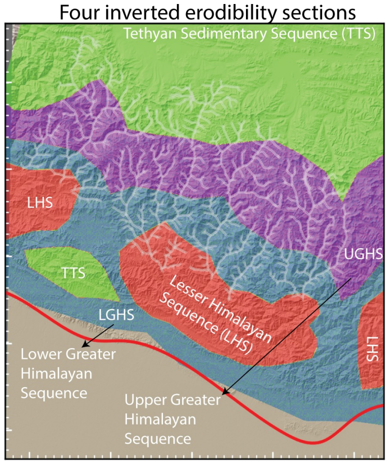

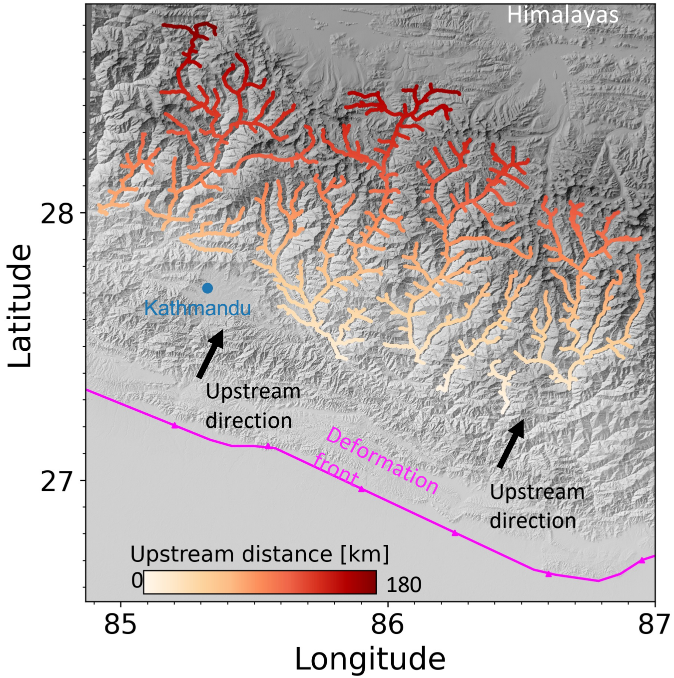

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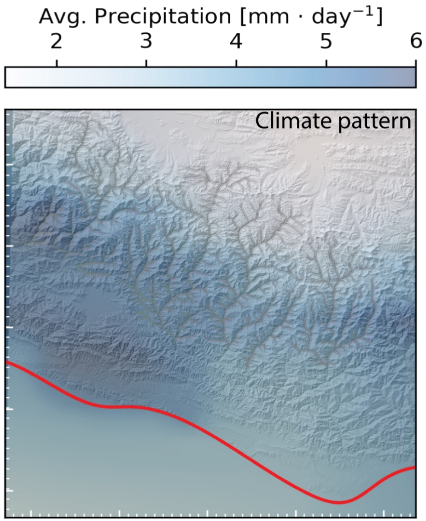
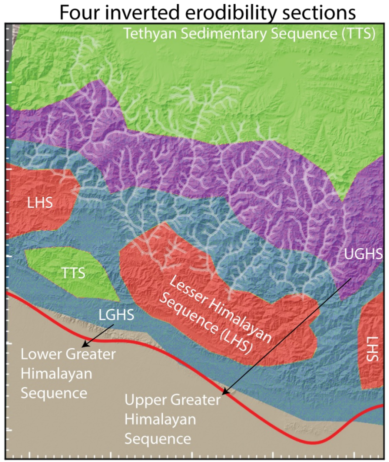
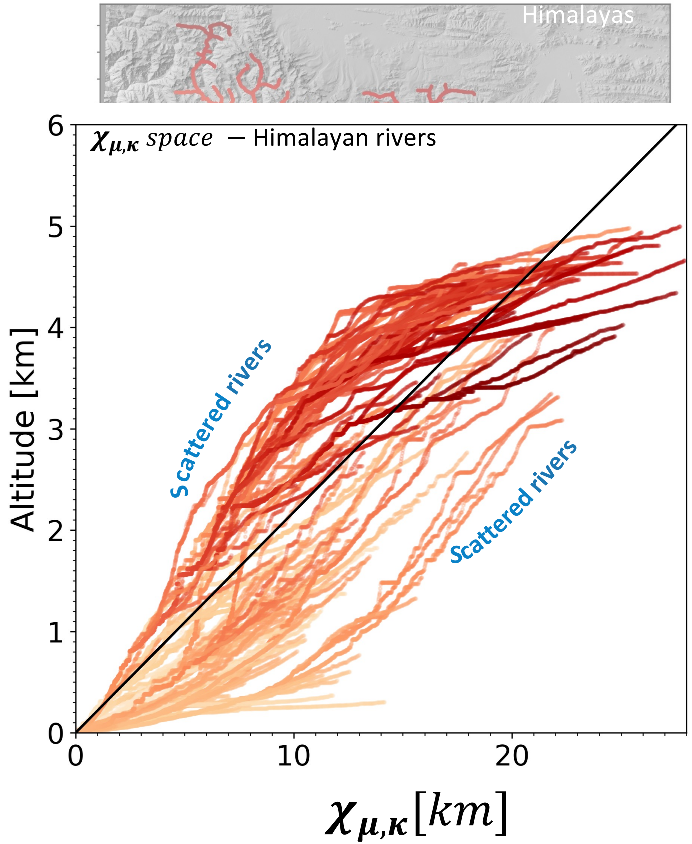
2. Map the spatial distribution of major lithological sections for piecewise erodibility values.
3. Describe uplift using B-spline interpolating functions that extend across river network.
4. Invert for uplift and erodibility values minimizing $\chi_{\mu,\kappa}$.







