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

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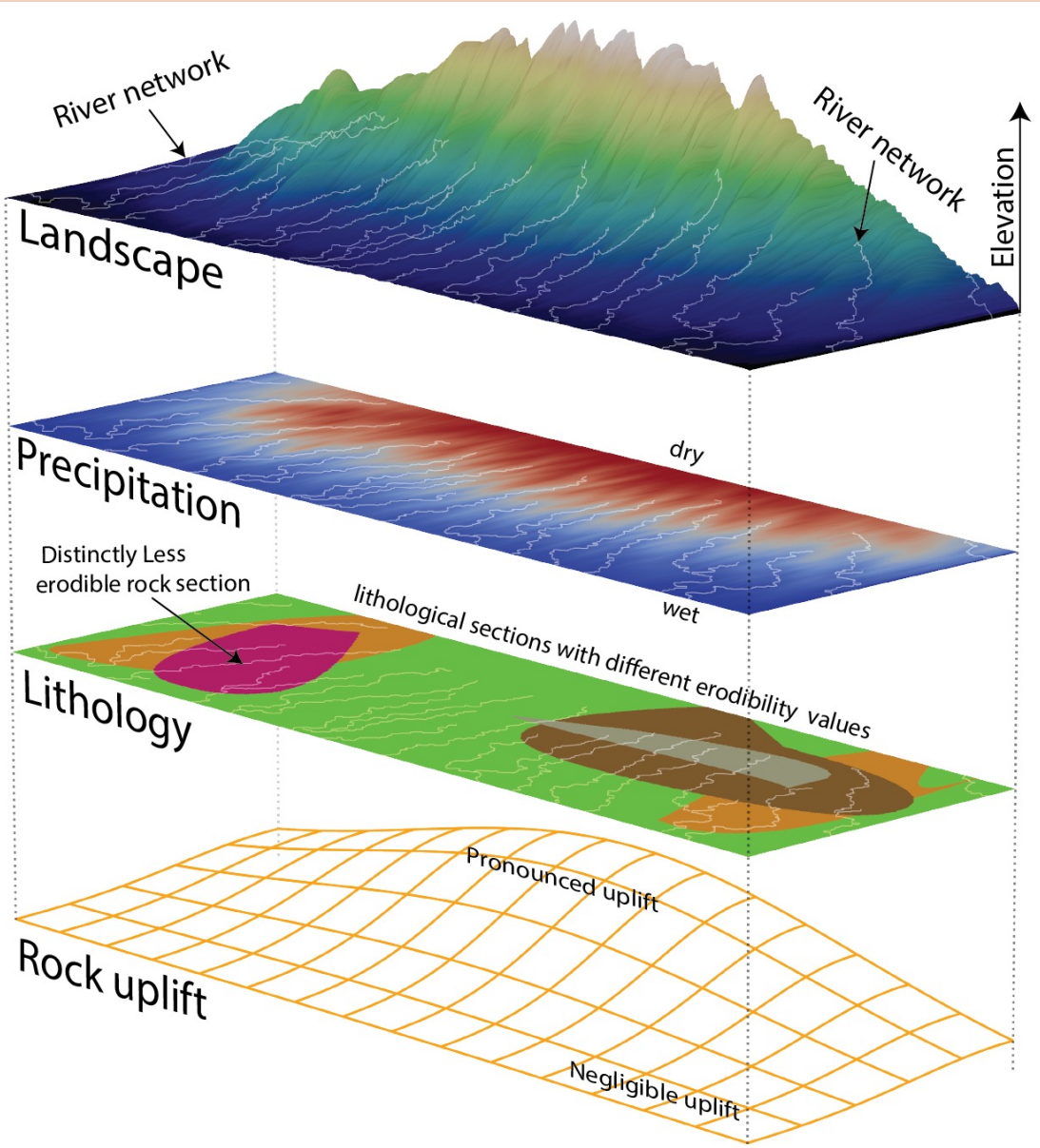
SHAPING FLUVIAL LANDSCAPES

- Landscapes encode the combined forcing of tectonics, climate and rock erodibility.
- Disentangling their contributions is essential for using landscapes as quantitative records of crustal deformation.



Oryan et al., 2024 (preprint)

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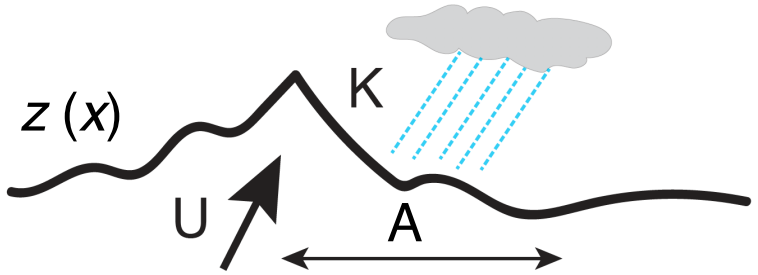
RIVER INCISION AT STEADY STATE



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

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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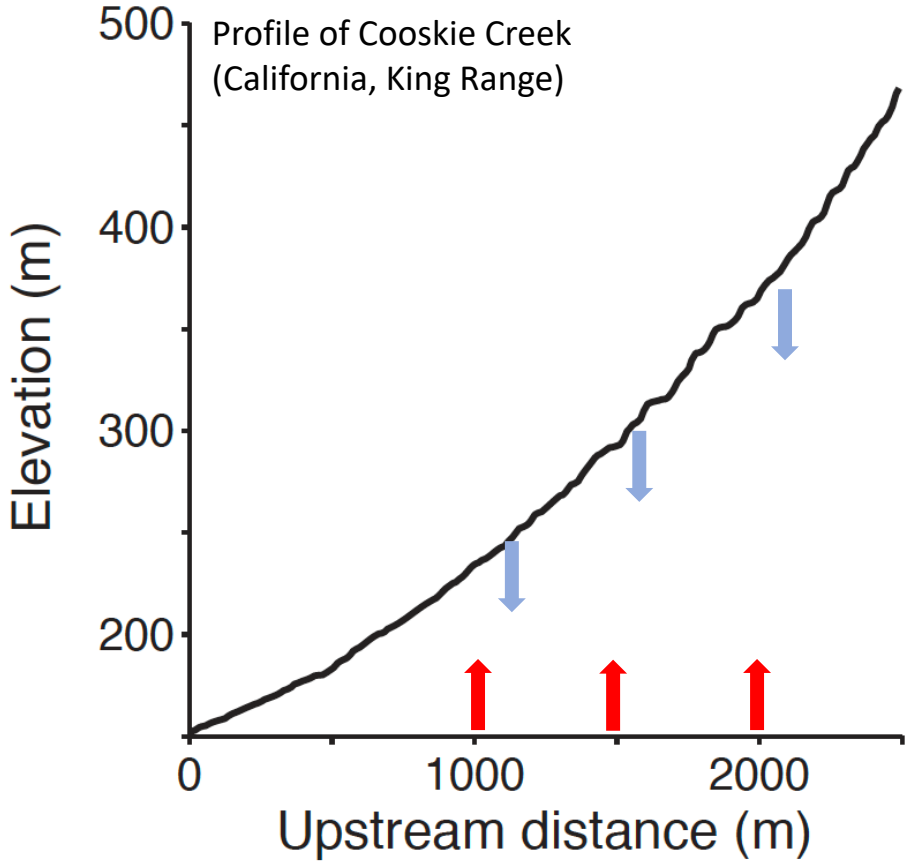

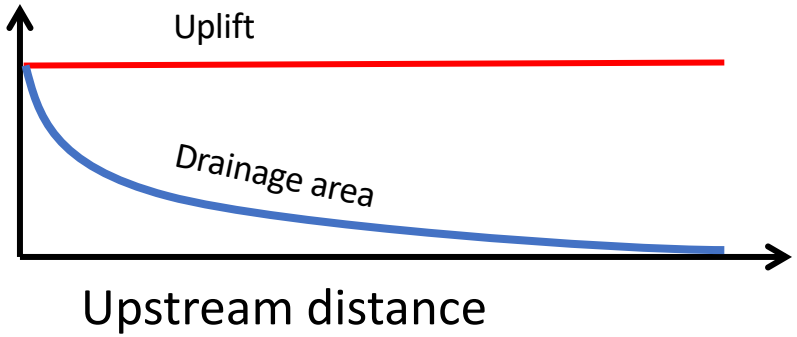

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Perron & Royden, 2013

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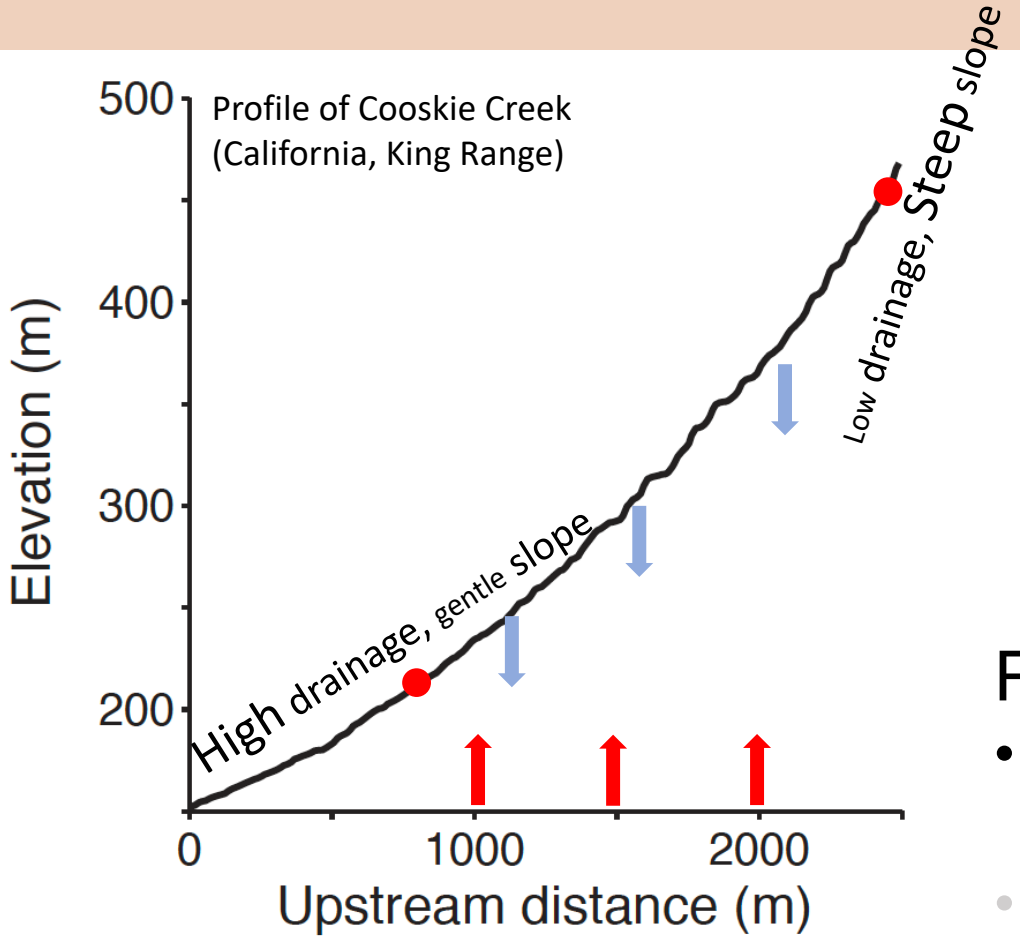

