Utagawa Kokunimasa, woodblock print, 1896

Bar Oryan

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GREAT MEGATHURST EARTHQUAKES IN THE PAST 20 YEARS

1. **2004 Sumatra-Andaman Earthquake (Mw 9.3)**
   - **Date:** December 26, 2004
   - **Location:** Off the west coast of northern Sumatra, Indonesia
   - **Impact:** Triggered a catastrophic tsunami, causing over 230,000 deaths across 14 countries.

2. **2010 Maule Earthquake (Mw 8.8)**
   - **Date:** February 27, 2010
   - **Location:** Offshore Maule region, Chile
   - **Impact:** Over 500 fatalities and extensive infrastructure damage, including port and road failures.

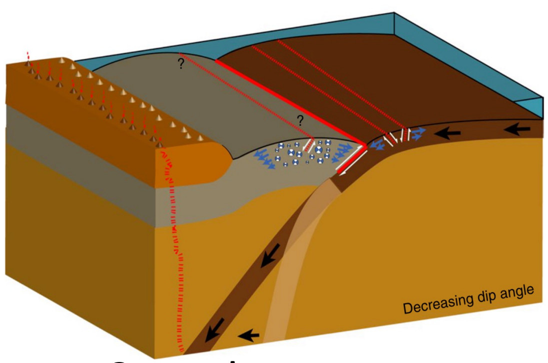
3. **2011 Tōhoku Earthquake (Mw 9.1)**
   - **Date:** March 11, 2011
   - **Location:** Off the east coast of Honshu, Japan
   - **Impact:** Generated a massive tsunami, leading to nearly 16,000 deaths and the Fukushima nuclear disaster.

 MY RESREACH INTRESTS

I am a **geophysicist** interested in studying the hazards posed by subduction earthquake cycles using an **interdisciplinary** approach ranging **a broad range of timescales** !

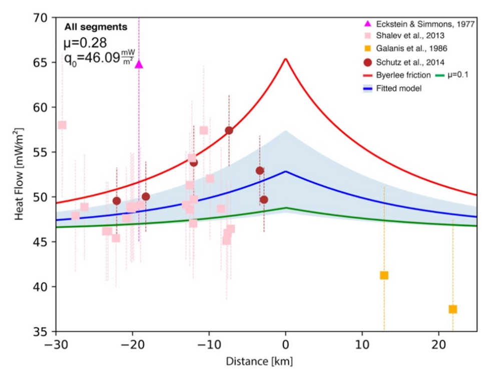
PHD work:

Thermomechanical numerical modeling and study how slow changes of subducting slabs geometry over millions of years affect megathrust hazard.



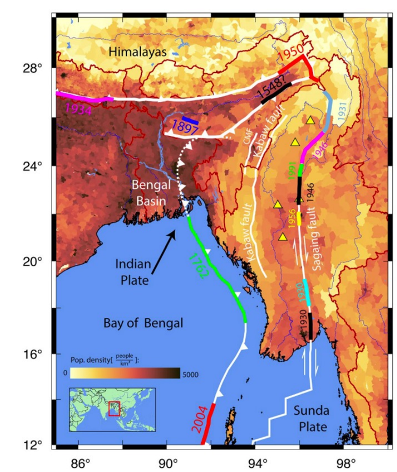
Oryan & Buck,2020, *Nature geoscience*

Analysis of **heat flow** data to constrain frictional properties of faults



Oryan & Savage ,2021, *G³*

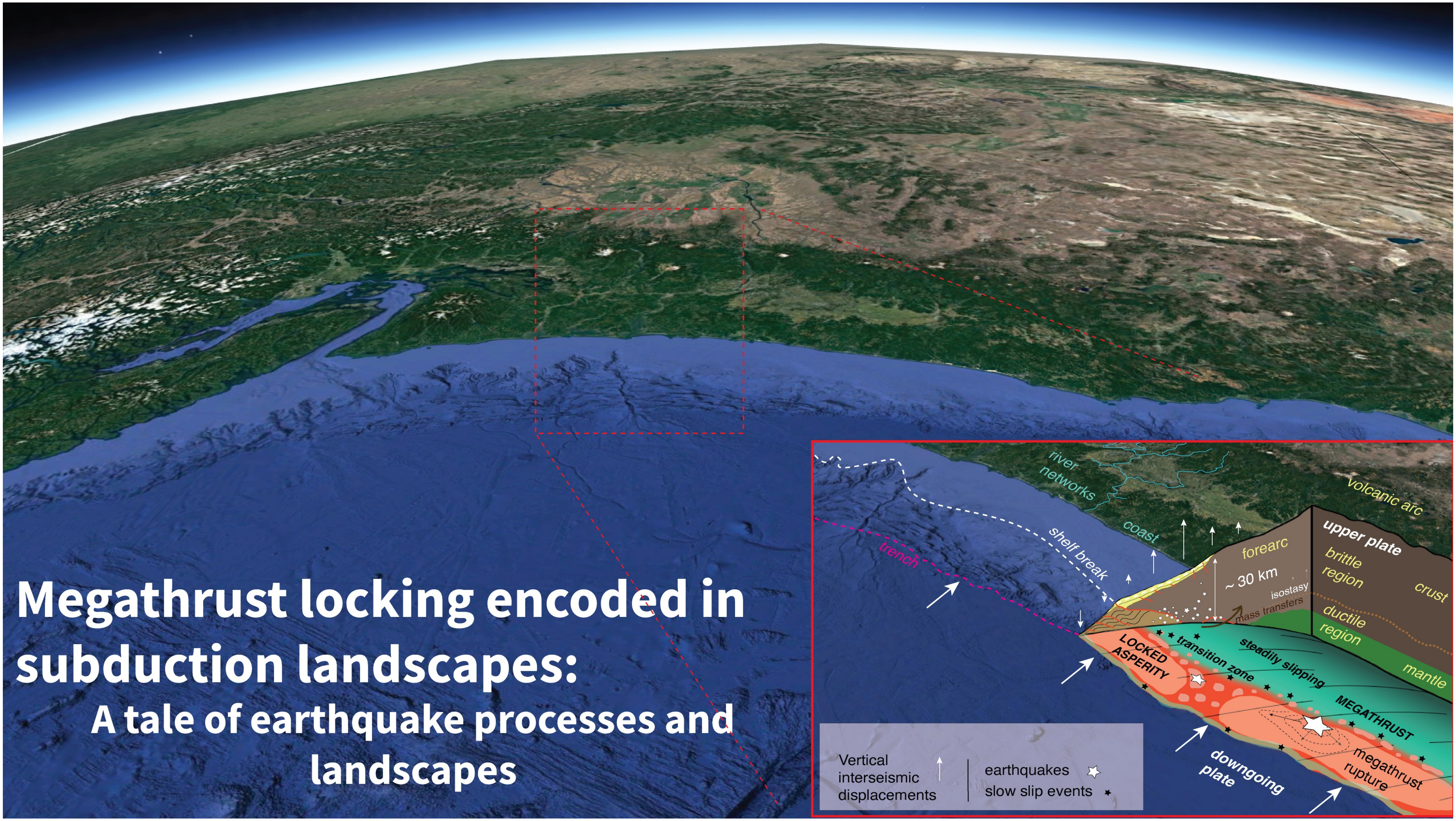
Inversion of Indo-Burma **geodetic** data to constrain megathrust hazard

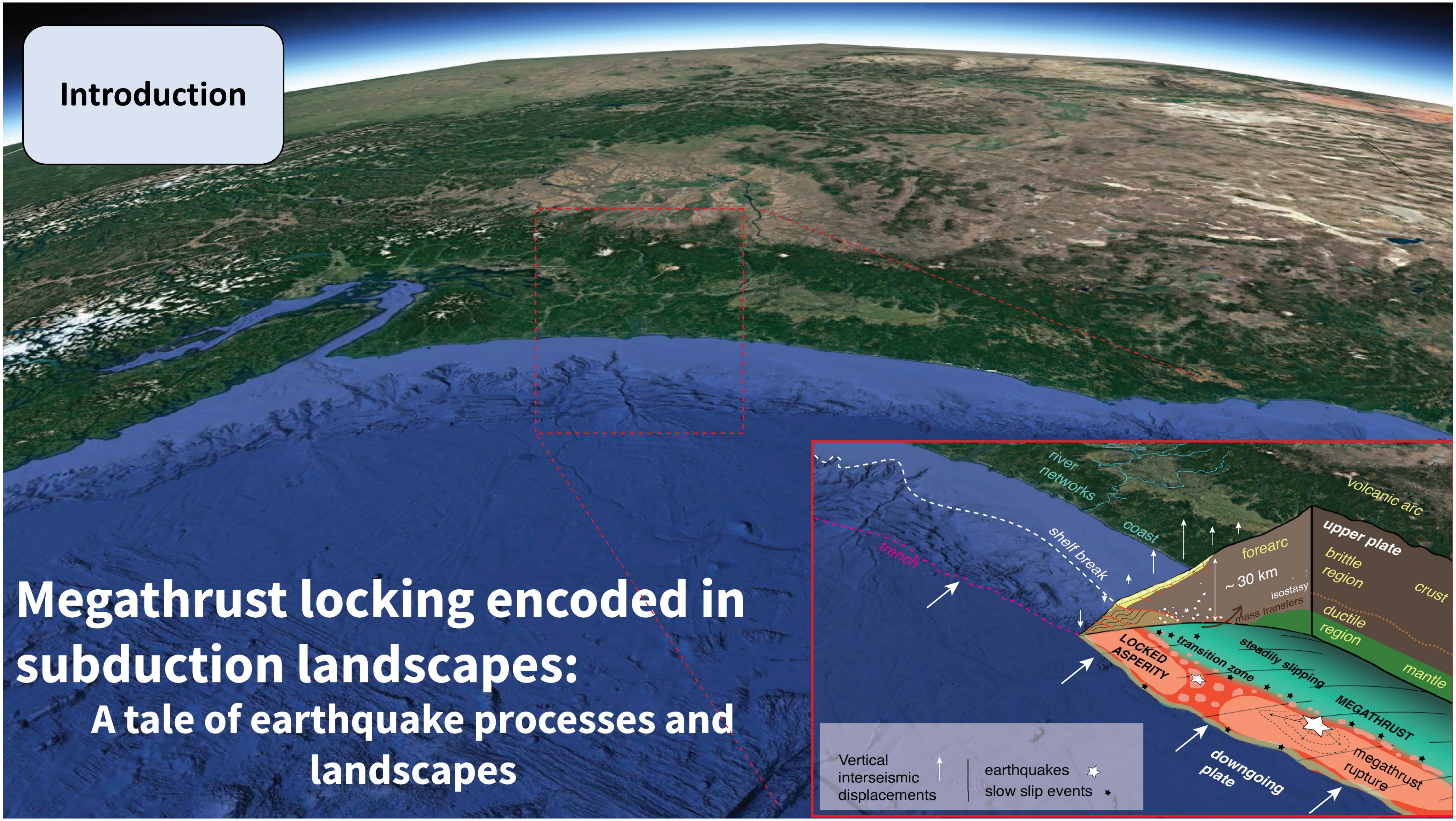


Oryan et al., 2023, JGR

Megathrust locking encoded in subduction landscapes:

A tale of earthquake processes and landscapes

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Megathrust locking encoded in subduction landscapes:
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river networks
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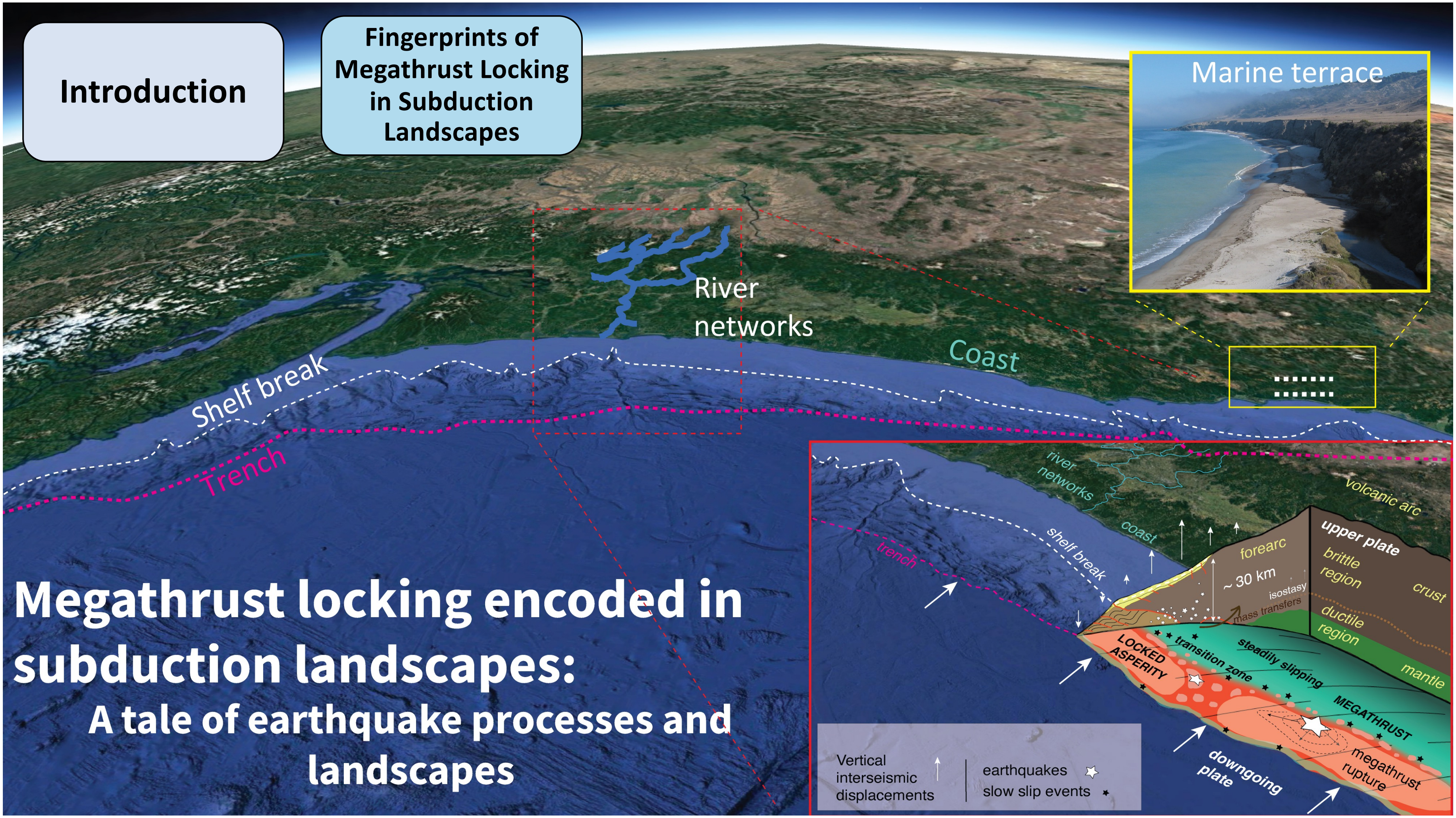
volcanic arc
shelf break
trench
forearc
upper plate
brittle region
crust
~ 30 km
isostasy
mass transfers
ductile region
mantle
LOCKED ASPERITY
transition zone
steadily slipping
MEGATHRUST
downgoing plate
megathrust rupture
Vertical interseismic displacements
earthquakes
slow slip events



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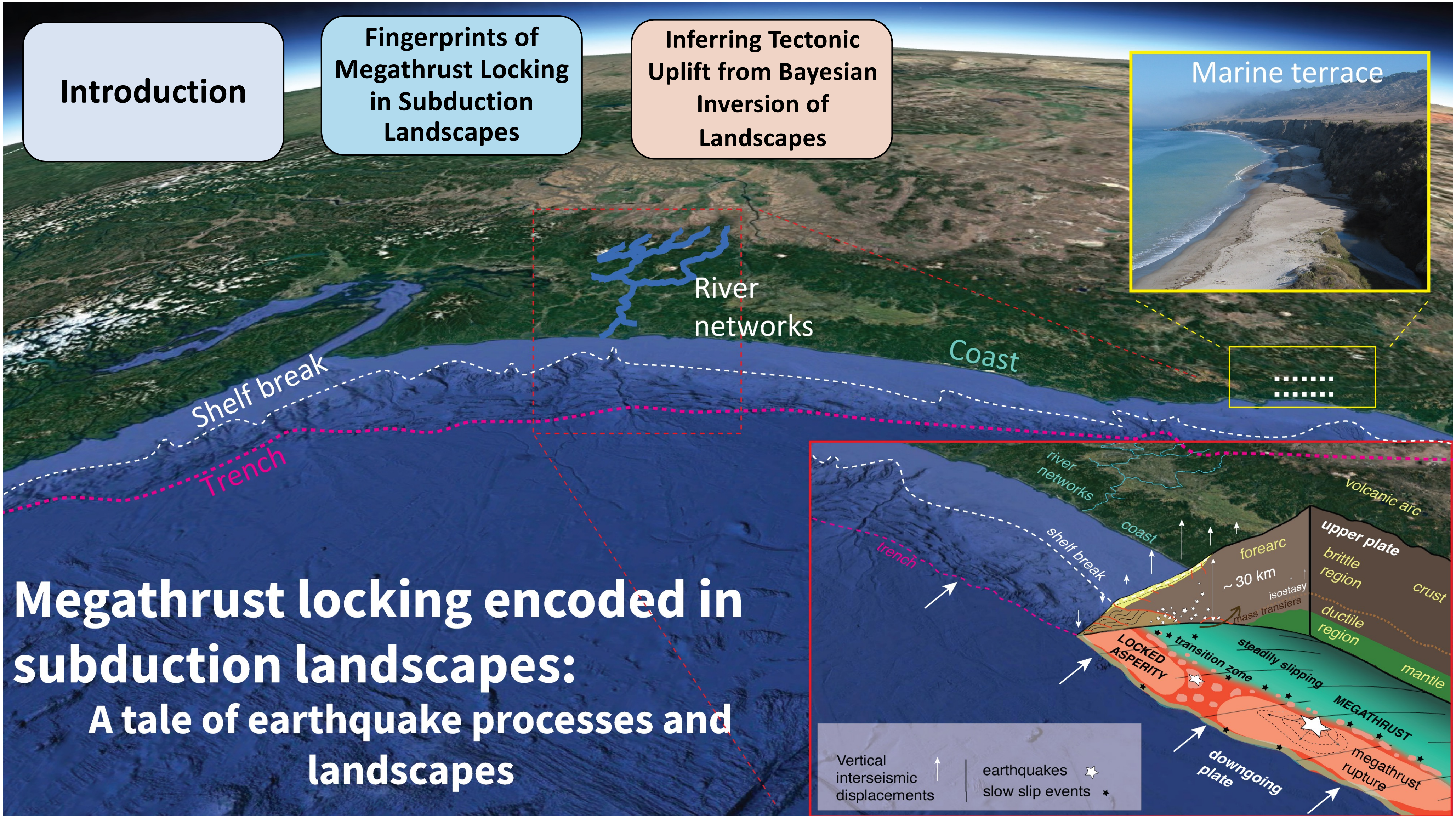
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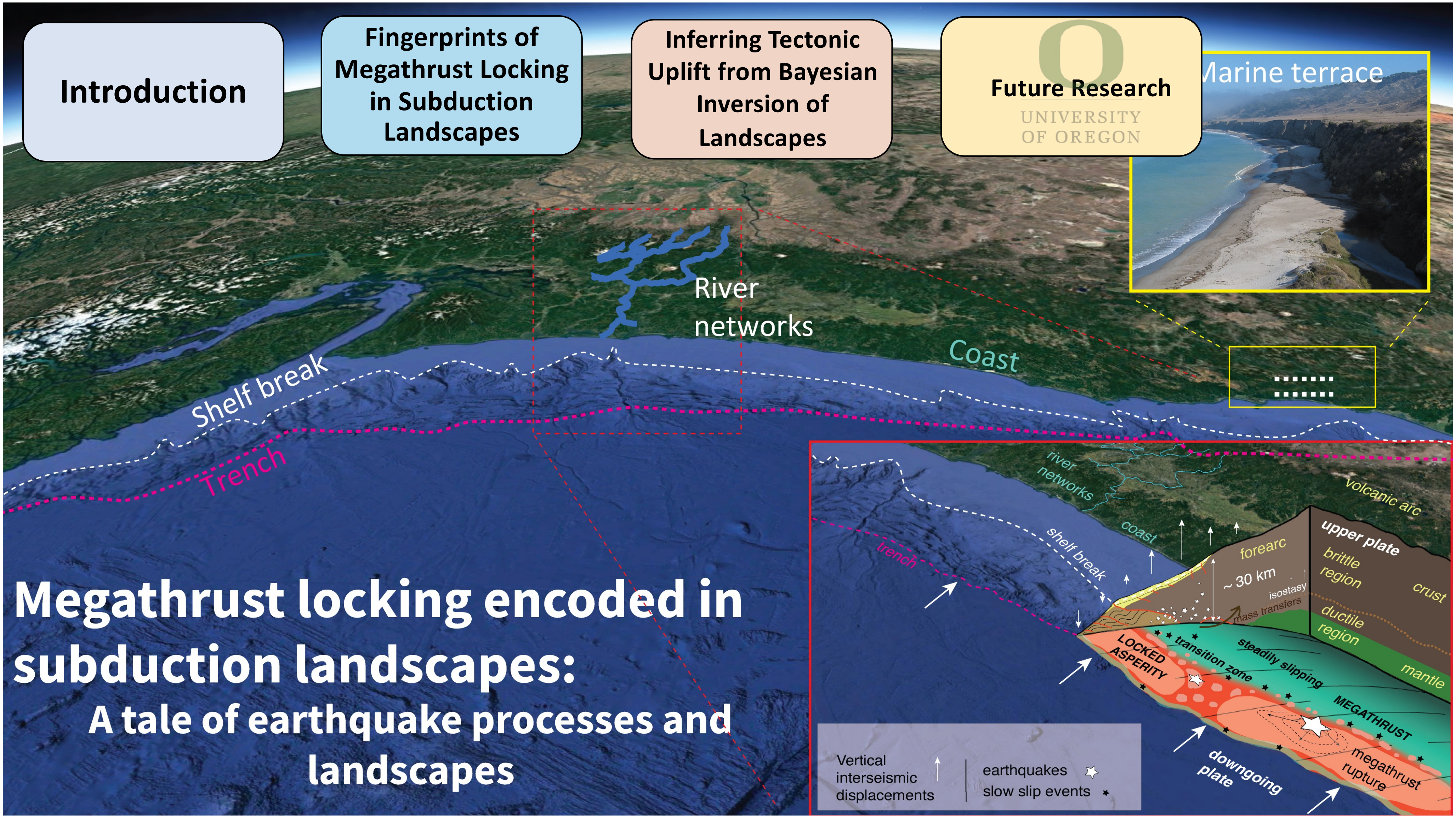
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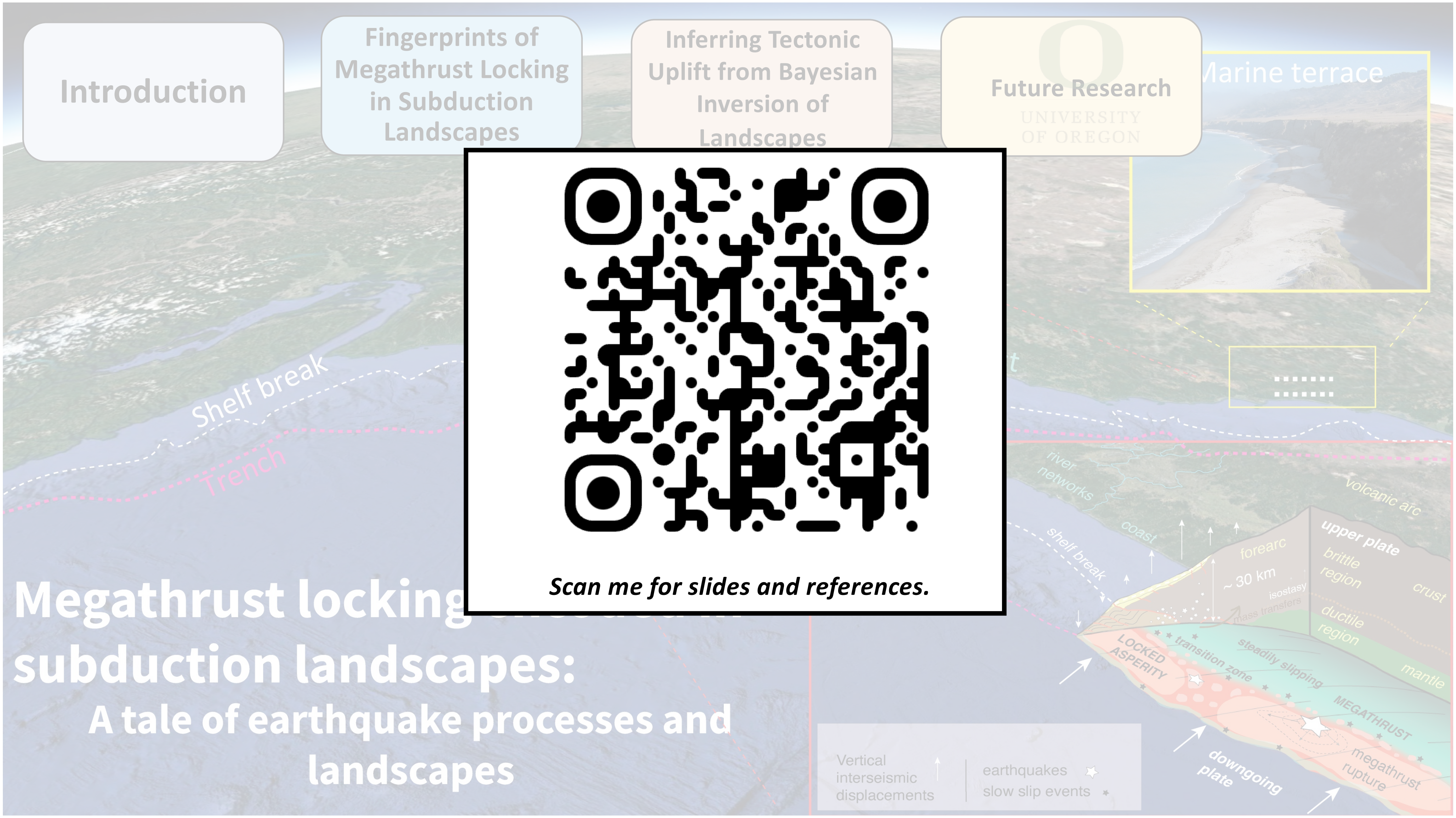
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Scan me for slides and references.
Megathrust locking
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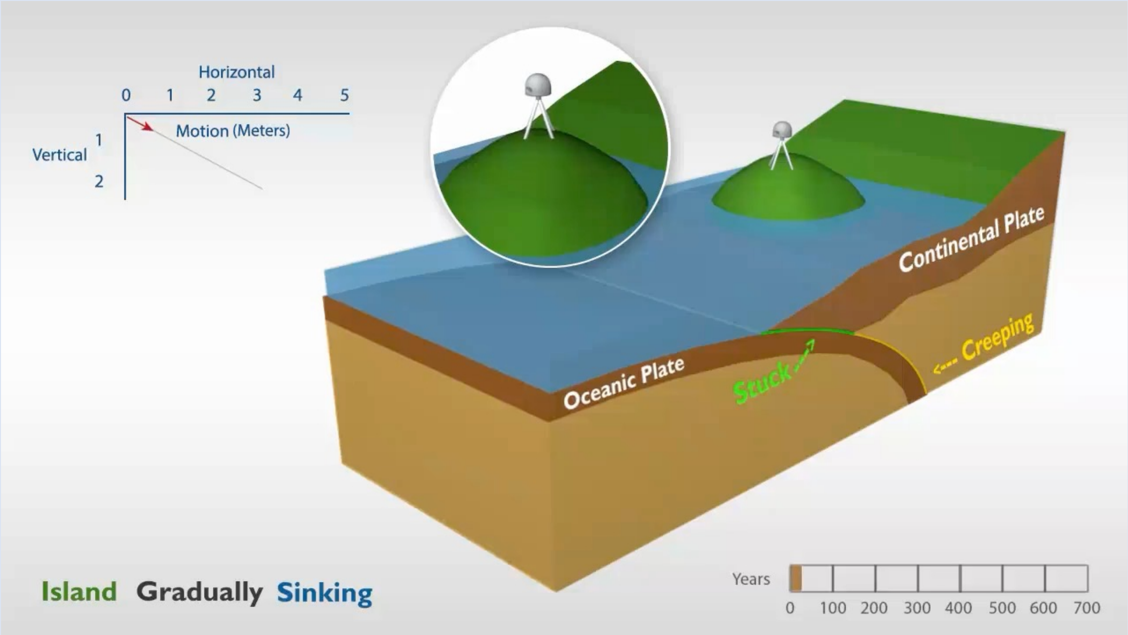
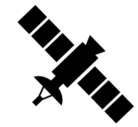
Section 1 - Introduction



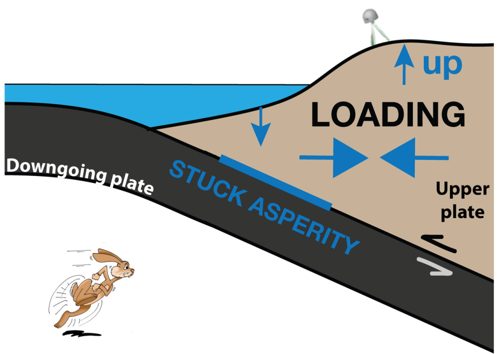
EARTHQUAKE CYCLES IN SUBDUCTION ZONES

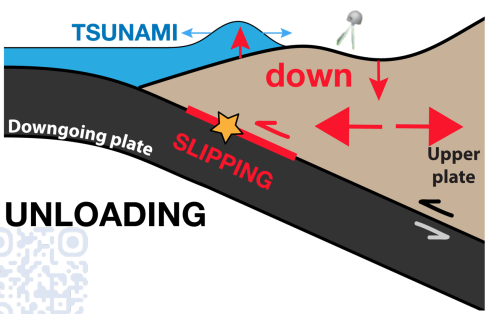
Long-term: downgoing plate descends beneath the upper plate in stick-slip fashion.



Interseismic: locked section is “stuck”. Creeping section moves slowly.

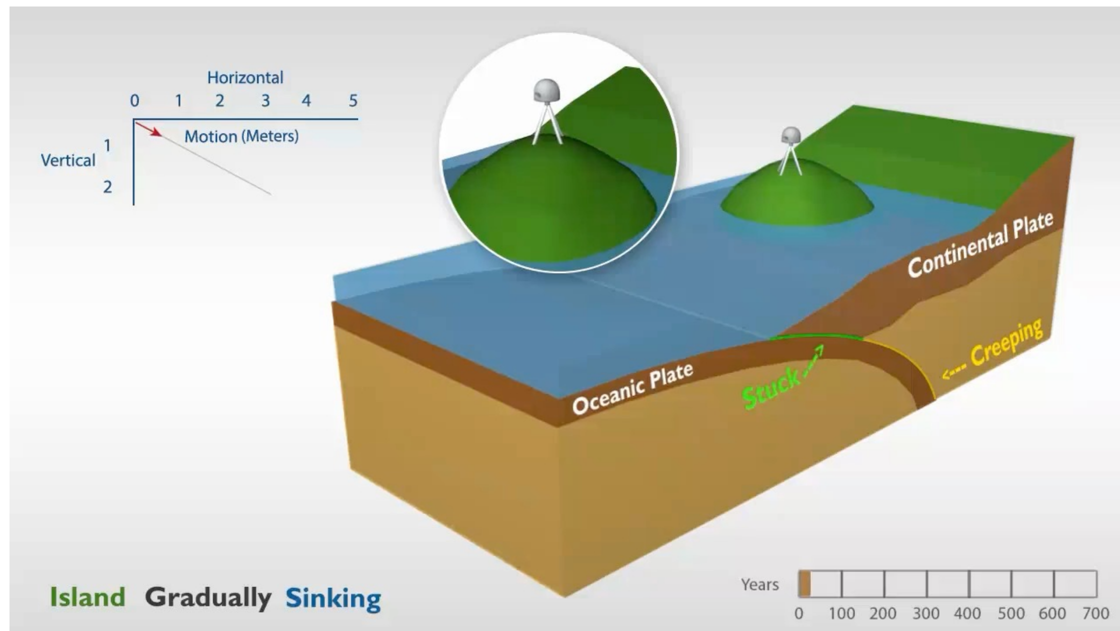
Stress build up





Coseismic: locked section moves abruptly.

Stress release



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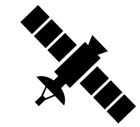

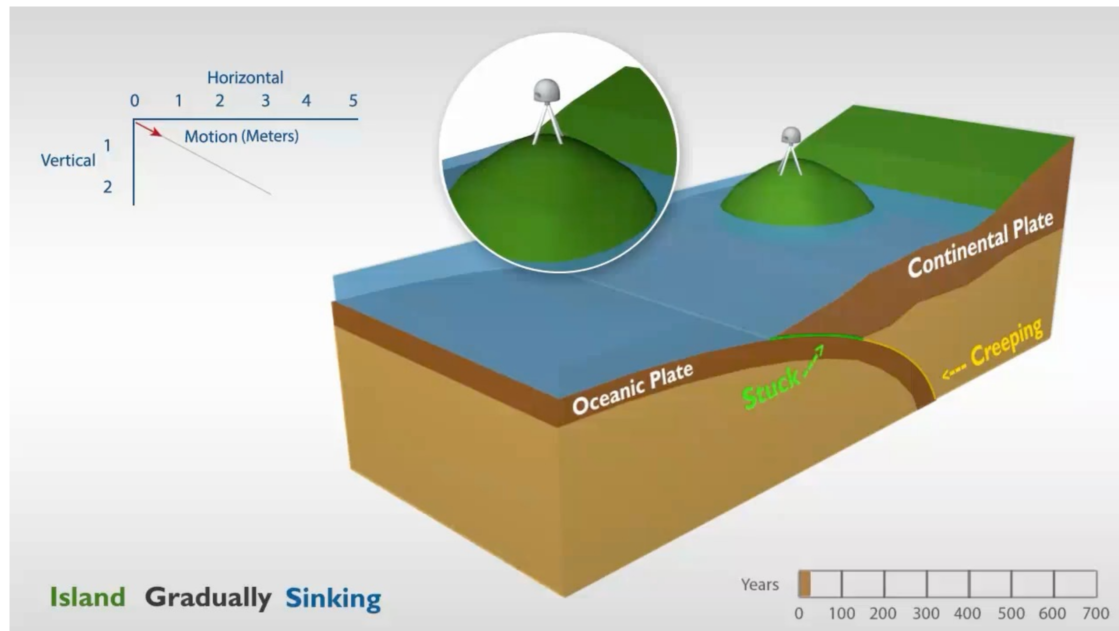

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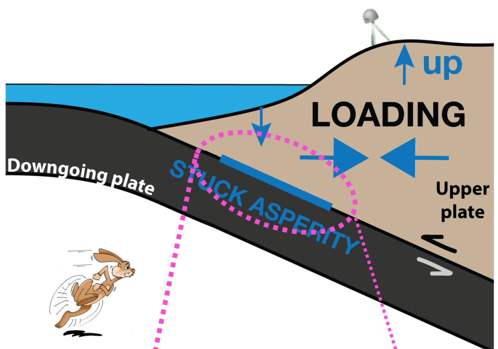

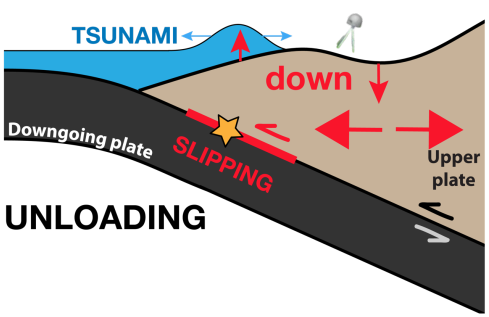

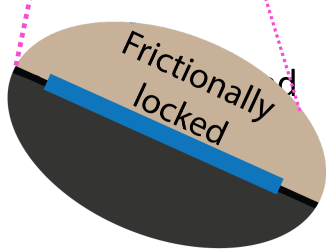

Stress release

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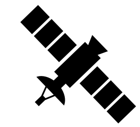

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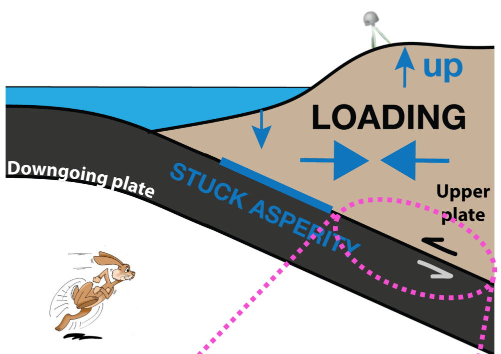

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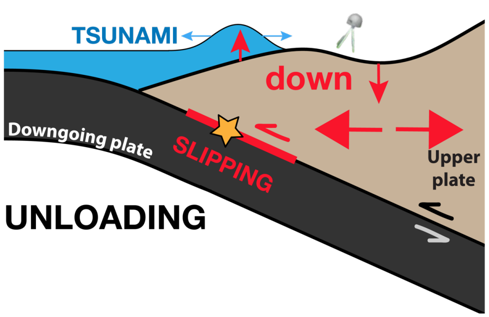

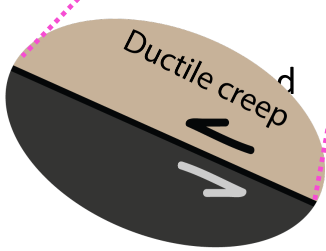

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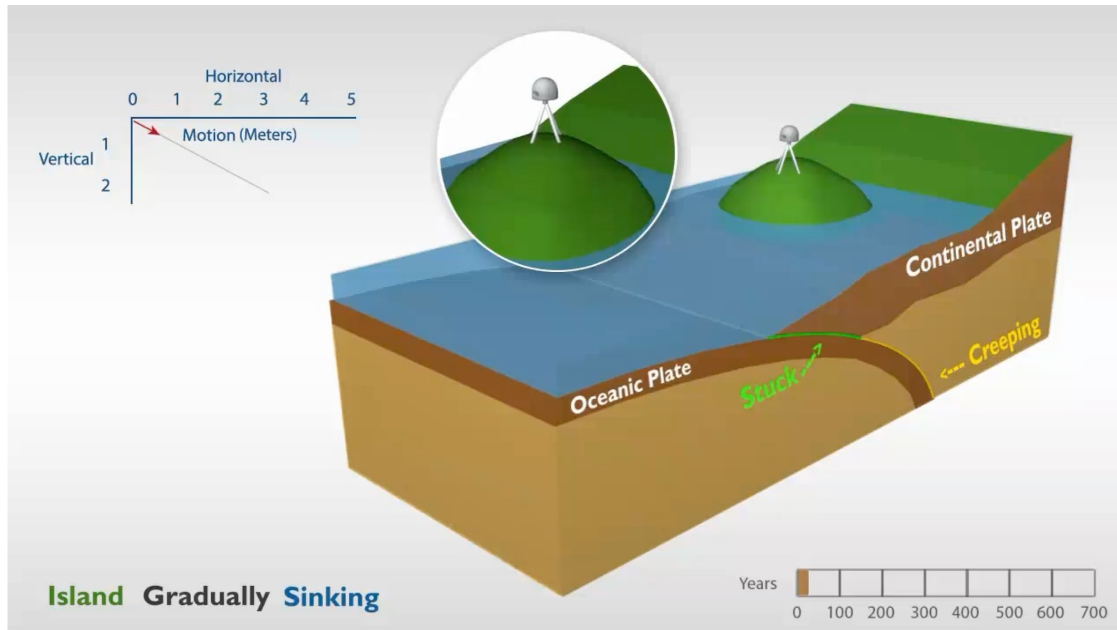

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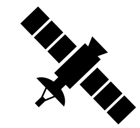
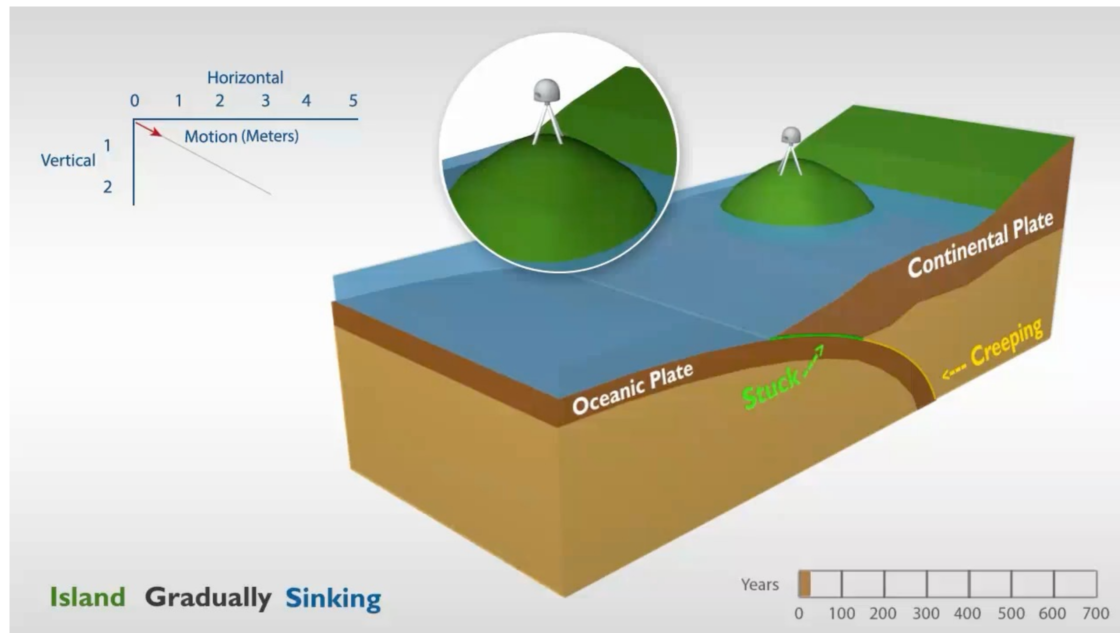
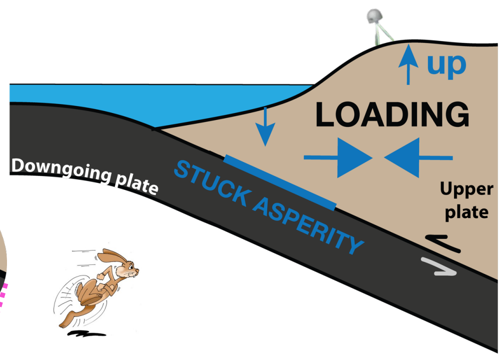
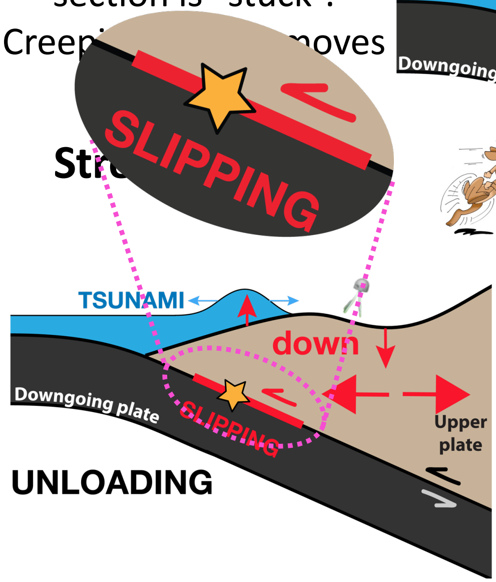




Interseismic: locked section is "stuck".
Creep... moves

Str...