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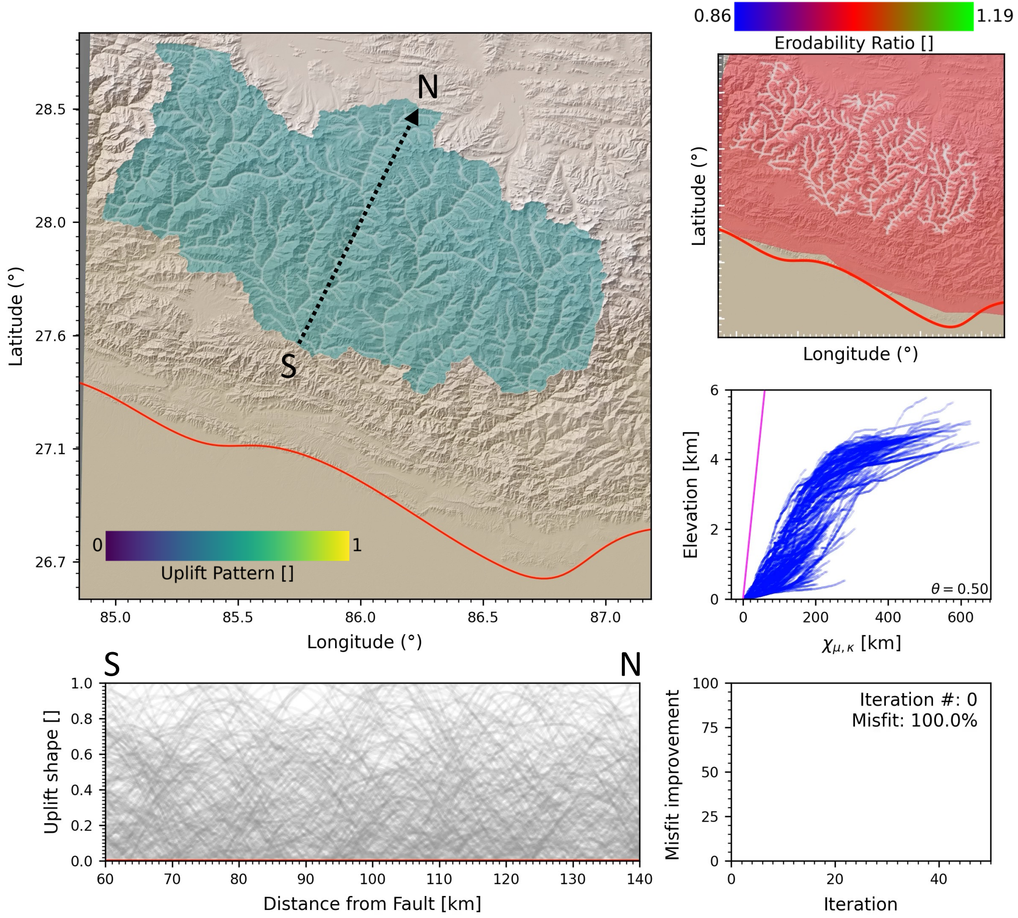
INVERTING HIMALAYAS USING $\chi_{\mu,\kappa}$ TRANSFORMATION

- Quasi-Newton inversion method with 120,000 river nodes spanning 18,000 km^2.
- Inversion finds 144 parameters describing uplift shape and 4 erodibility values that best linearizes river profile in χ space.