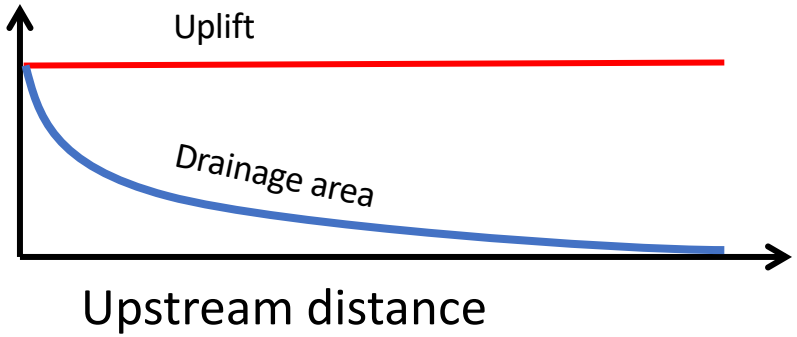

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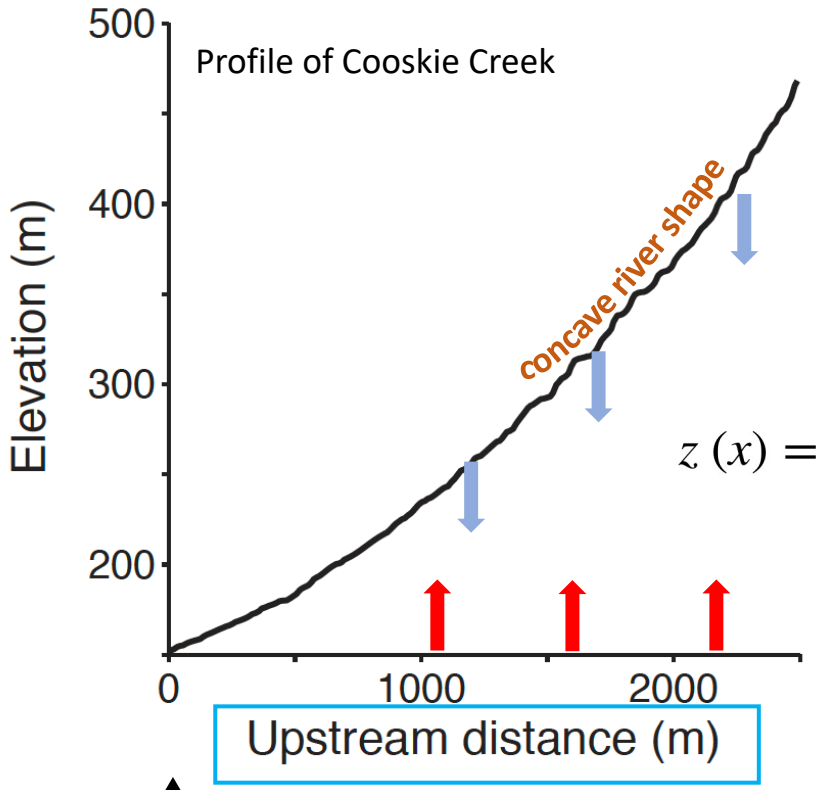
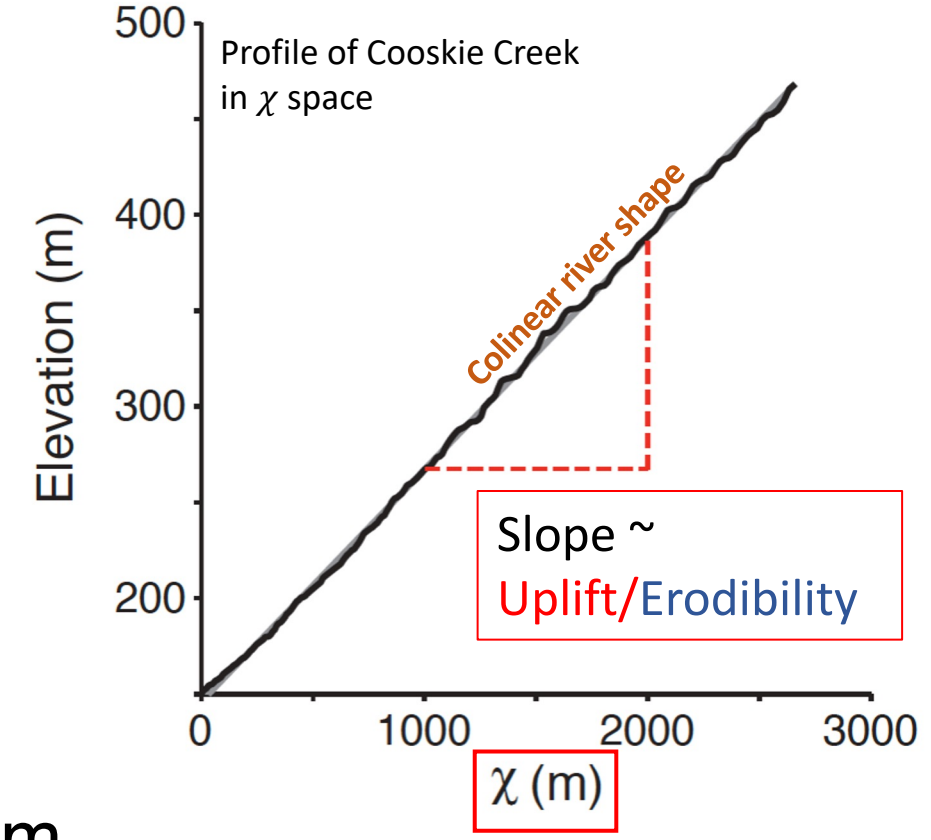
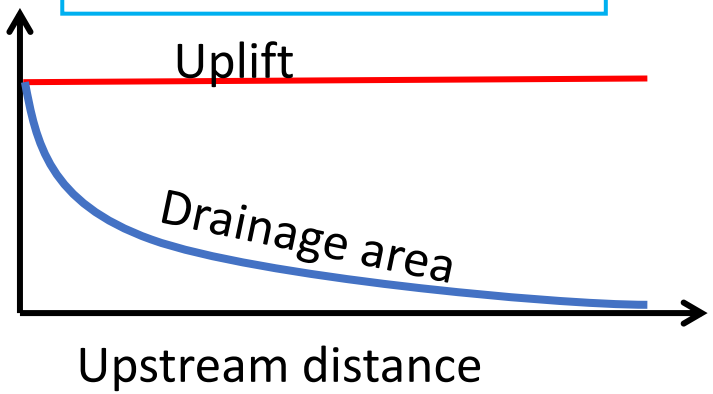
χ – TRANSFORMATION OF RIVERS



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

χ – TRANSFORMATION





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

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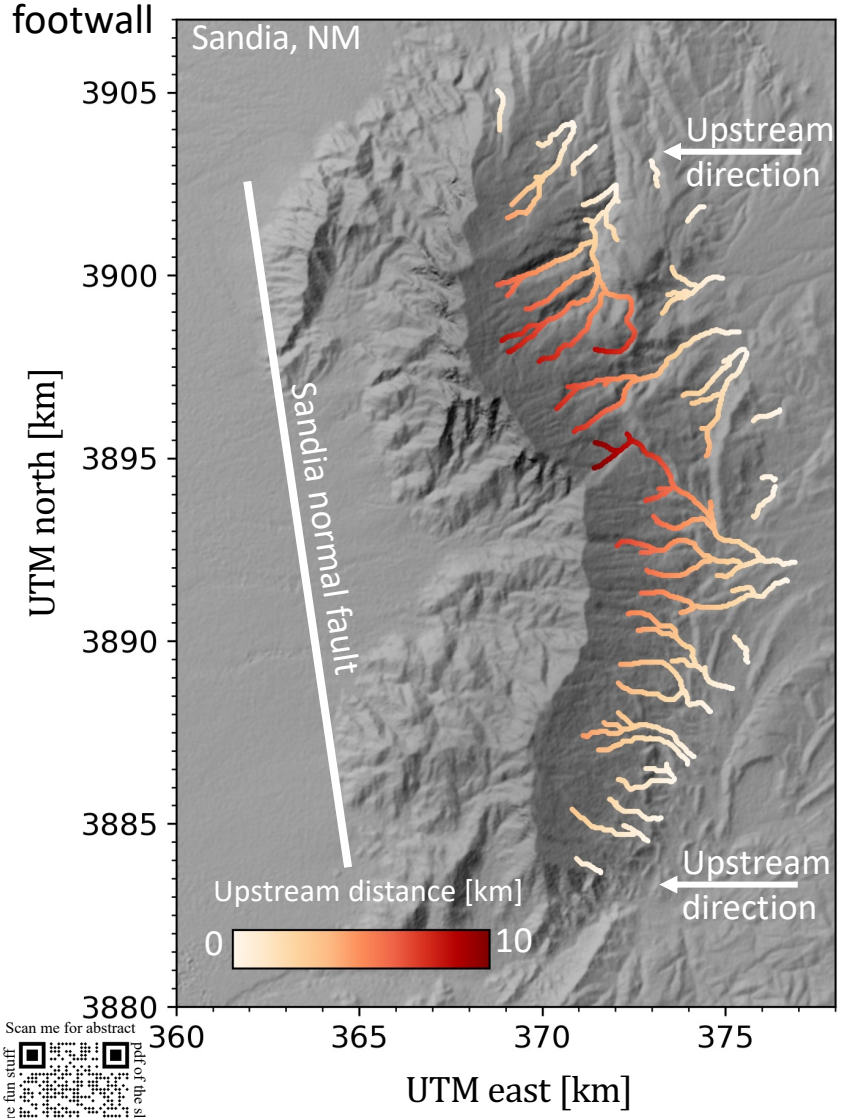
Perron & Royden, 2013

χ – TRANSFORMATION OF RIVER PROFILES IN SANDIA

Application to simple tectonic settings - normal fault footwall



River concavity reflects:

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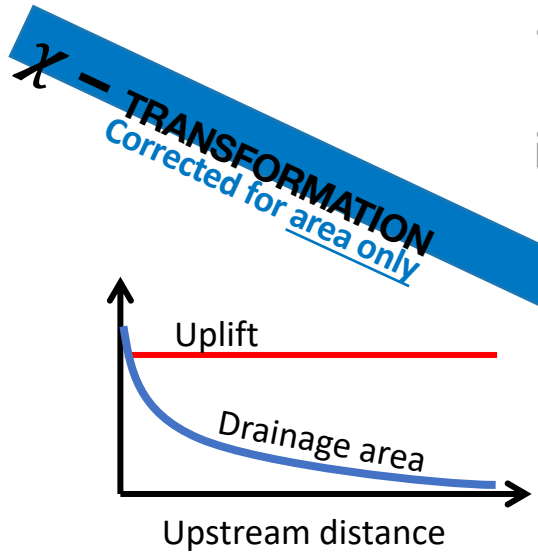
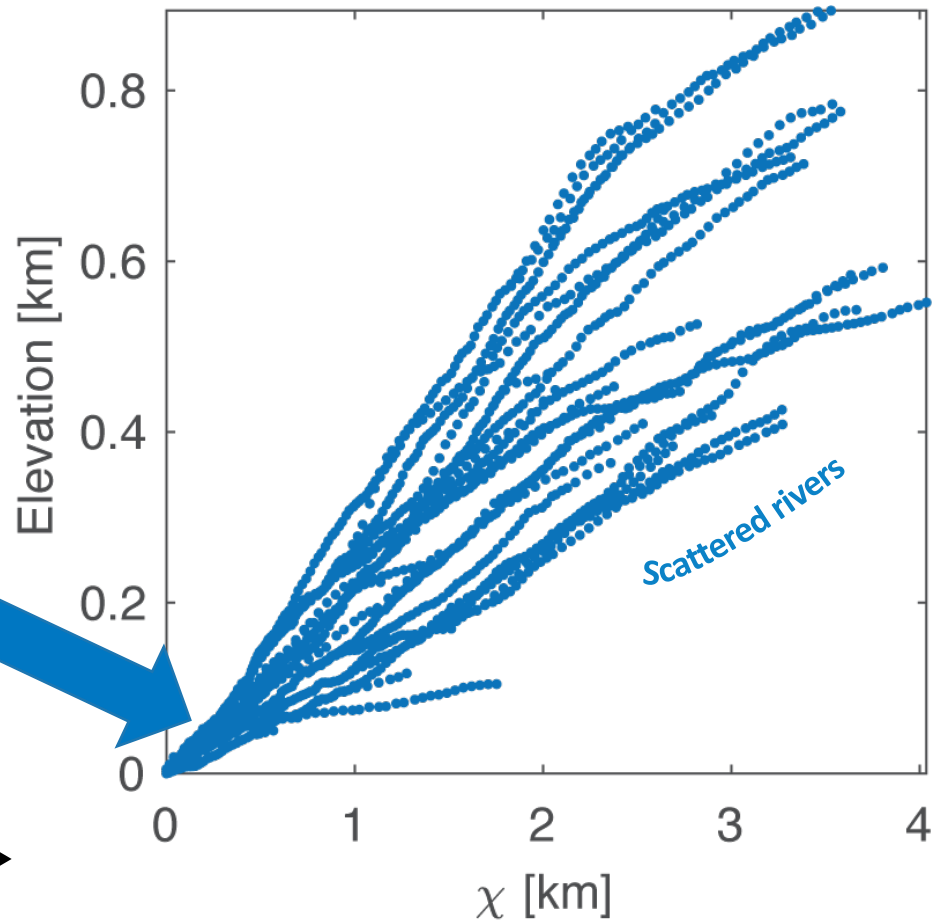
- Spatially variable erodibility and climate



χ *space* —Sandia rivers



Olive et al., 2022

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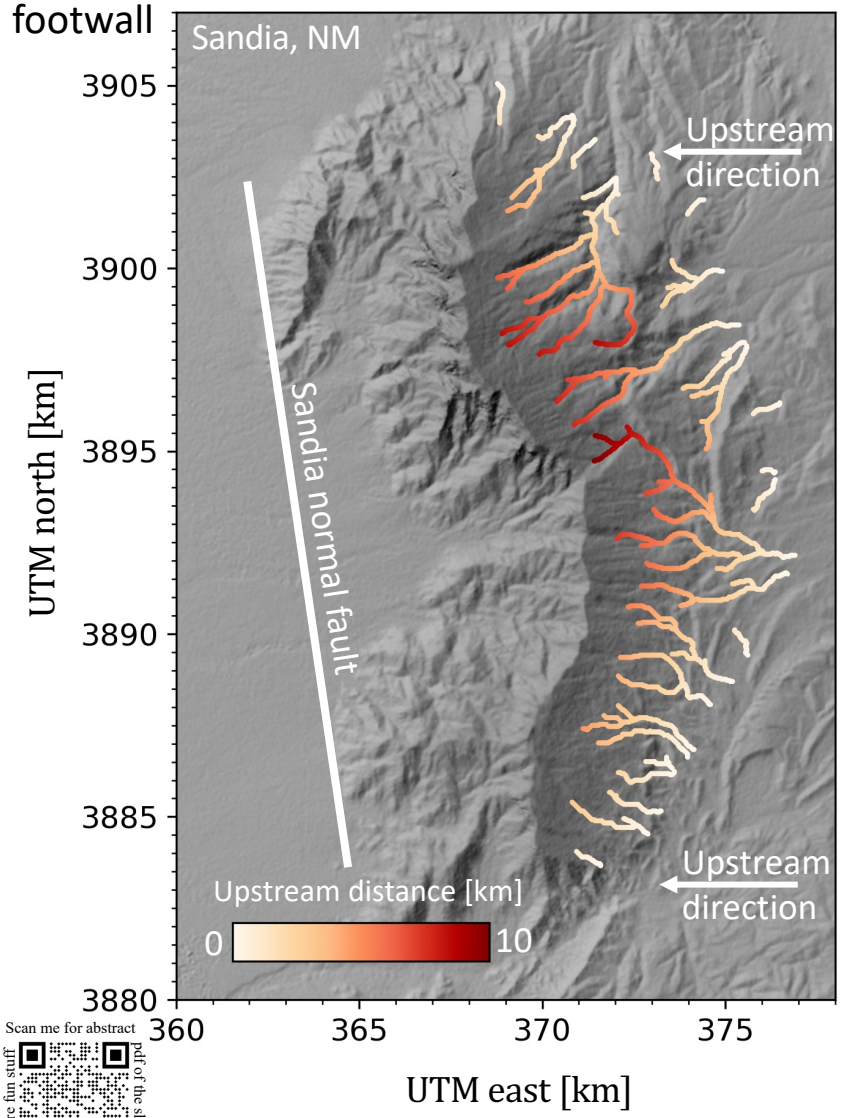
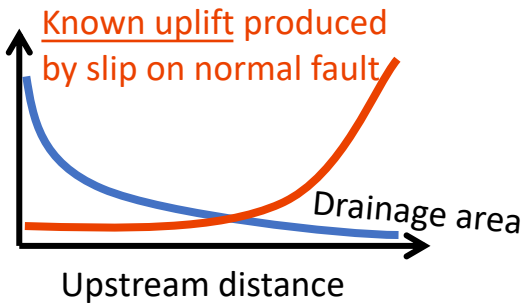