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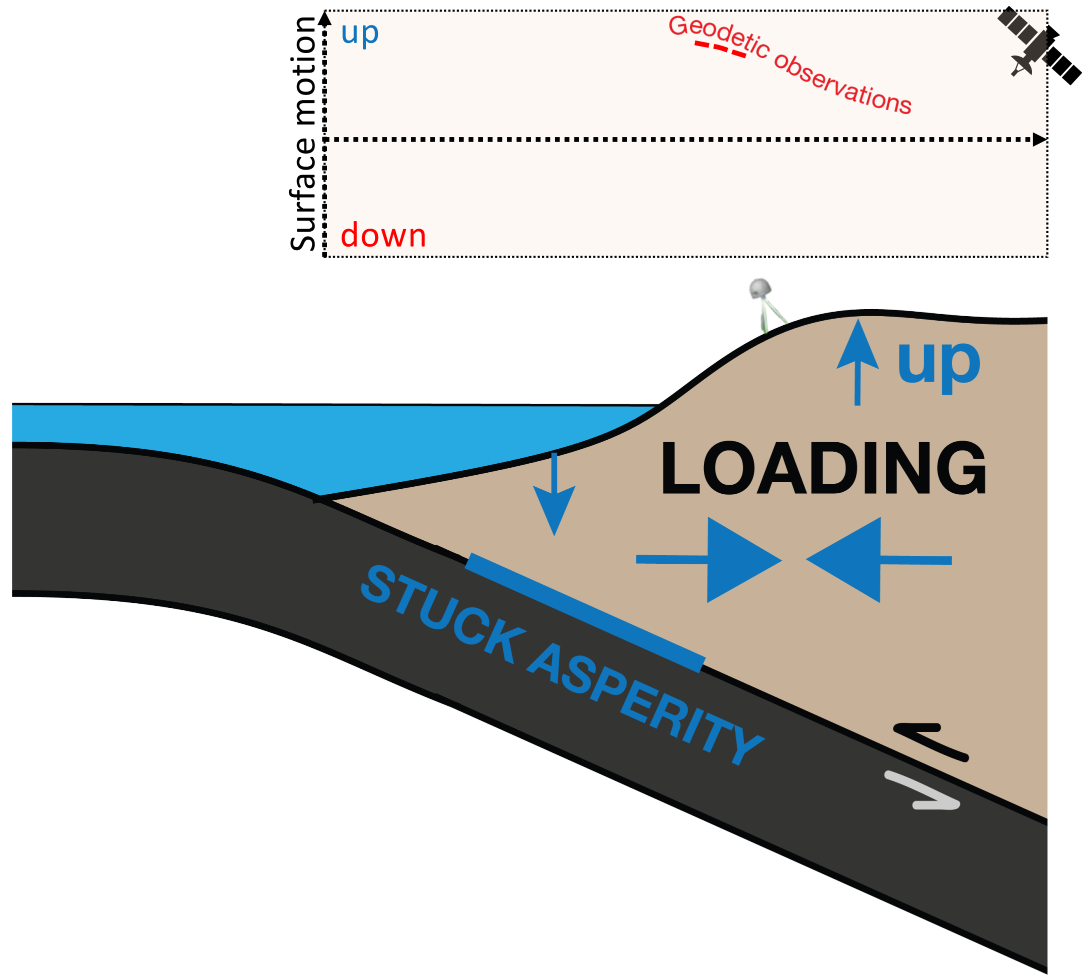
CONSTRAINING MEGATHRUST HAZARD IN SUBDUCTION ZONES

- Deployment of GNSS stations and InSAR data collection have greatly **improved** the **availability** of **geodetic** data in recent decades.



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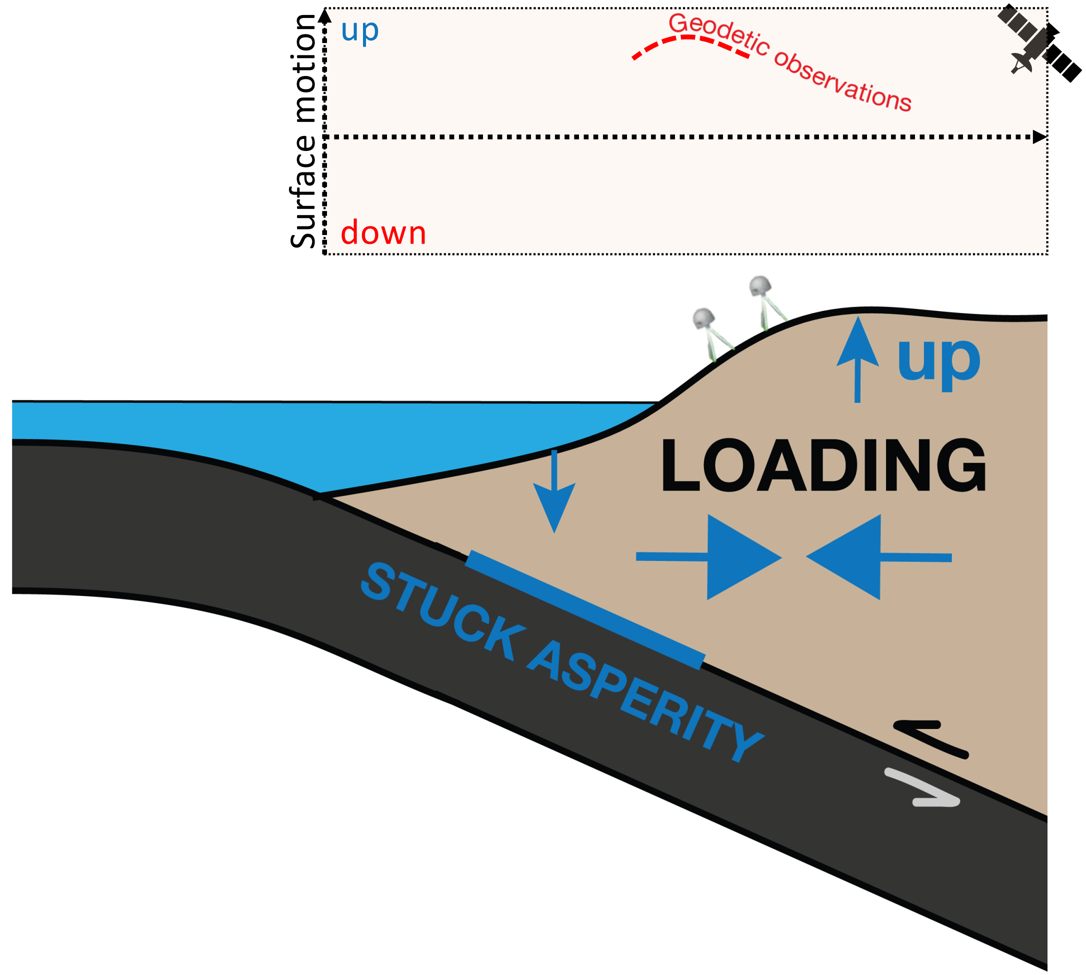

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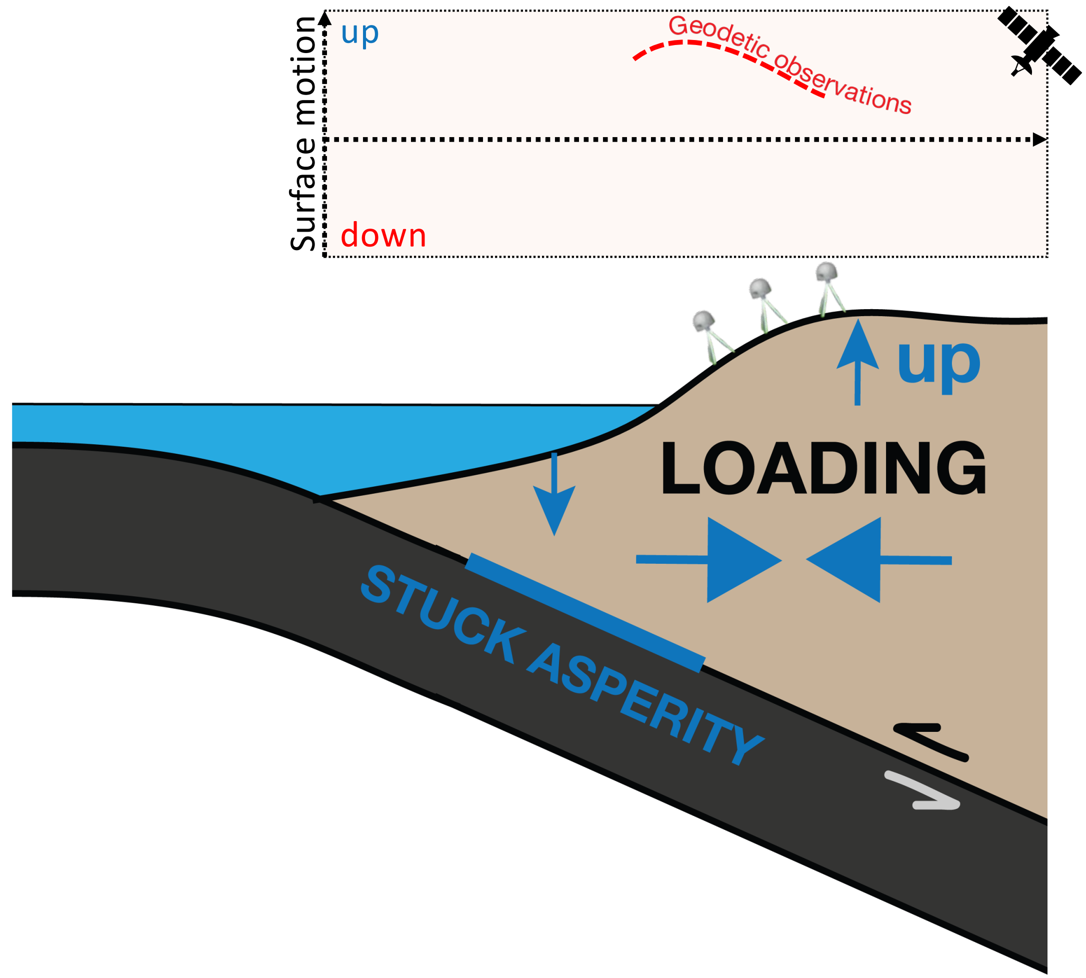

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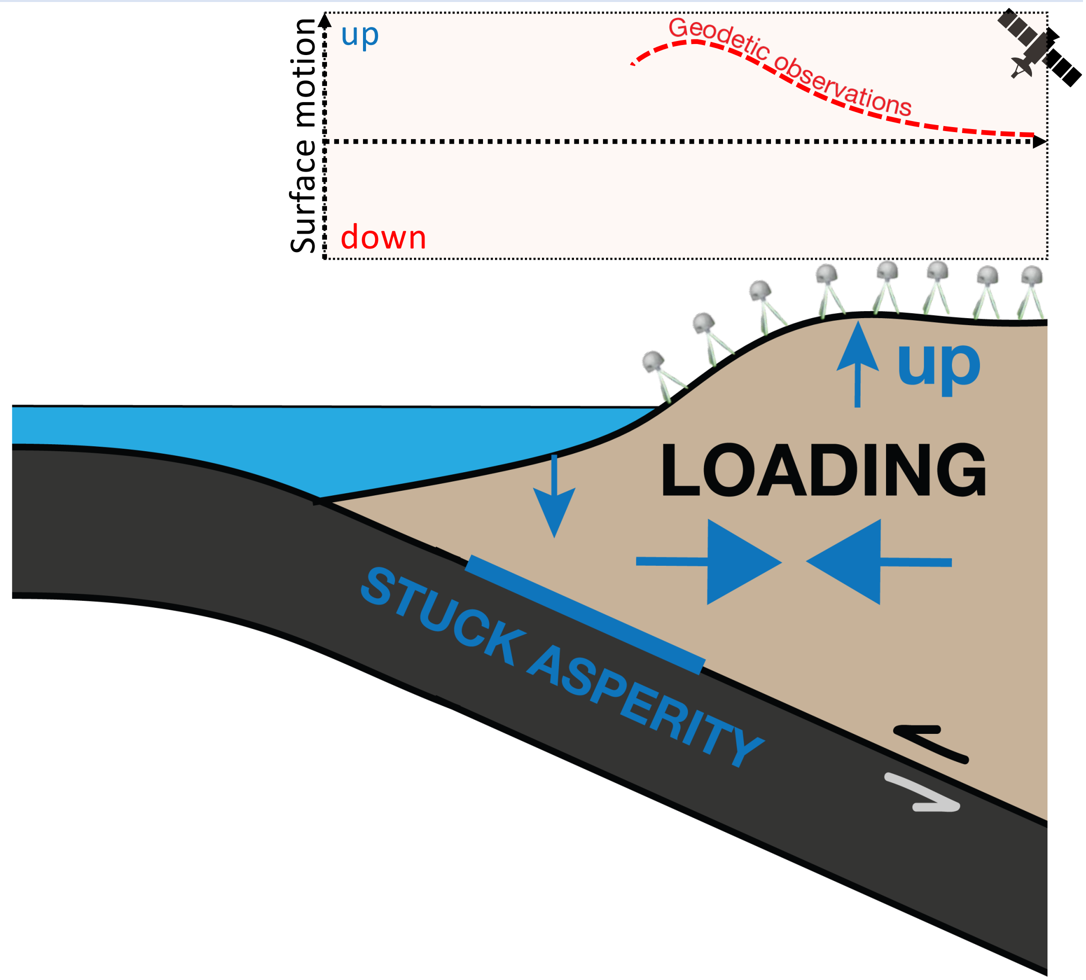
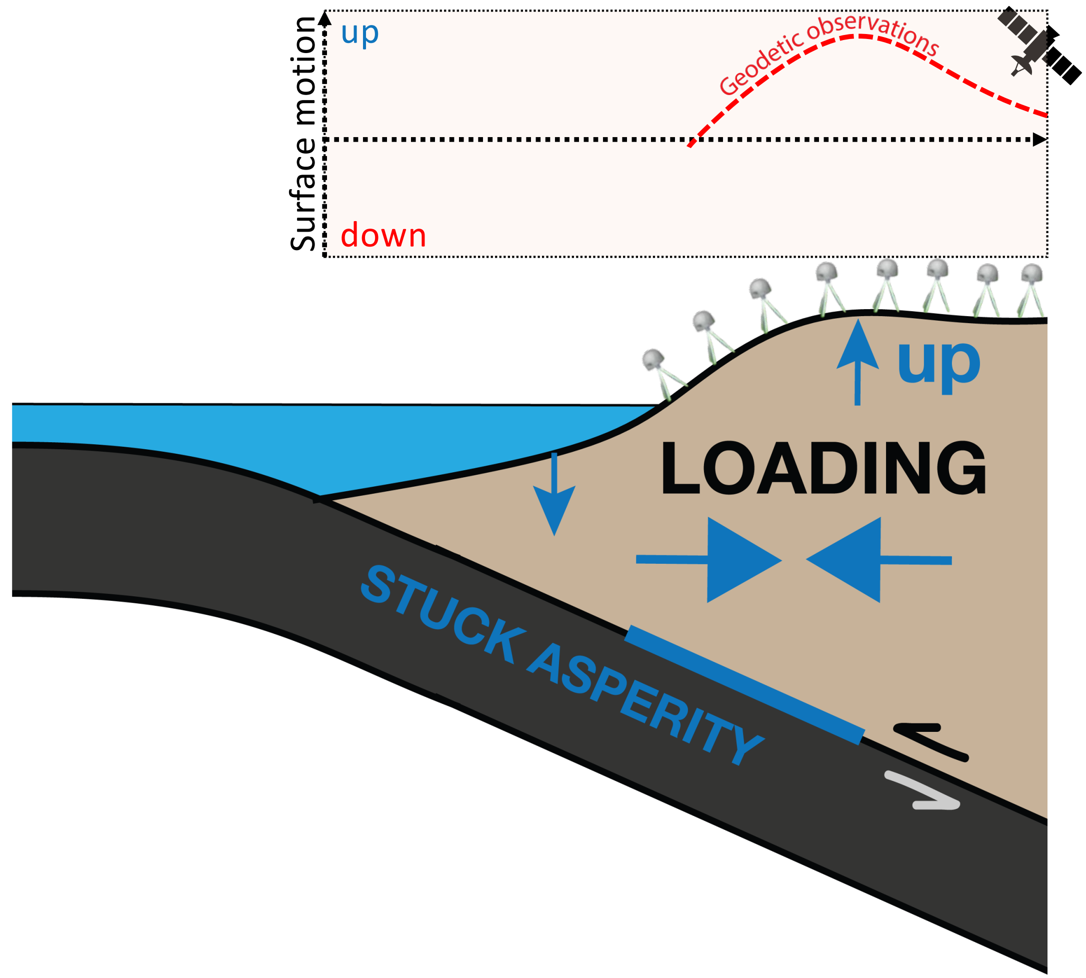


CONSTRAINING MEGATHRUST HAZARD IN SUBDUCTION ZONES

- Deployment of GNSS stations and InSAR data collection have greatly **improved** the **availability** of **geodetic** data in recent decades.
- It allows to determine the **dimensions and position of locked asperities** in subduction zones with well constrained megathrust geometry.



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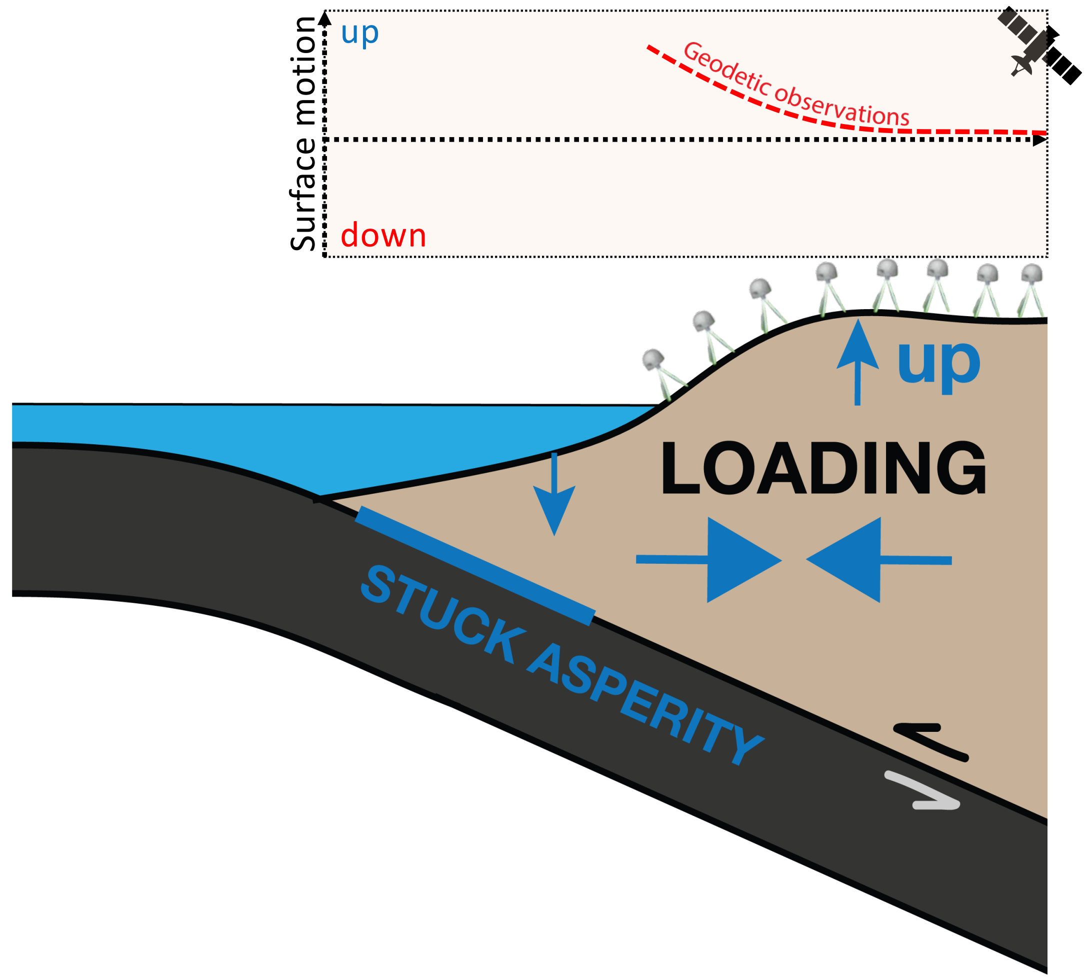

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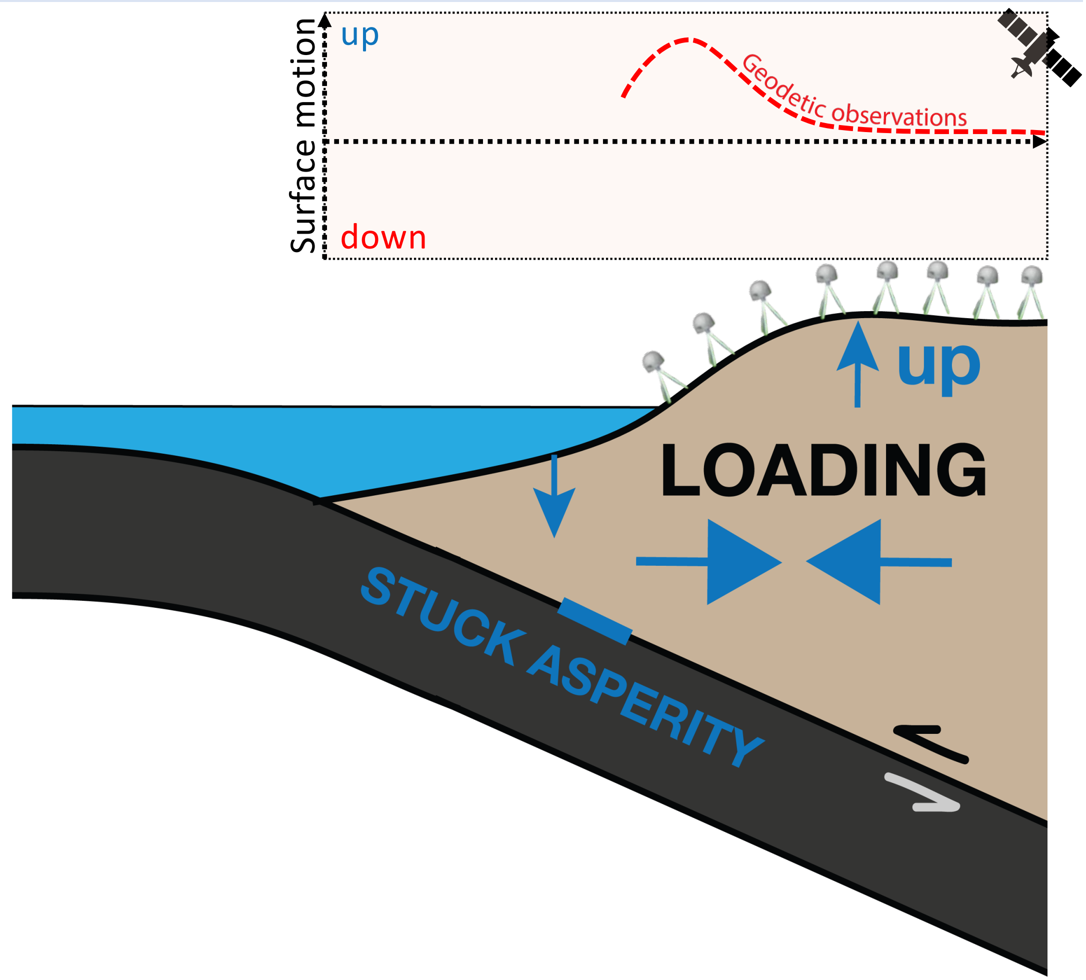

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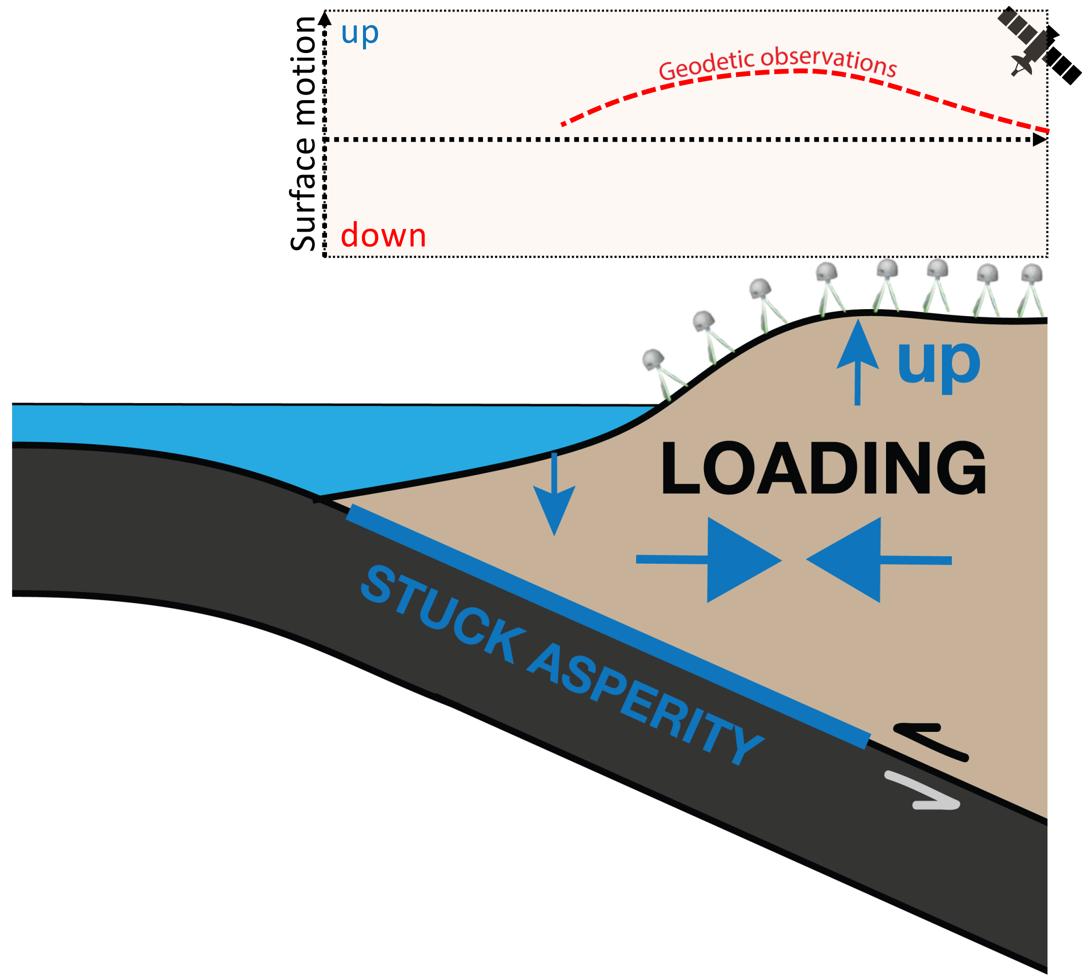

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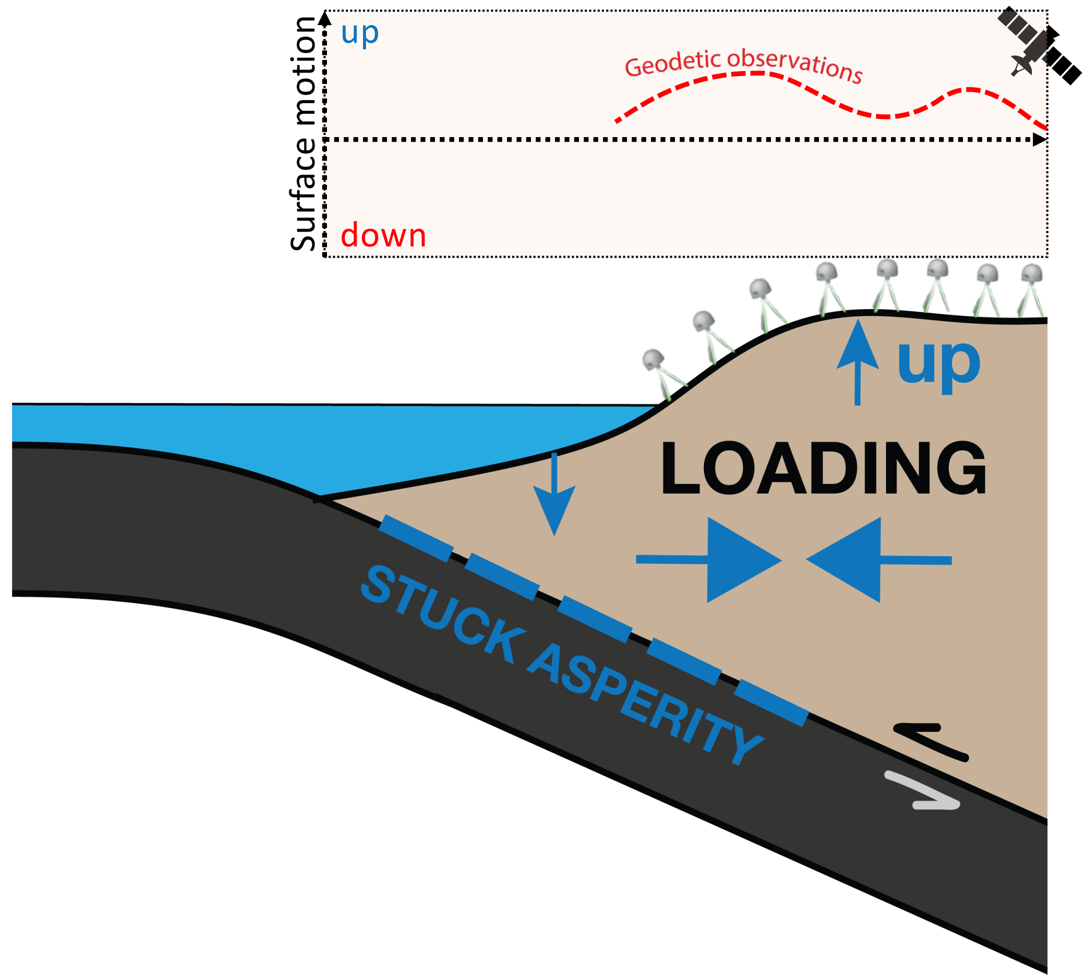

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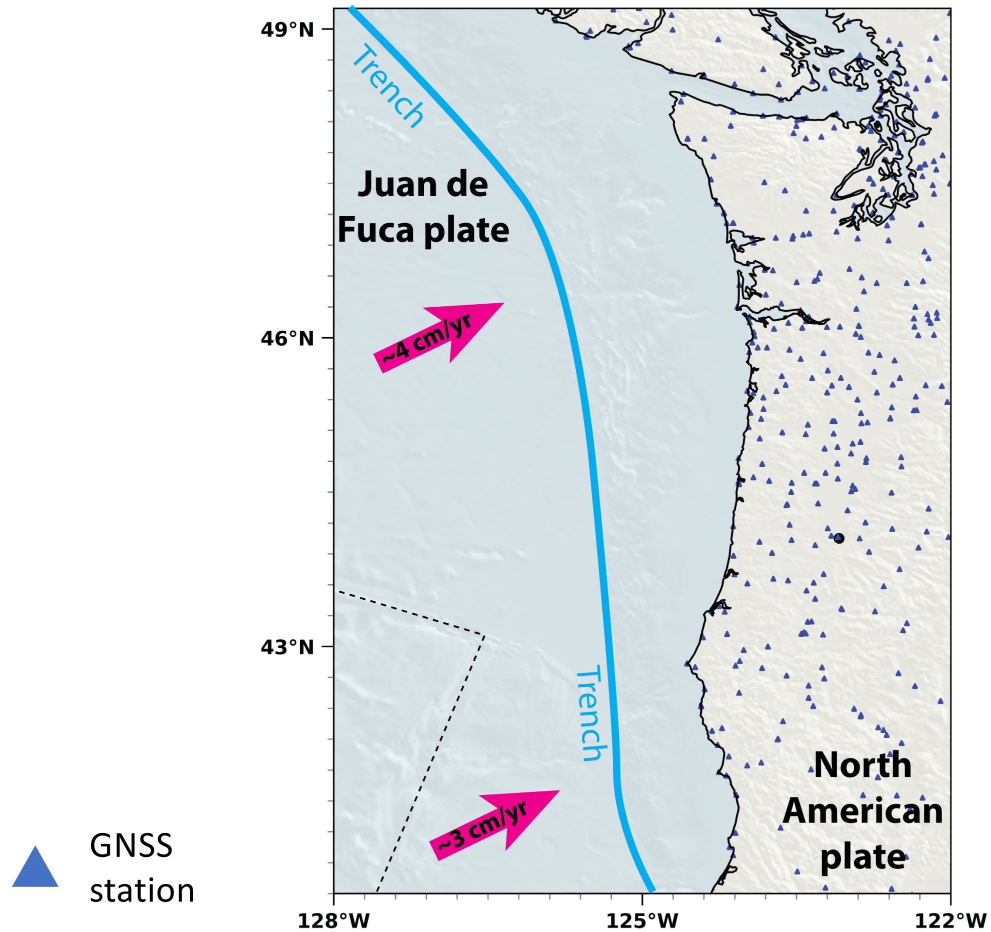
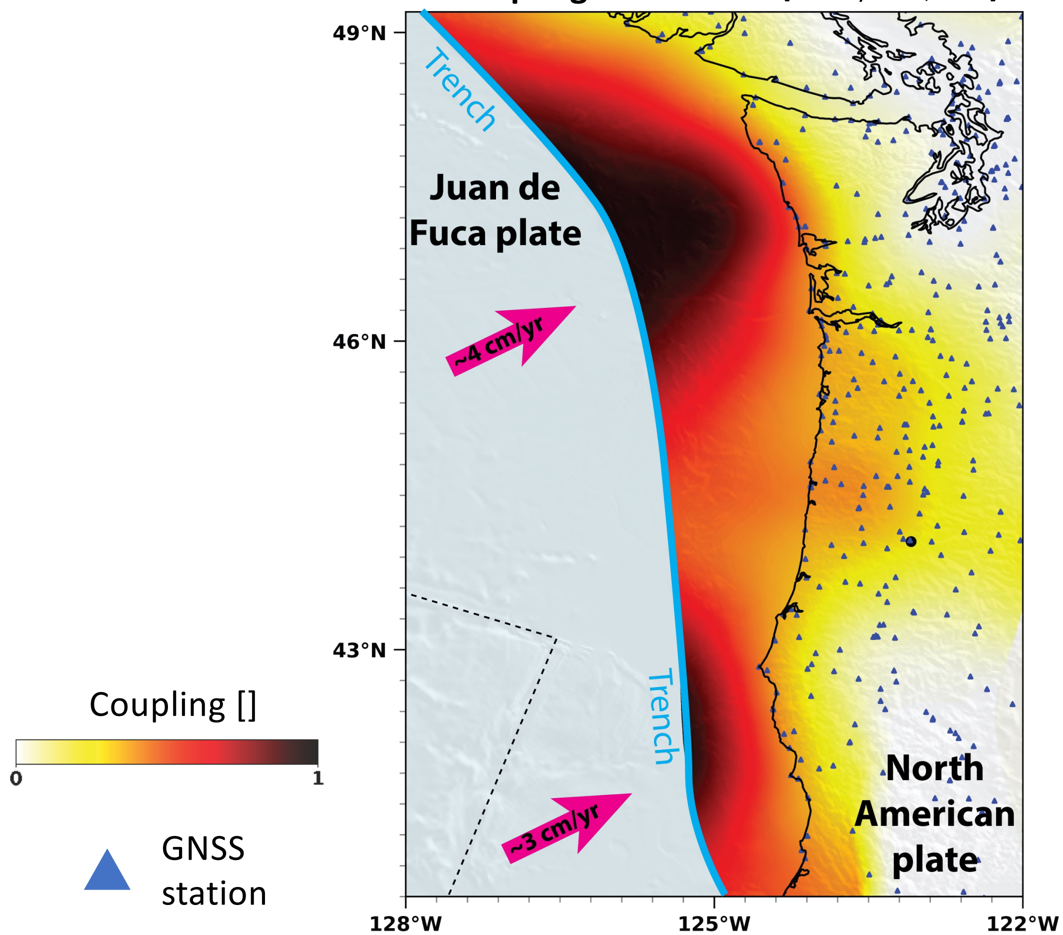


CONSTRAINING MEGATHRUST HAZARD IN SUBDUCTION ZONES

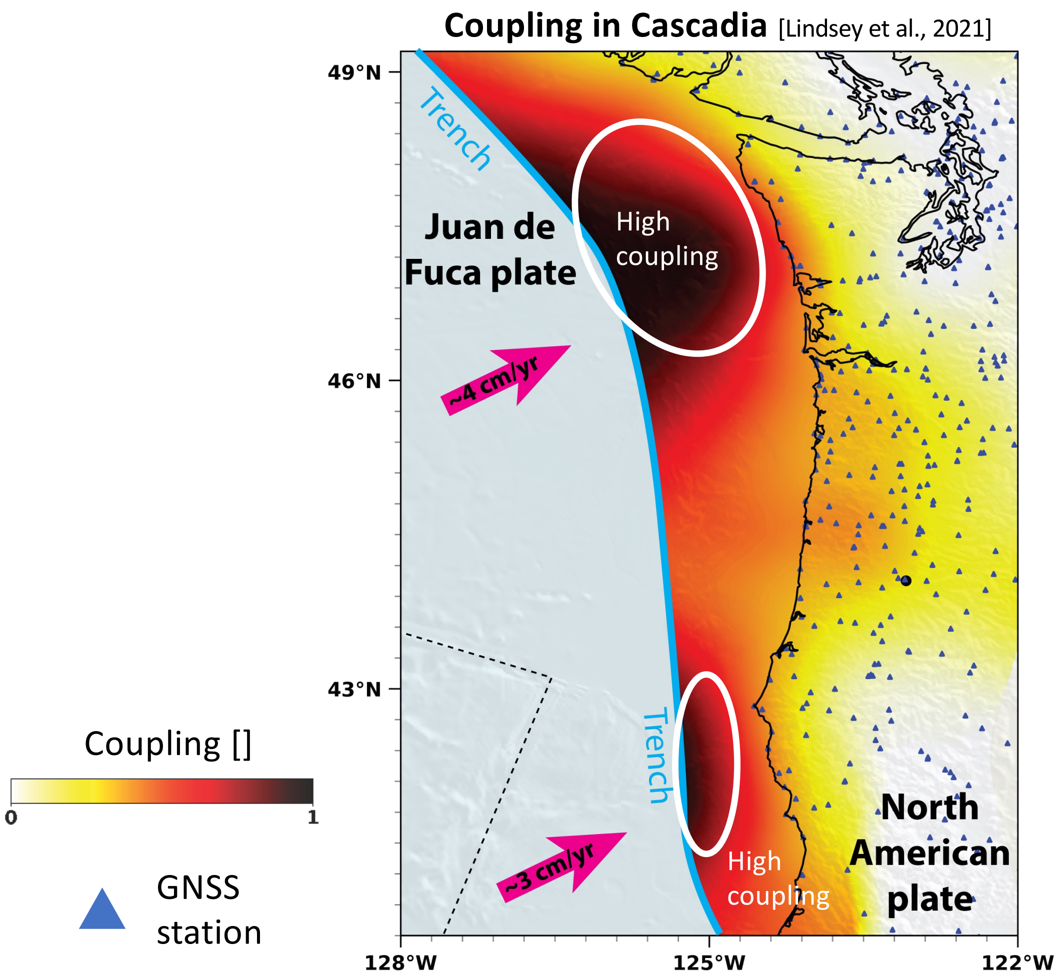
- Locked asperities along the megathrust are often represented using coupling maps.