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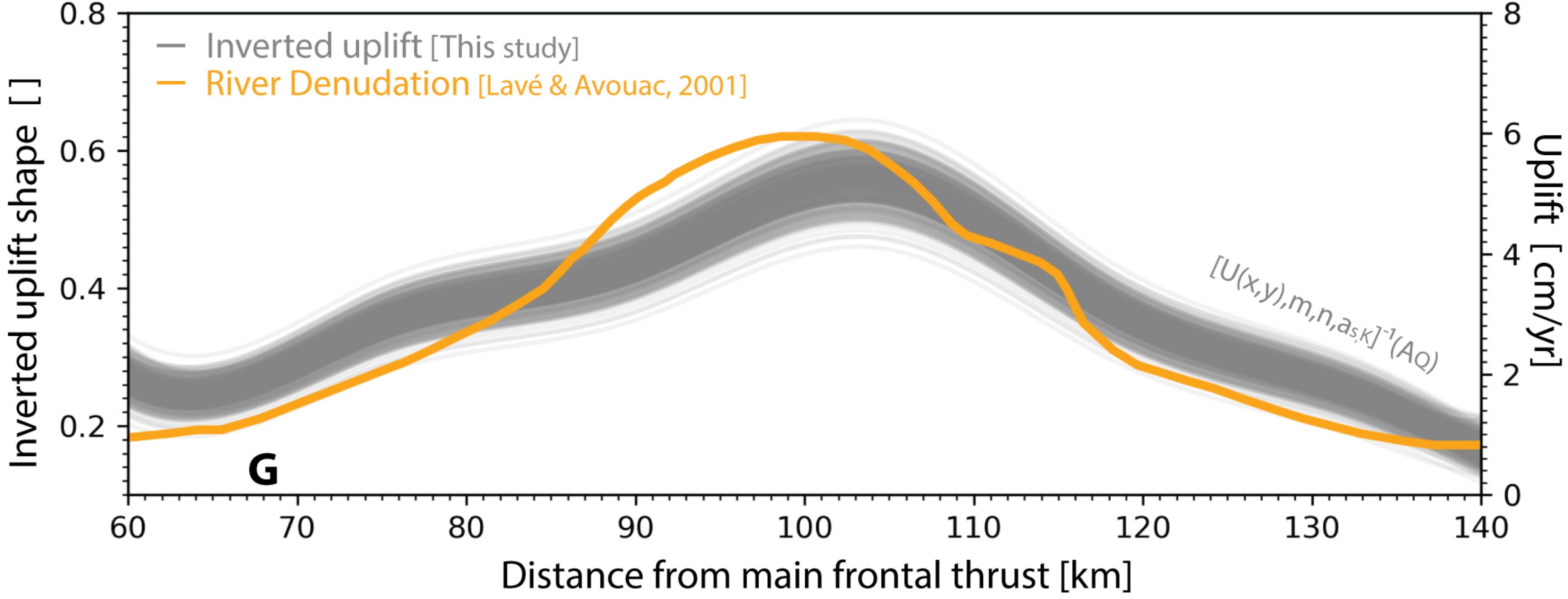
RETRIEVED UPLIFT PATTERN RESEMBLE PREVIOUS ESTIMATES

- Inferred long-term uplift matches denudation rates.



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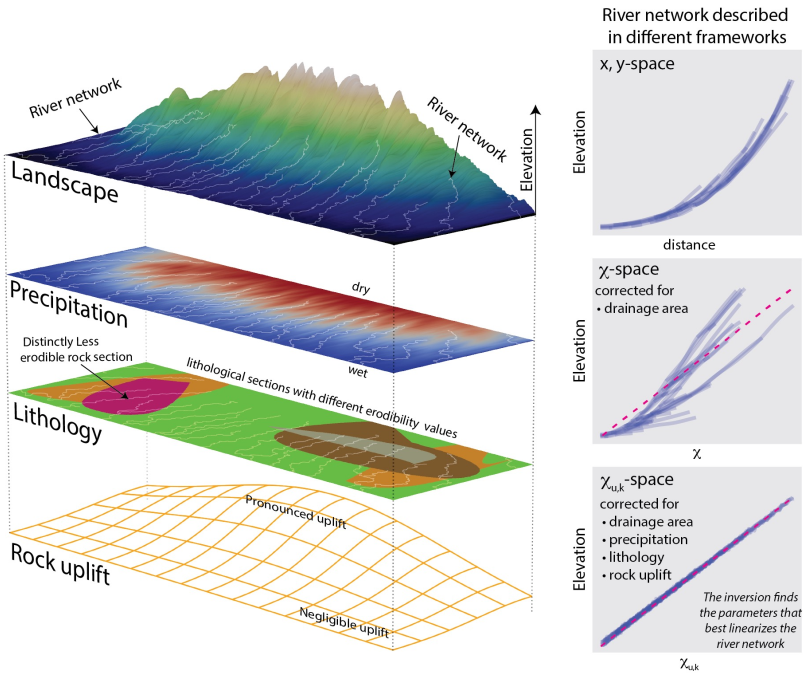
TAKE AWAY MESSAGE

- We demonstrate how we can disentangle the contributions of tectonics, climate and erodibility from landscapes.
- This opens the door to leveraging time-averaged signals captured and infer crustal deformation on different timescales.



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