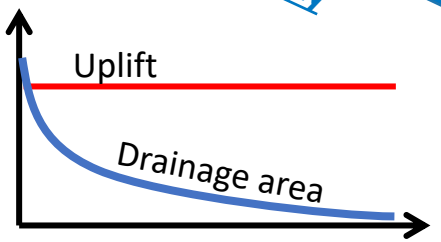


Corrected for area and uplift shape

χ – TRANSFORMATION

χ – TRANSFORMATION

Corrected for area only



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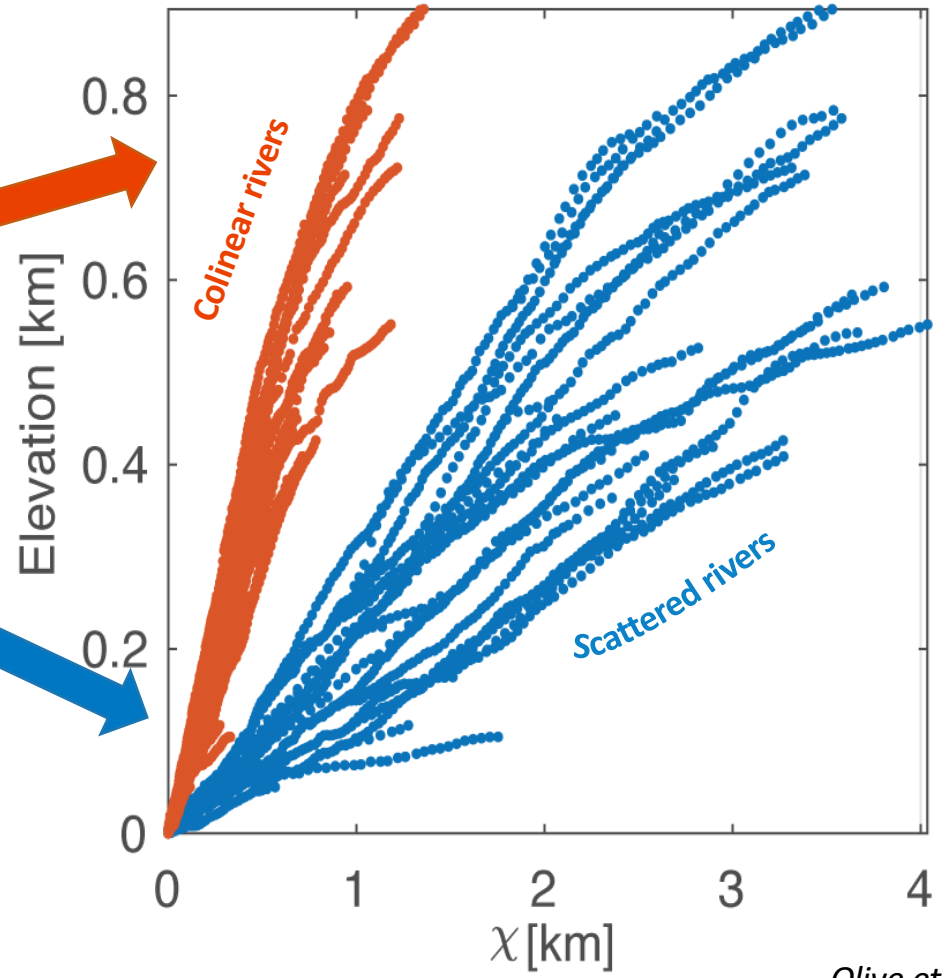

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Olive et al., 2022

χ – TRANSFORMATION OF RIVER PROFILES IN THE HIMALAYAS

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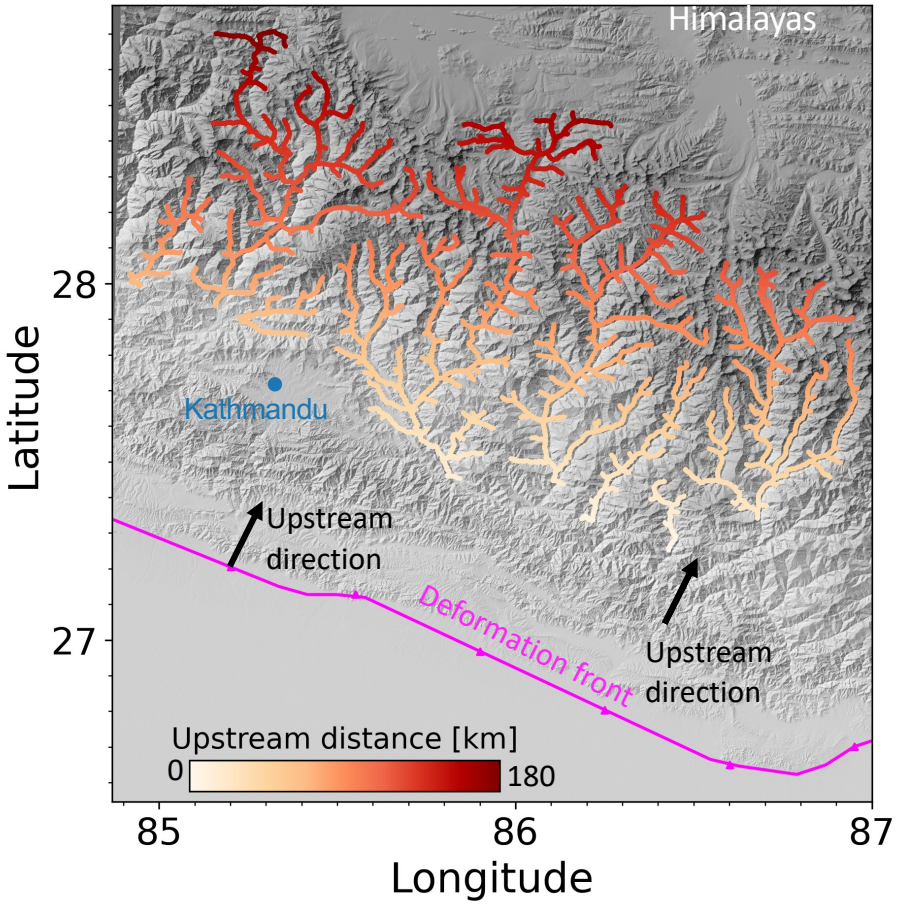

χ – TRANSFORMATION

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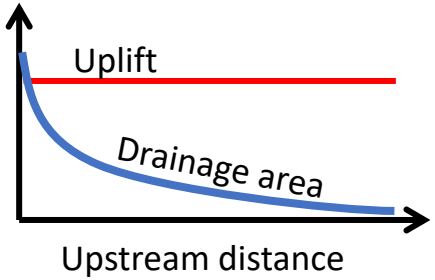