Coupling in Cascadia [Lindsey et al., 2021]



CONSTRAINING MEGATHRUST HAZARD IN SUBDUCTION ZONES

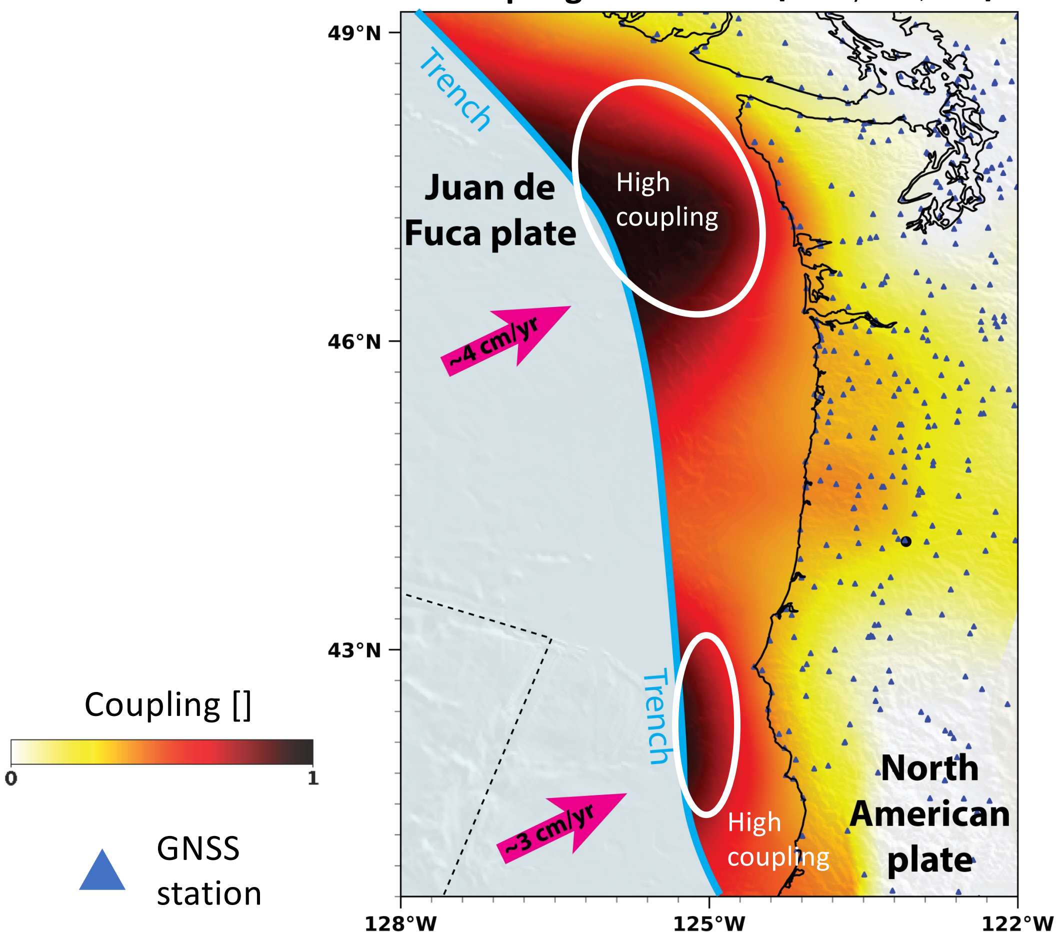
- Locked asperities are often represented using coupling maps.
- Regions with high coupling values are considered locked and stationary.



CONSTRAINING MEGATHRUST HAZARD IN SUBDUCTION ZONES

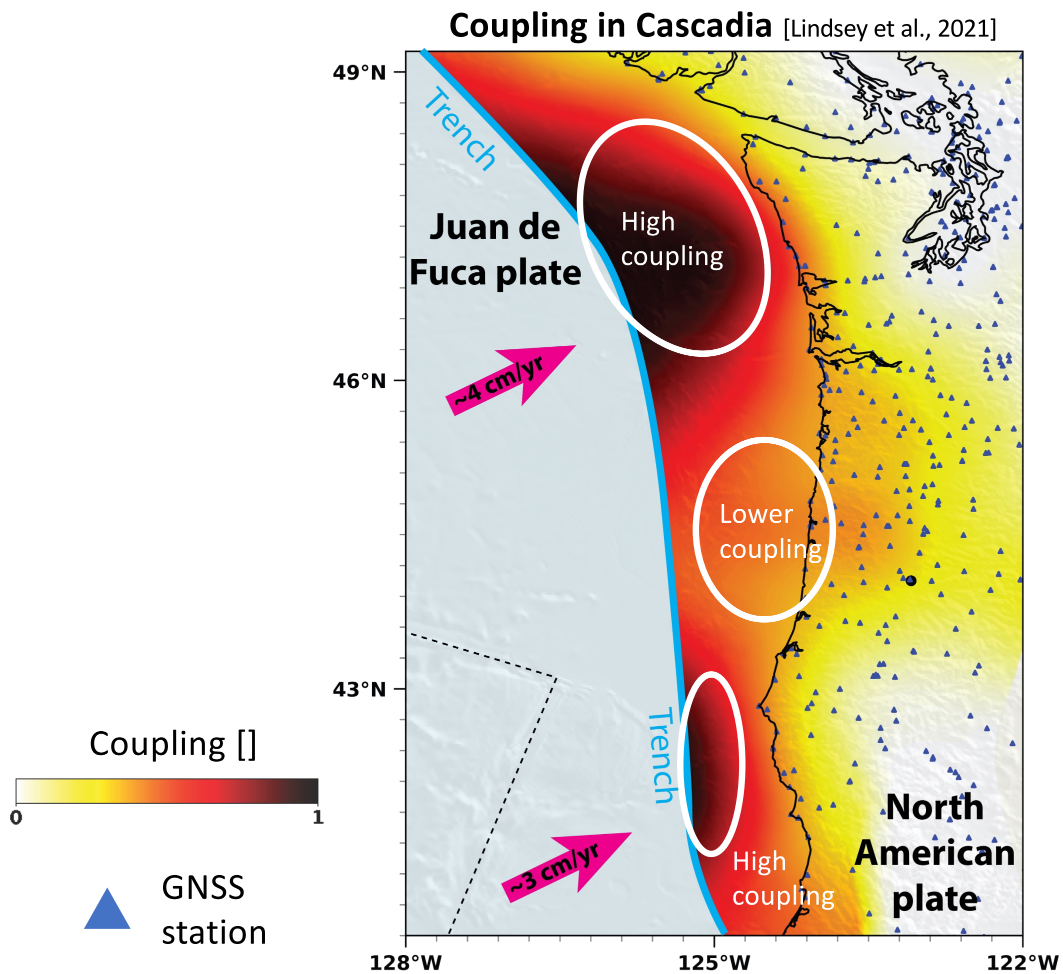
- Locked asperities are often represented using coupling maps.
- Regions with high coupling values are considered locked and stationary.
- These locked regions are believed to accumulate interseismic stresses and are more likely to generate megathrust events.

Coupling in Cascadia [Lindsey et al., 2021]



CONSTRAINING MEGATHRUST HAZARD IN SUBDUCTION ZONES

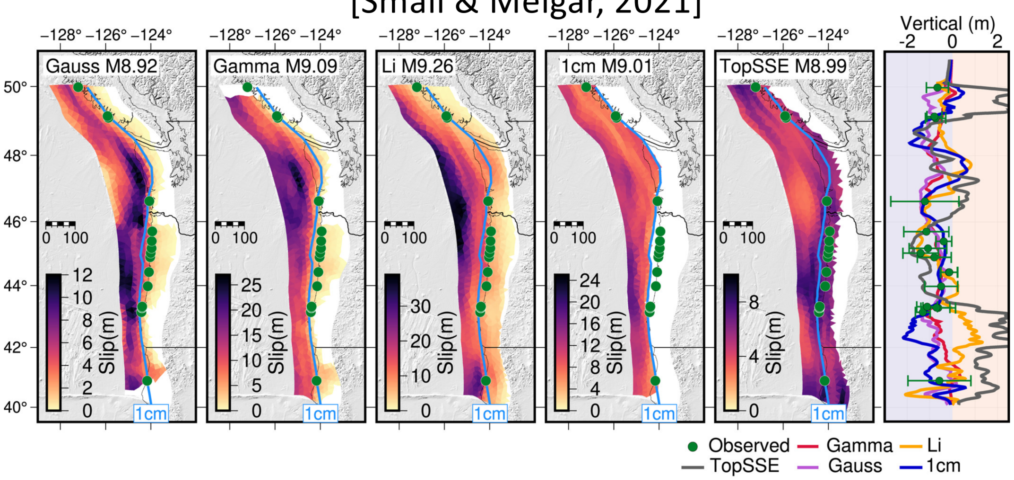
- Locked asperities are often represented using coupling maps.
- Regions with high coupling values are considered locked and stationary.
- These locked regions are believed to accumulate interseismic stress and are more likely to generate megathrust events.
- In contrast, regions with low coupling values are thought to creep during the interseismic period and are less likely to rupture.



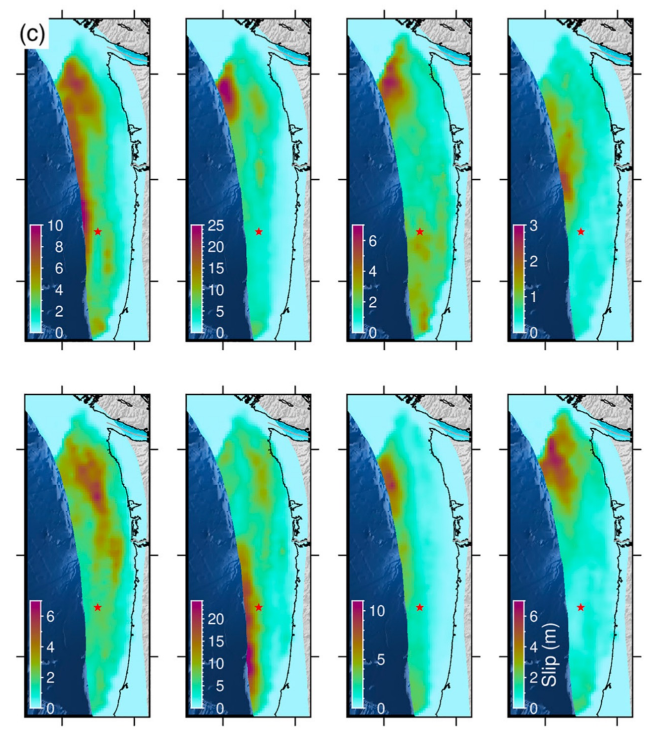
CONSTRAINING MEGATHRUST HAZARD IN SUBDUCTION ZONES

The hazard associated with megathrusts is often inferred from **coupling fields**

Five Cascadia rupture scenarios computed from different coupling estimations and slip assumptions
[Small & Melgar, 2021]



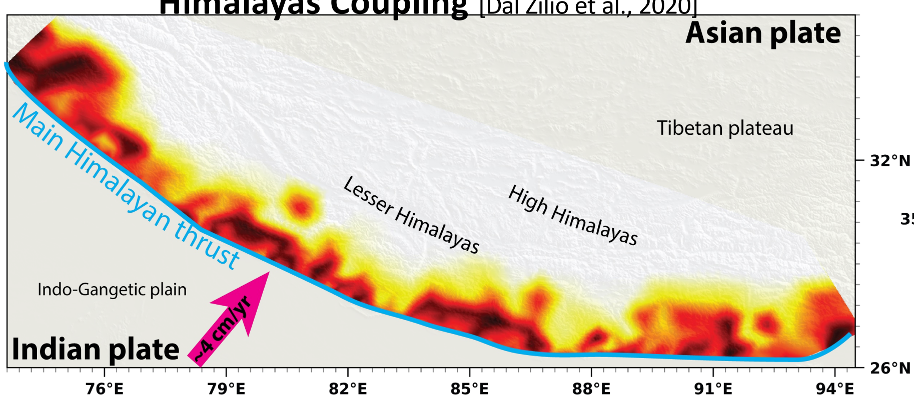
Eight Cascadia megathrust scenarios computed directly from coupling map
[Small & Melgar, 2021]



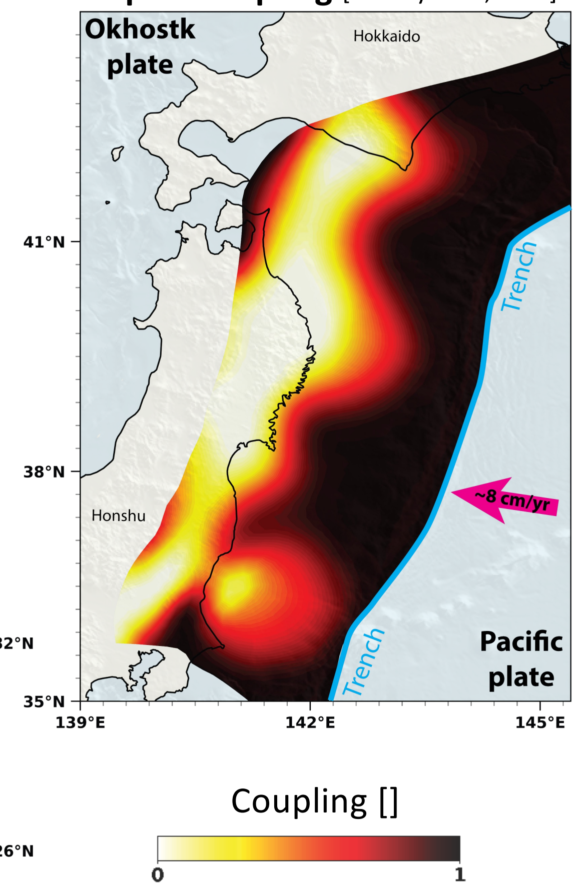
CONSTRAINING MEGATHRUST HAZARD IN SUBDUCTION ZONES

Coupling maps are used to illustrate fault locking variability across **nearly all megathrusts where geodetic data is available.**

Himalayas Coupling [Dal Zilio et al., 2020]

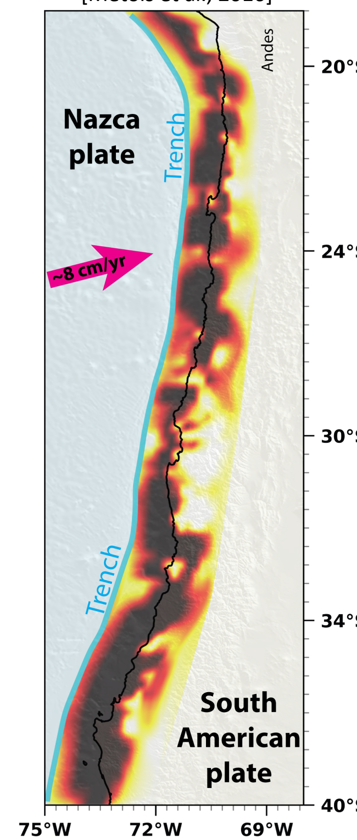


Japan Coupling [Lindsey et al., 2021]

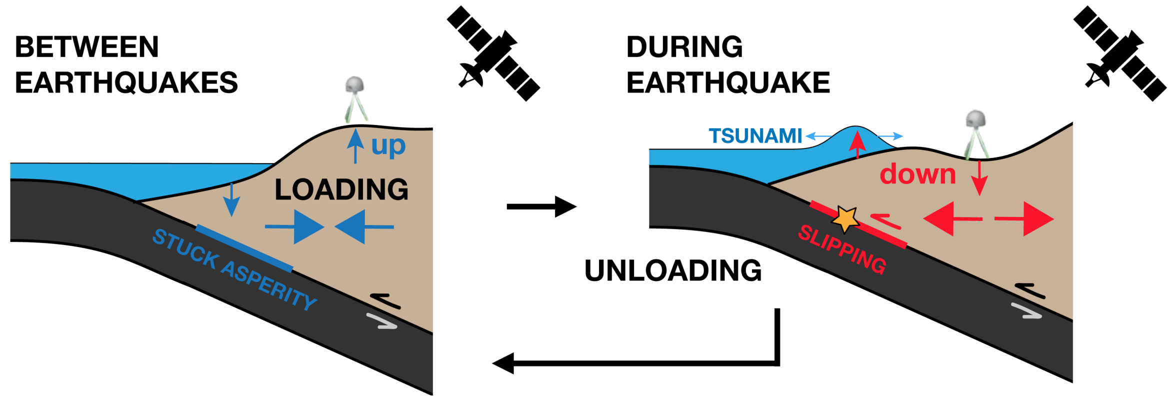


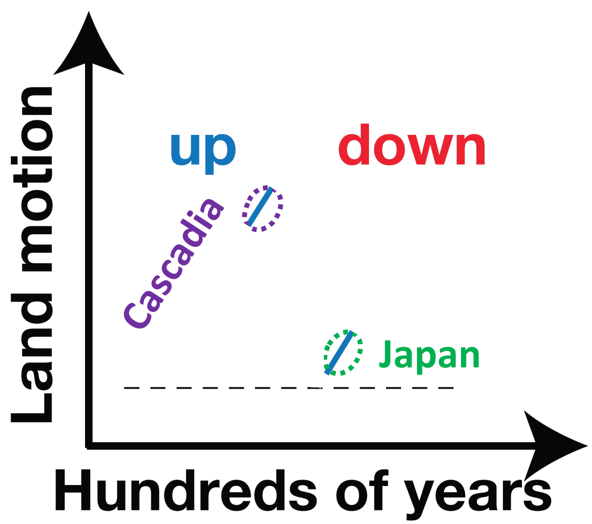
Chile Coupling

[Métois et al., 2016]



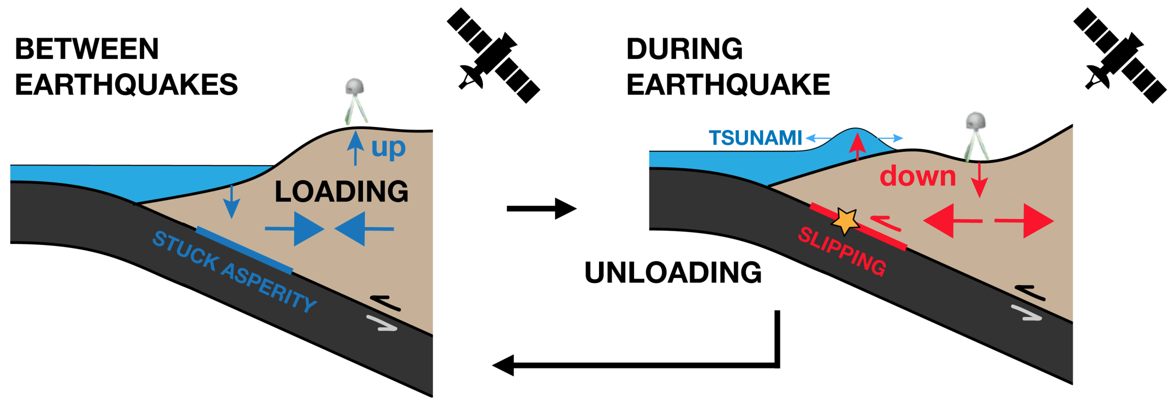
TEMPORAL LIMIATIONS OF GEODETIC DATA COVERAGE

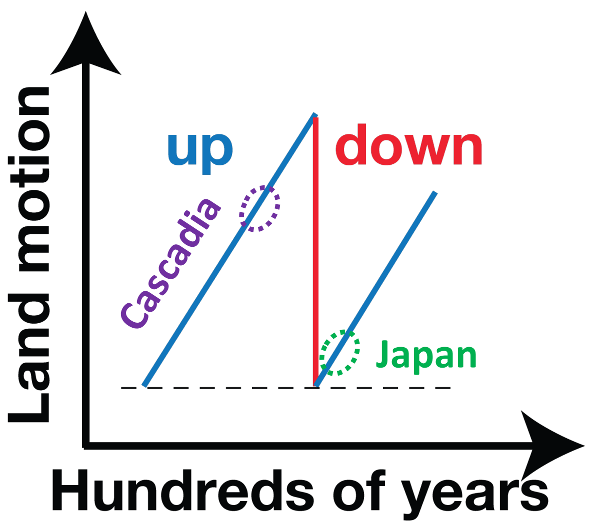




- Geodetic data only captures a **small fraction** of the timescale over which **earthquake cycles operate.**

TEMPORAL LIMIATIONS OF GEODETIC DATA COVERAGE





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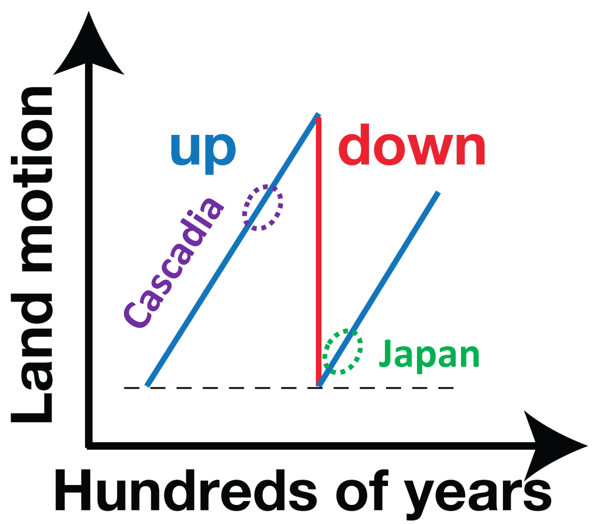
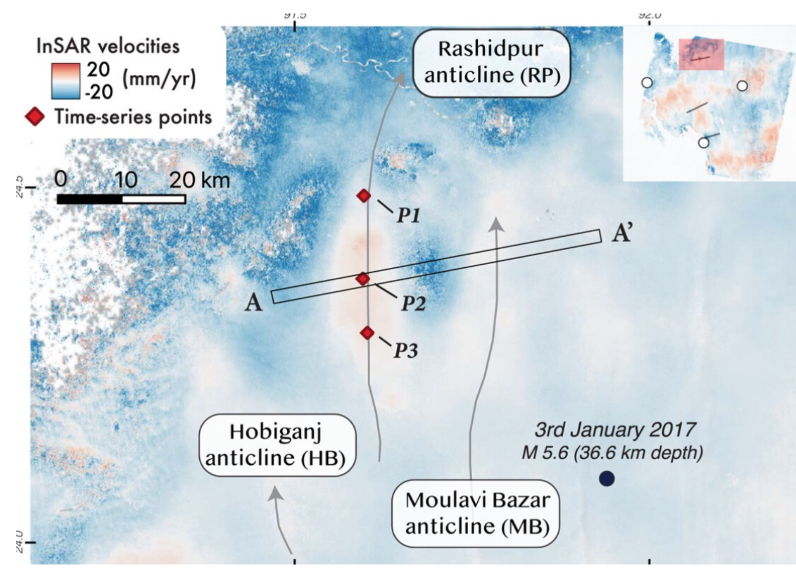


Viscous interseismic uplift of anticlines in the Indo-Burma subduction zone [Chong , **Oryan**, et al., 2024]



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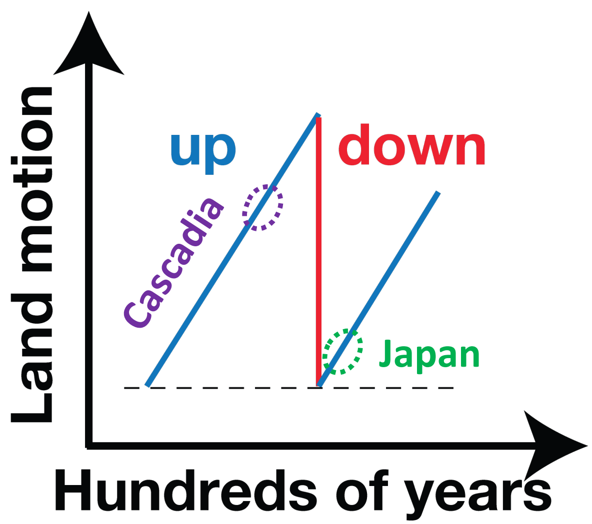
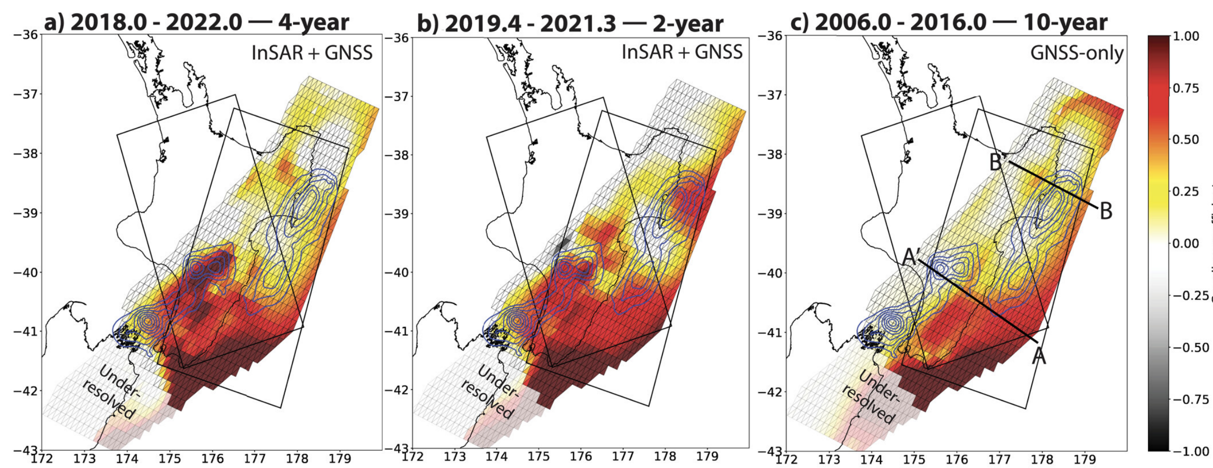


Locking in Hikurangi Subduction Zone varations based on different temporal resolution [Maubant et al., 2023].



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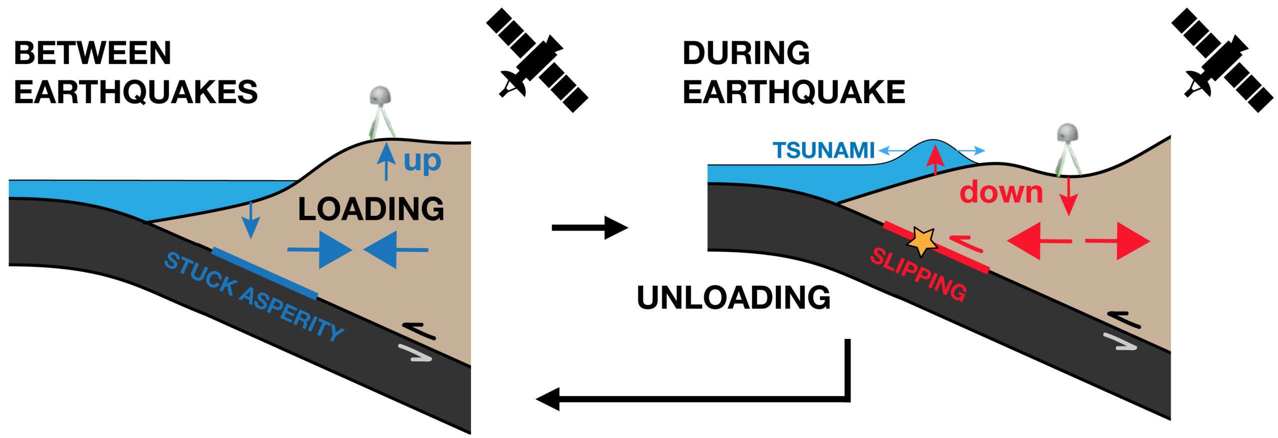
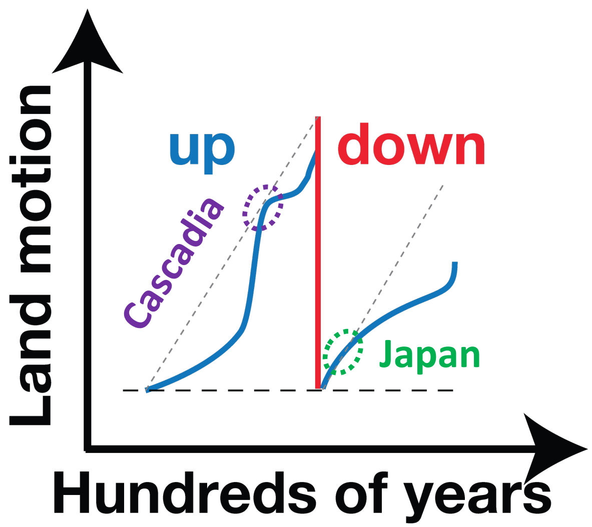
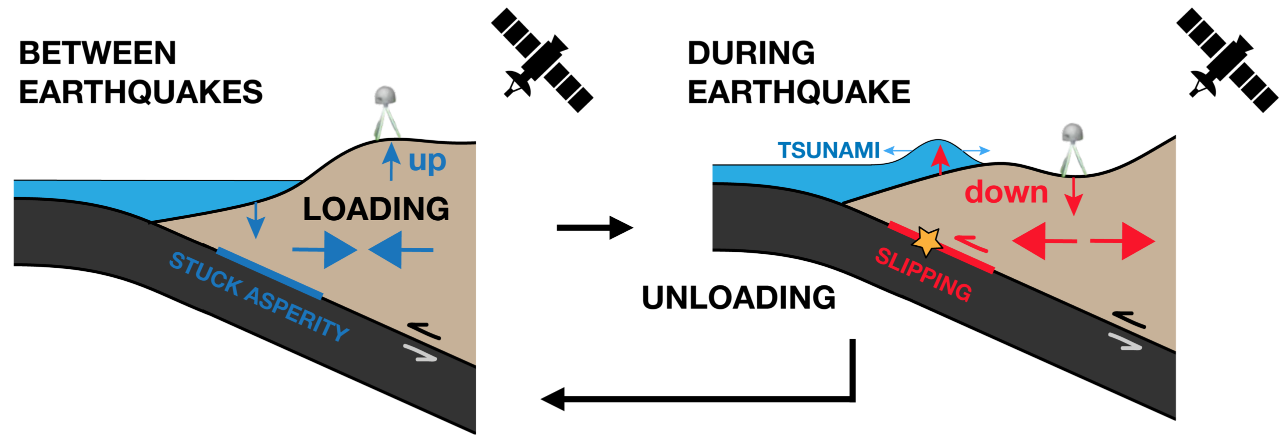


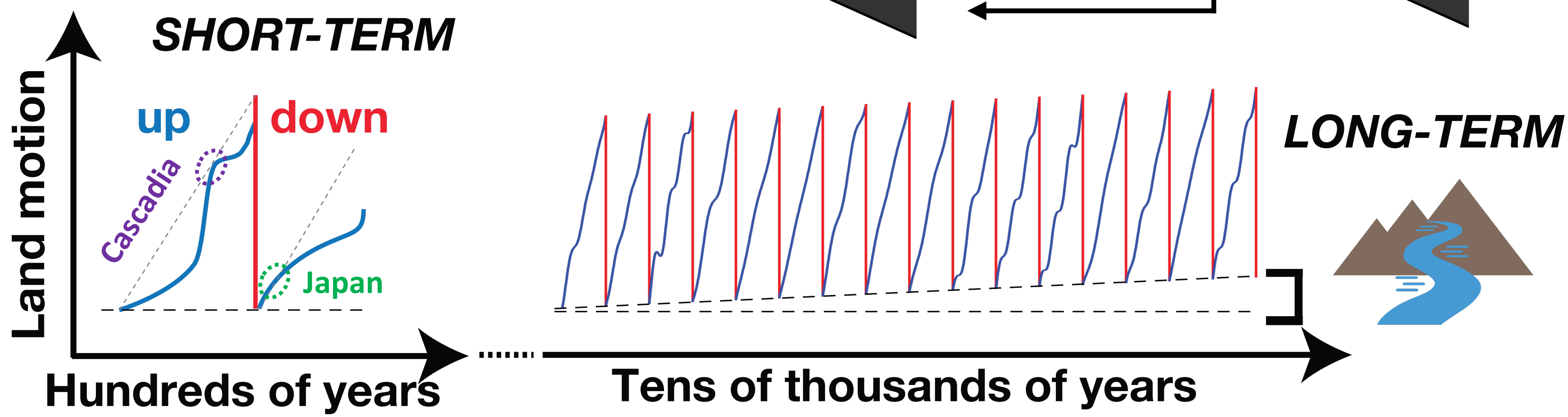


Current geodetic efforts to constrain coupling may be **overlooking key deformation components.**

SUBDUCTION LANDSCAPES AS LONG-TERM RECORDS OF EARTHQUCKE CYCLES DEFOMATION

Landscapes record deformation on time-scales of **hundreds of thousands of years and** could point to the **persistent plate locking.**





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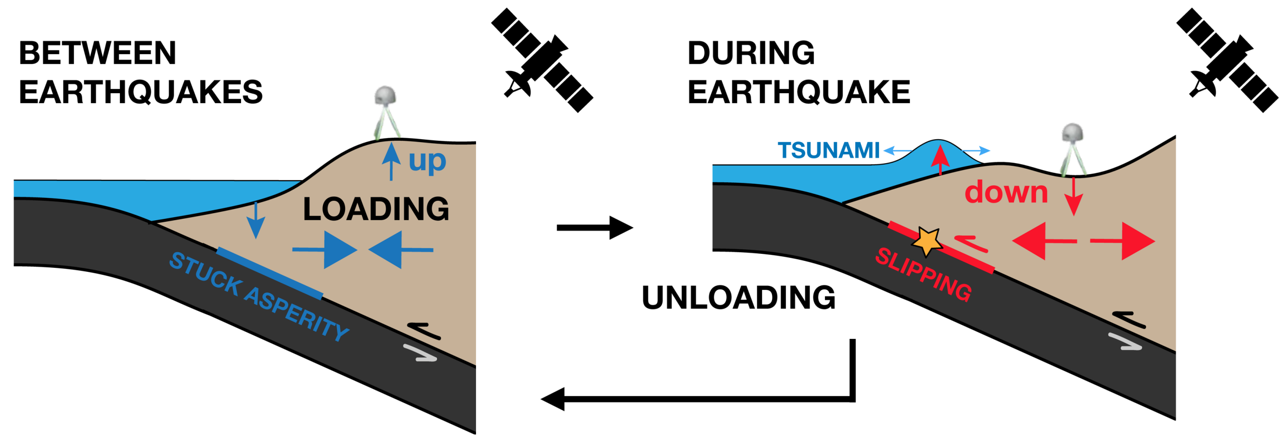