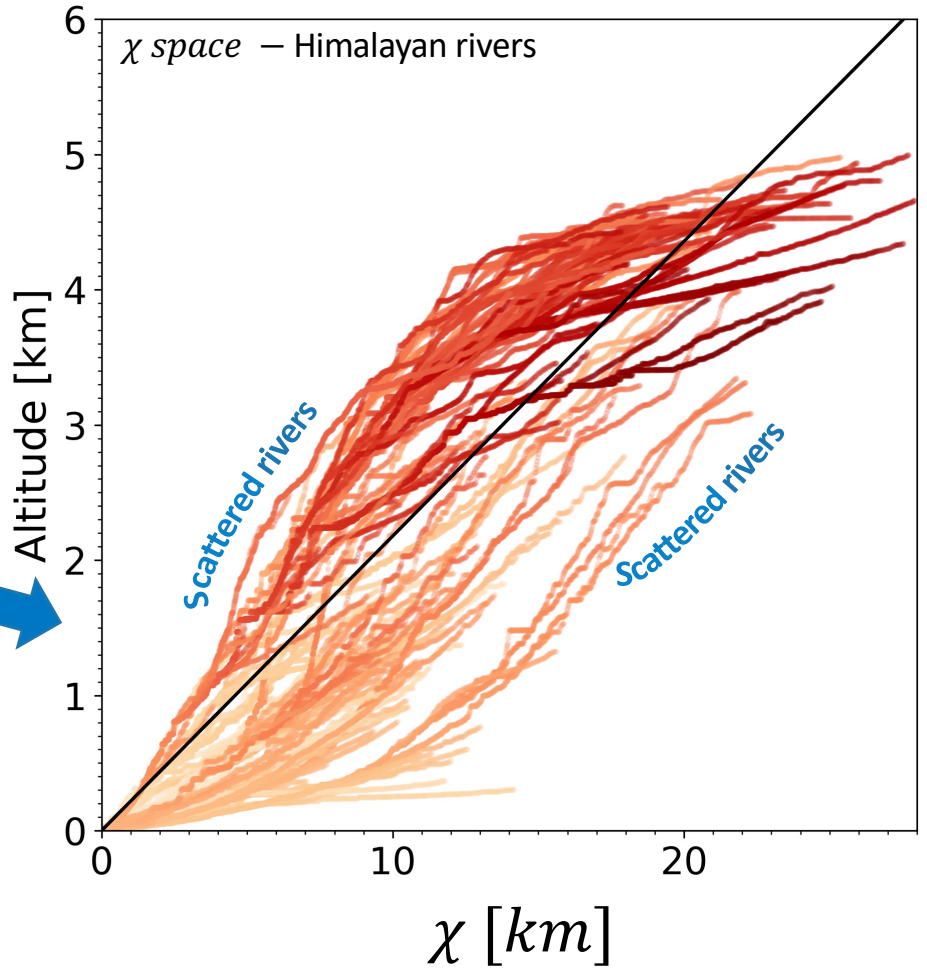

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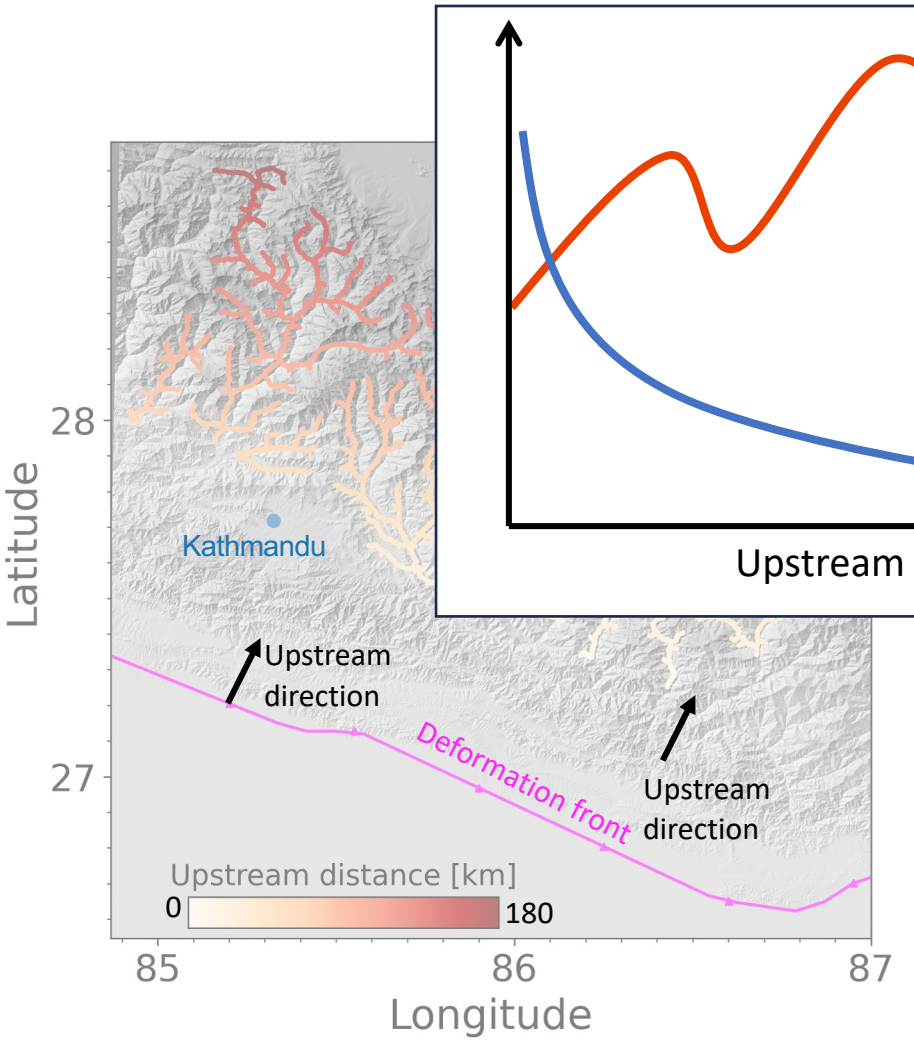
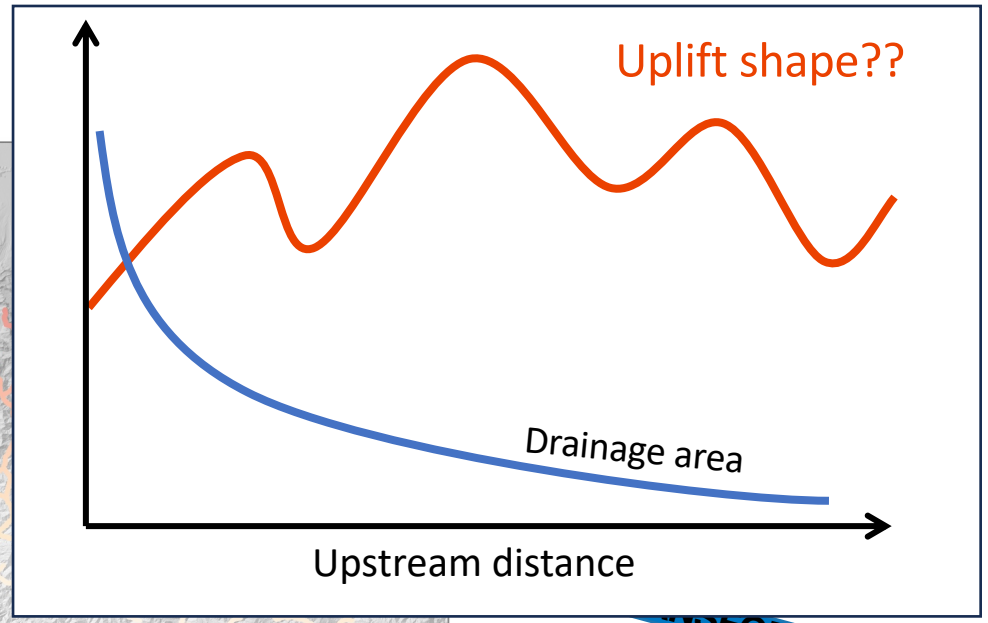
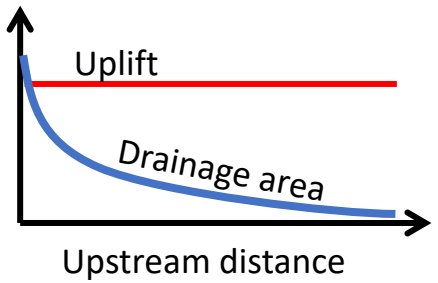


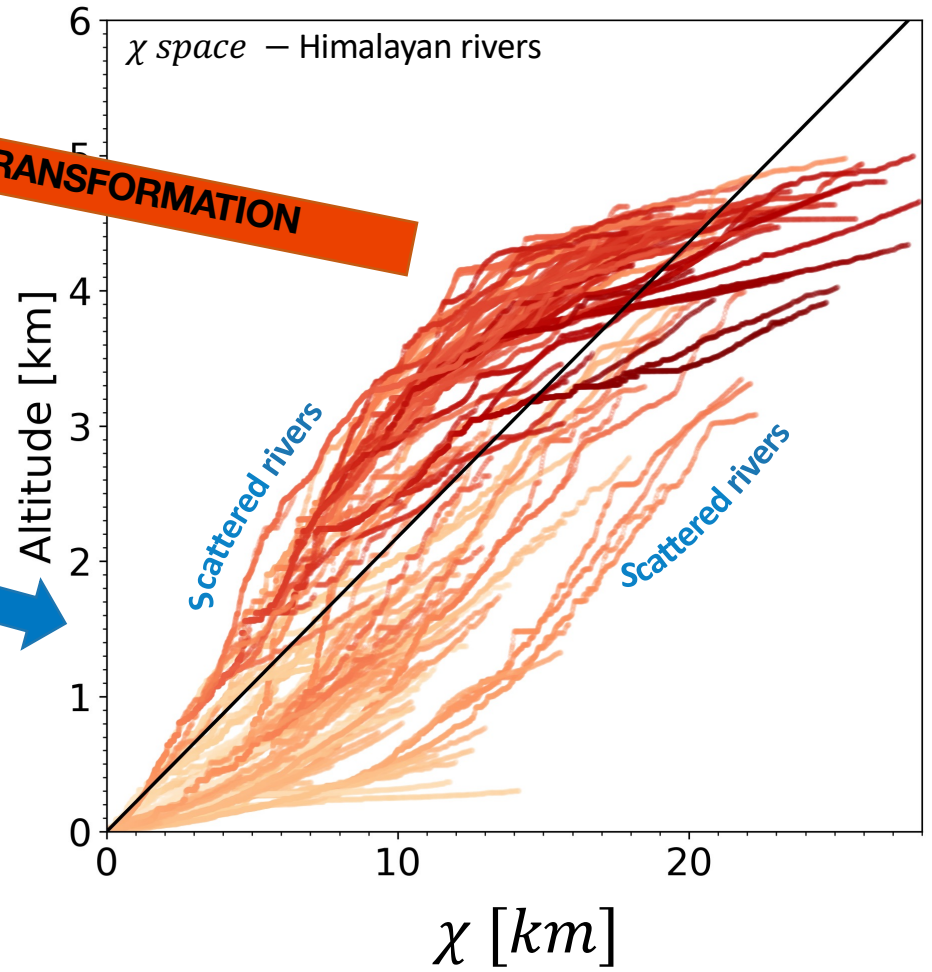


Invert for uplift shape that minimize rivers scatteredness

χ – TRANSFORMATION

Corrected for area only





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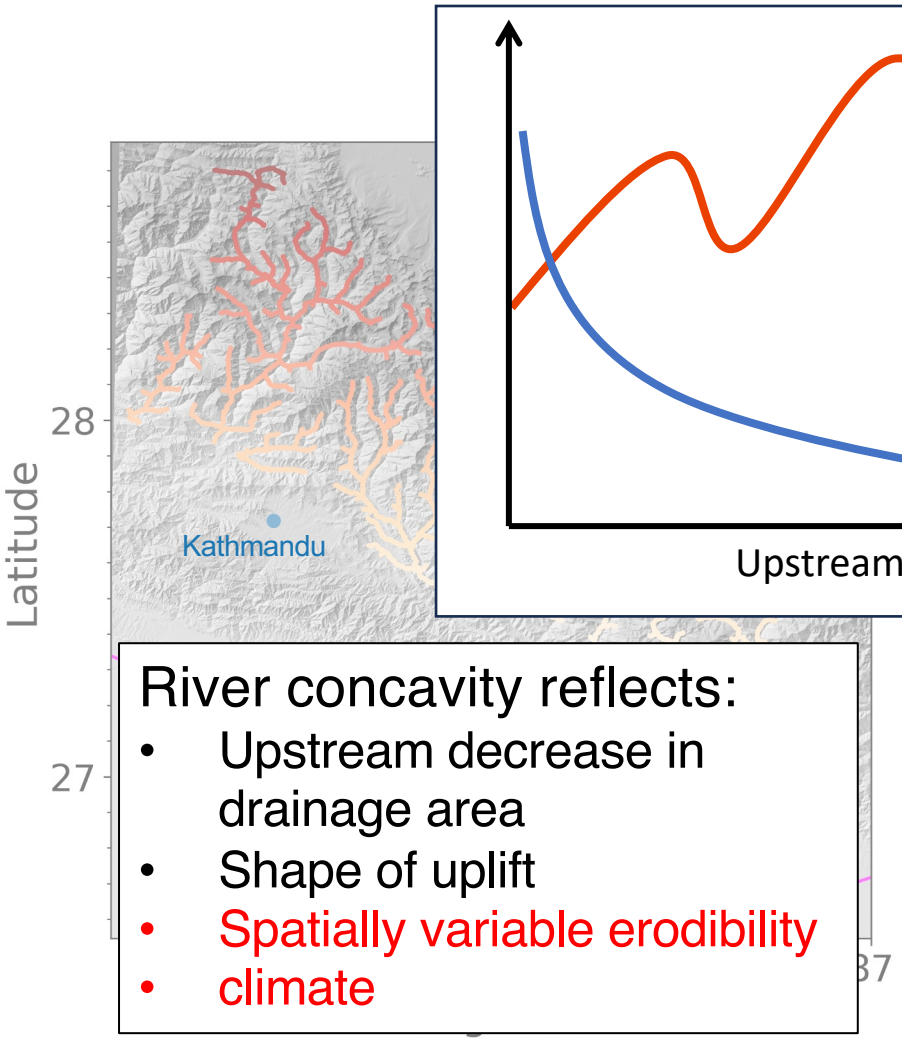

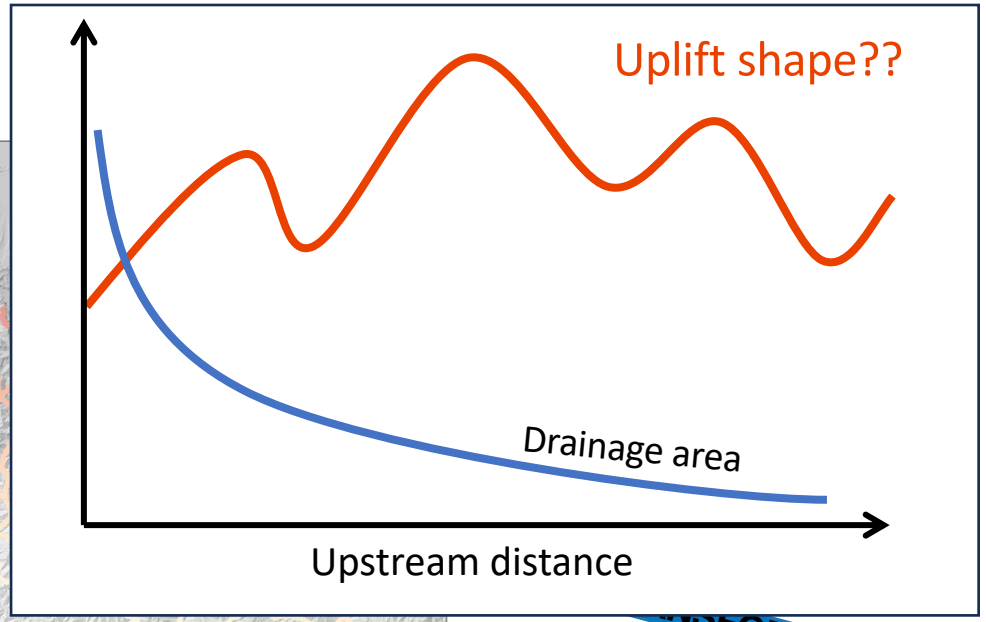

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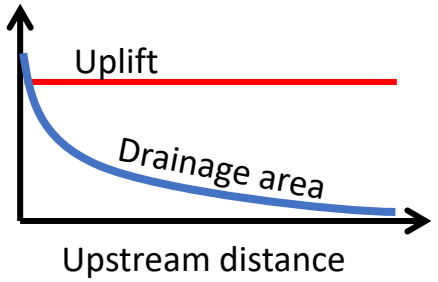

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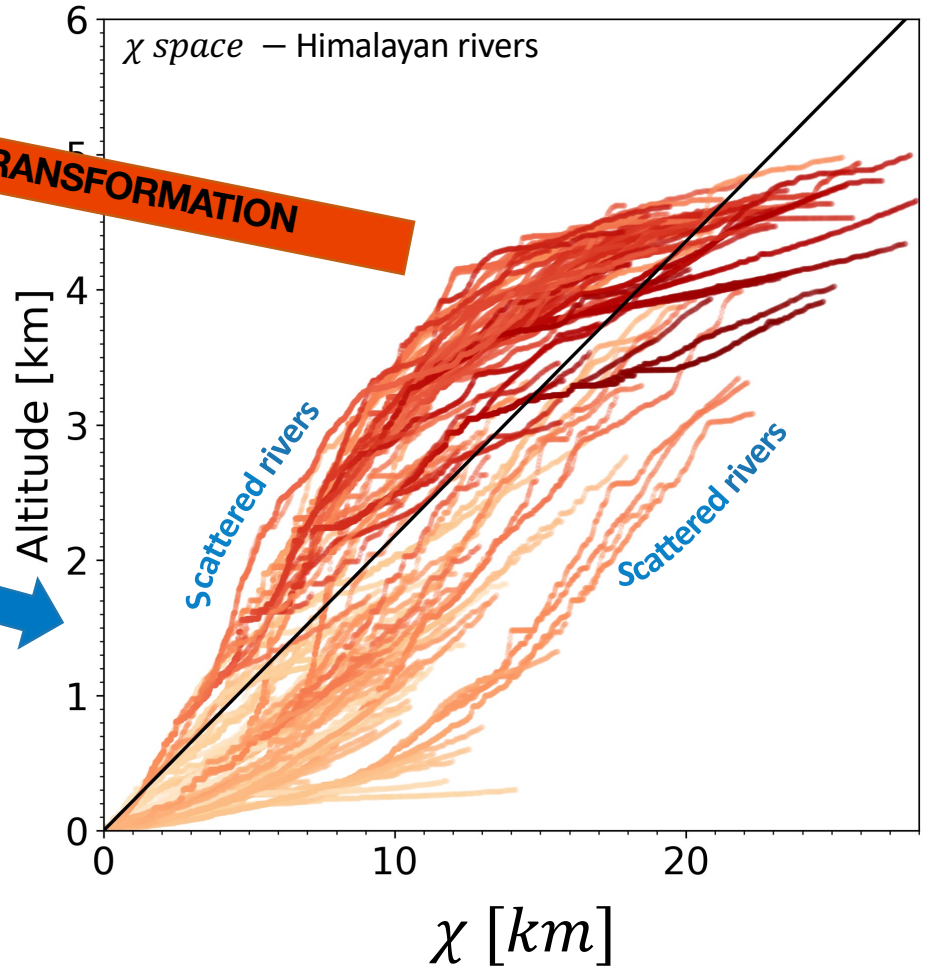