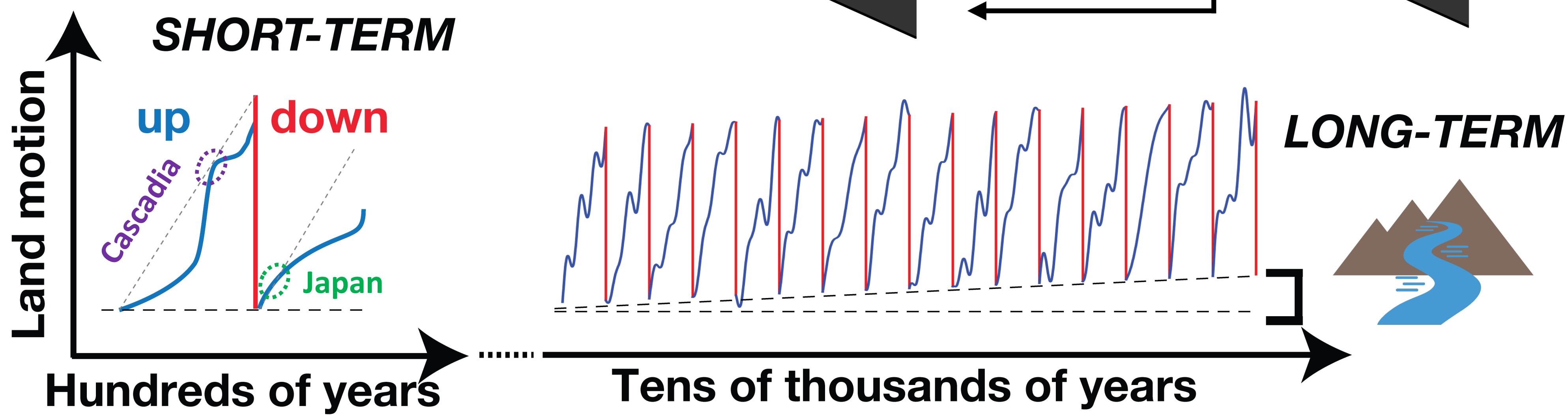

KEY POINTS SO FAR

- Geodetic documentation of upper plate deformation help constrain the hazard associated with megathrust earthquakes**.**
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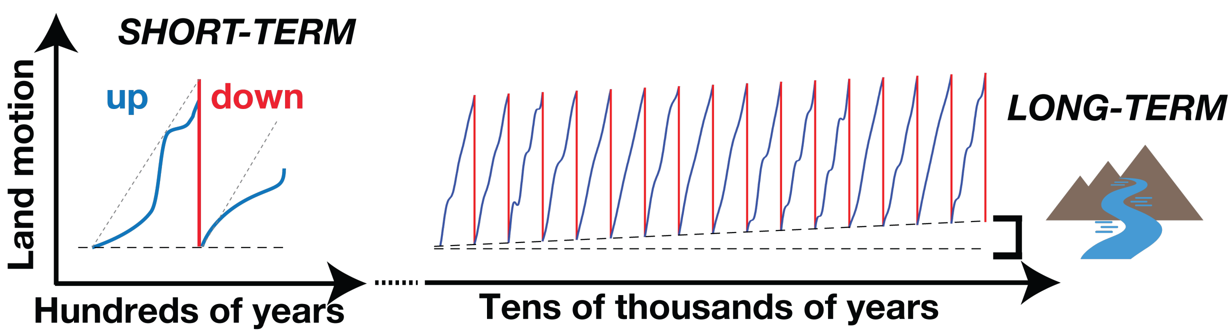
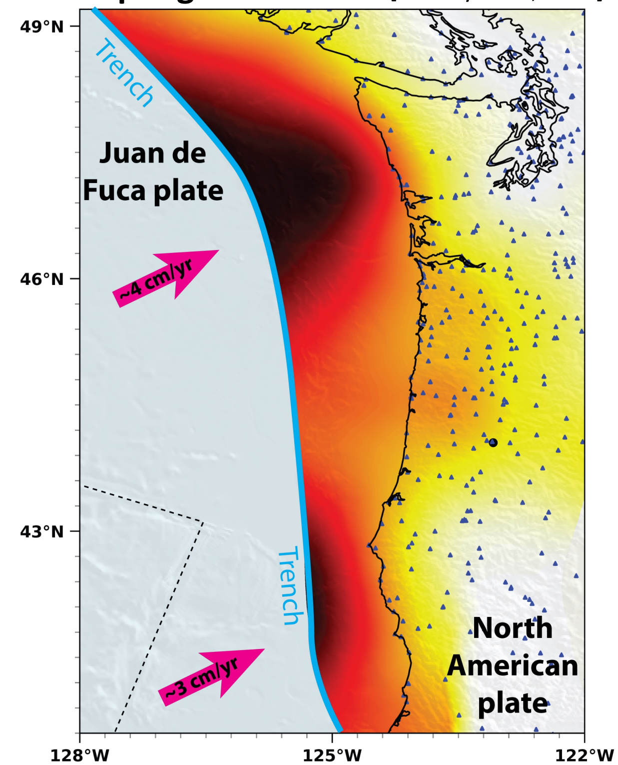
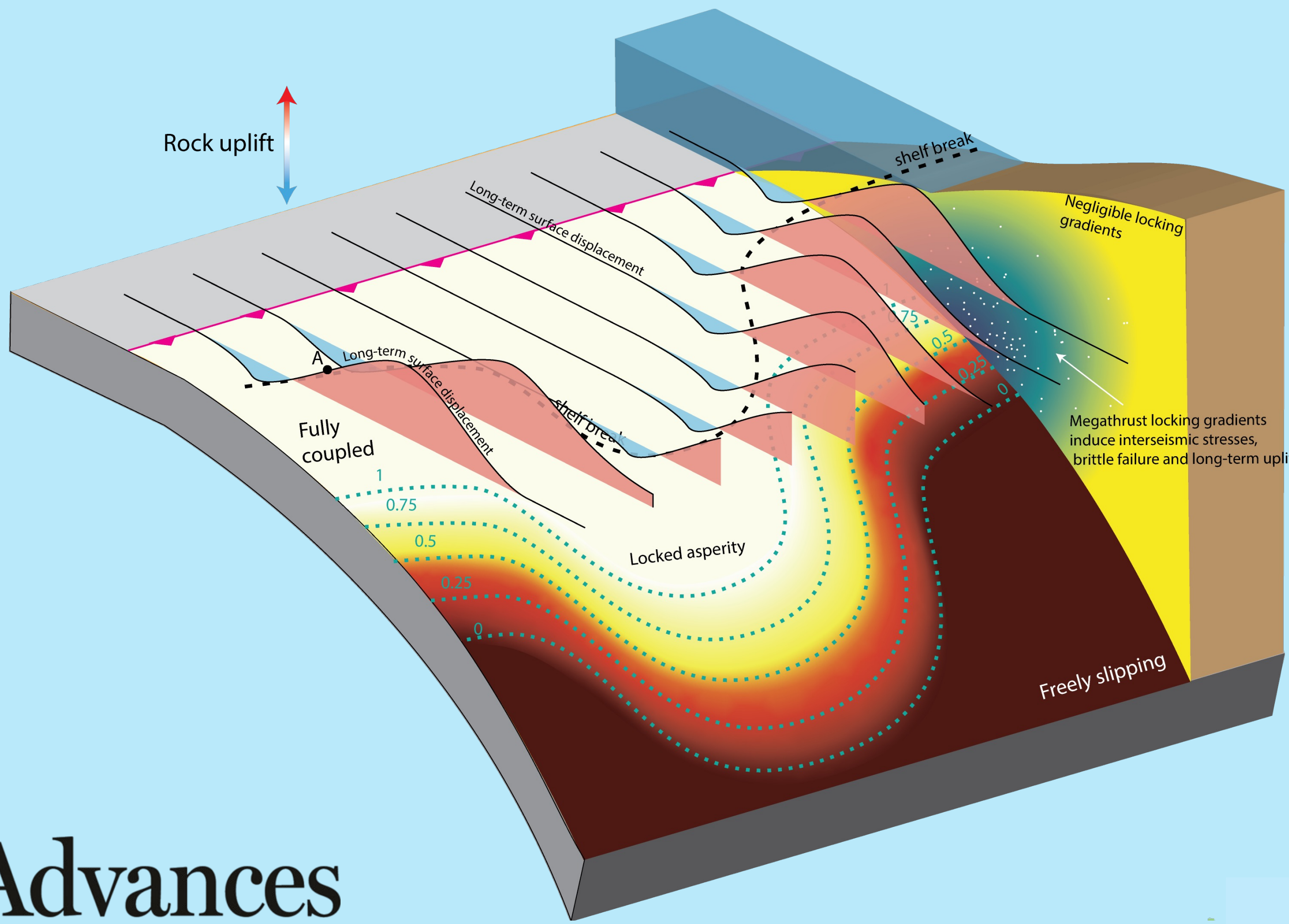


Coupling in Cascadia [Lindsey et al., 2021]



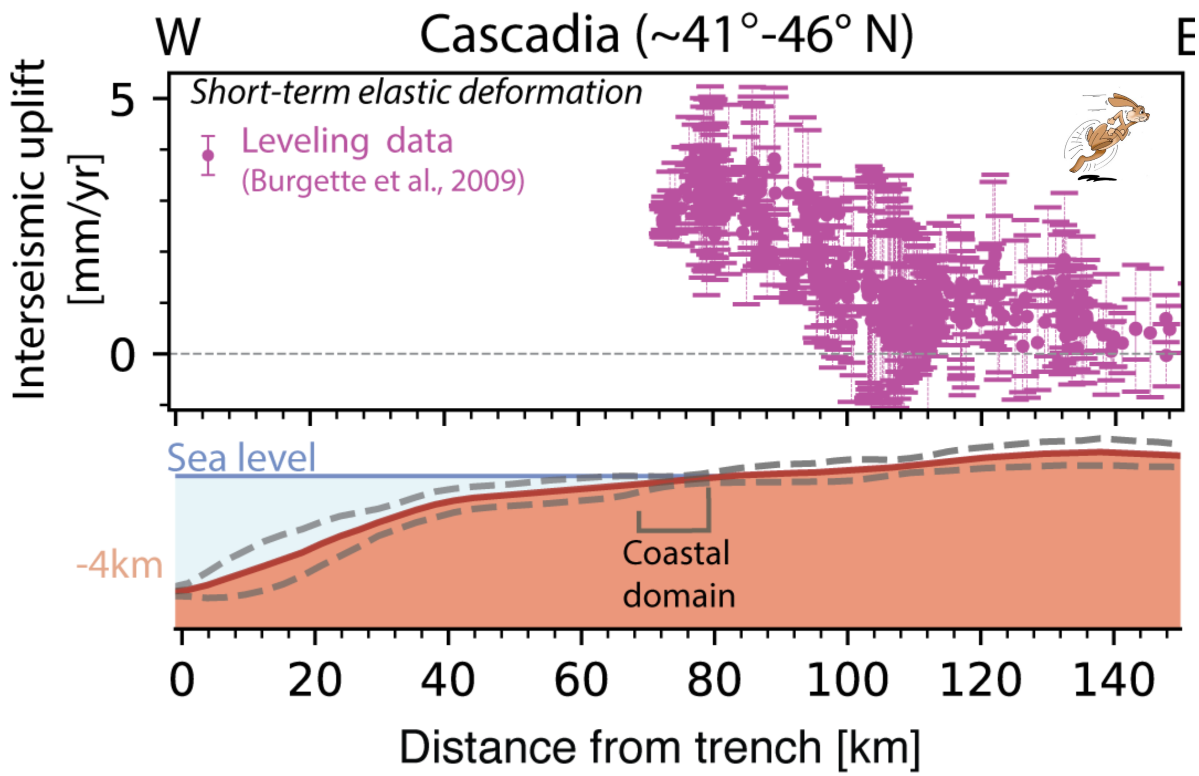
Section 2 - Fingerprints of Megathrust Locking in Subduction Landscapes



ScienceAdvances

Oryan et al., 2024

SHORT-TERM DEFORMATION IN CASCADIA



Oryan et al., 2024

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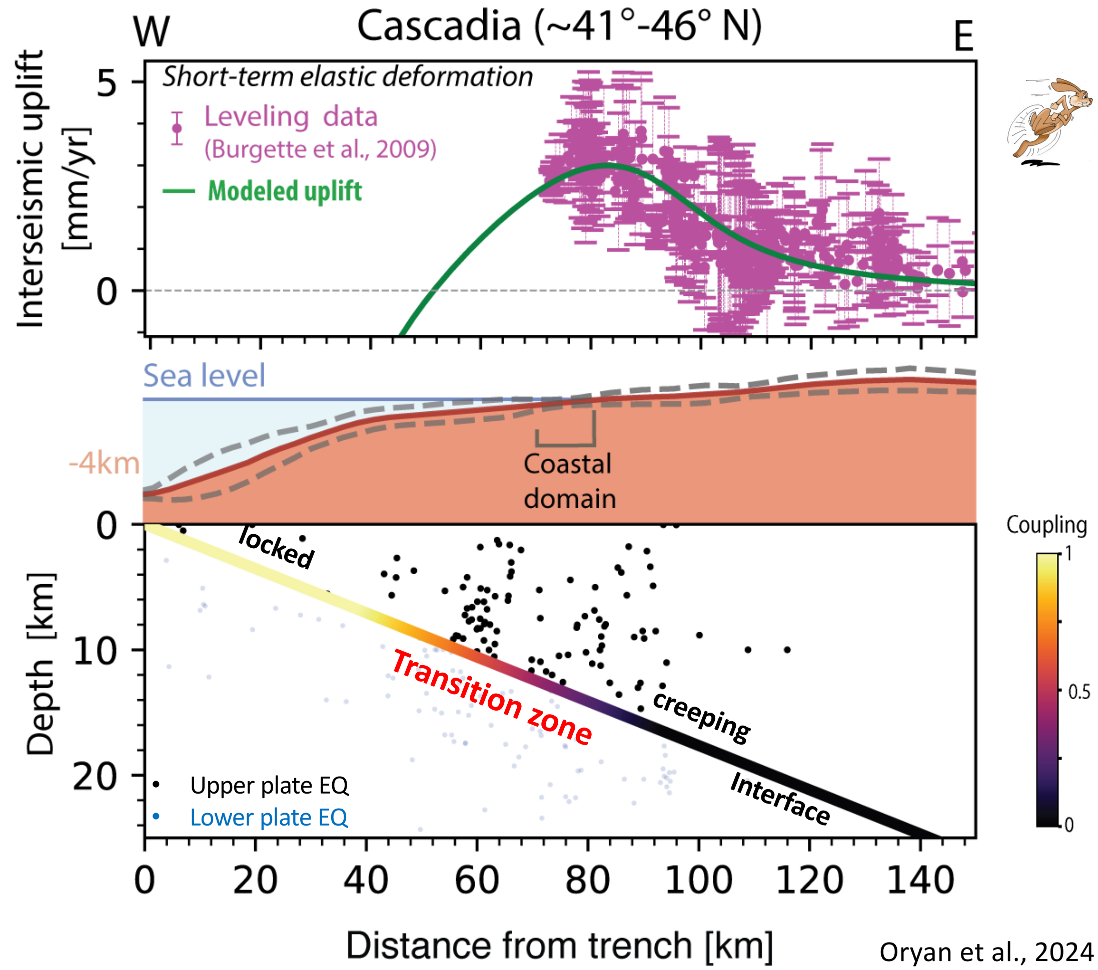

Oryan et al., 2024

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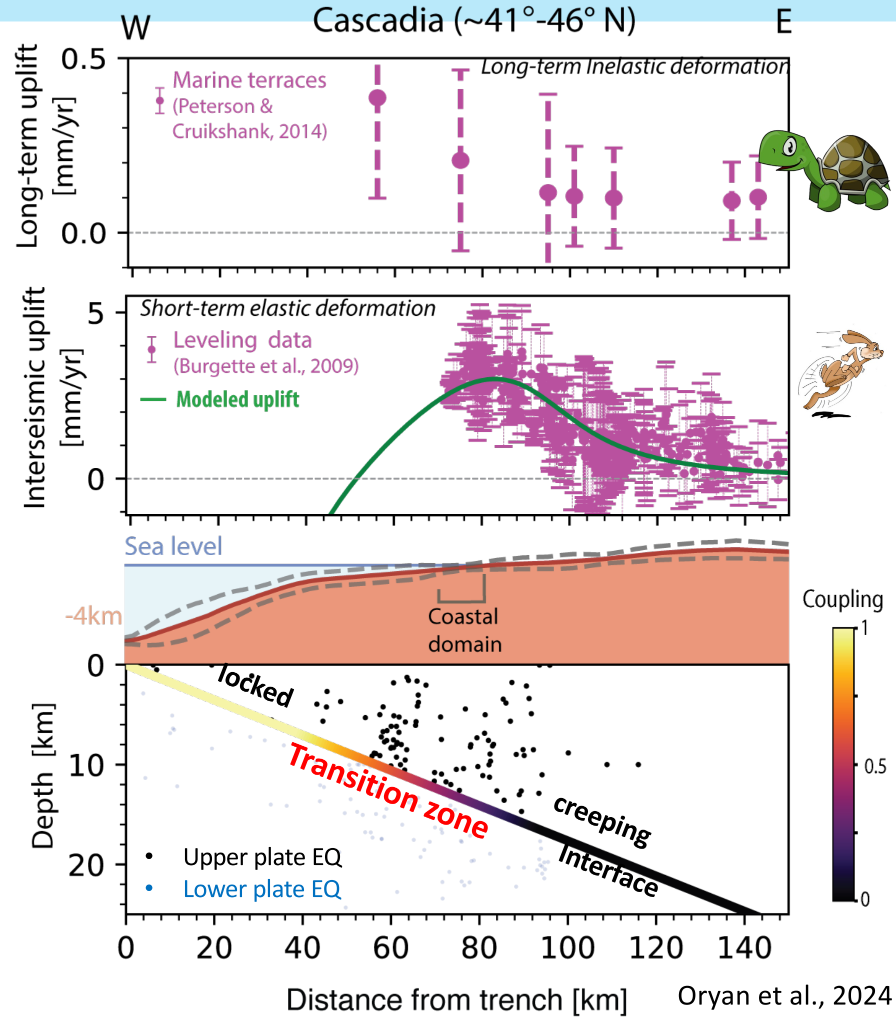

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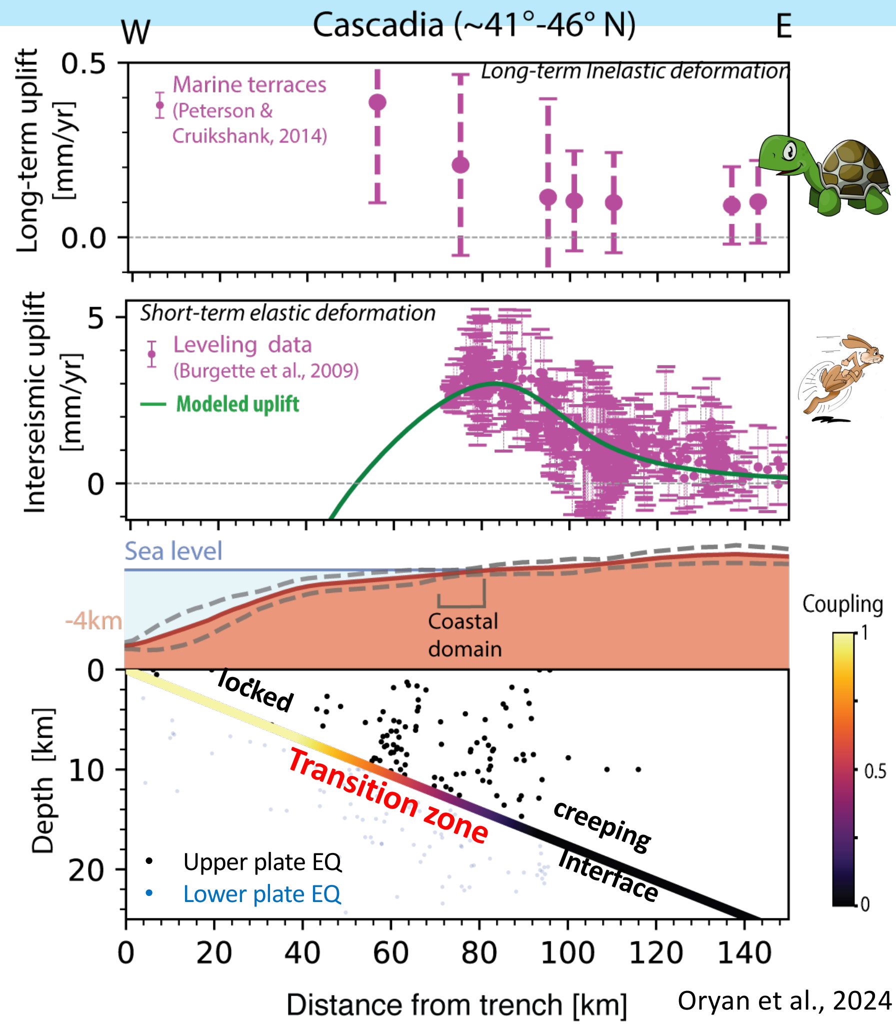

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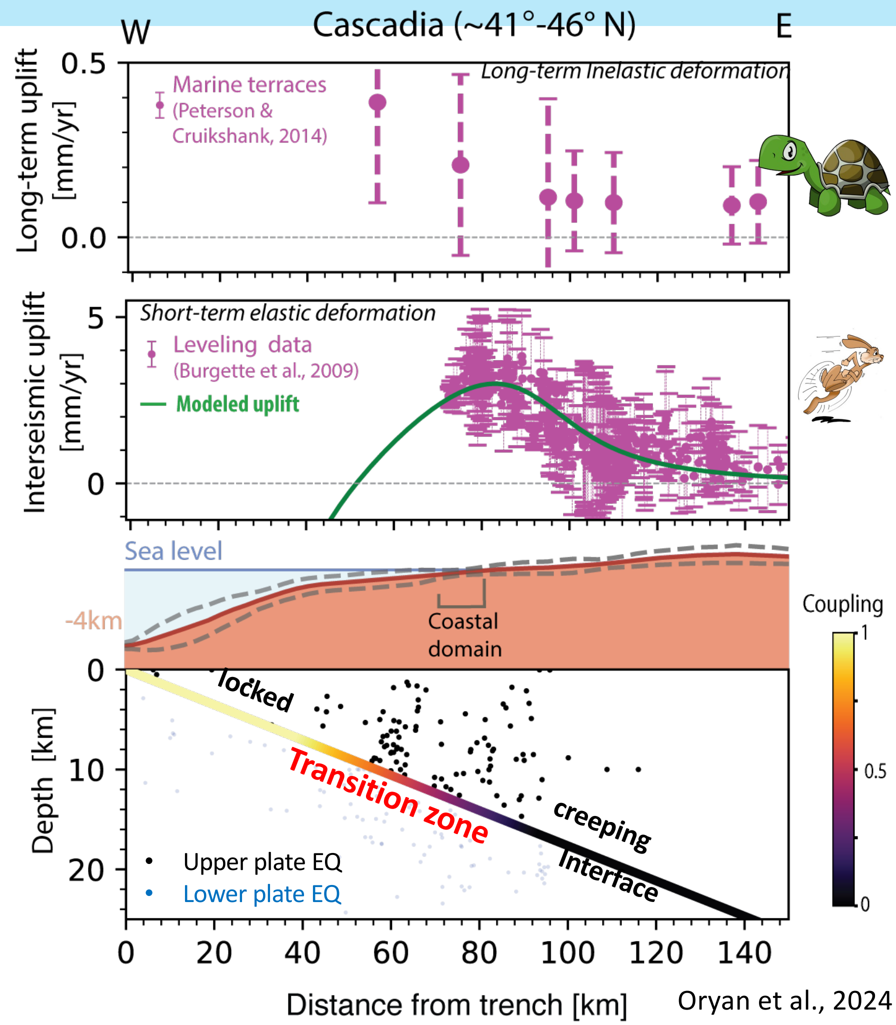

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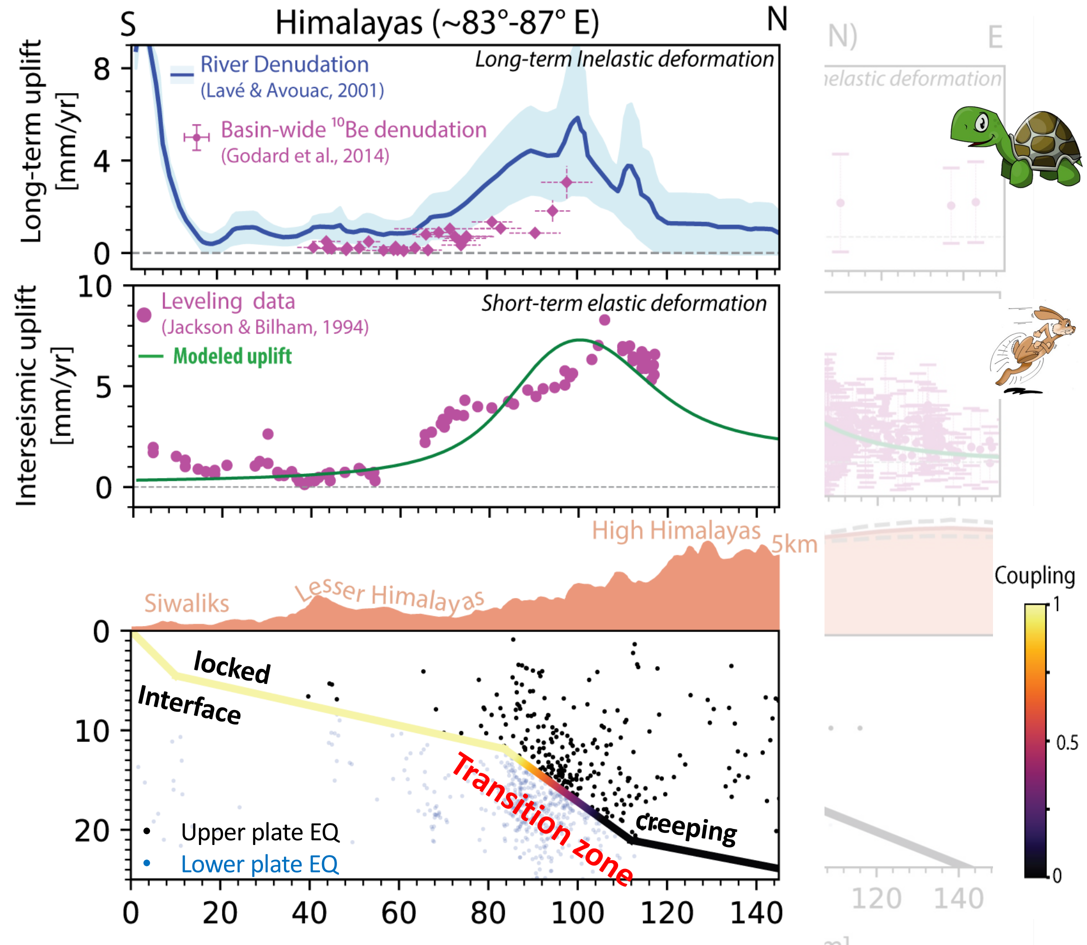

Oryan et al., 2024

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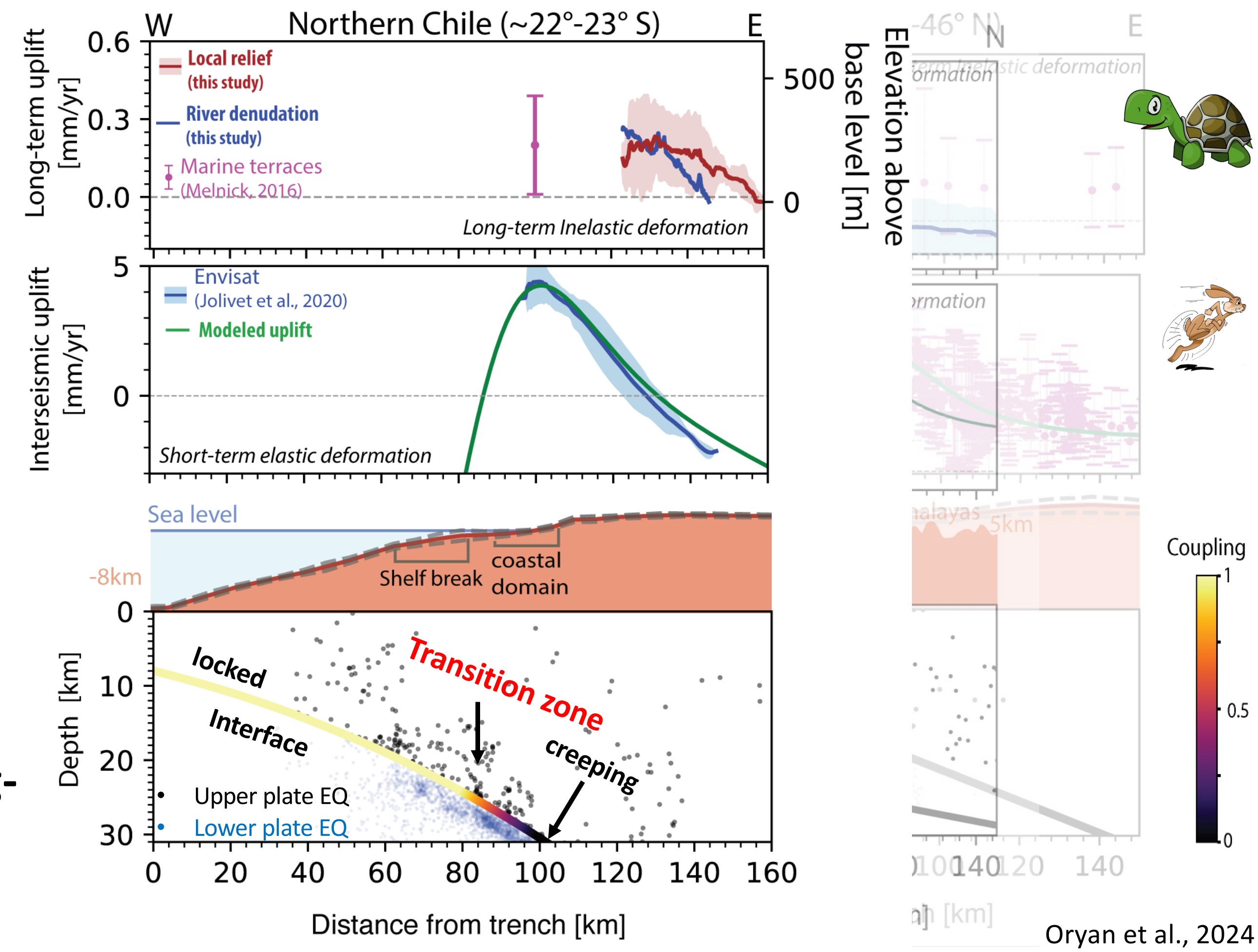

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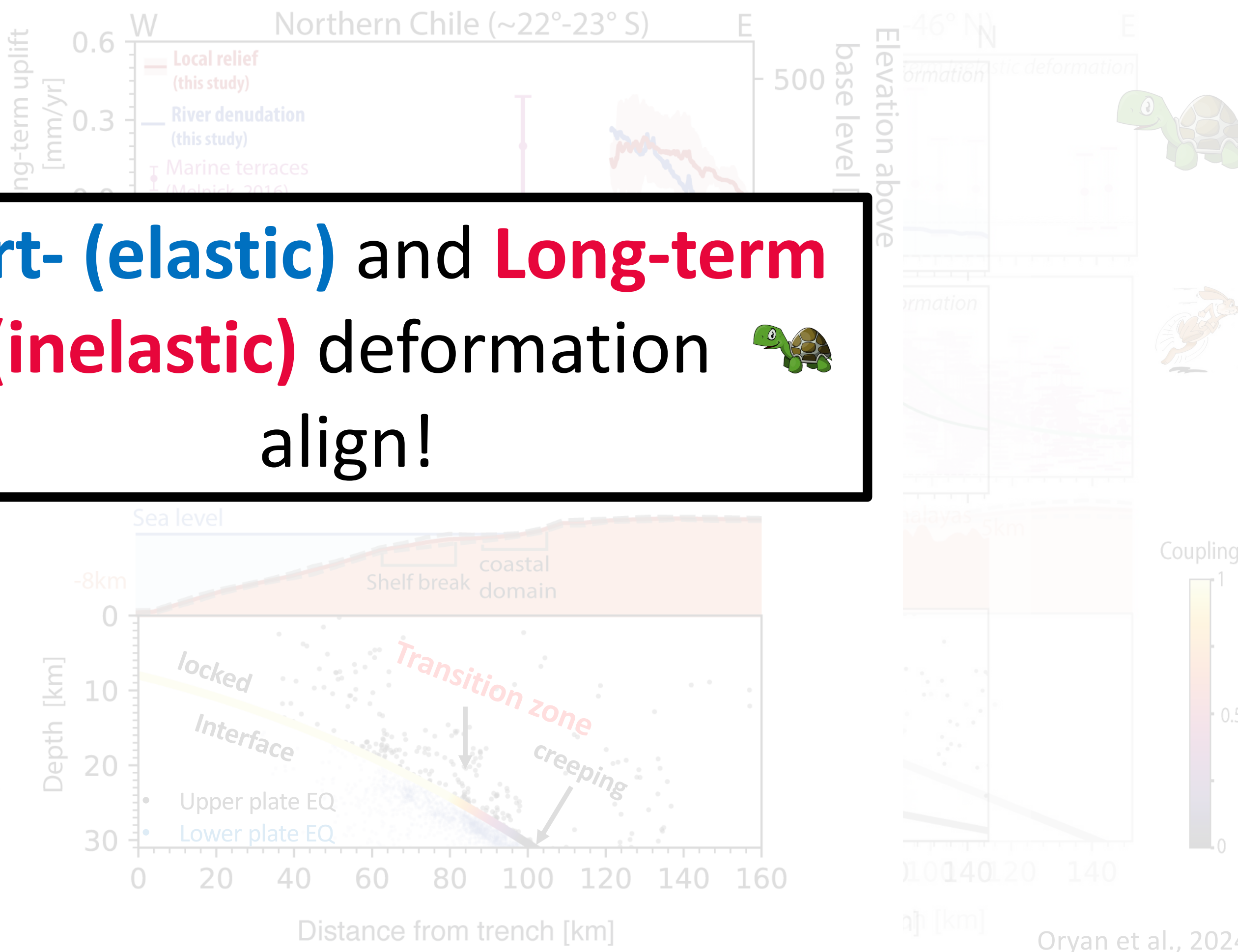
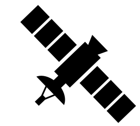
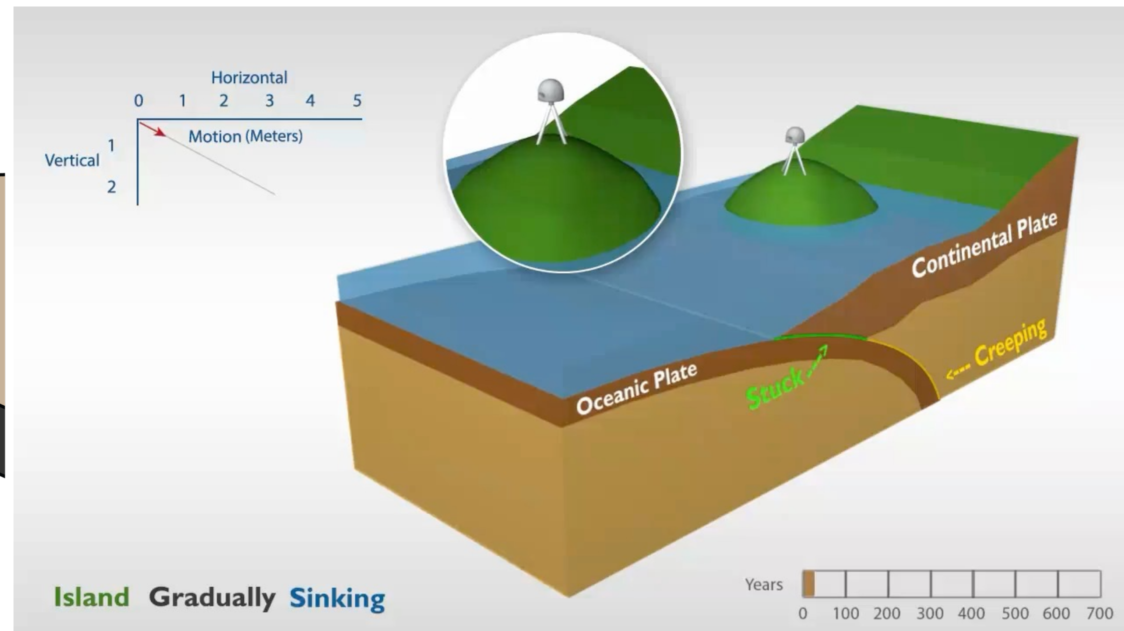


Oryan et al., 2024

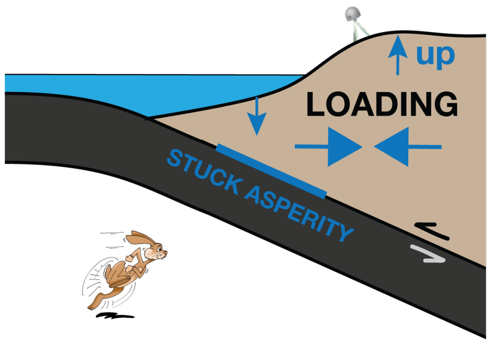
ELASTIC EARTHQUAKE CYCLES IN SUBDUCTION ZONES

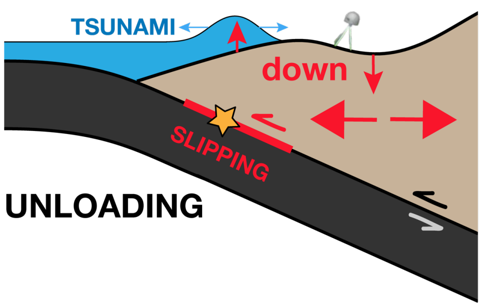


Long-term: downgoing plate descends beneath the upper plate in stick-slip fashion.



Interseismic: locked section is "stuck". Creeping section moves slowly. Upper plate deform **elastically**





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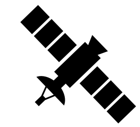

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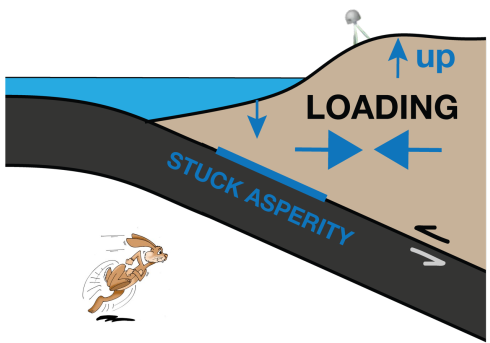

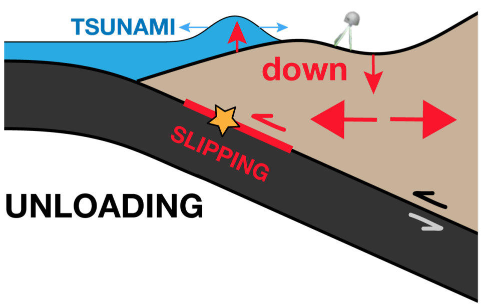

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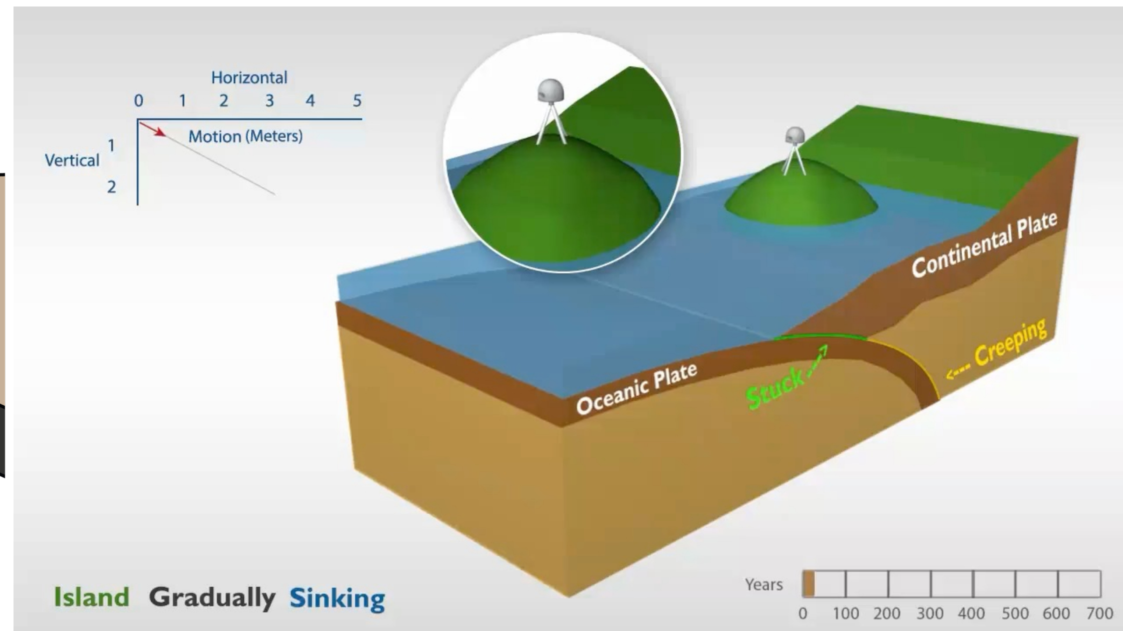
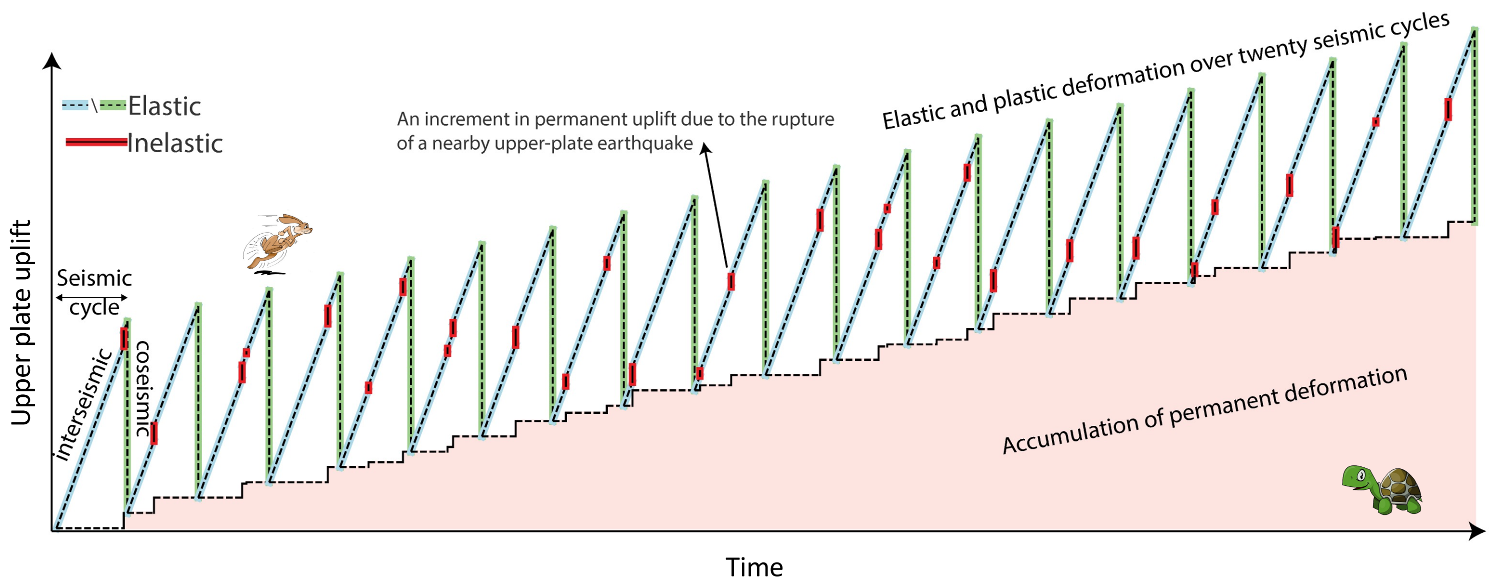


No off-fault permanent deformation!

HOW INTERSEISMIC FAULT LOCKING IMPRINTS SUBDUCTION LANDSCPES ?

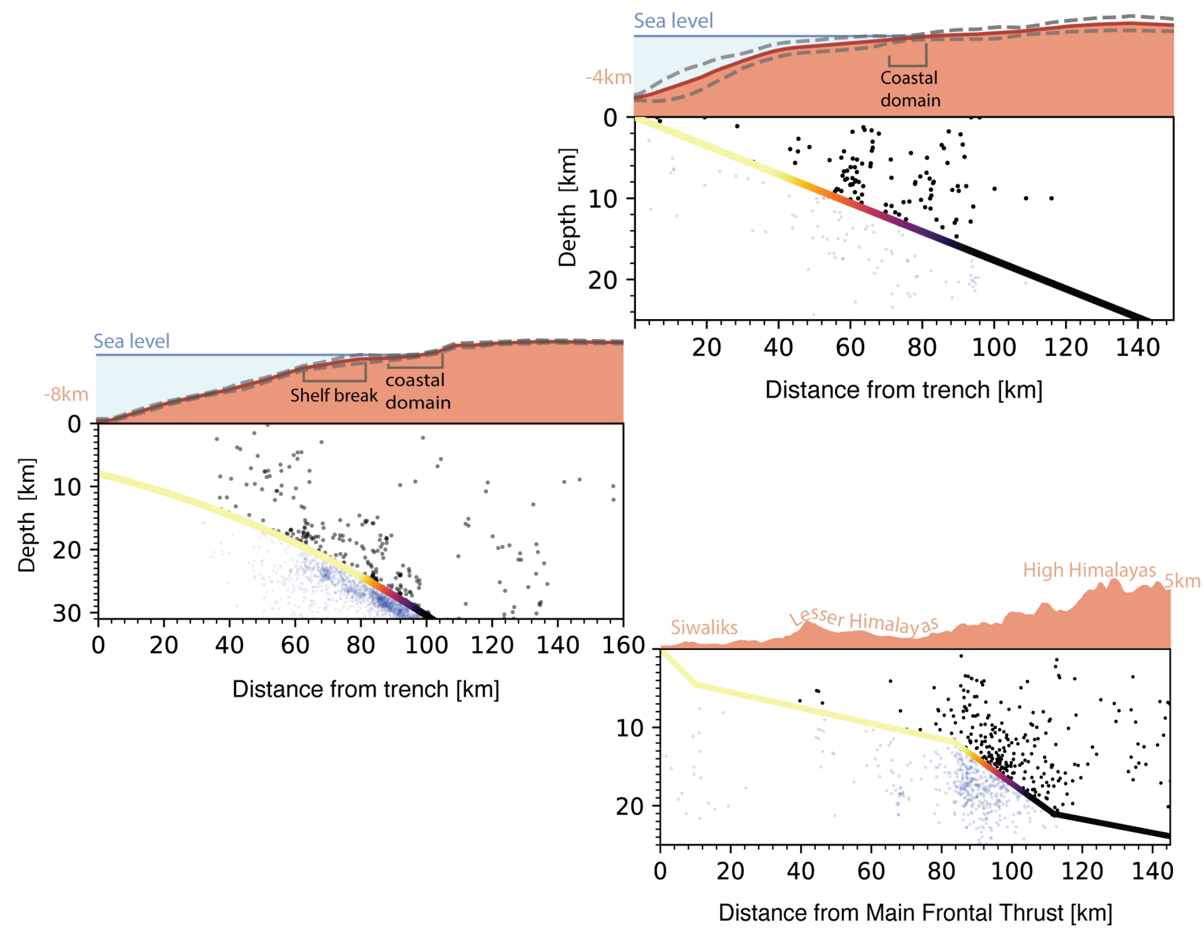
- **Interseismic upper plate stresses** induced by locking gradients push parts of the upper plate to **failure** generating overriding plate earthquakes.
- Repeated **failure** over multiple earthquake cycles explains the overlap between short- and long-term deformation.



Oryan et al., 2024

MODELING INTERSEISMIC INELASTIC DEFORMATION ACROSS UPPER PLATES

- Current interseismic recorded seismicity represents a **snapshot of the long-term processes** that gradually shape topography.
- We extend the upper plate seismic record by generating upper plate earthquakes, **representing the complete signature of earthquake cycles**.

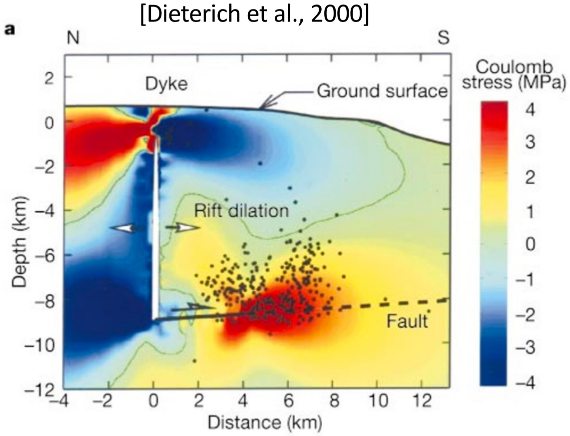


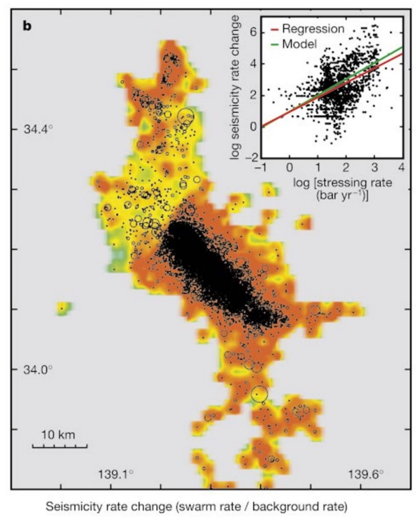
Oryan et al., 2024

MODELING INTERSEISMIC INELASTIC DEFORMATION ACROSS UPPER PLATES

We rely on the Dieterich approach and link **seismicity rate** with **temporal and spatial stressing rates**.

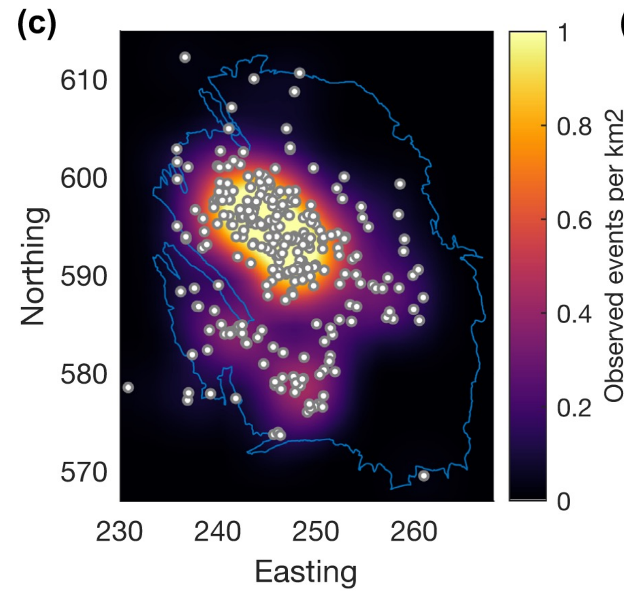
Inverting earthquake rate data to infer stress changes
[Dieterich et al., 2000]





Predicting seismicity distribution arising from magma intrusions
[Toda et al., 2002]

Predicting seismicity distribution from induced stress changes at Groningen gas field
[Heimisson et al., 2021]



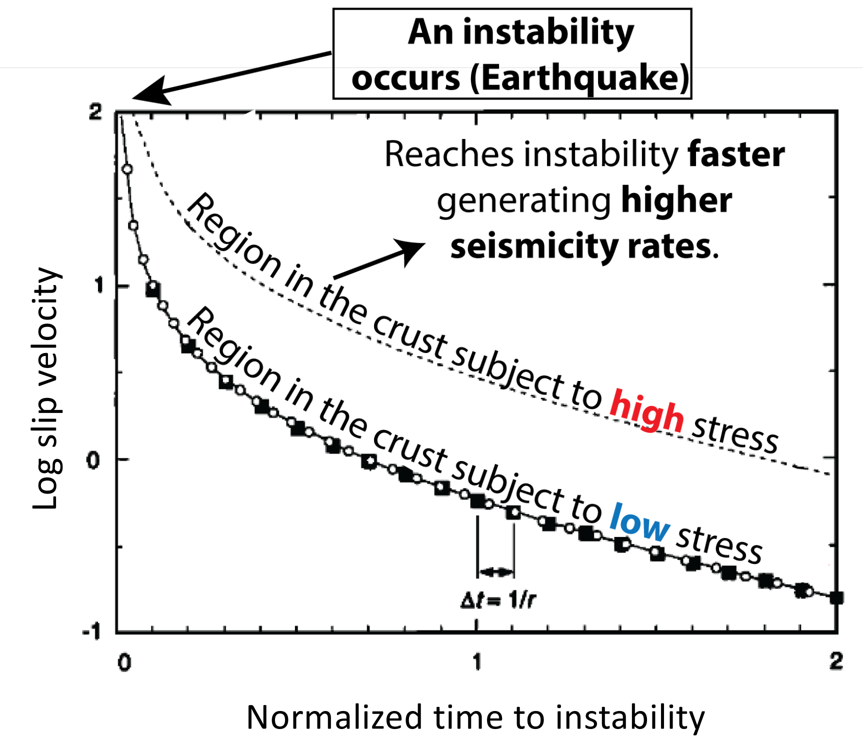
MODELING INTERSEISMIC INELASTIC DEFORMATION ACROSS UPPER PLATES

- The Dieterich approach models the crust as a series of independent nucleation points governed by rate-and-state friction, progressing toward instability.
- Higher stressing rate will reduce the time to reach instability.

<u>Underlying assumption:</u>

The state variable, θ, in rate-and-state friction follows $\frac{\theta\dot{\delta}}{D_c}$>>1 so $\theta=\theta_0\exp(-\frac{\delta}{D_c})$ and as such the slip velocity:

$$\dot{\delta} = \left\{ \left[\frac{1}{\dot{\delta}_0} + \frac{H\sigma_{\mathrm{n}}}{\dot{\tau}} \right] \exp\left(-\frac{\dot{\tau} t}{A\sigma_{\mathrm{n}}} \right) - \frac{H\sigma_{\mathrm{n}}}{\dot{\tau}} \right\}^{-1}.$$



Dieterich 1994

MODELING INTERSEISMIC INELASTIC DEFORMATION ACROSS UPPER PLATES

- We rely on the Dieterich

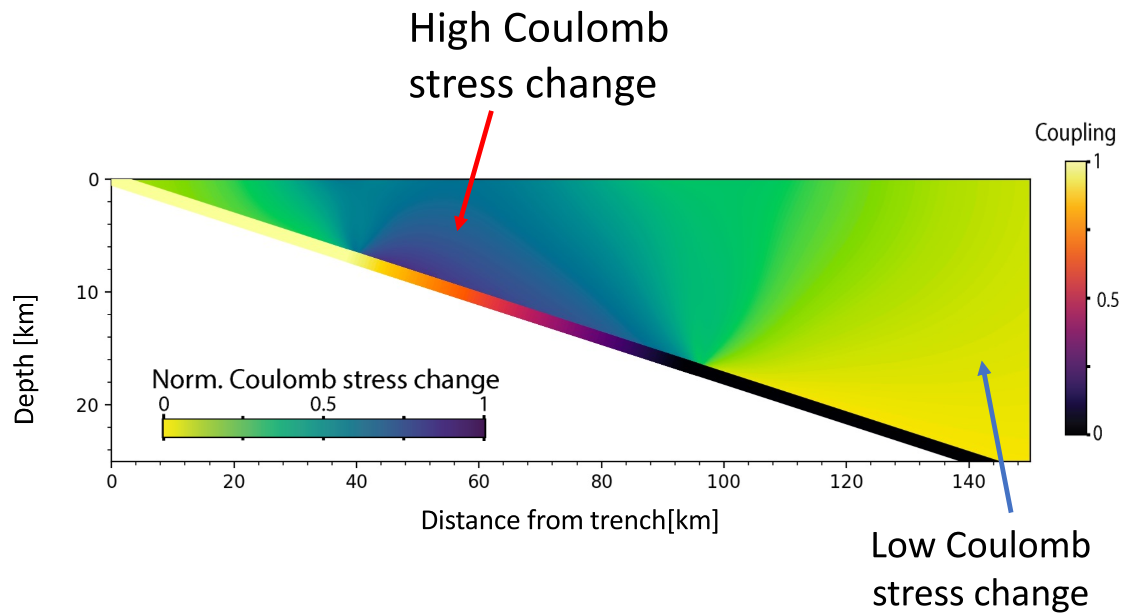
Predicting seismicity distribution

The Dieterich framework is widely used to describe the **spatial** and temporal distribution of **seismicity from changes in stress and stress rate**:

[Stein et al. (1997); Parsons et al. (2000); Toda et al. (2002); Helmstetter & Shaw (2006); Segall & Lu (2015); Kroll et al. (2017); Heimisson & Segal (2018); Cappa et al. (2019); Hager et al. (2021); Toda & Stein (2022); Heimisson et al. (2022) and more]

MODELING INTERSEISMIC INELASTIC DEFORMATION ACROSS UPPER PLATES

- We compute upper plate Coulomb stress change imparted by **locking gradients.**
- We **populate millions of synthetic earthquakes** spanning thousands of years and dozens of seismic cycles according to the **Coulomb stress change**.
- Apply the Okada solution to compute **cumulative long –term surface** displacements from seismic events.

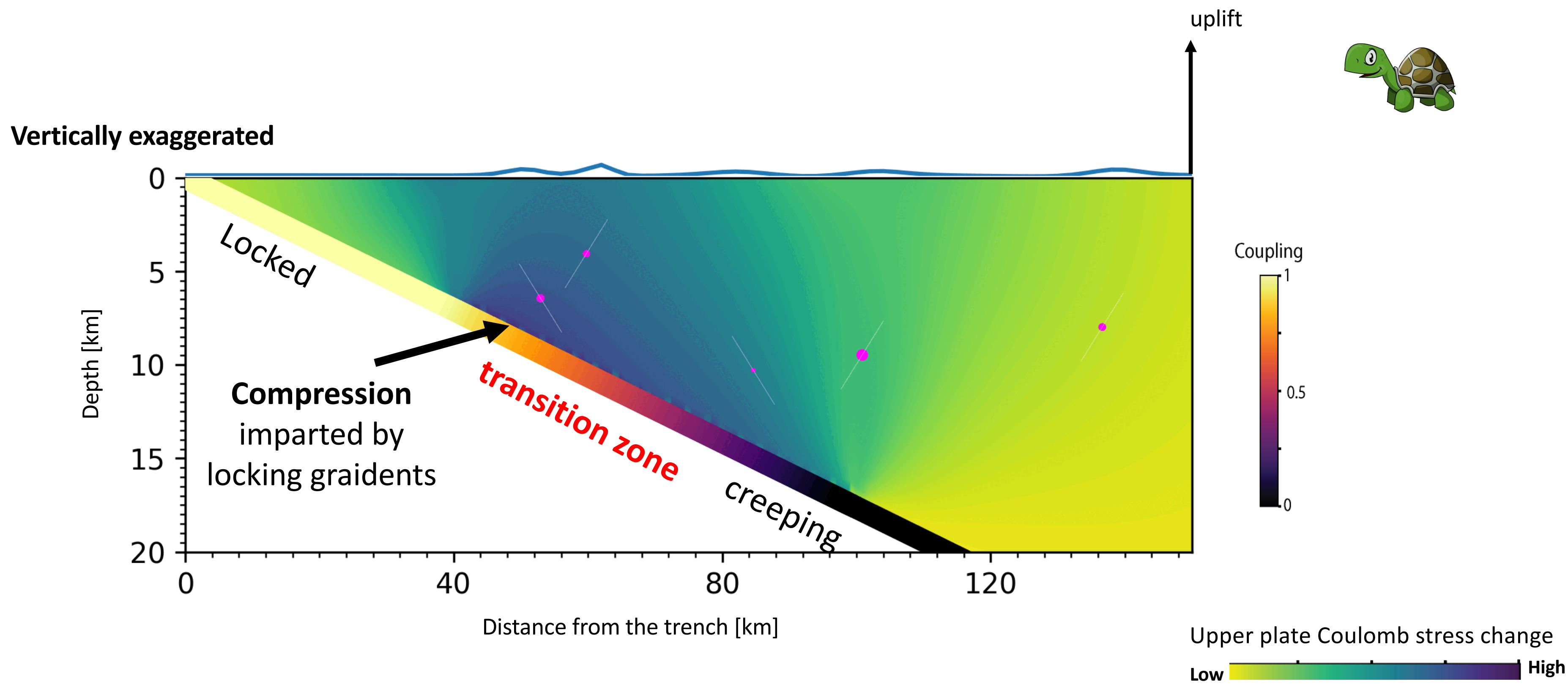


Coulomb stress change assuming thrust optimally orientated faults (30°)

MODELING INTERSEISMIC INELASTIC DEFORMATION ACROSS UPPER PLATES

10 degree dip, fully locked to 40km

Uplift during three seismic cycles producing average **long-term** rate of 0.1 mm/yr



MODELING INTERSEISMIC INELASTIC DEFORMATION ACROSS UPPER PLATES

10 degree dip, f
locked to 40kr

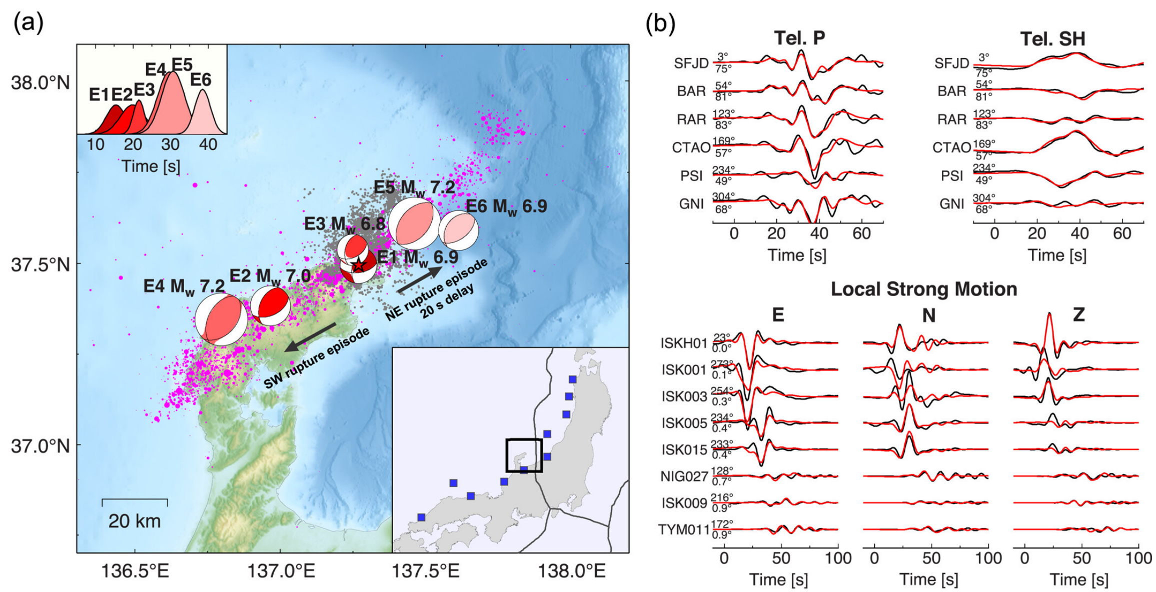
ing
r

The approach of generating multiply synthetic **events** based on a probability density function has been previously utilized in other studies.

Vertically

Depth [km]

Bayesian inversion of seismic data is used to generate earthquakes and estimate the surface deformation for the **2024 Noto earthquake.**



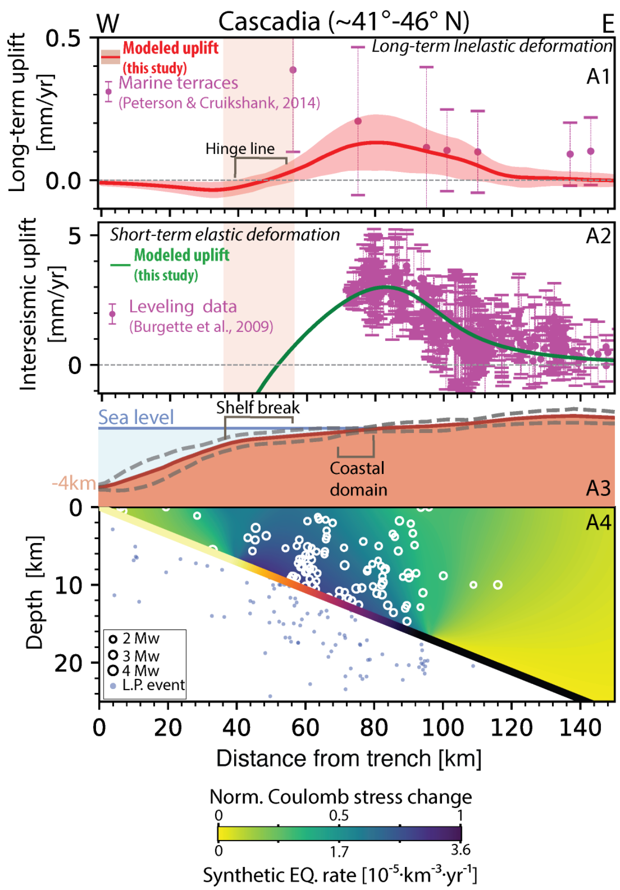
Kutschera, Jia, **Oryan** et al., [2024]

Distance from the trench [km]

Upper plate Coulomb stress change

Low High

DEFORMATION IN CASCADIA,HIMALYAS AND CHILE



Oryan et al., 2024

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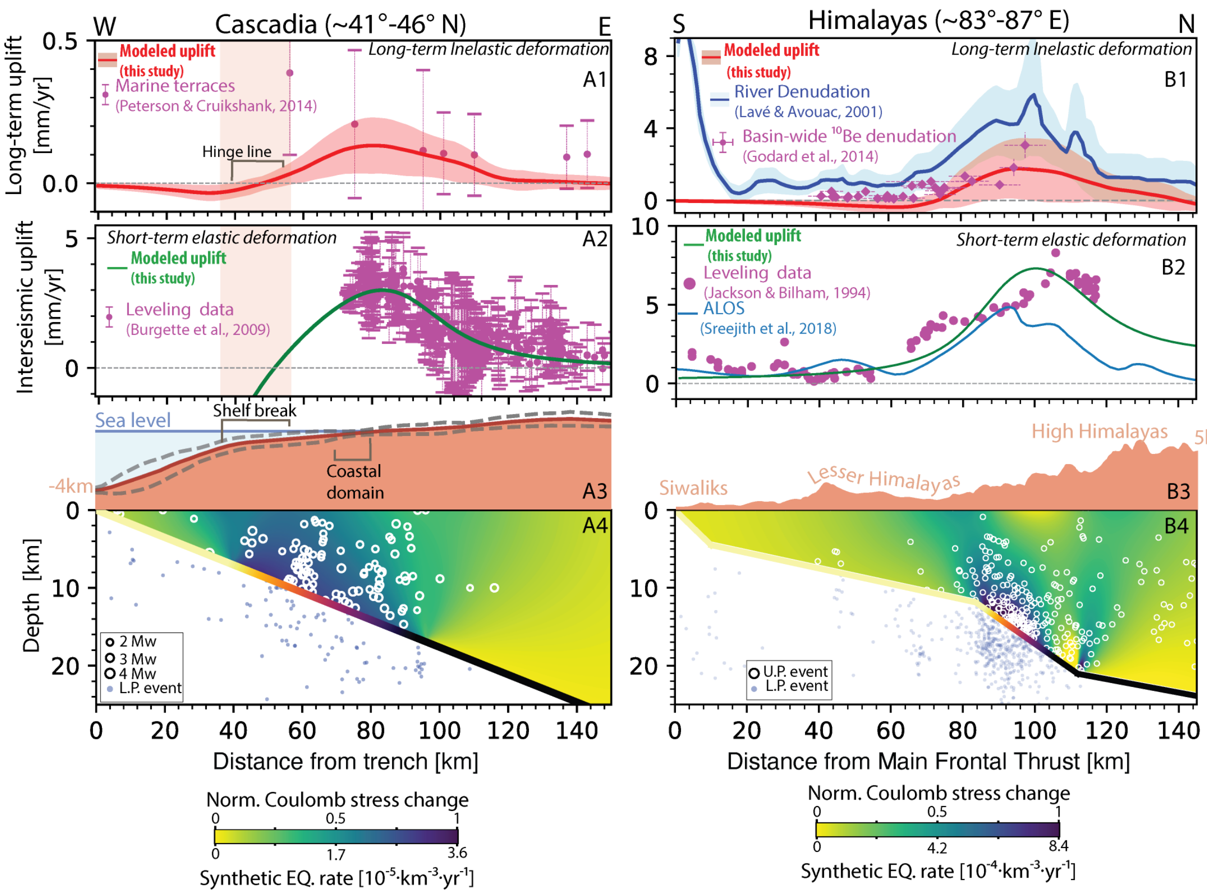

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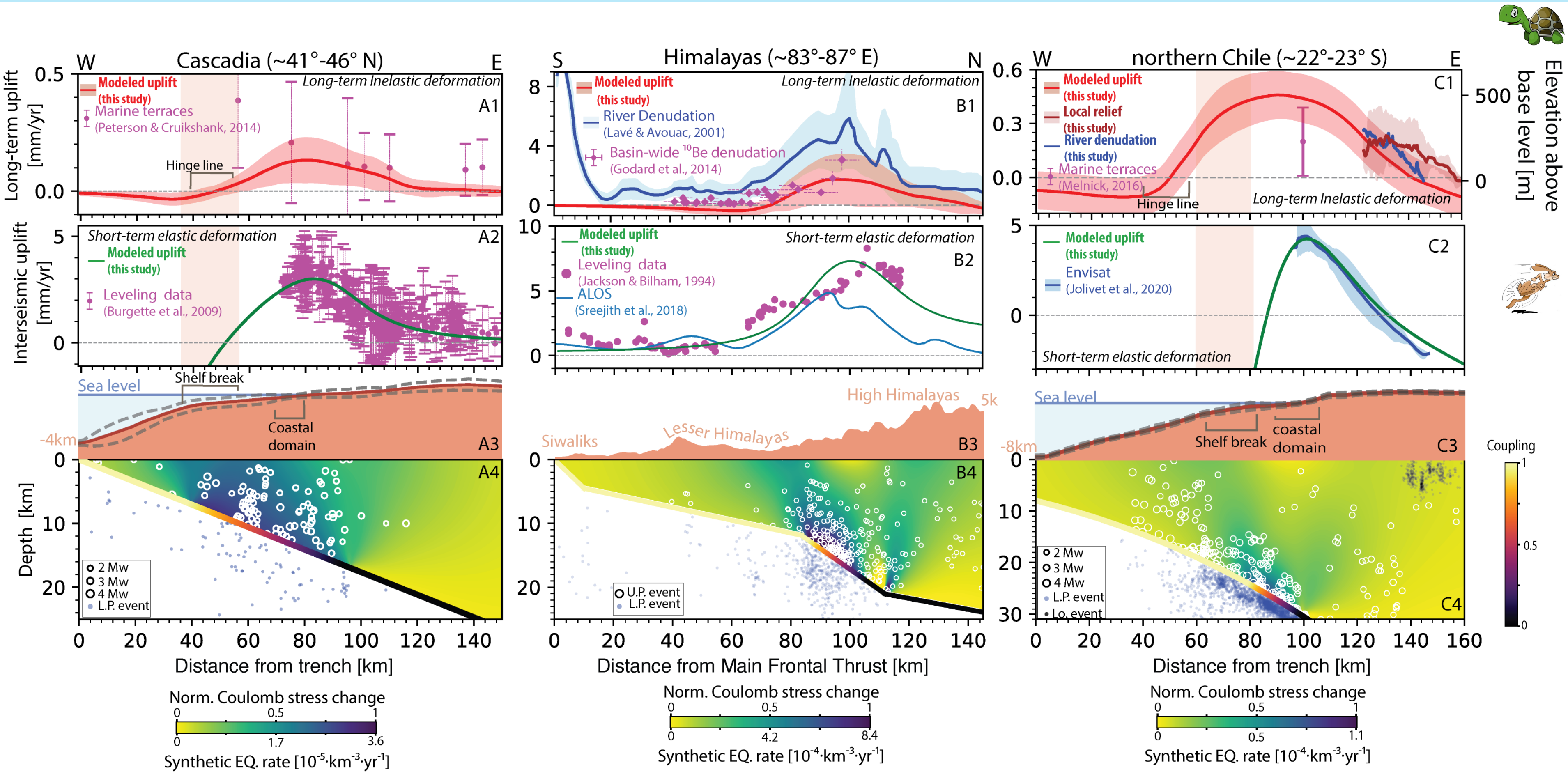
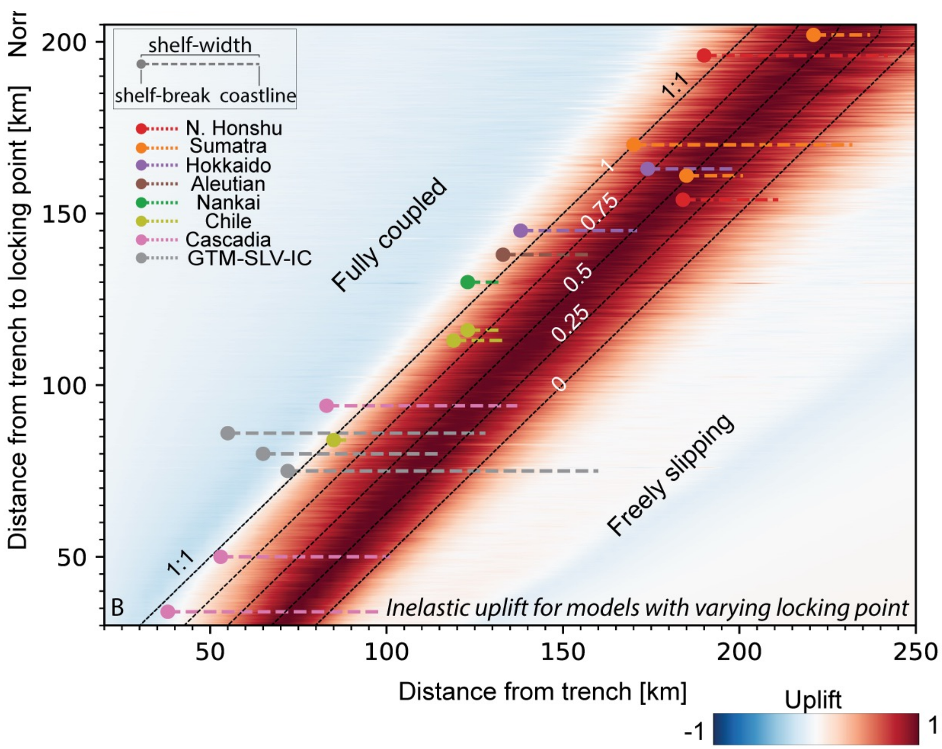
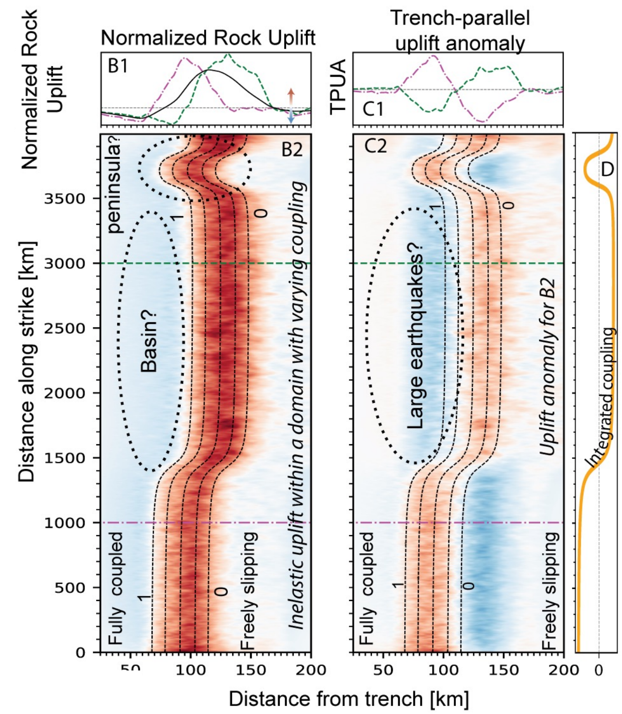


Oryan et al., 2024

MODELING GLOBAL TRENDS IN SUBDUCTION LANDSCAPES

Our model also explains first-order observations of the correlations found between long-term fields such as **gravity anomalies**, **shelf breaks**, and **peninsulas** with short term processes like **megathrust earthquakes** and **fault locking**.