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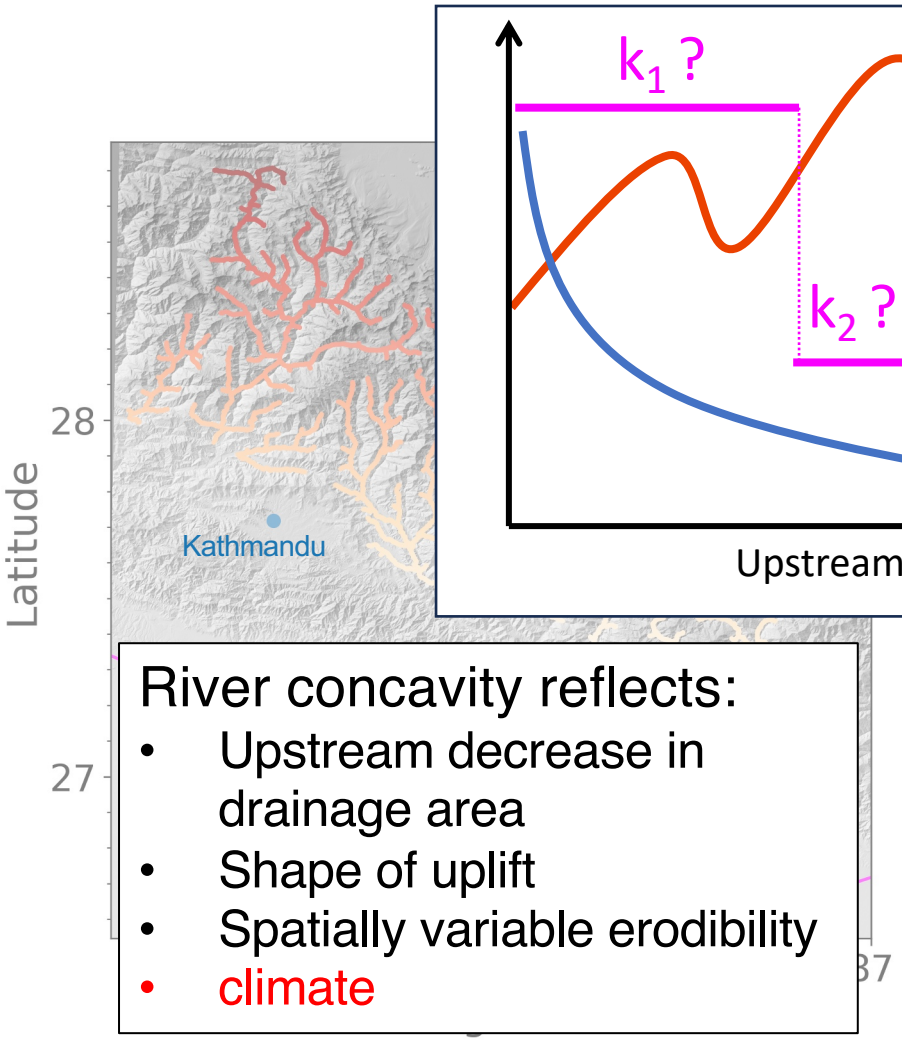
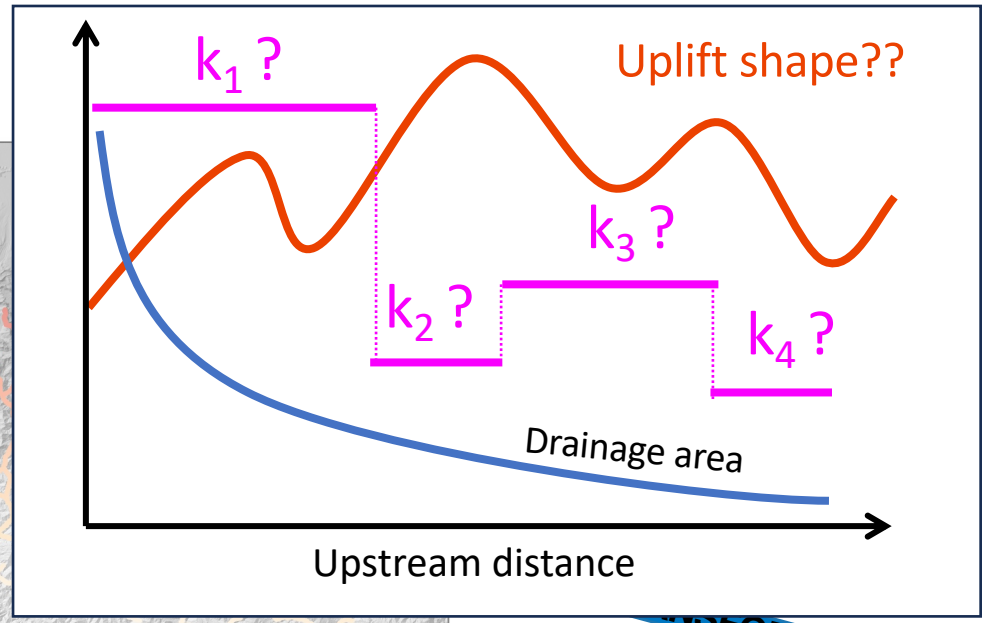
$\chi_{u,k}$ – TRANSFORMATION OF RIVER PROFILES IN THE HIMALAYAS





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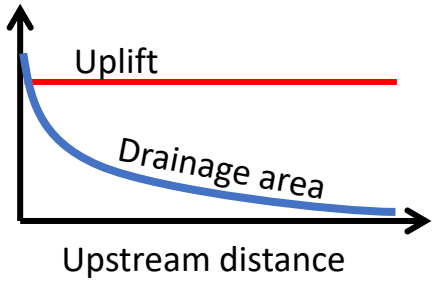
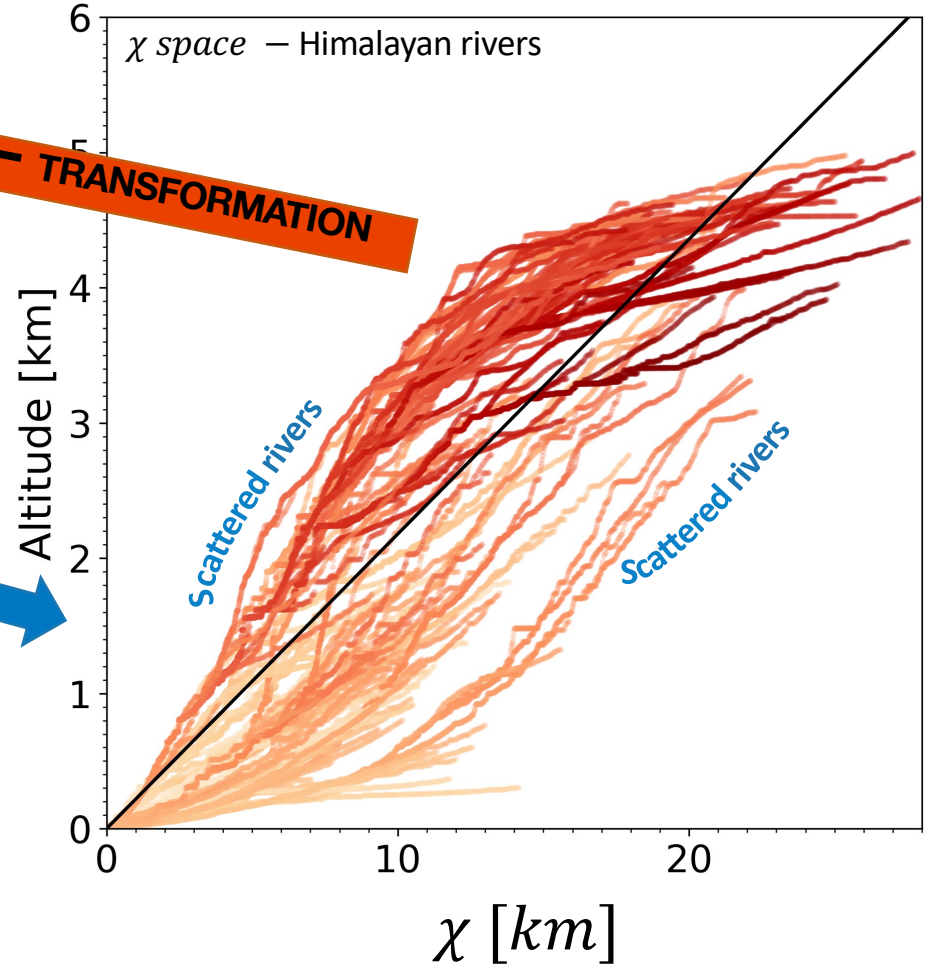


Invert for uplift shape that minimize rivers scatteredness

$\chi_{\mu,\kappa}$ – TRANSFORMATION



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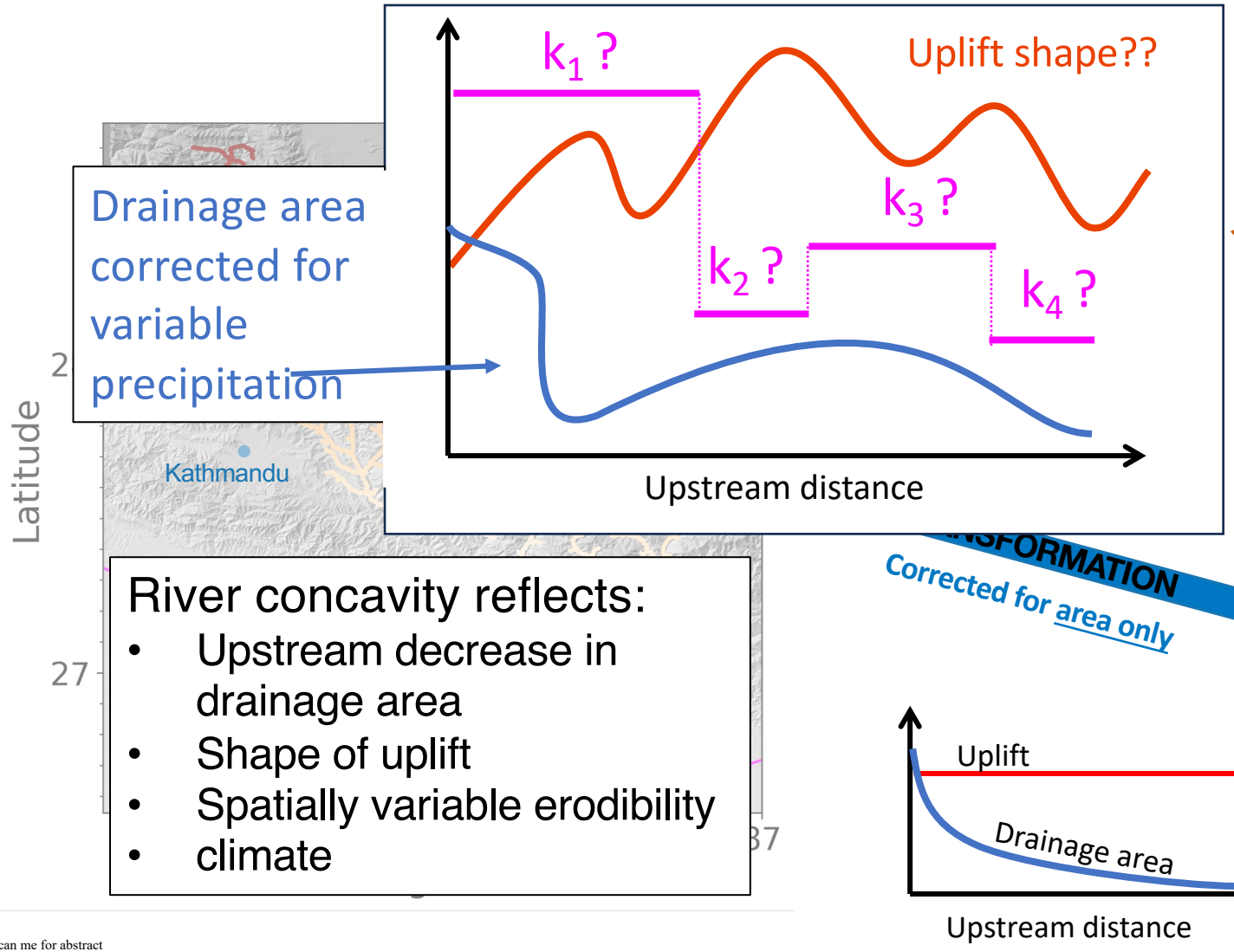