Oryan et al., 2024

MODELING INTERSEISMIC INELASTIC DEFORMATION ACROSS UPPER PLATES

- Simulations of seismic cycles along a megathrust fault, combined with discrete, randomly distributed upper plate faults governed by rate-and-state friction laws, reveal that:
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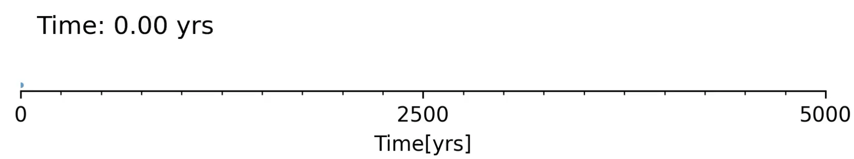
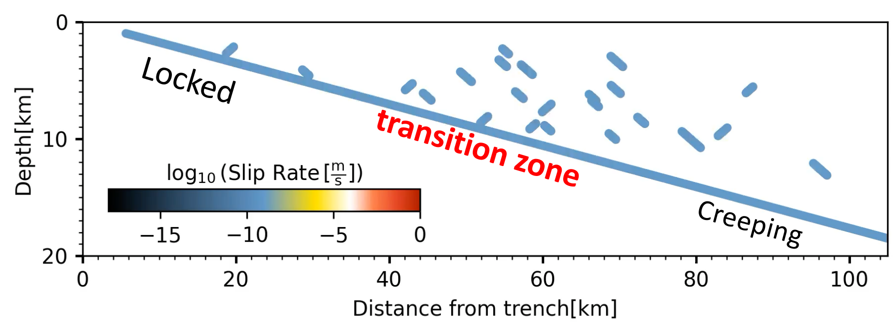


Simulation of sequences of earthquakes along a 10 degree megathrust and **25 upper plate faults**



Oryan et al., in prep.

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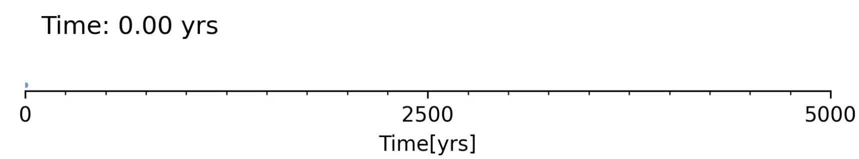

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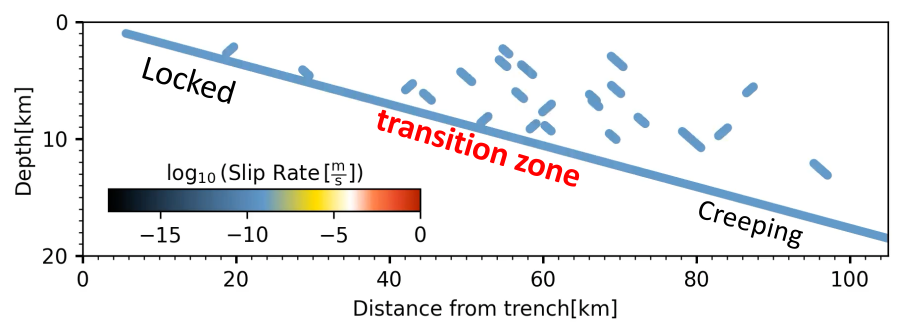

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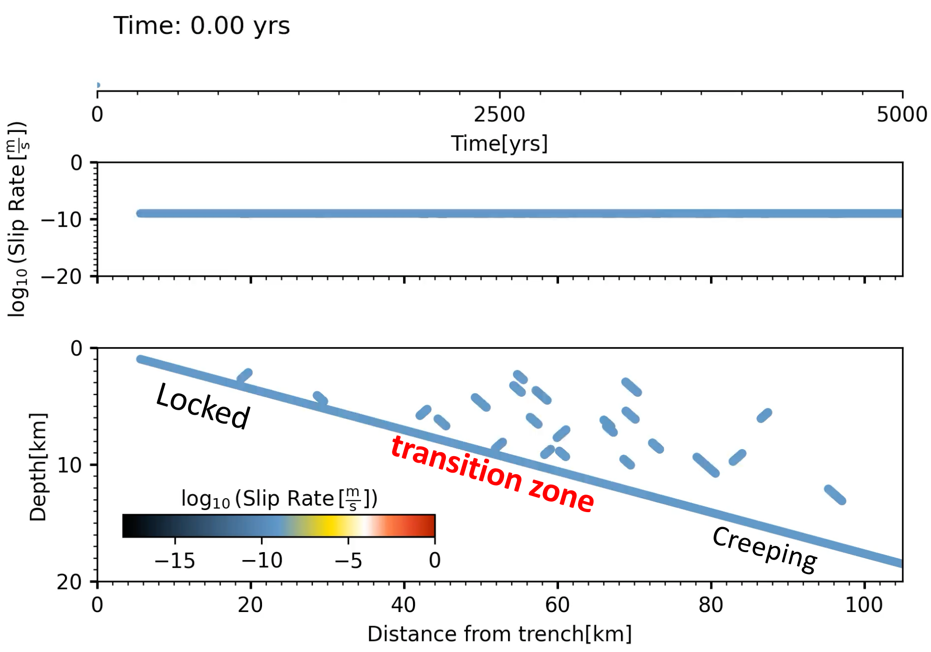
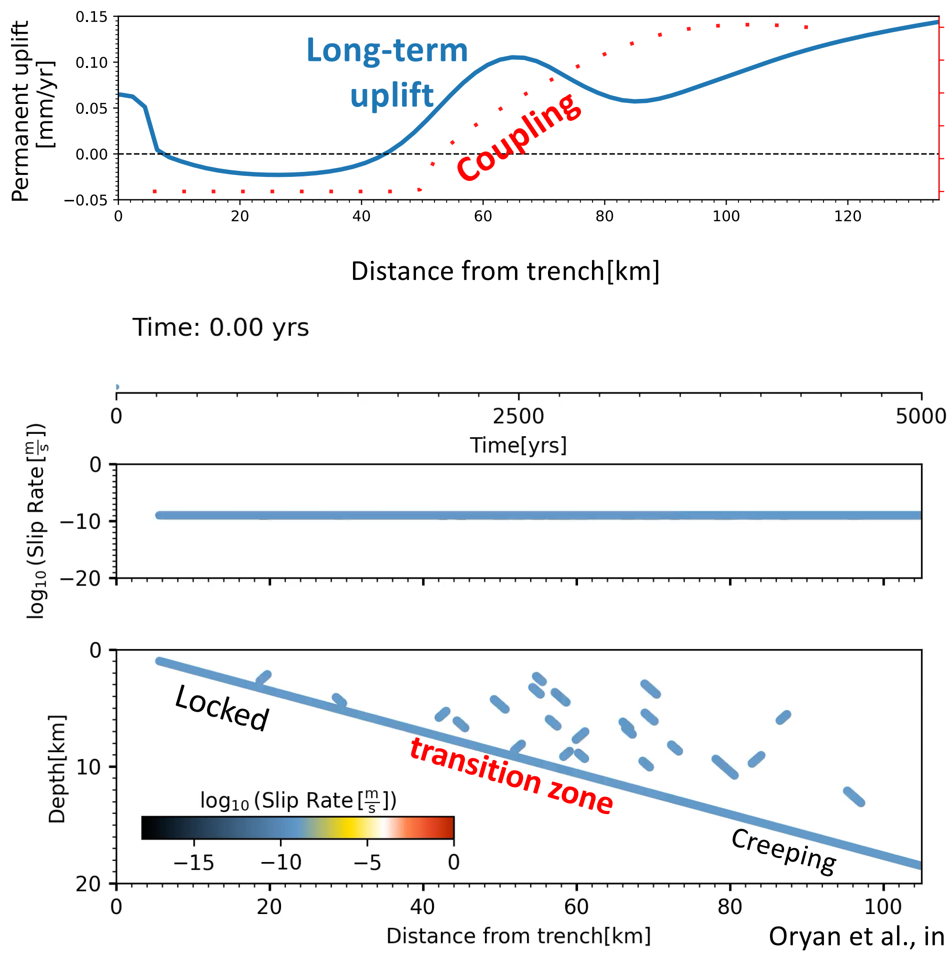


Oryan et al., in prep.

MODELING INTERSEISMIC INELASTIC DEFORMATION ACROSS UPPER PLATES

- Simulations of seismic cycles along a megathrust fault, combined with discrete, randomly distributed upper plate faults governed by rate-and-state friction laws, reveal that:
  - Upper plate faults can **fail interseismically** and generate earthquakes.
  - **Permanent uplift**, observed after four seismic cycles, **peaks above the transition zone**.

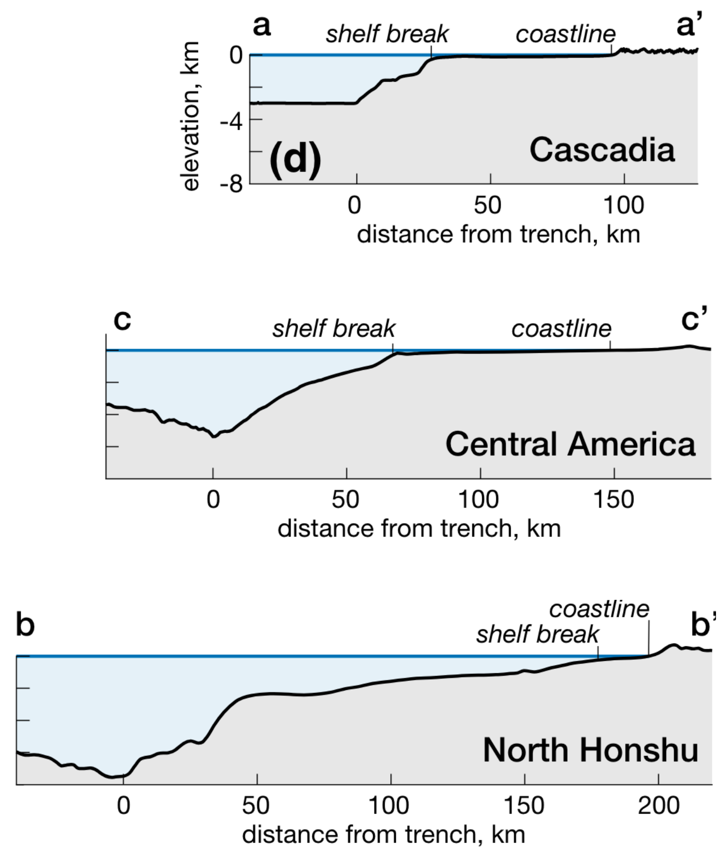
Oryan et al., in prep.



Oryan et al., in prep.

IMPLICATIONS FOR LONG-TERM PLATE COUPLING

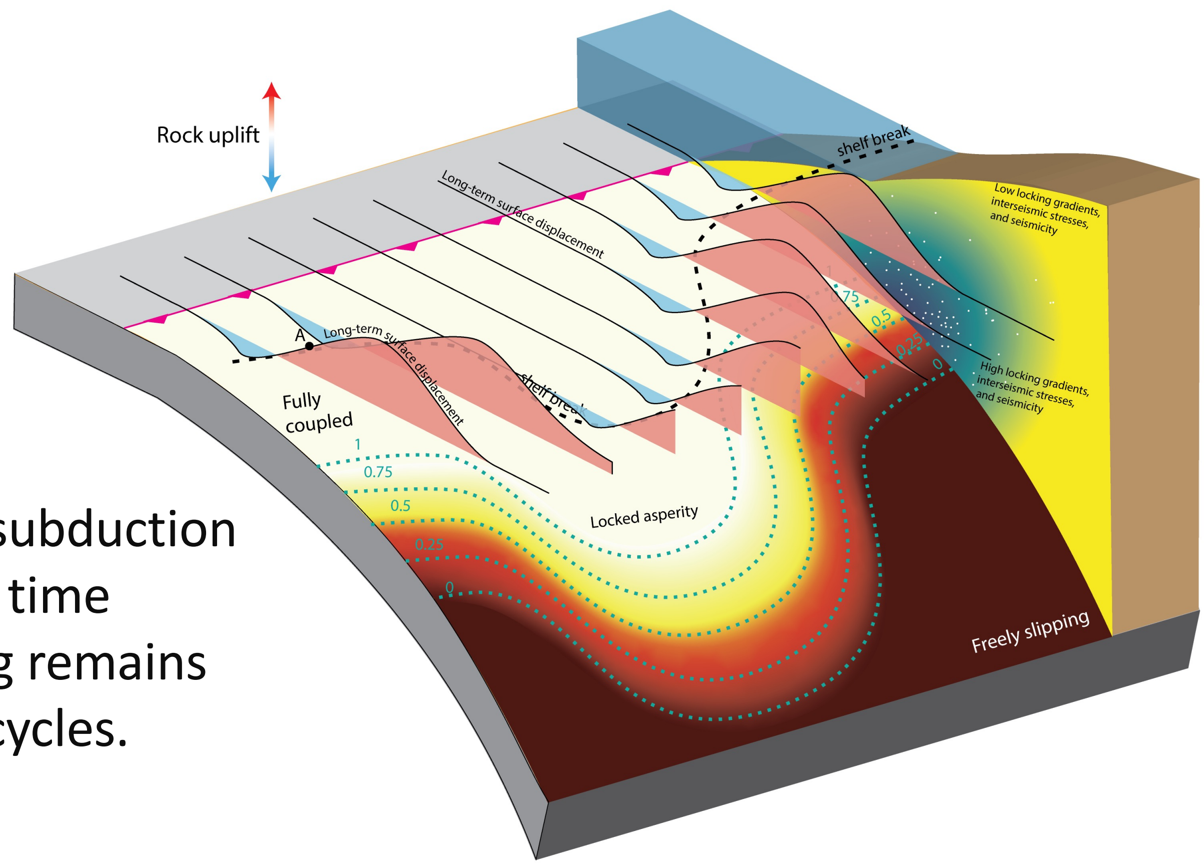
- Our results imply that the downdip pattern of megathrust locking tends to **remain steady over hundreds of thousands of years**.
- Could the absence of a landscape signature indicative of **frequent changes in megathrust coupling**?



Malatesta et al [2021]

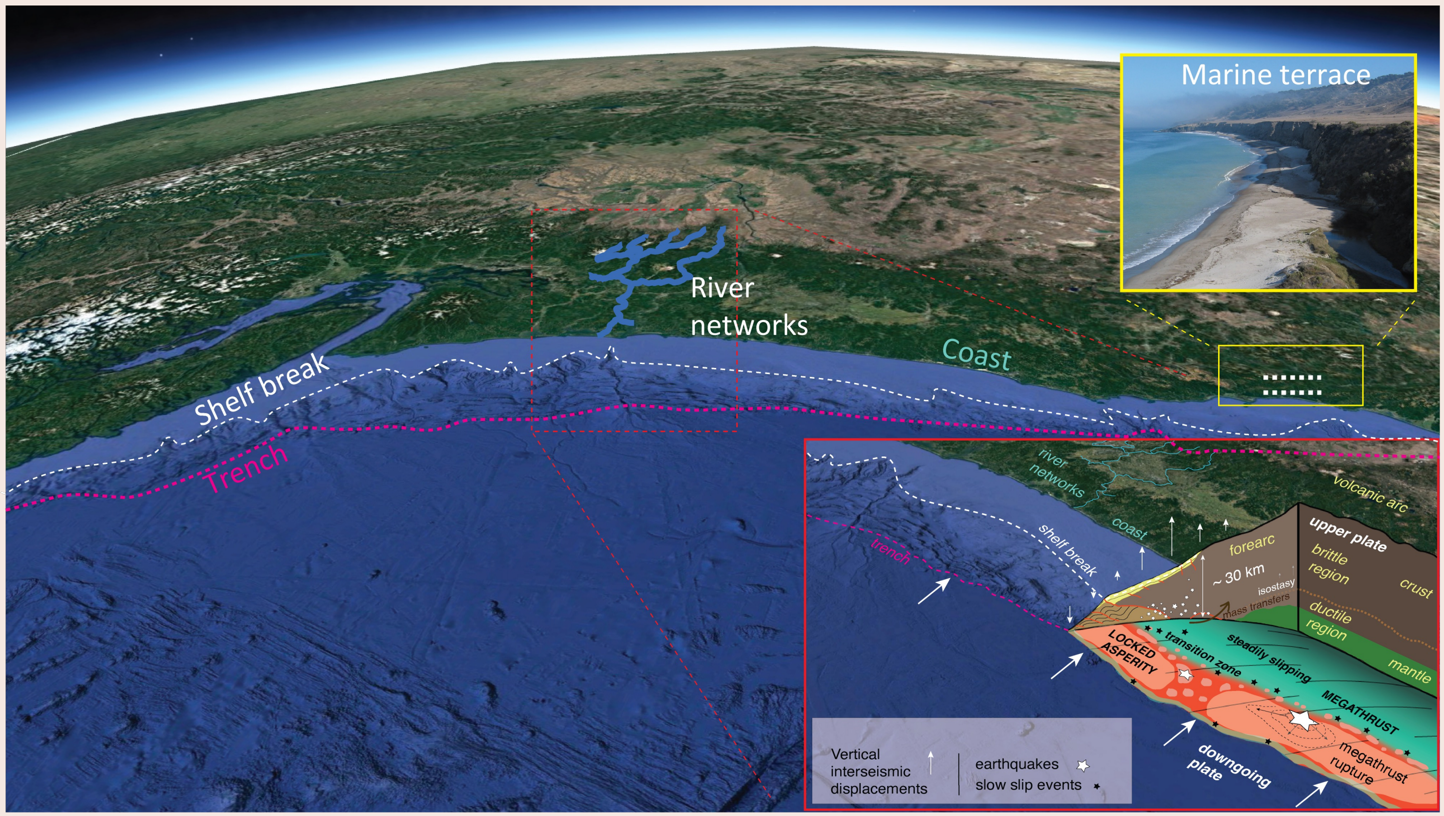
KEY POINTS SO FAR

- Variations in the degree of **megathrust locking** generate increments of **non-recoverable brittle deformation** within the overriding plate.
- This is expressed primarily as interseismic **upper plate seismicity**.
- Over time, this process **imprints** subduction landscapes one seismic cycle at a time
- This hints that megathrust locking remains stable over multiple earthquake cycles.



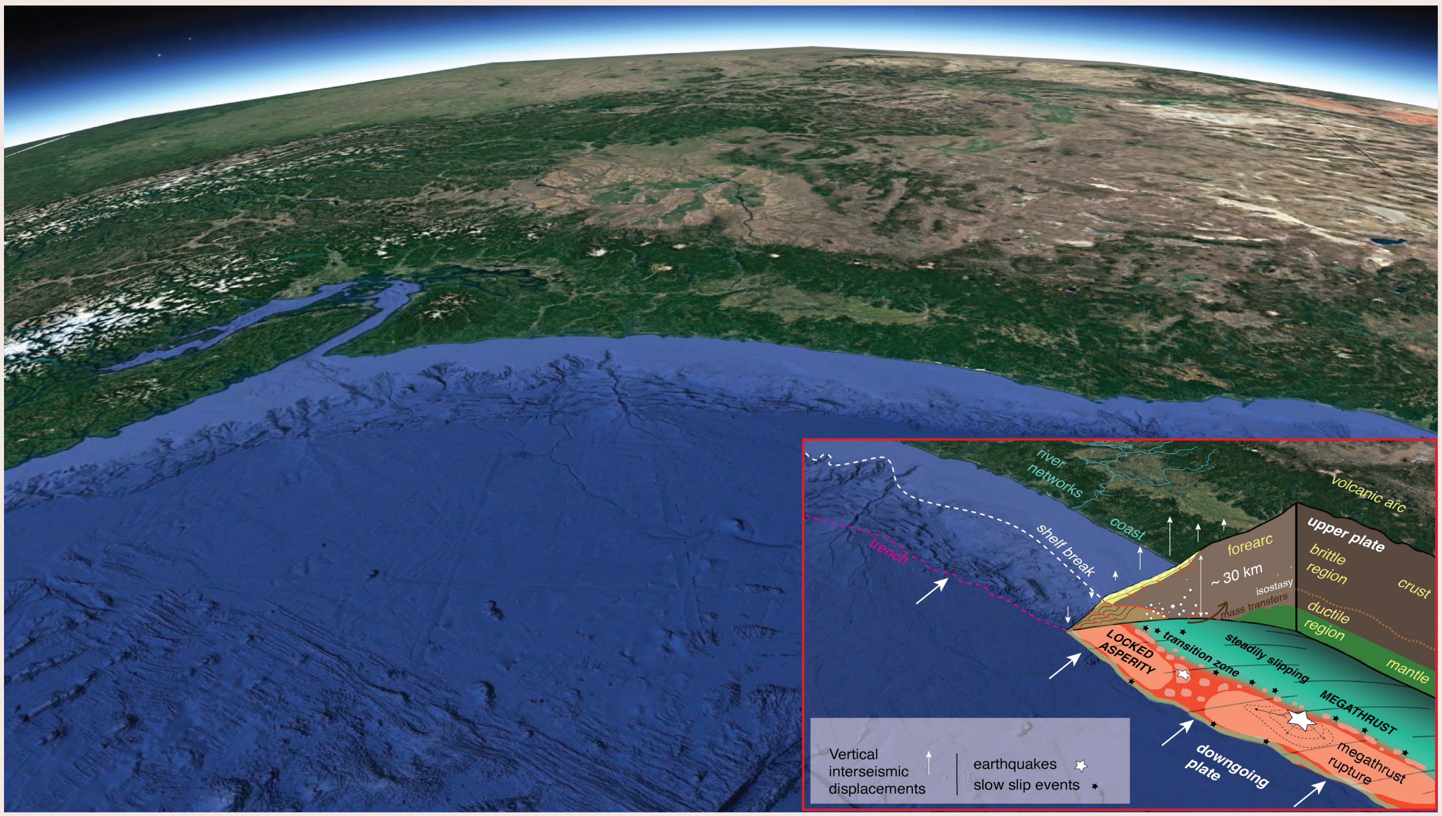
Oryan et al., 2024

Section 3 - Inferring Long-Term Tectonic Uplift from Bayesian Inversion of Landscapes



Oryan et al., in review , https://doi.org/10.31223/X5T407

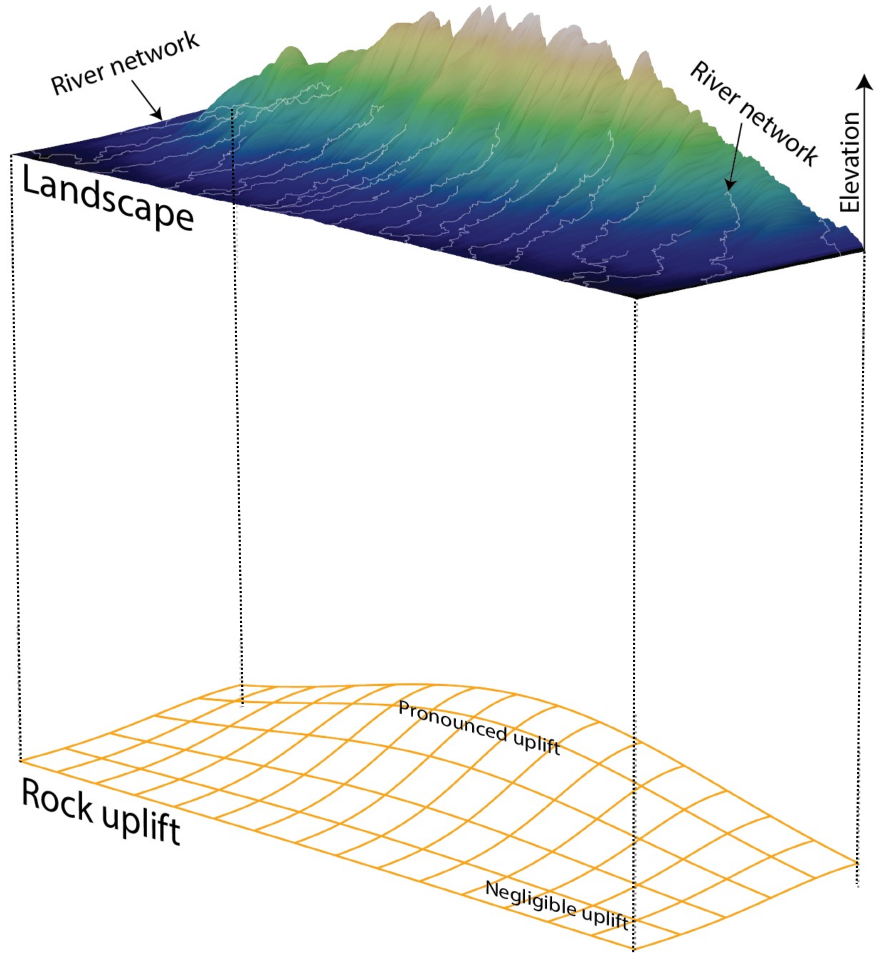
Section 3 - Inferring Long-Term Tectonic Uplift from Bayesian Inversion of Landscapes



Oryan et al., in review , https://doi.org/10.31223/X5T407

INFERRING LONG-TERM TECTONIC UPLIFT FROM BAYESIAN INVERSION OF LANDSCAPES

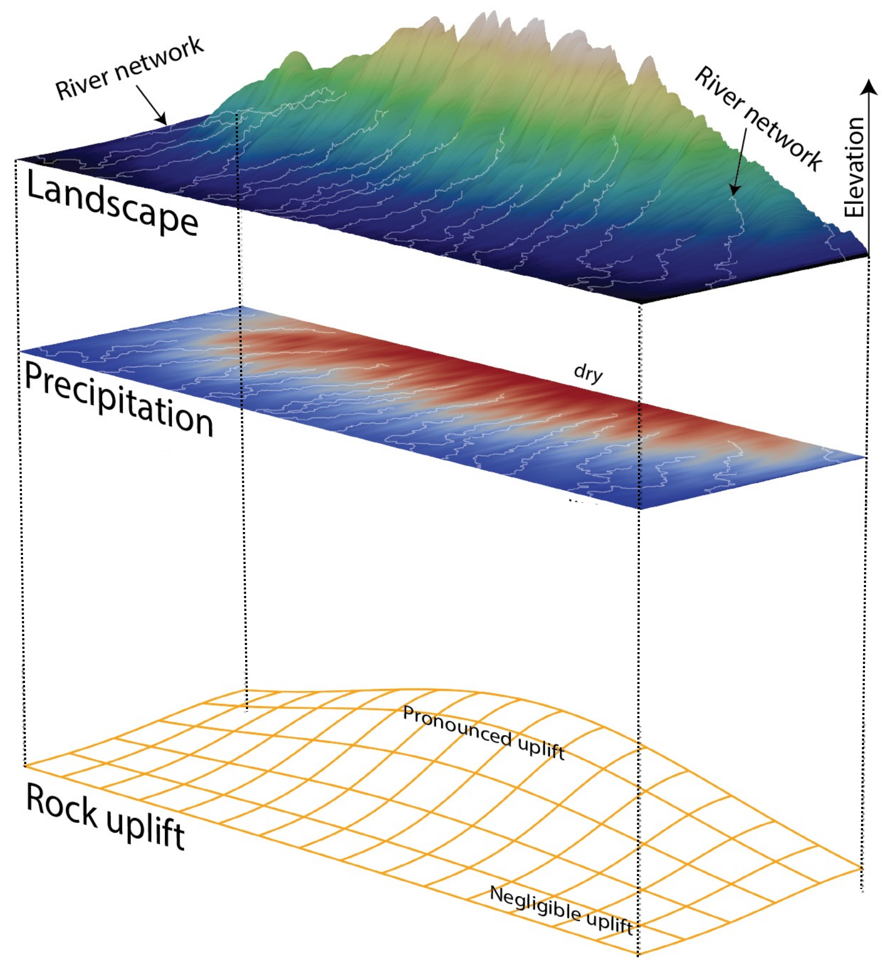
- Landscapes encode the forcing of **tectonic uplift**



Oryan et al., 2024 (in review)

INFERRING LONG-TERM TECTONIC UPLIFT FROM BAYESIAN INVERSION OF LANDSCAPES

- Landscapes encode the combined forcing of **tectonic uplift** and erosion driven by **climate**



Oryan et al., 2024 (in review)

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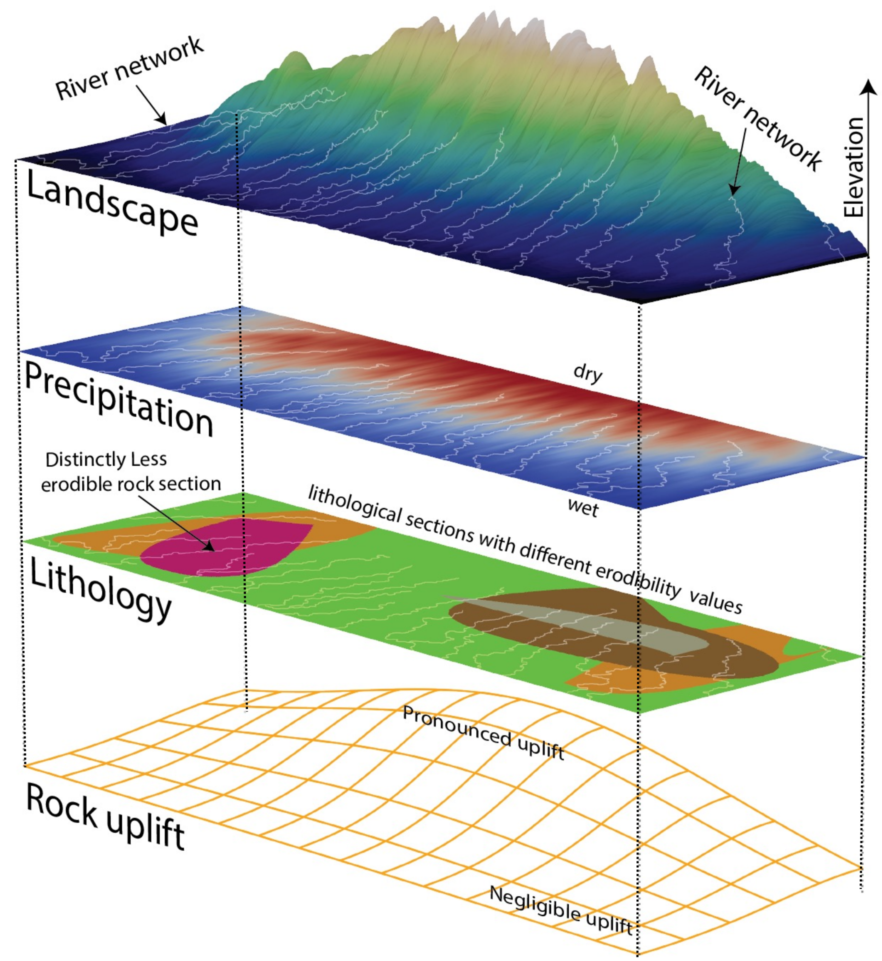
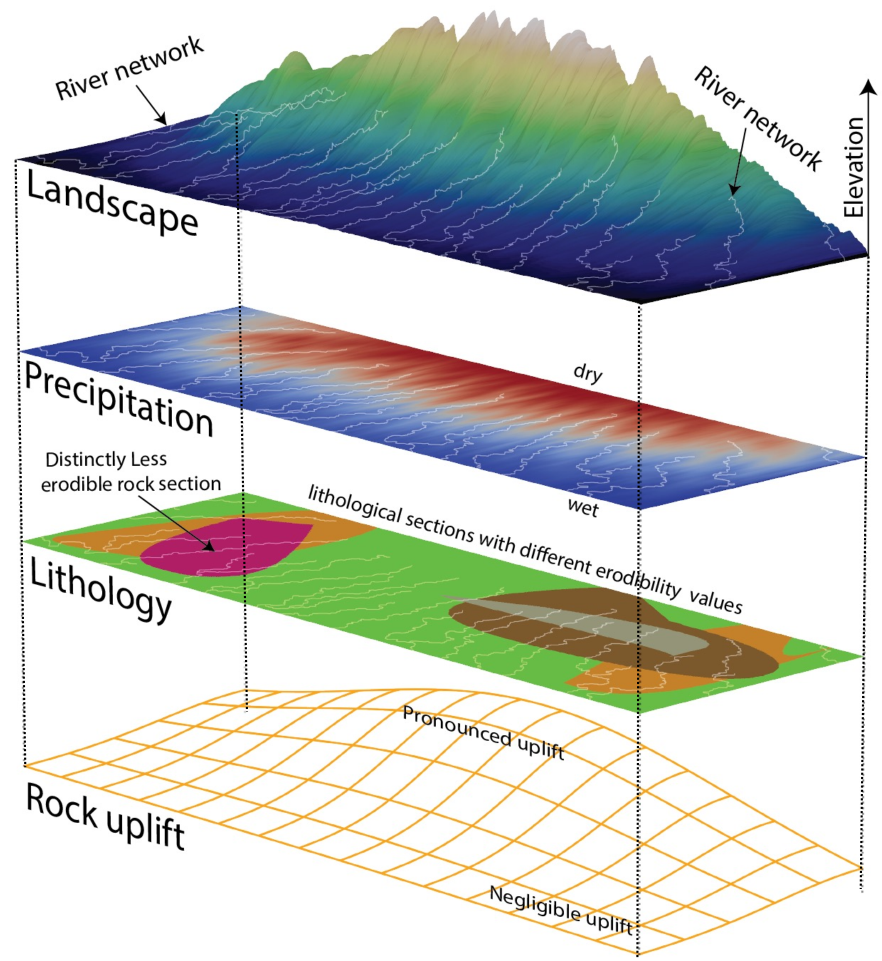


Oryan et al., 2024 (in review)

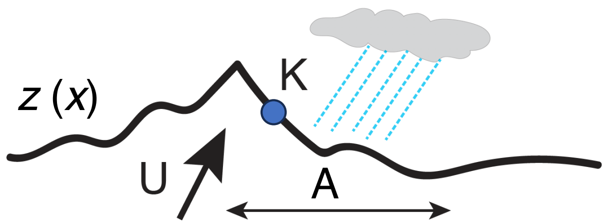
INFERRING LONG-TERM TECTONIC UPLIFT FROM BAYESIAN INVERSION OF LANDSCAPES

- Landscapes encode the combined forcing of **tectonic uplift** and erosion driven by **climate** and **rock erodibility**.
- Disentangling their contributions is essential for using landscapes as quantitative records of crustal deformation.



Oryan et al., 2024 (in review)

RIVER INCISION AT STEADY STATE



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

Tectonic uplift

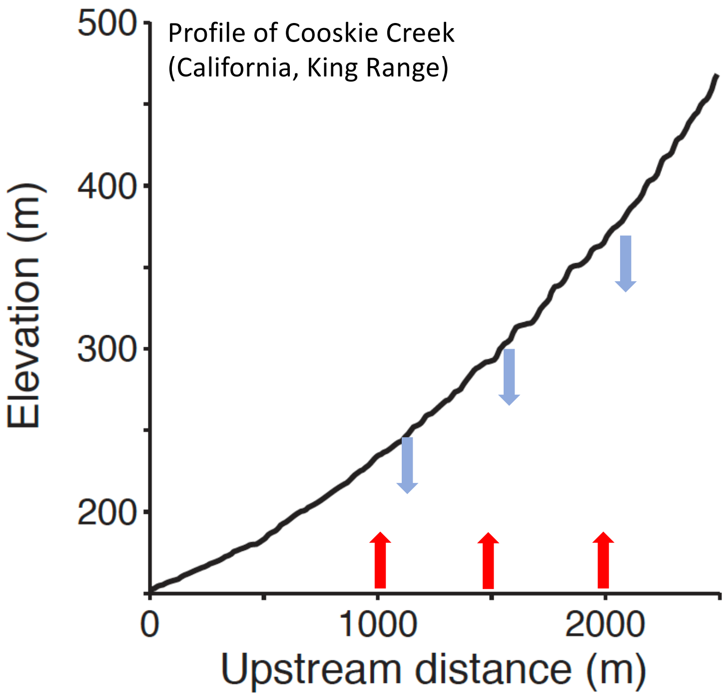
Local incision rate

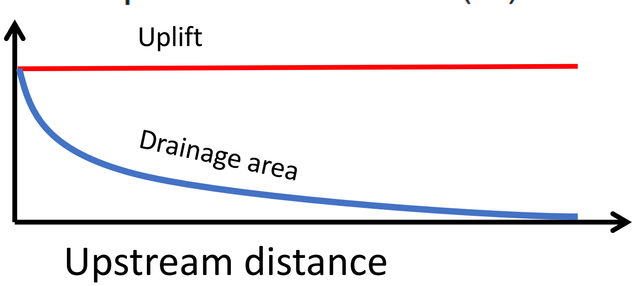
*(faster for steeper slope **S**, with more water flowing and larger erodibility)*

Parameters:

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

RIVER INCISION AT STEADY STATE





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- Spatially variable erodibility
- climate

Perron & Royden, 2013

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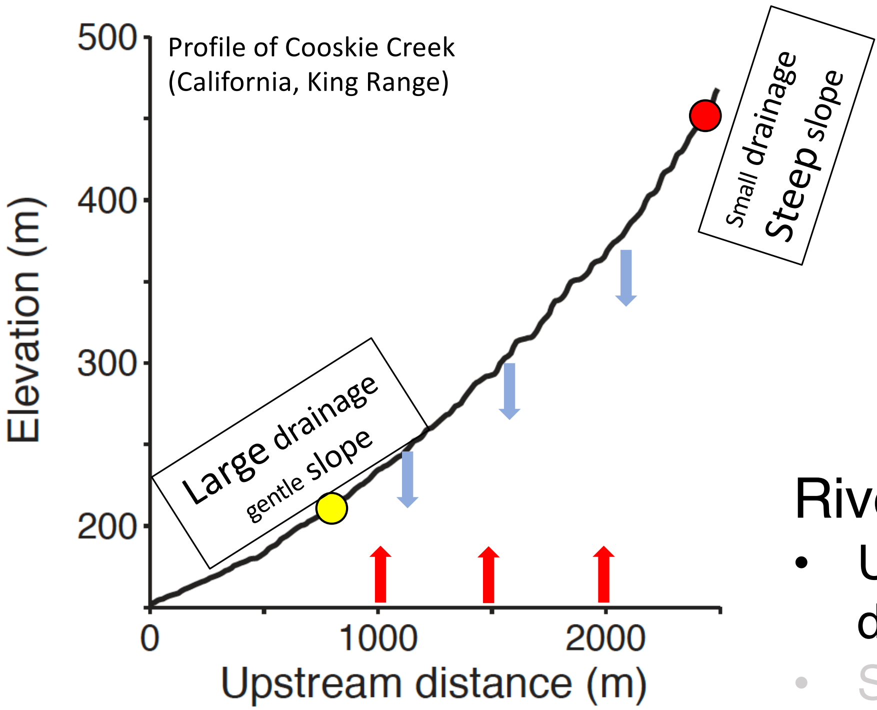

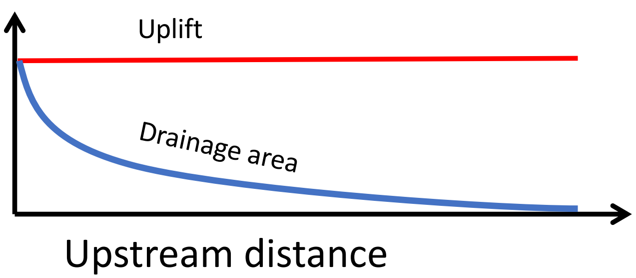

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Perron & Royden, 2013

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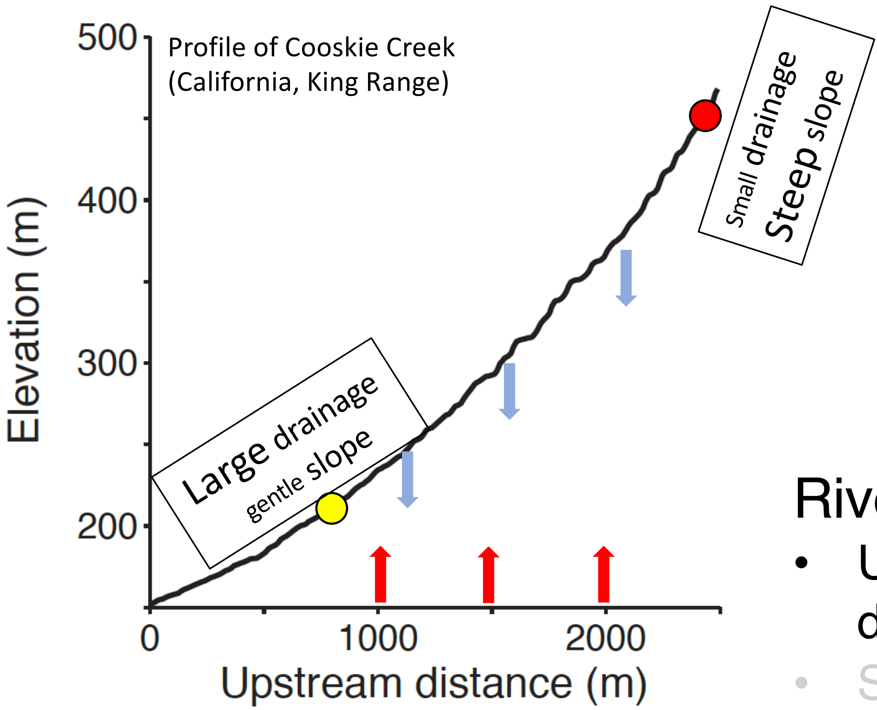

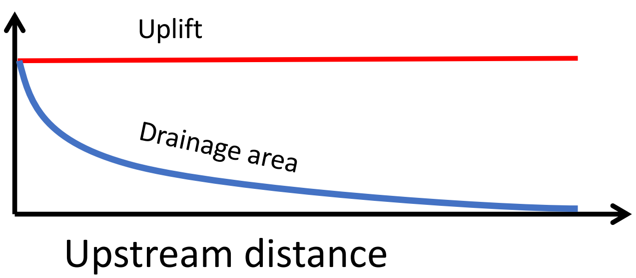

Rive
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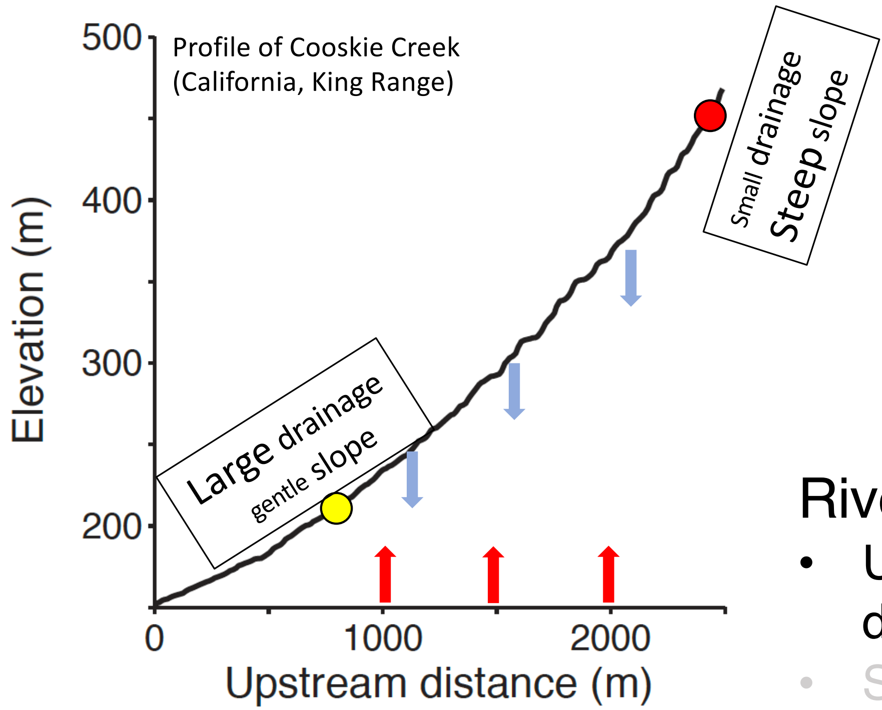
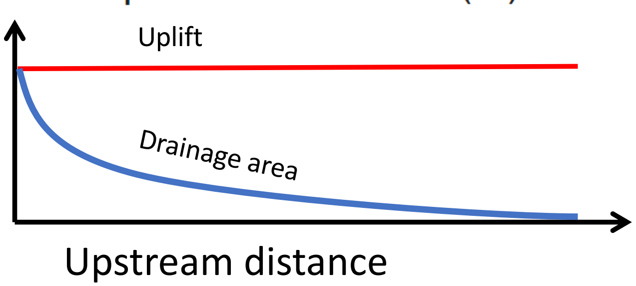
- S
- cl

Perron & Royden, 2013

RIVER INCISION AT STEADY STATE





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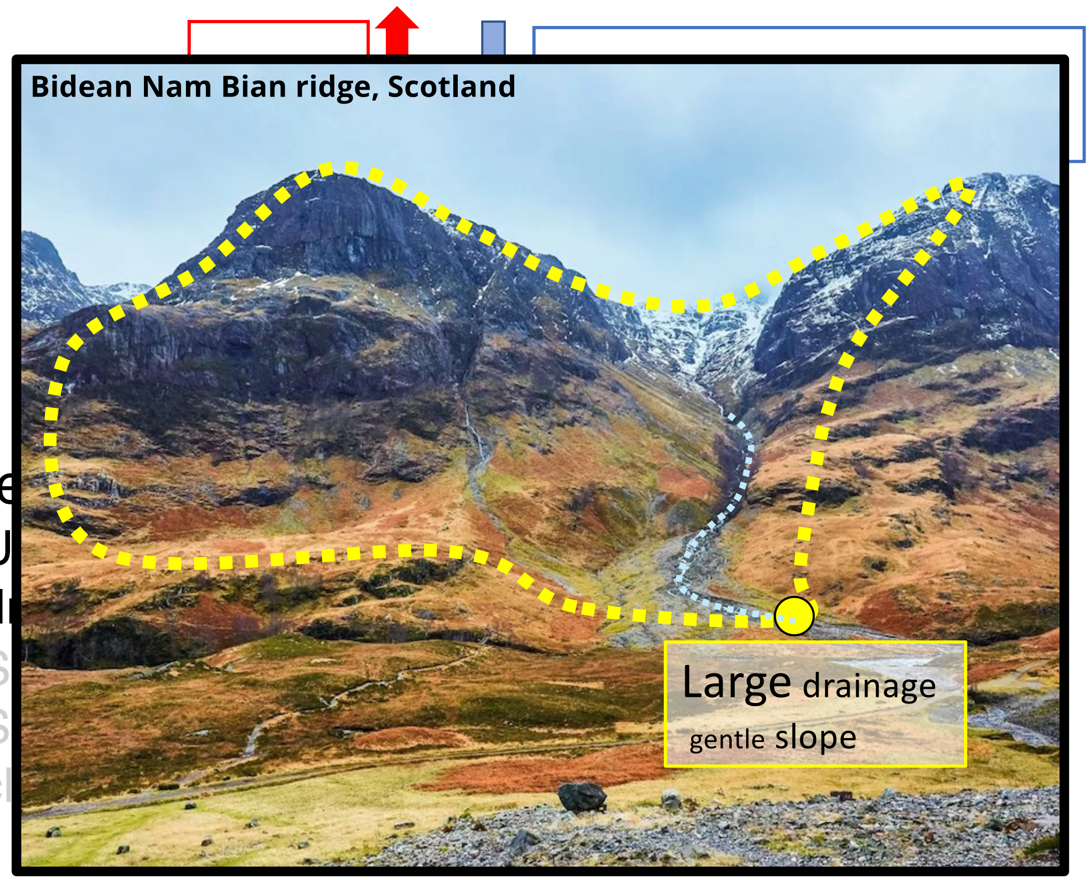

Perron & Royden, 2013

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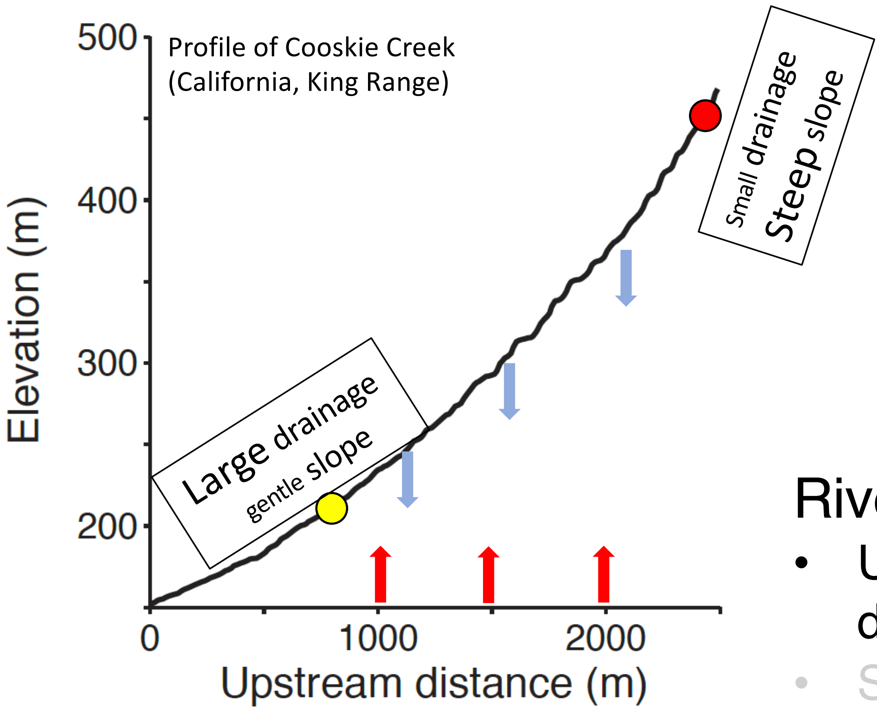

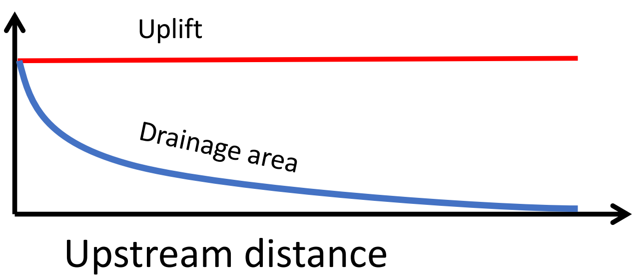

Rive
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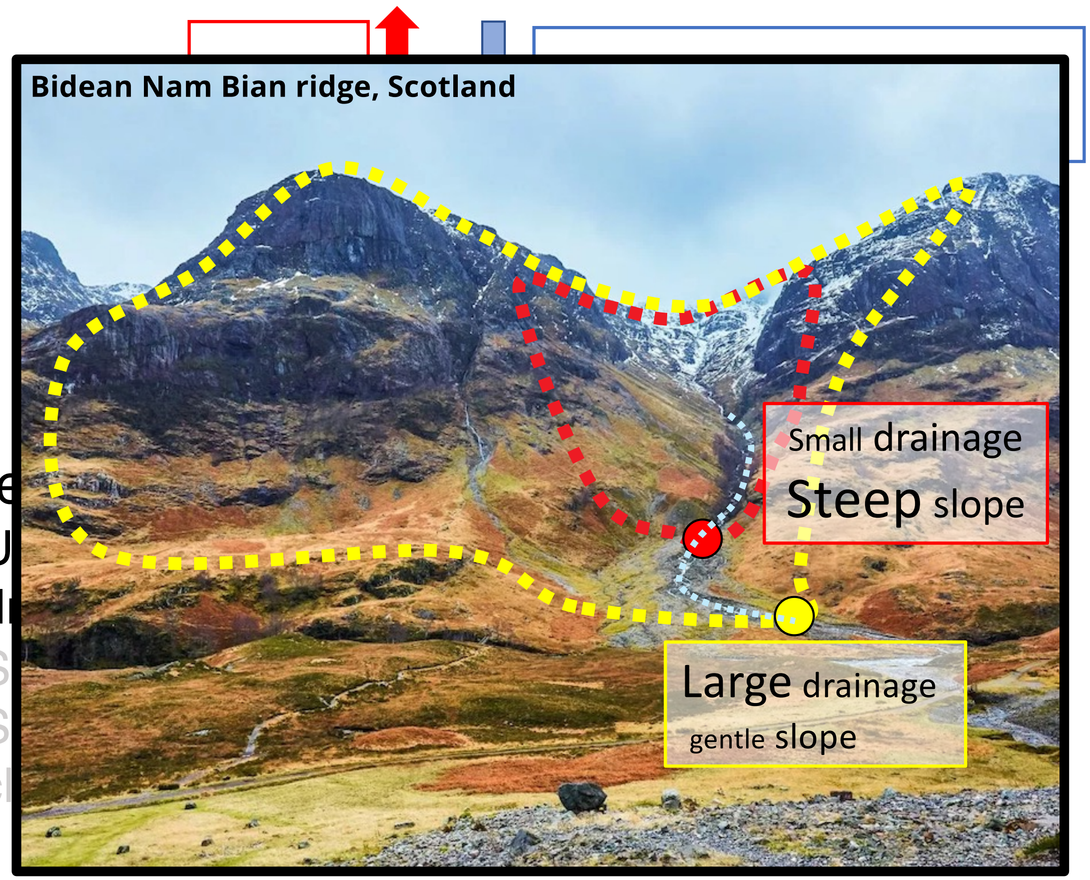
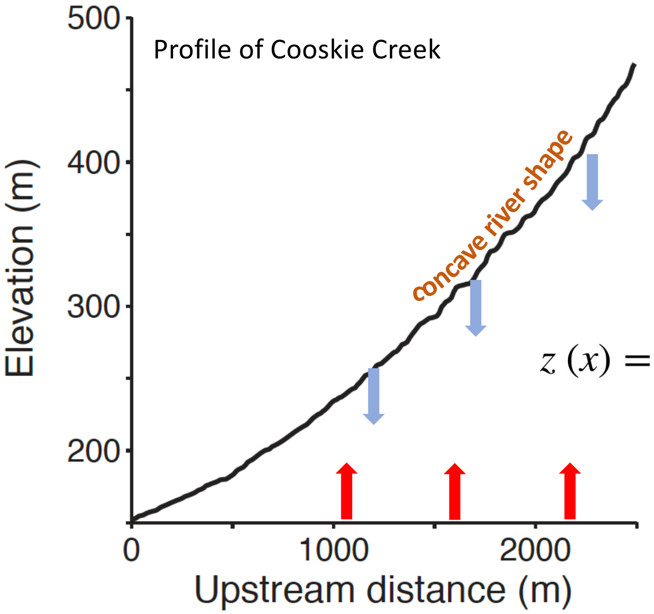


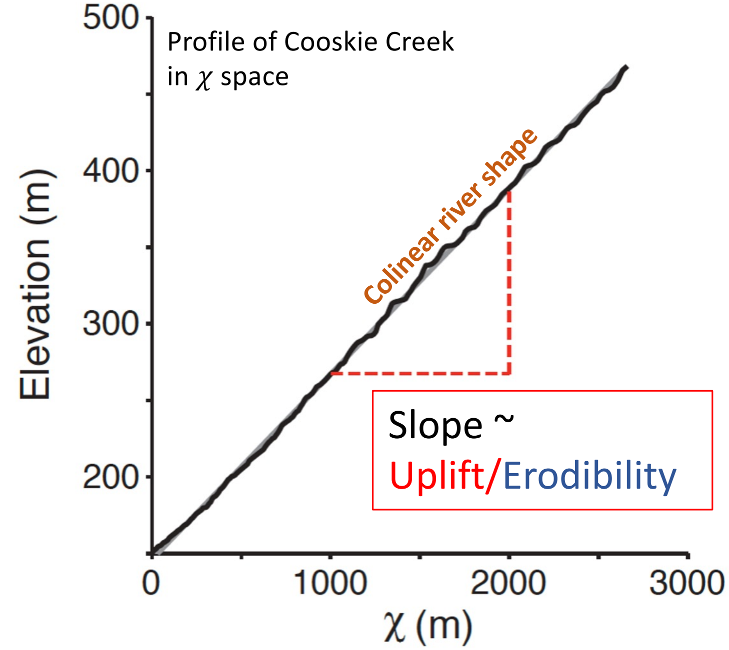
Perron & Royden, 2013

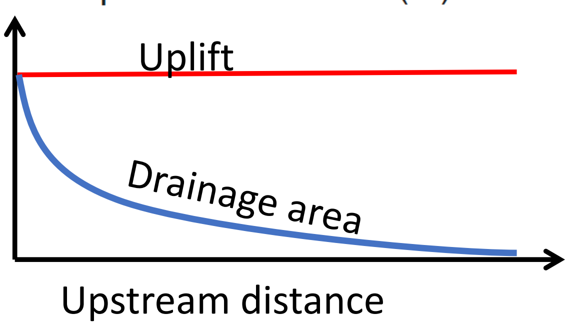
χ – TRANSFORMATION OF RIVERS



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

χ − TRANSFORMATION

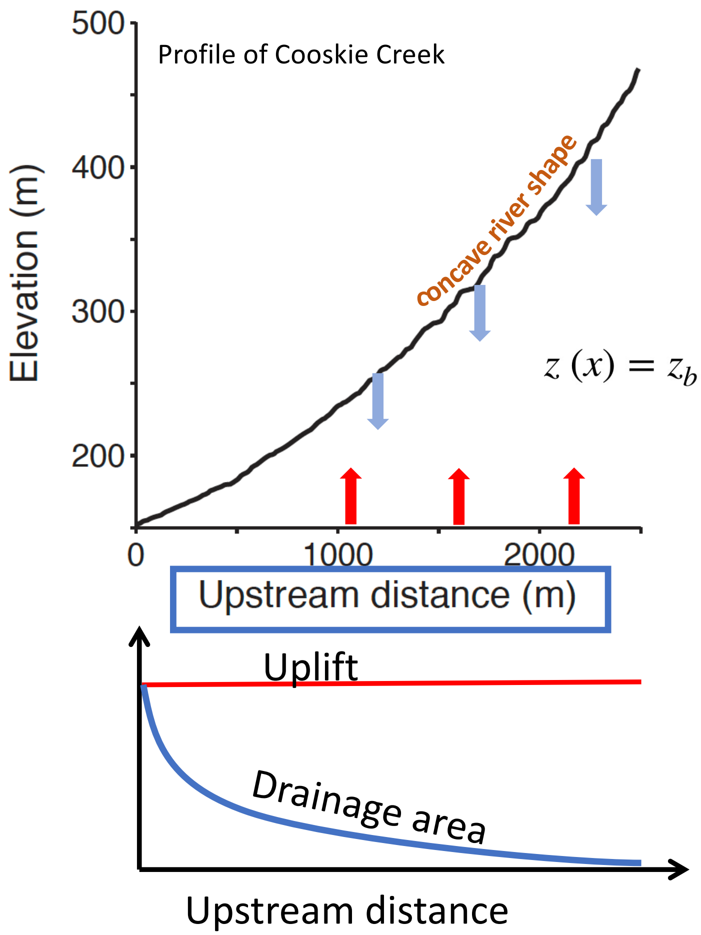




Corrects for upstream decrease in drainage area while assuming uniform spatial uplift

Perron & Royden, 2013

χ – TRANSFORMATION OF RIVERS



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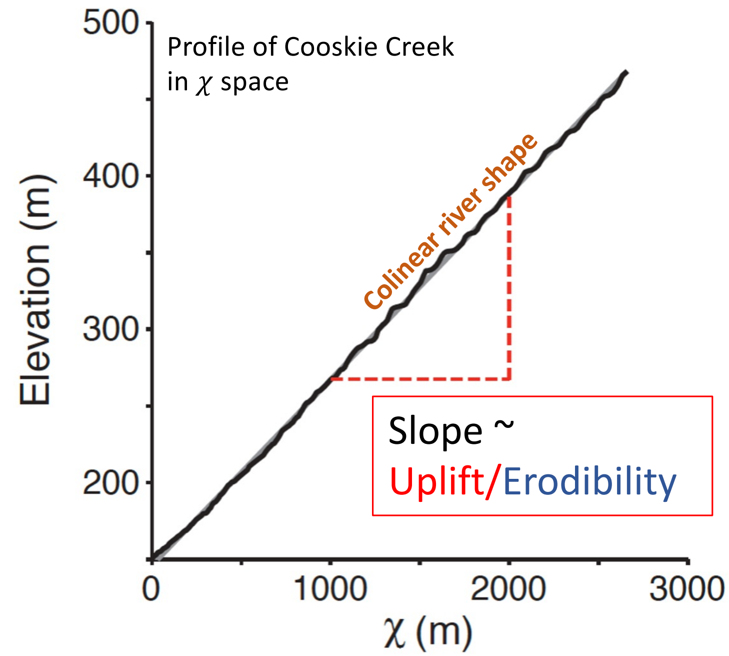

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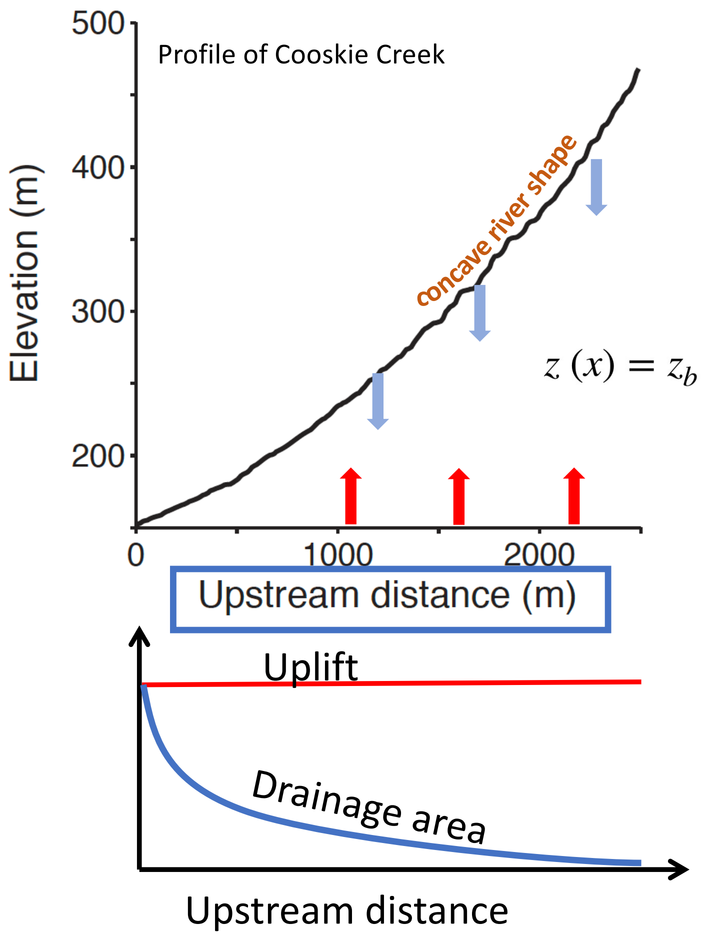

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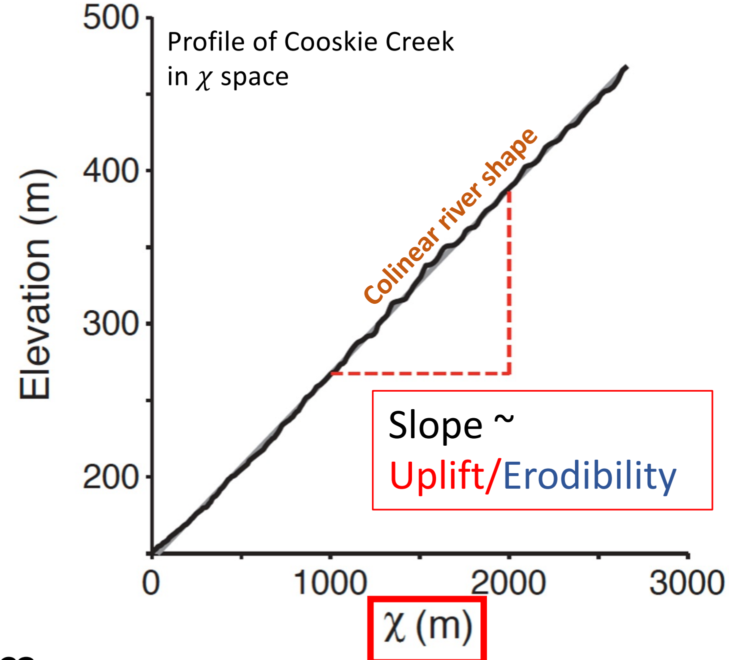
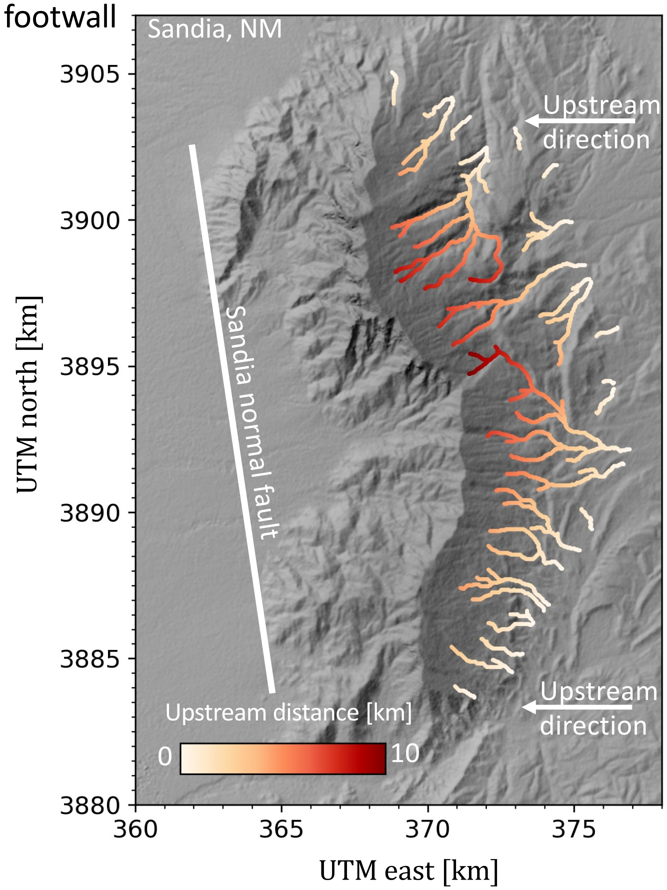


Corrects for upstream decrease in drainage area while assuming uniform spatial uplift

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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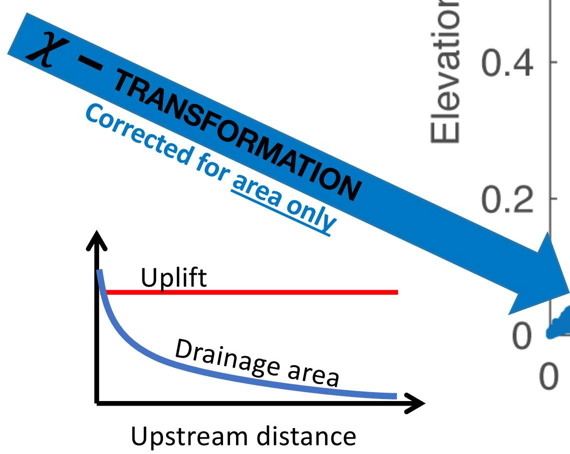
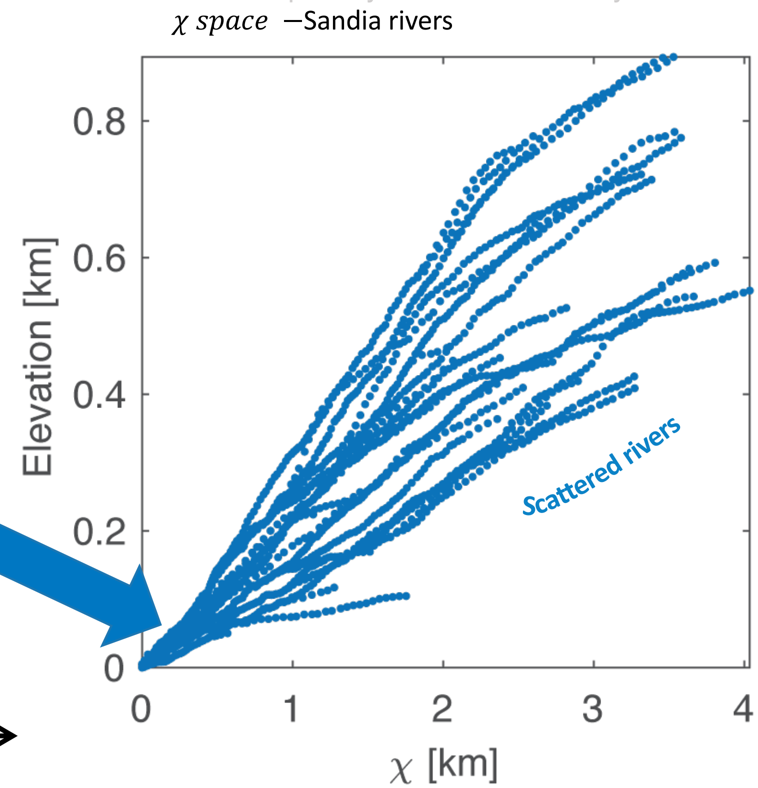
- Shape of uplift
- Spatially variable erodibility and climate





Olive et al., 2022

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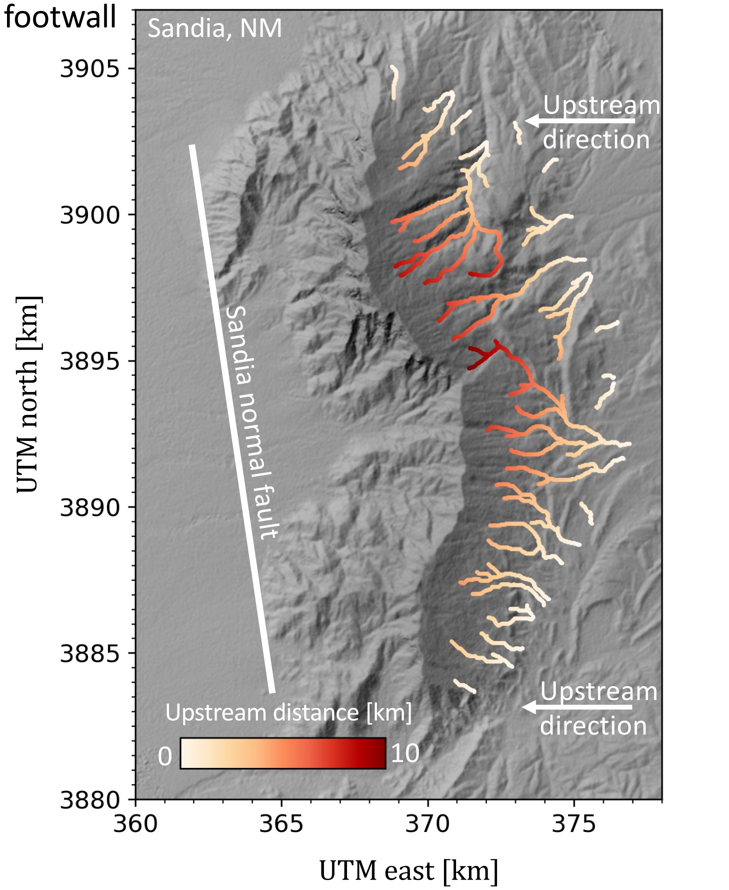

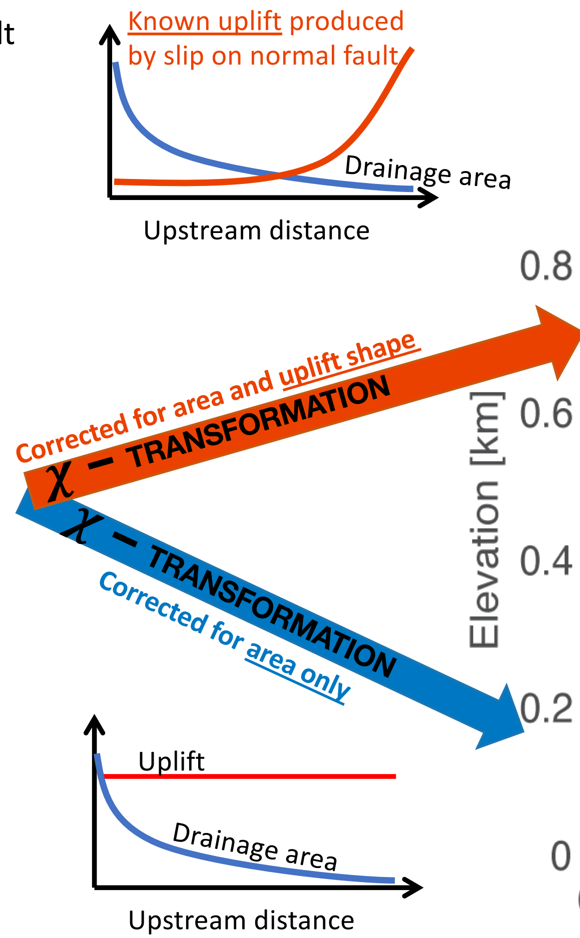

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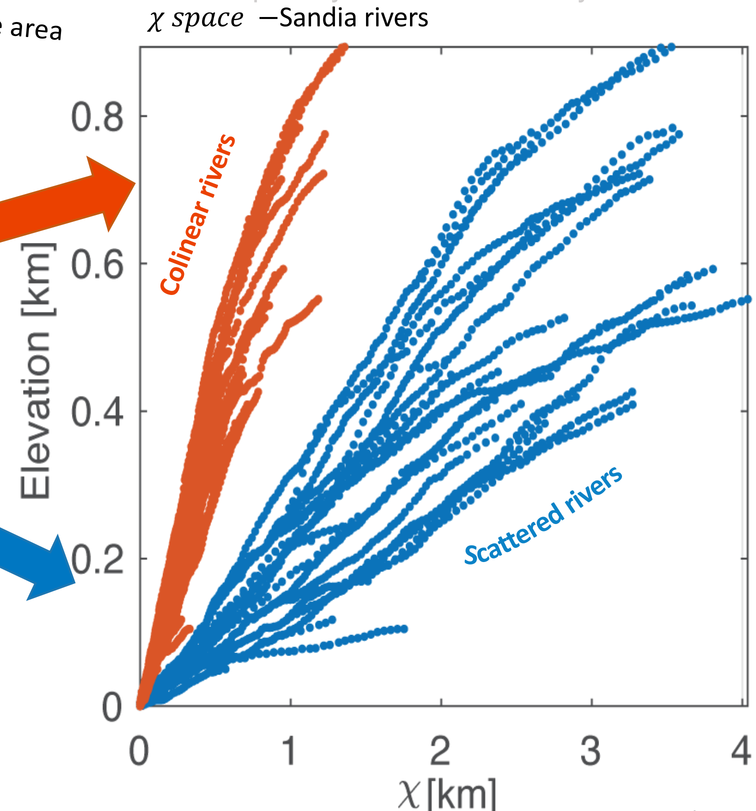

Olive et al., 2022

χ – TRANSFORMATION OF RIVER PROFILES IN THE HIMALAYAS

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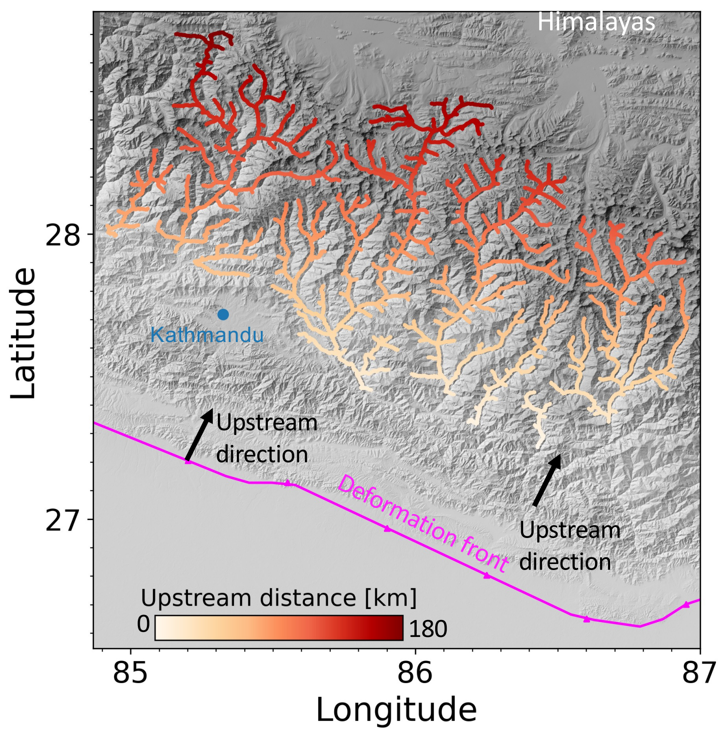