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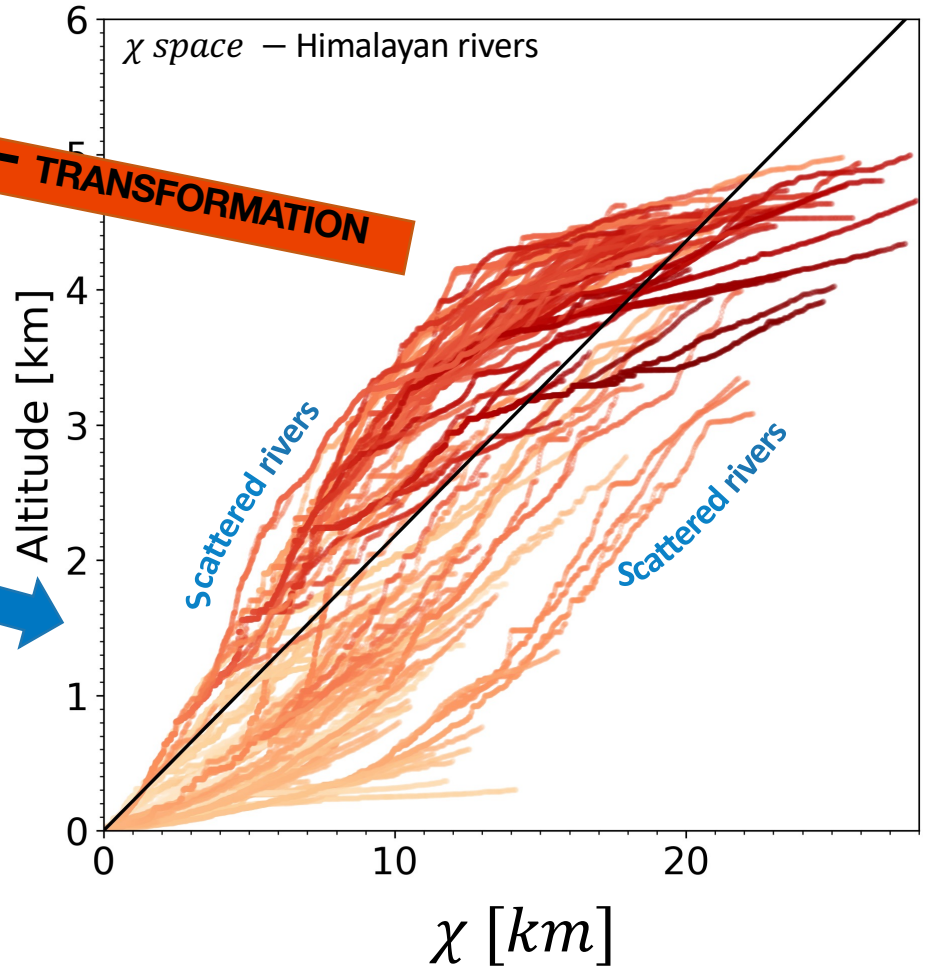

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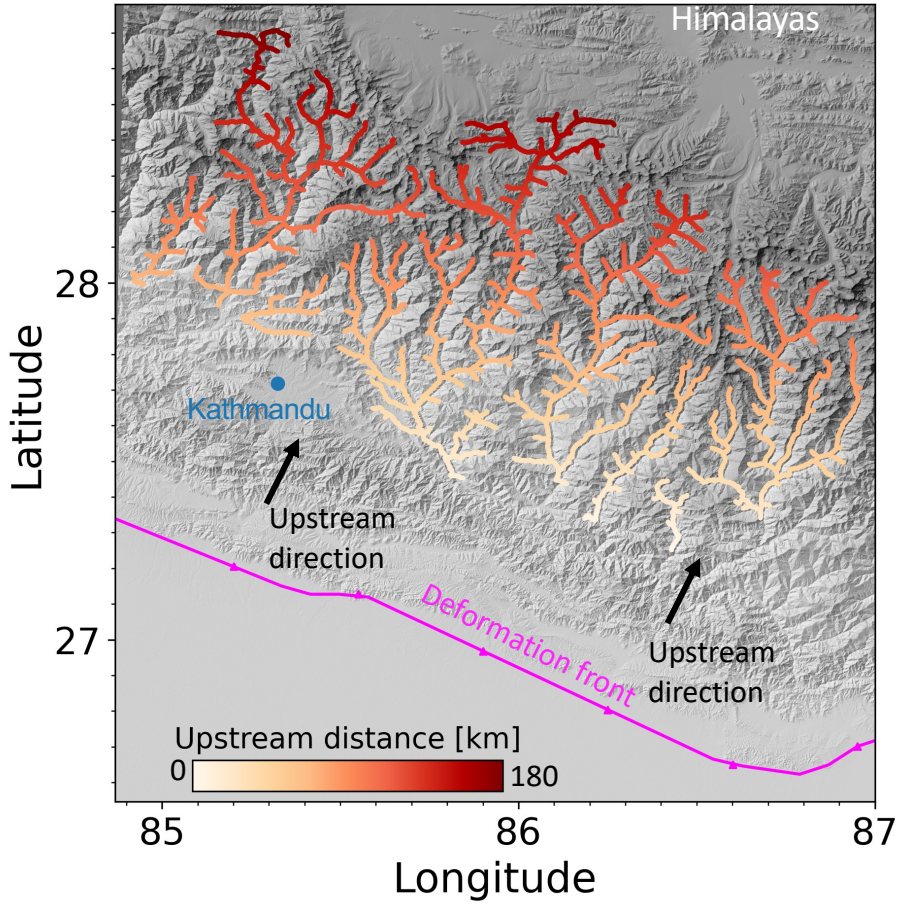
INVERTING HIMALAYAS USING $\chi_{u,k}$ TRANSFORMATION



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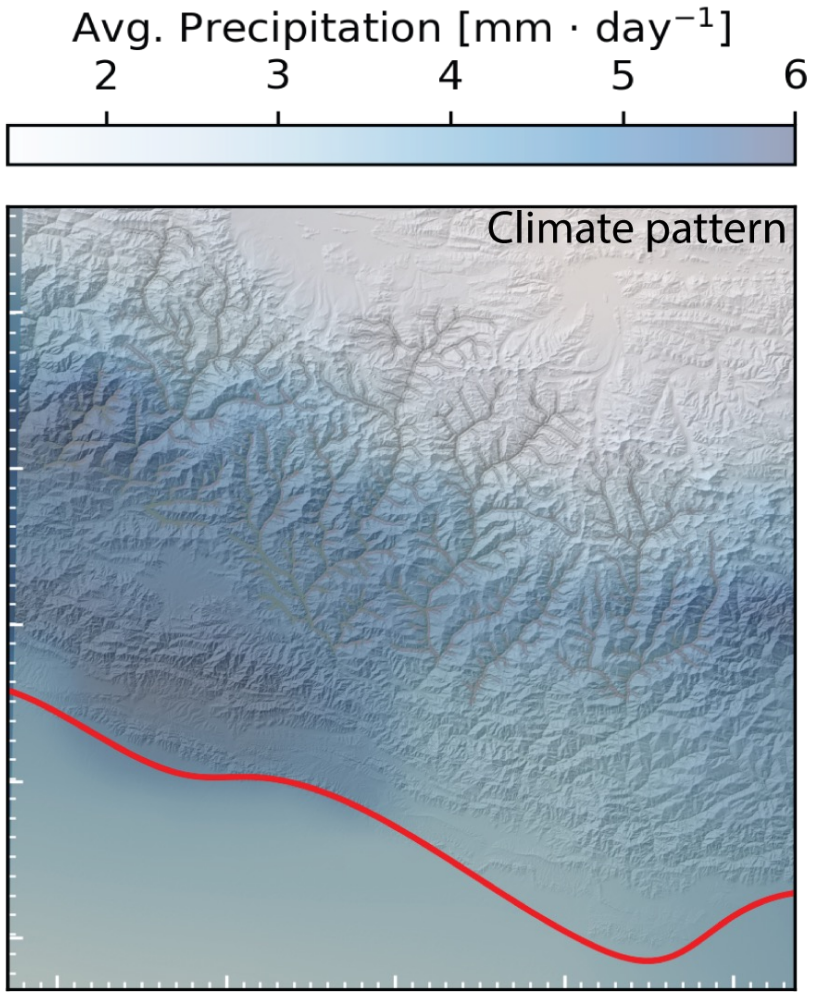

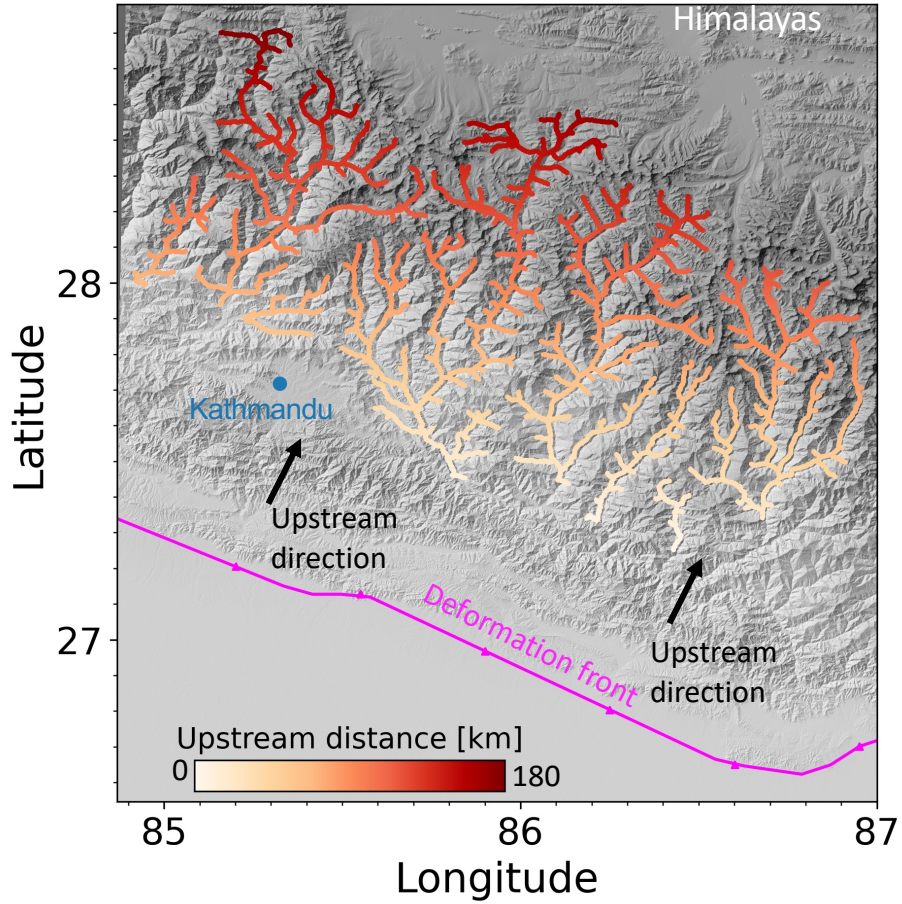

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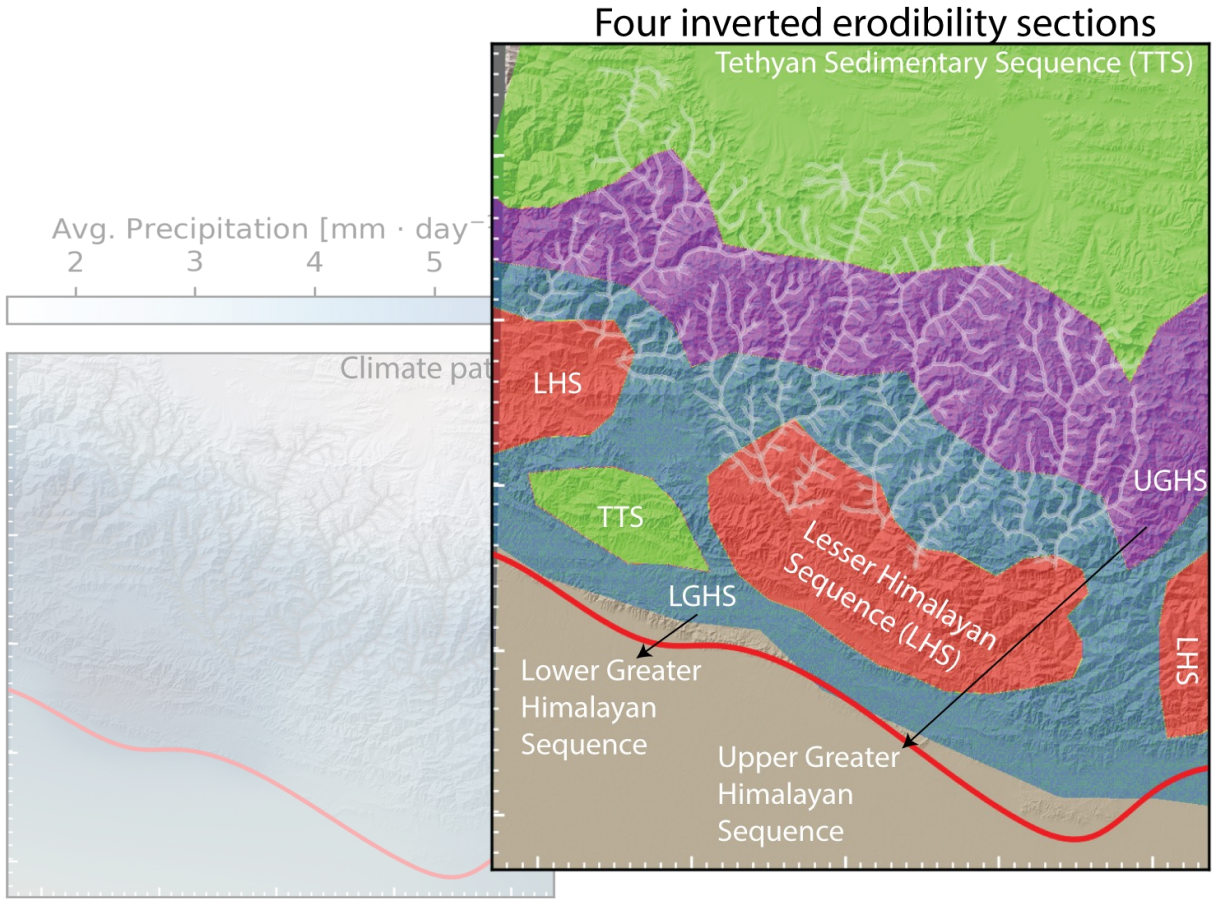

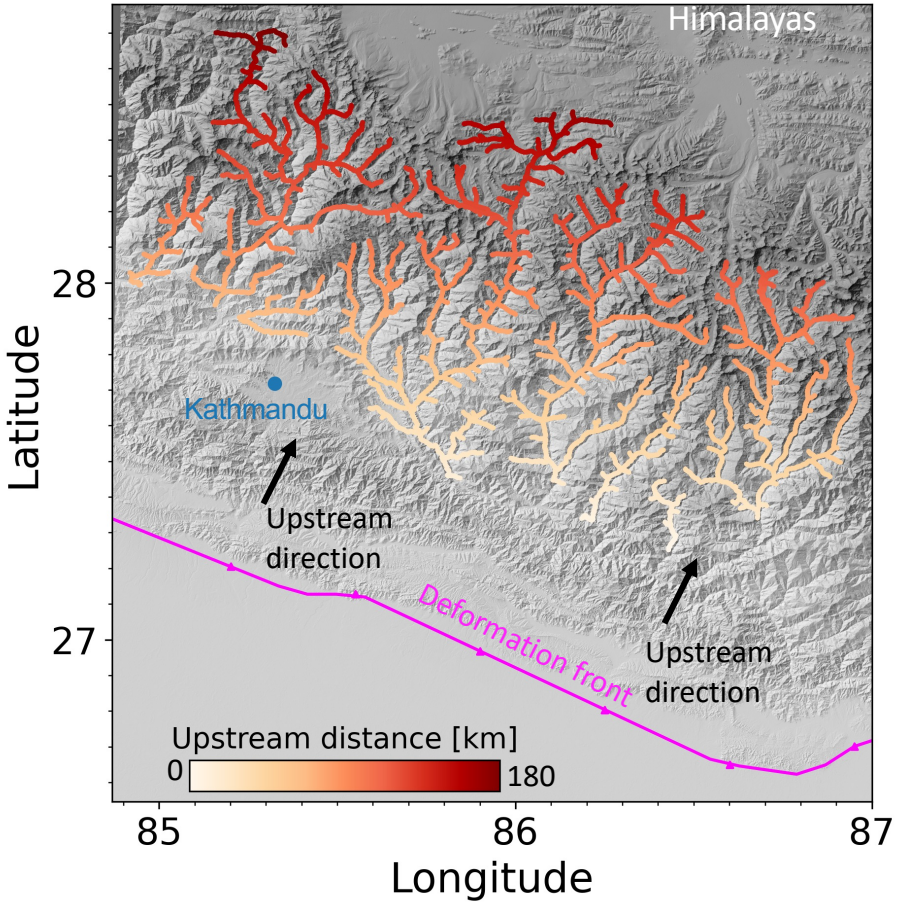

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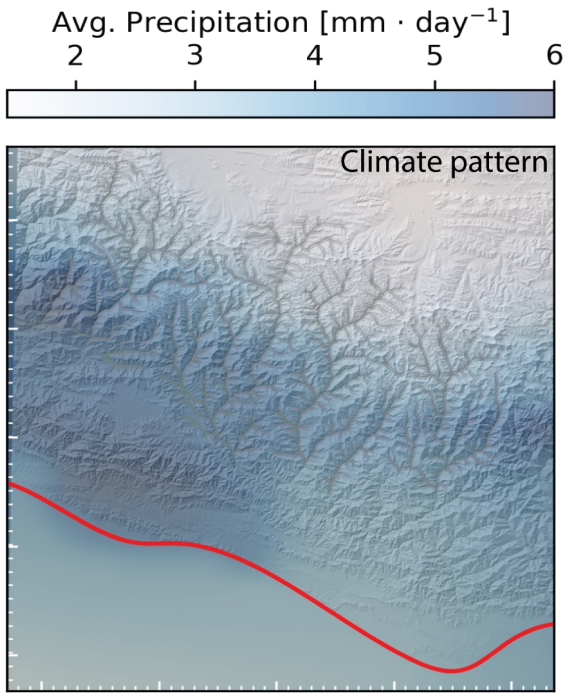

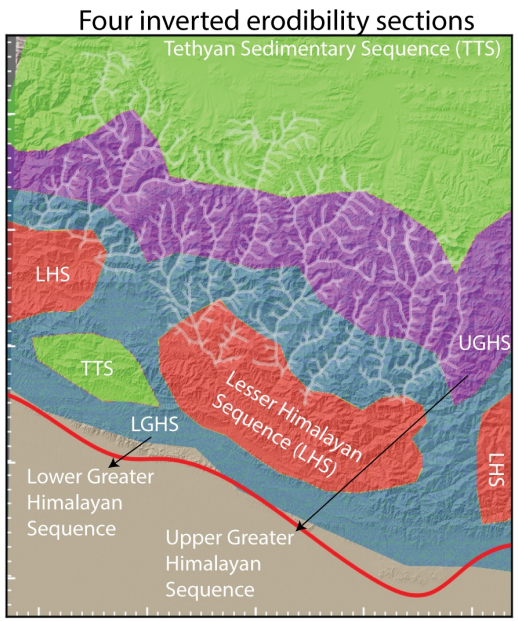

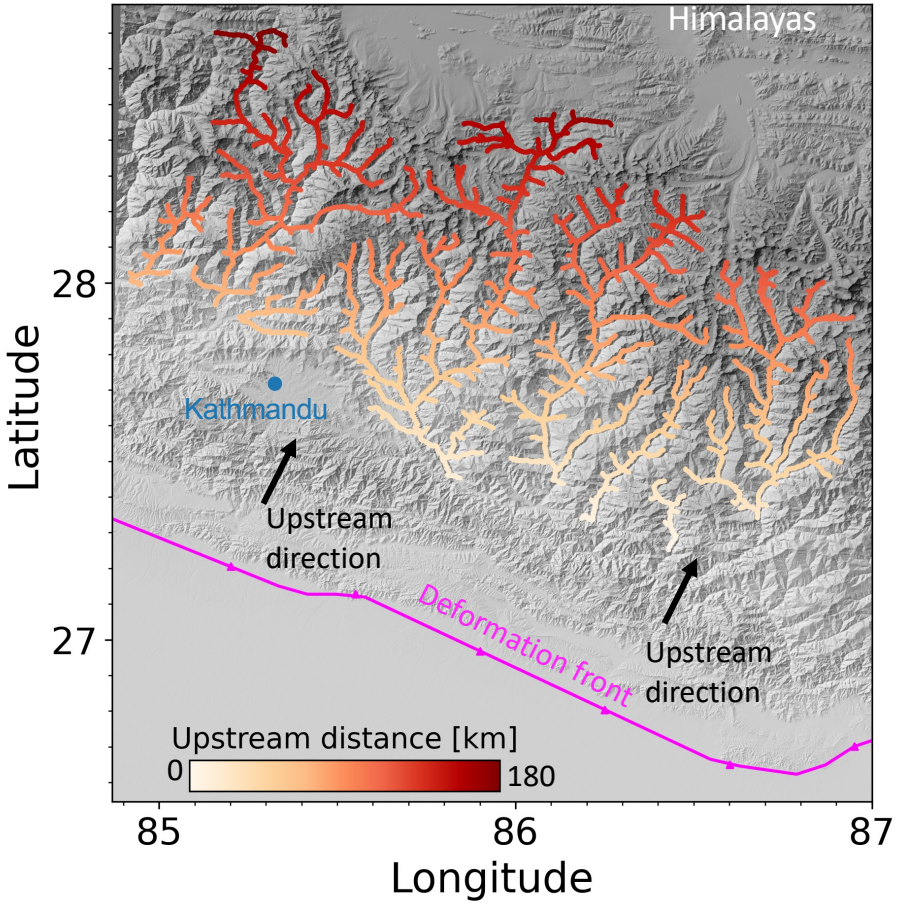

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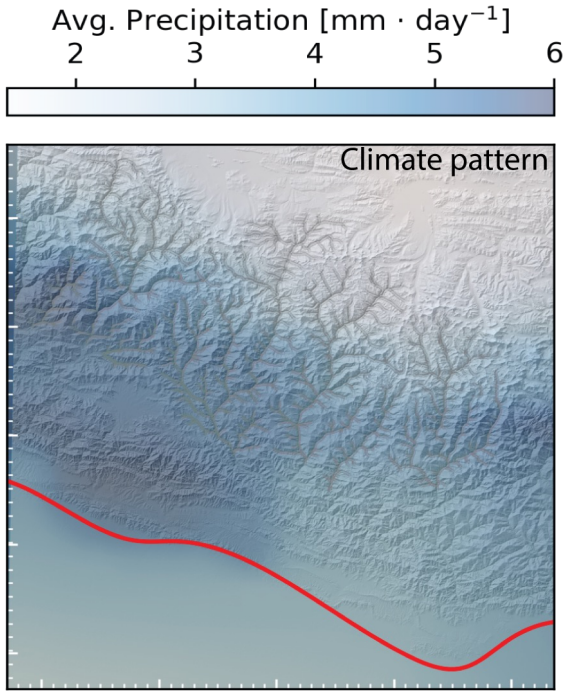
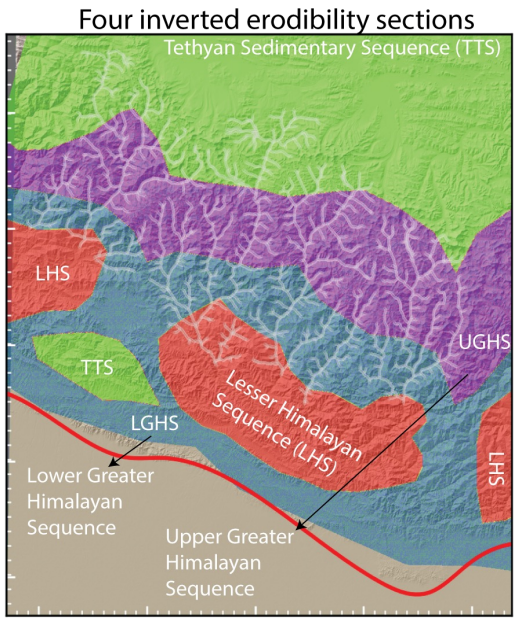
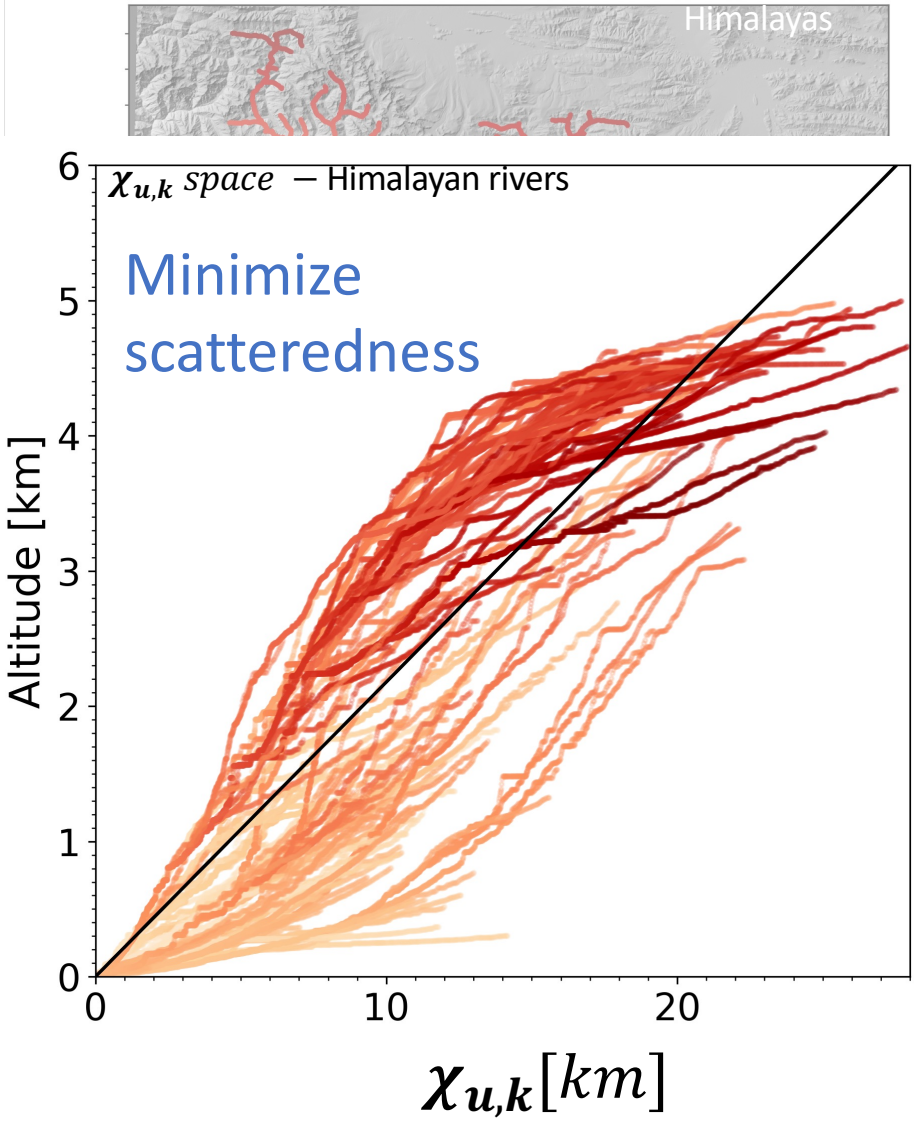
2. Map the spatial distribution of major lithological sections for piecewise rock erodibility values.
3. Describe uplift using B-spline interpolating functions that extend across river network.
4. Invert for uplift and erodibility values minimizing $\chi_{u,k}$.







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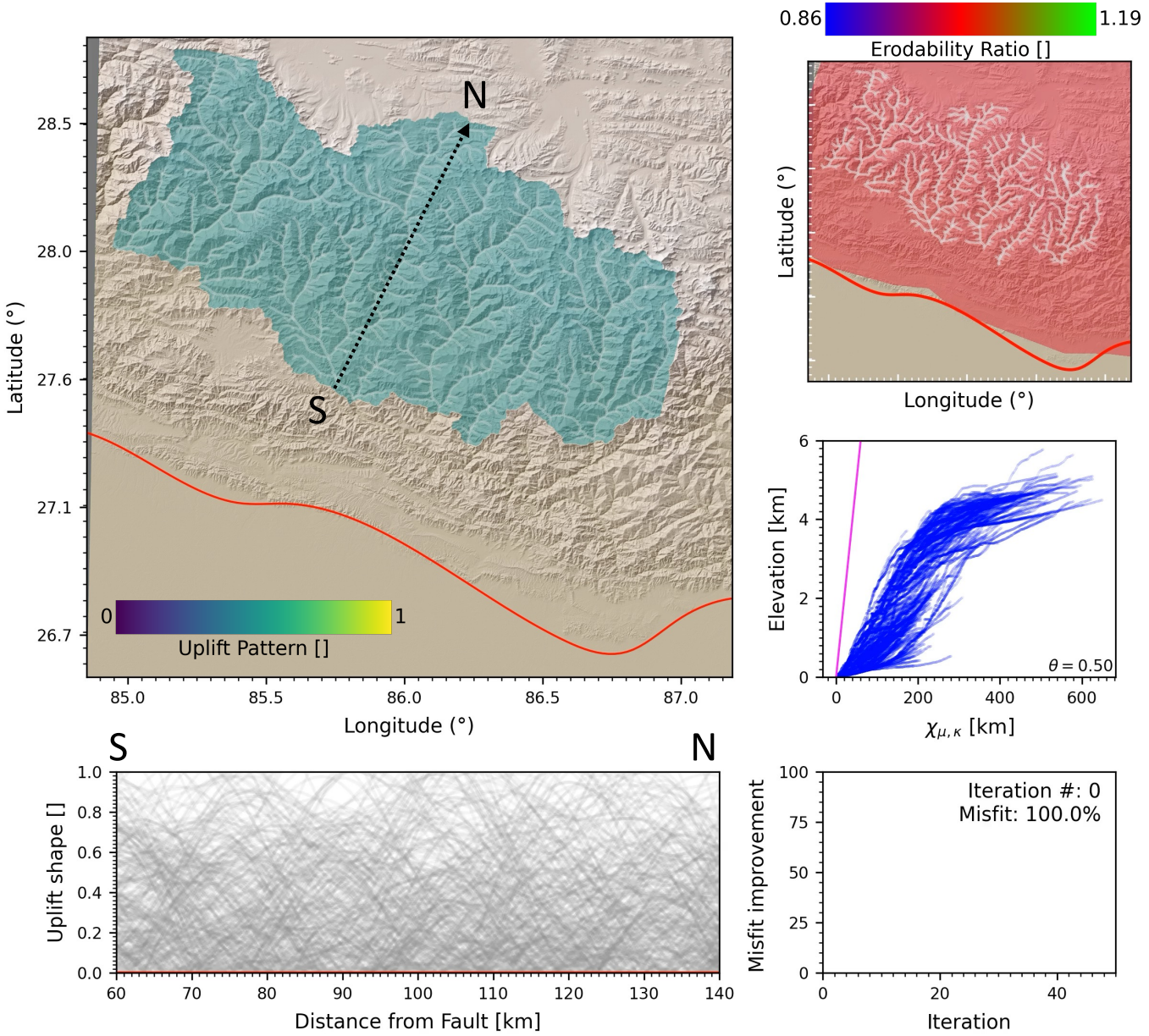
INVERTING HIMALAYAS USING $\chi_{u,k}$ TRANSFORMATION

- Quasi-Newton inversion method with 120,000 river nodes spanning 18,000 km².
- Inversion finds 144 parameters describing uplift pattern and 4 erodibility values that best linearizes river profile in $\chi_{u,k}$ space.



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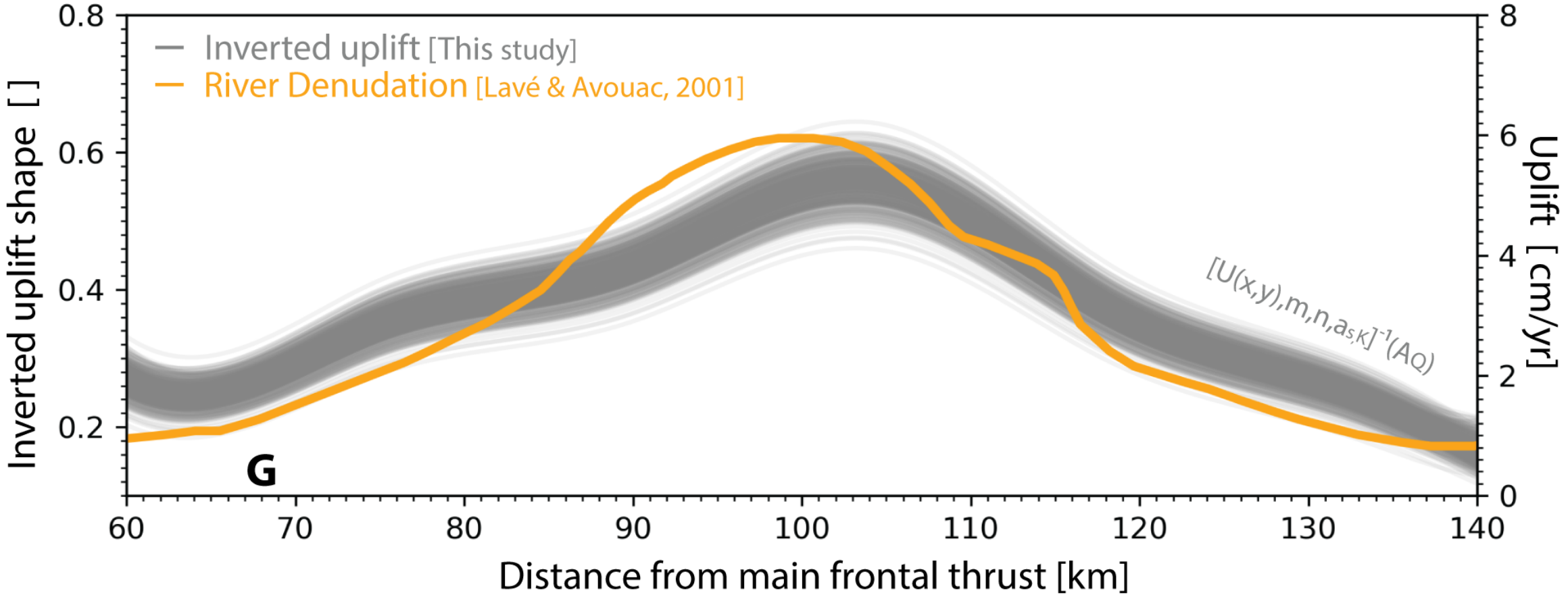
RETRIEVED UPLIFT PATTERN RESEMBLE PREVIOUS ESTIMATES

- Inferred long-term uplift matches denudation rates.



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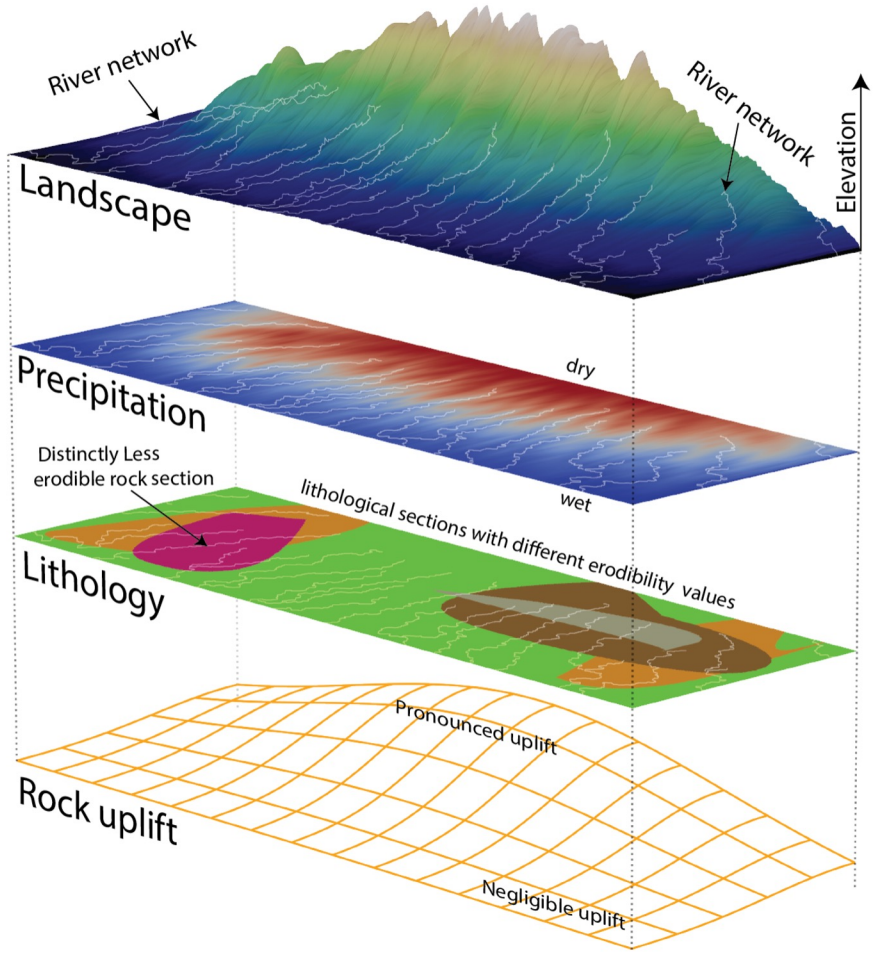
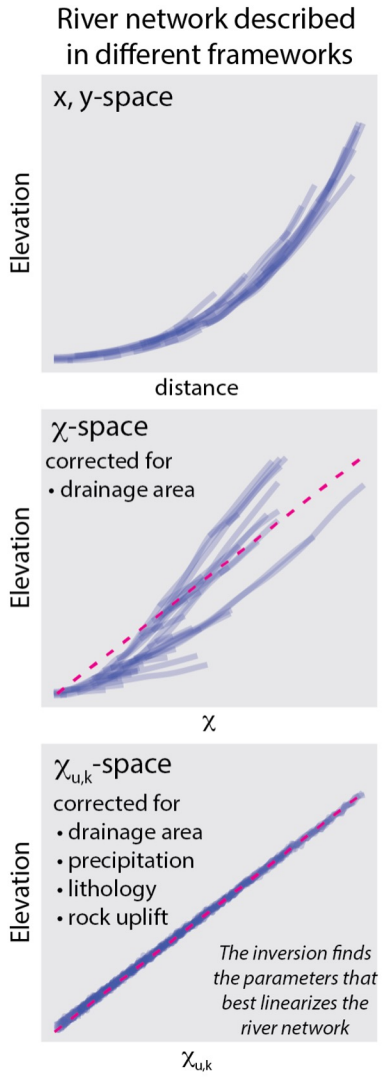
TAKE AWAY MESSAGE

- We demonstrate how $\chi_{u,k}$ inversion can disentangle the contributions of tectonics, climate and erodibility from landscapes.
- This approach opens the door to leveraging time-averaged signals preserved in landscapes to infer crustal deformation across different timescales.





Scan me for preprint and more!

Scan me for abstract

& more fun stuff

Oryan et al., 2024 (preprint)