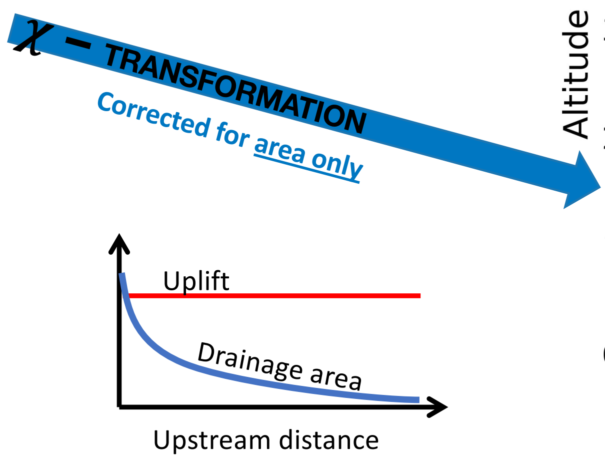

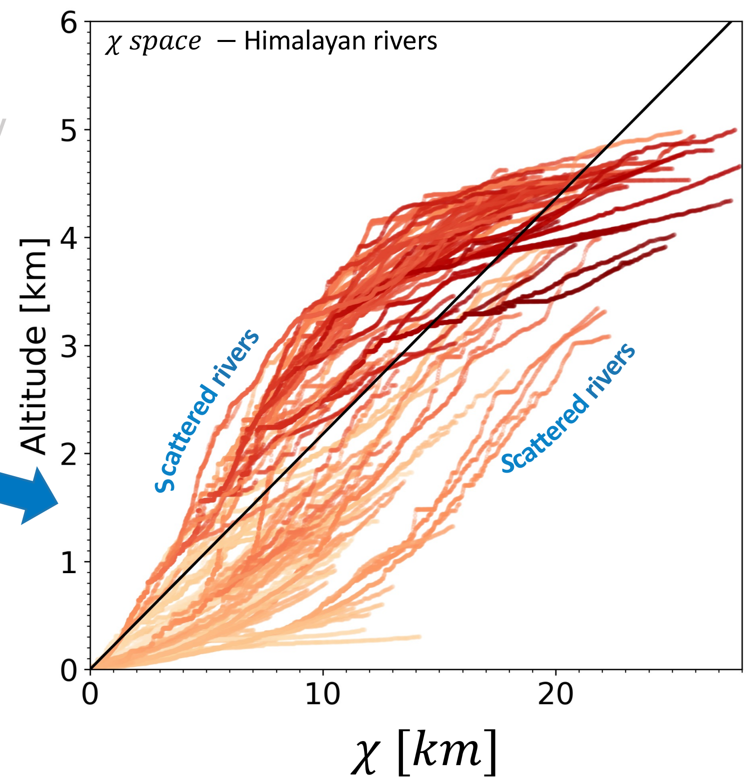

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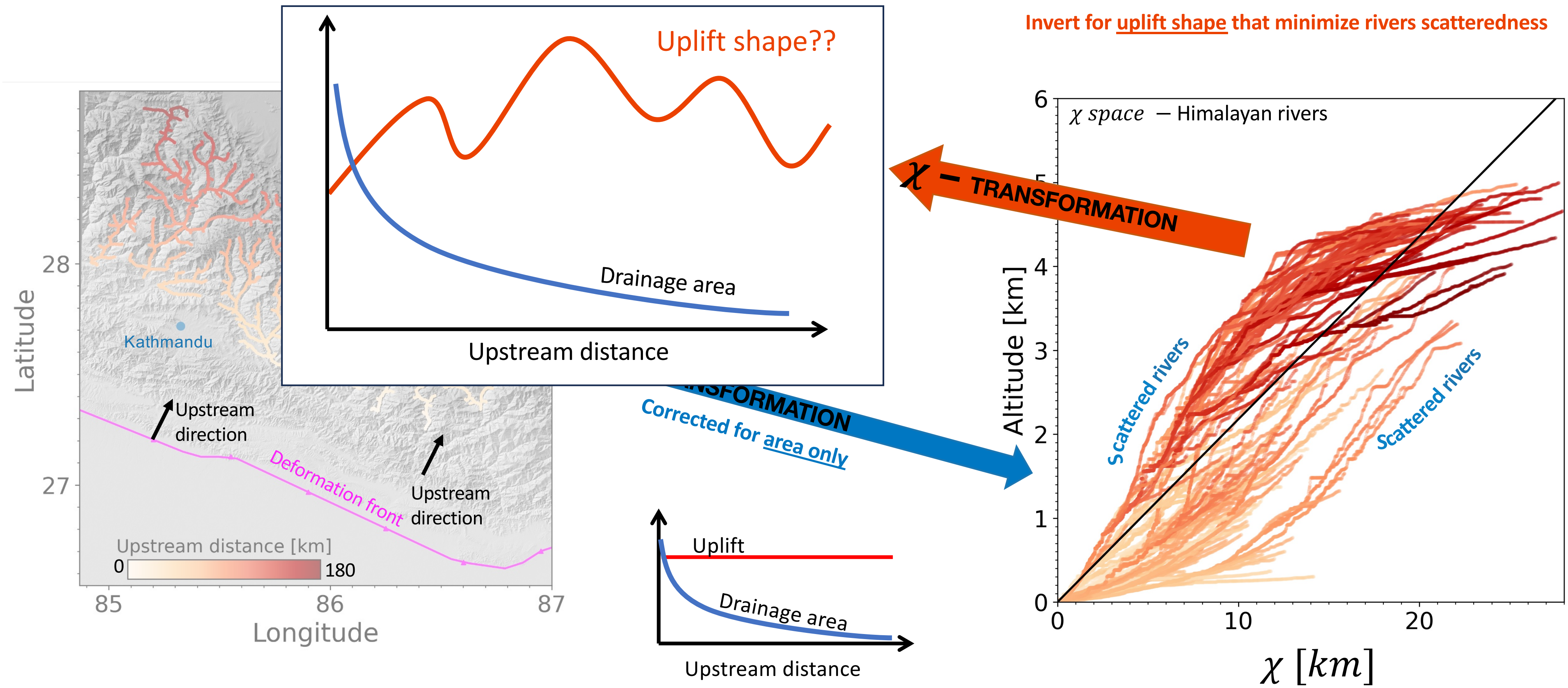

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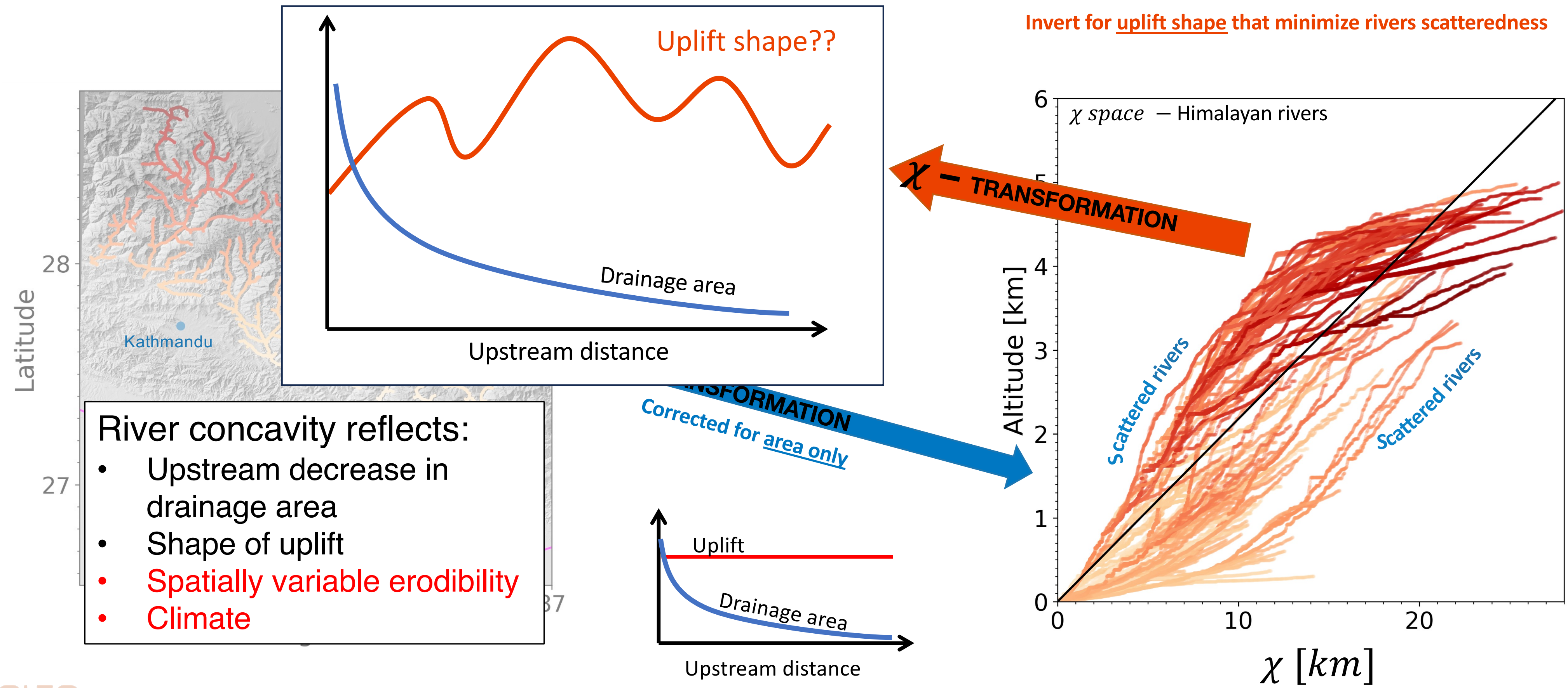

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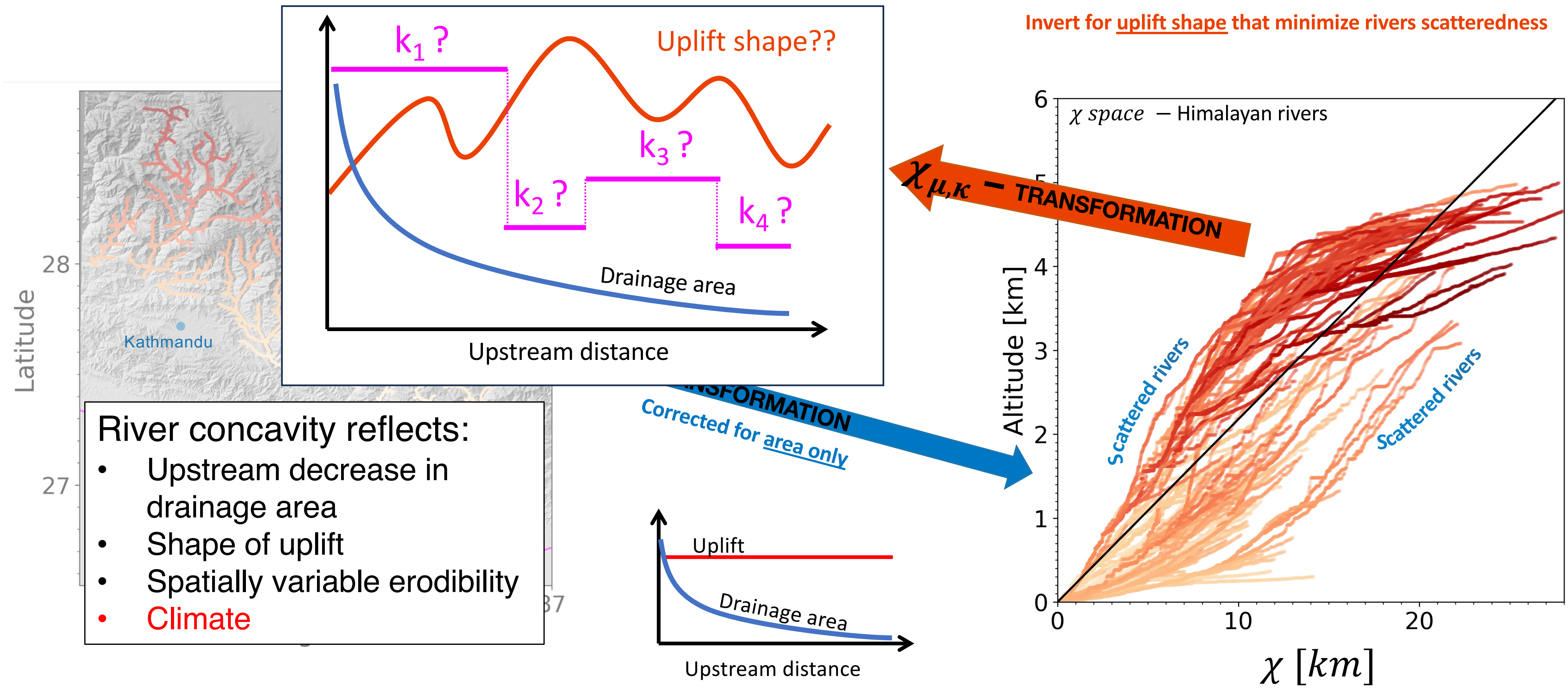
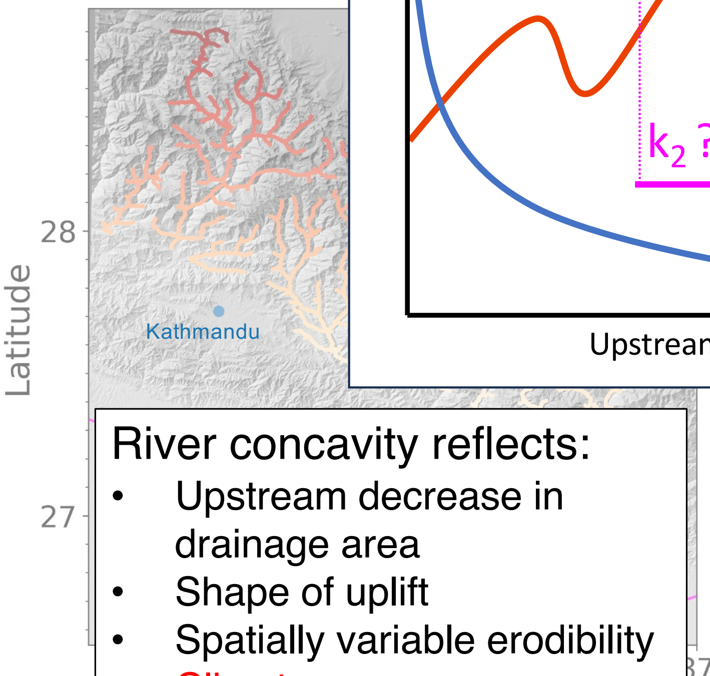
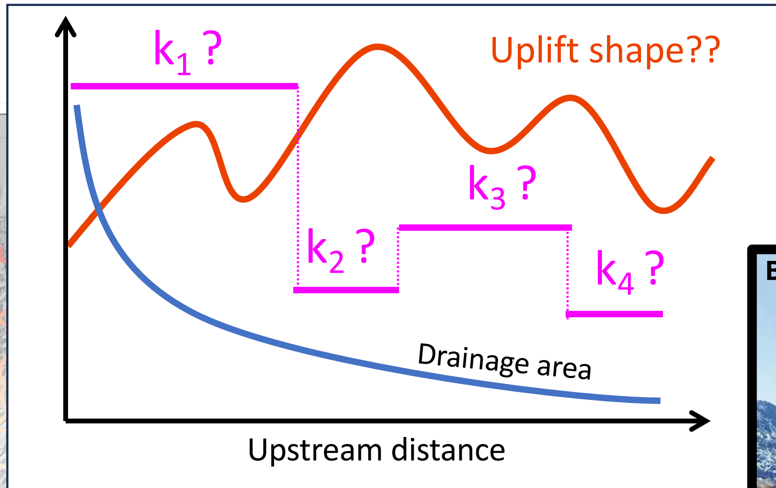


χ – TRANSFORMATION OF RIVER PROFILES IN THE HIMALAYAS





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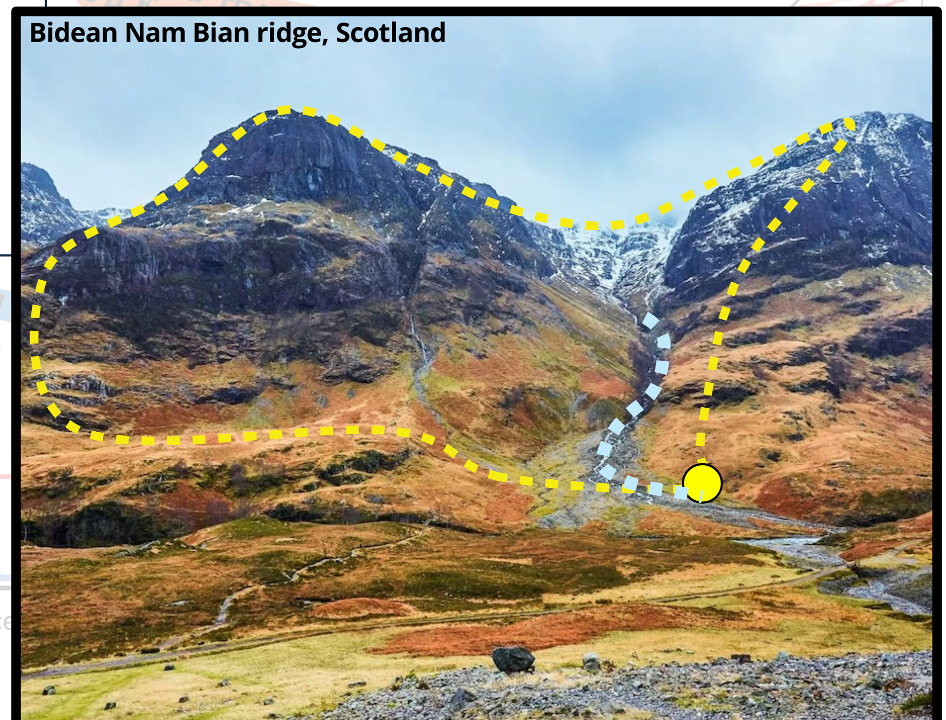
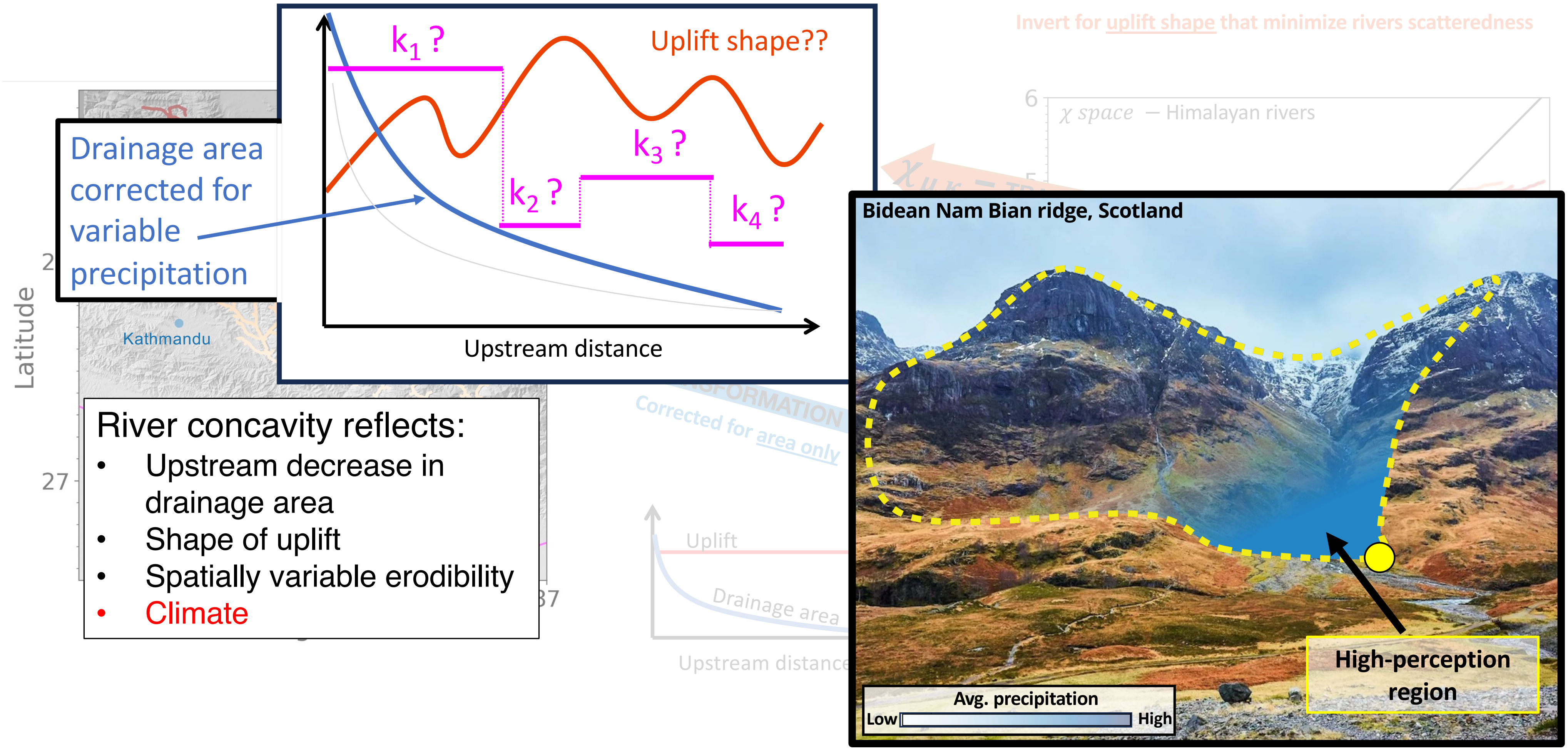
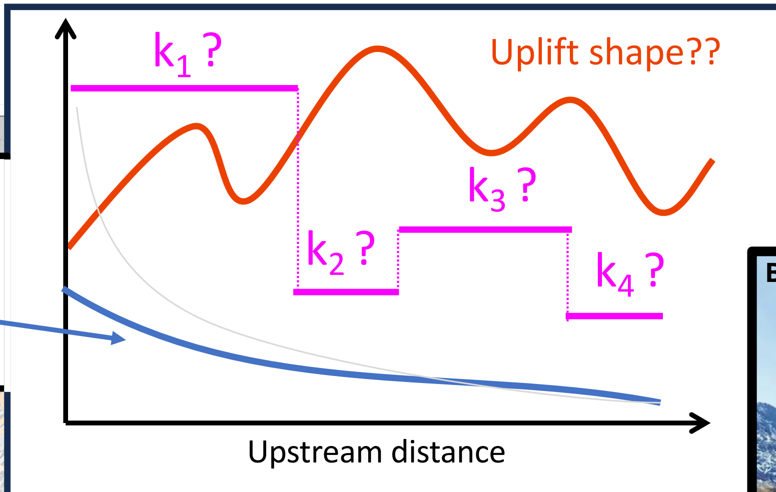


$\chi_{u,k}$ – TRANSFORMATION OF RIVER PROFILES IN THE HIMALAYAS



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

Drainage area corrected for variable precipitation



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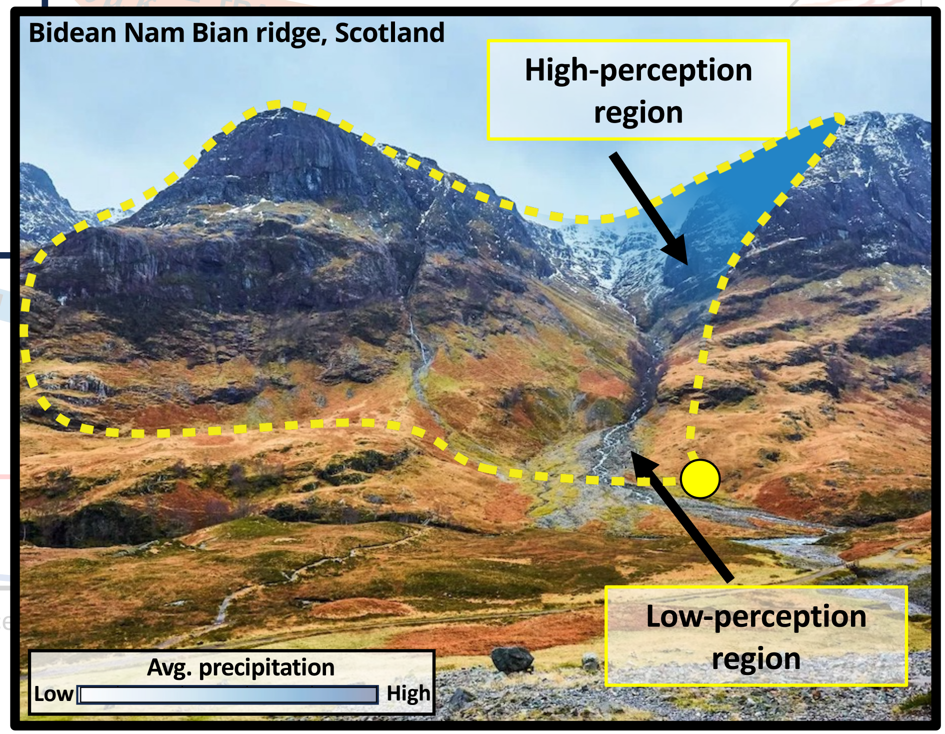
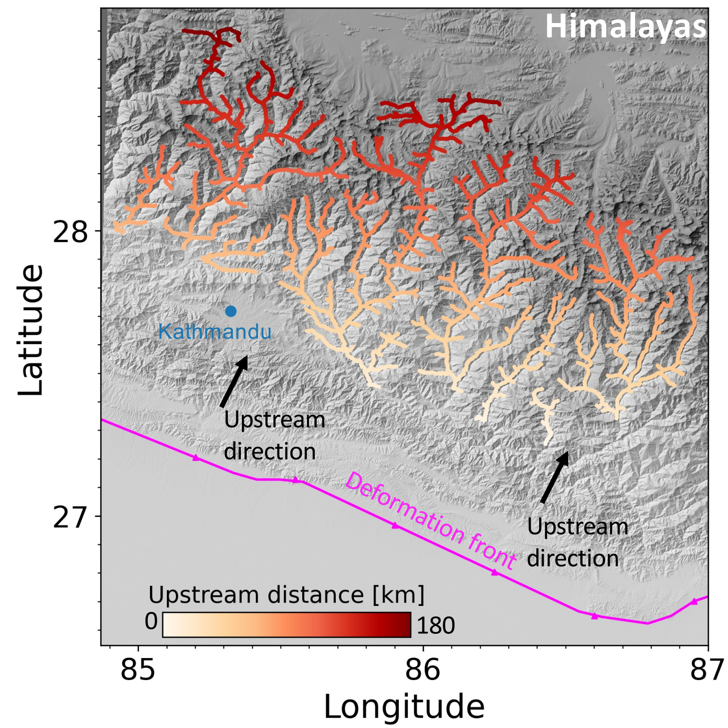


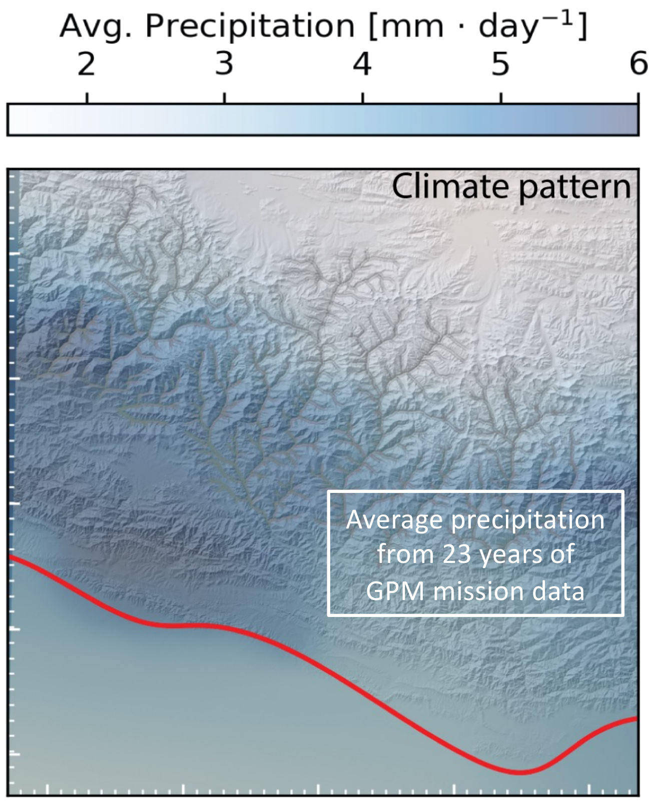
INVERTING HIMALAYAS USING $\chi_{u,k}$ TRANSFORMATION

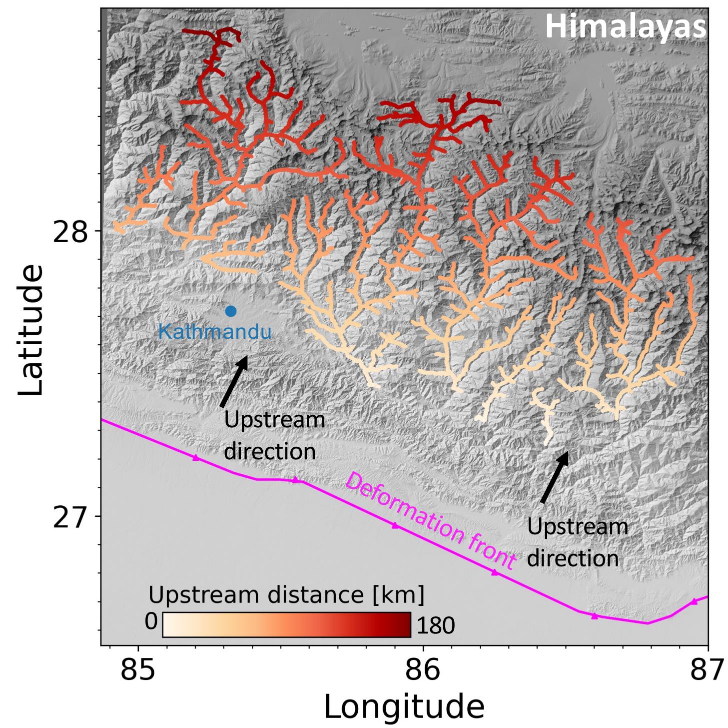


Oryan et al., 2024 (preprint)

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

1. Download a DEM and compute drainage area corrected for climate.

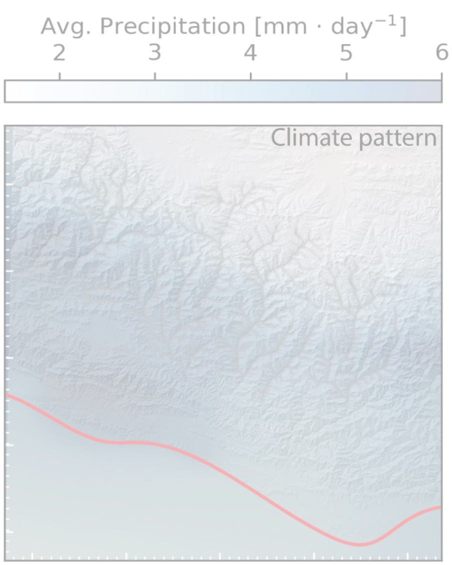




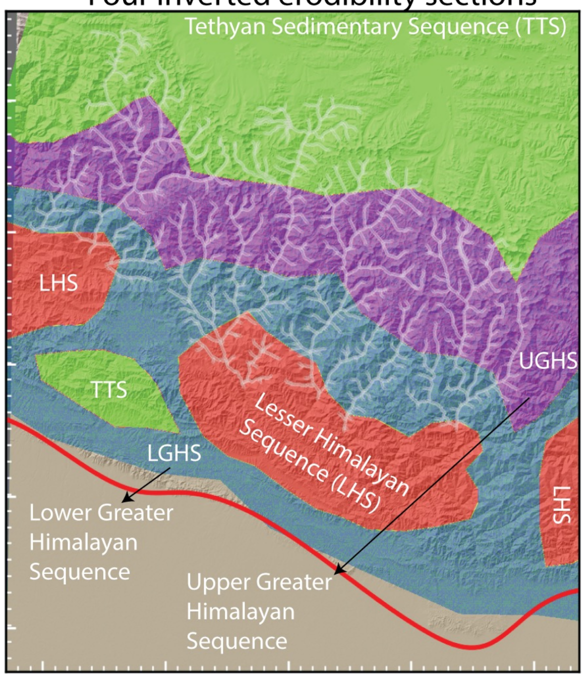
Oryan et al., in review

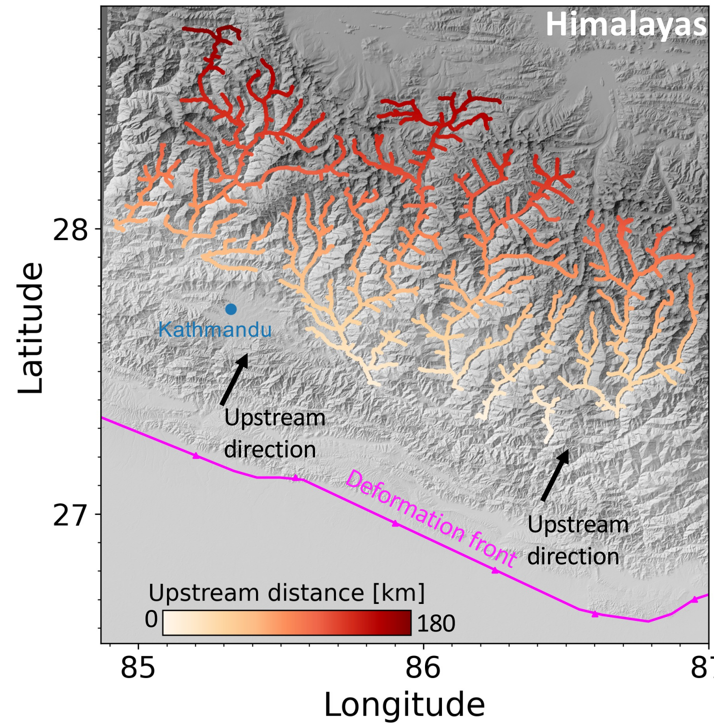
INVERTING HIMALAYAS USING $\chi_{u,k}$ TRANSFORMATION

1. Download a DEM and compute drainage area corrected for climate.
2. Map the spatial distribution of major lithological sections for piecewise rock erodibility values.



Four inverted erodibility sections

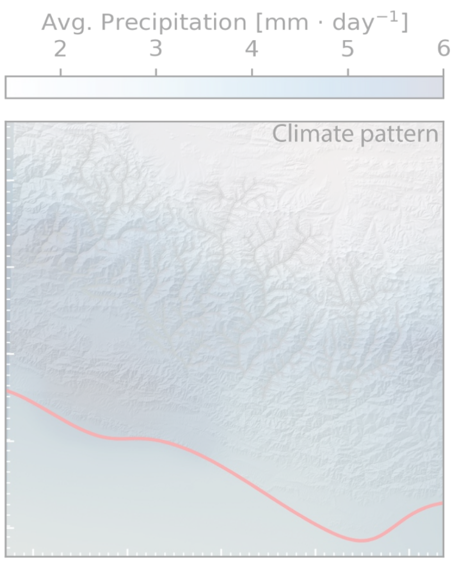


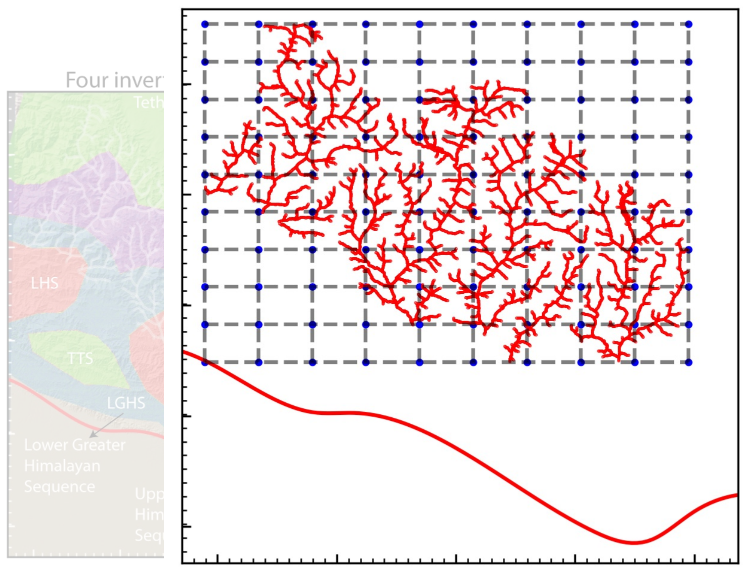


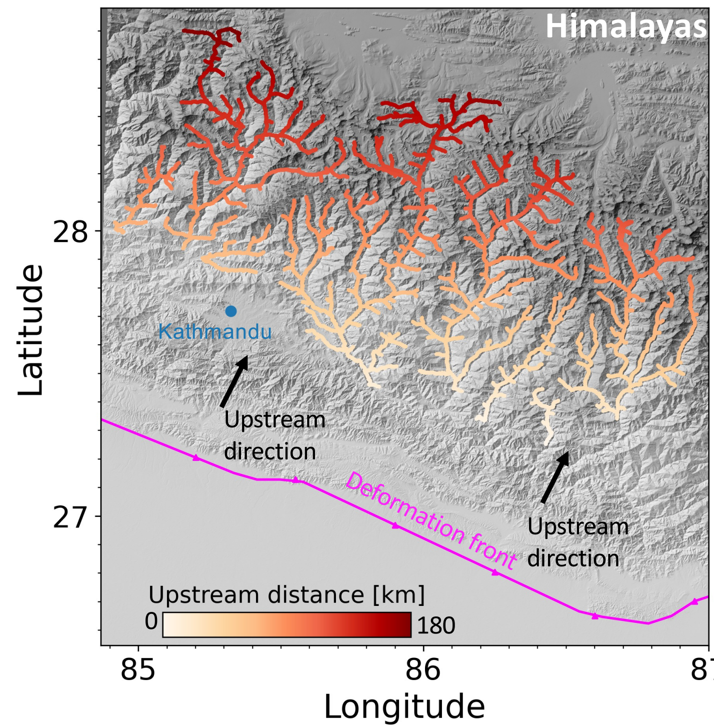
Oryan et al., in review

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

1. Download a DEM and compute drainage area corrected for climate.
2. Map the spatial distribution of major lithological sections for piecewise rock erodibility values.
3. Describe 2D uplift surface using interpolating B-spline functions extending across the river network.



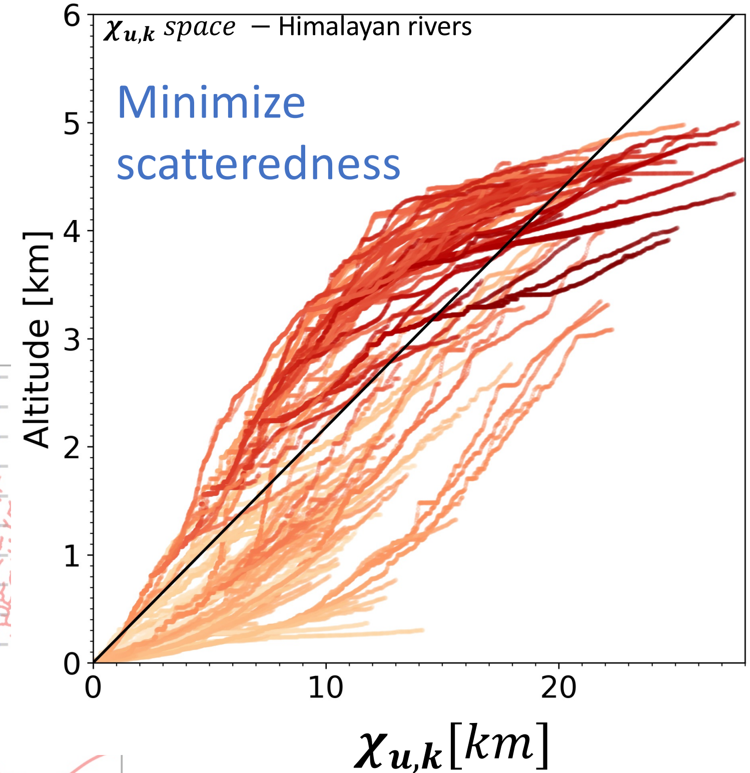


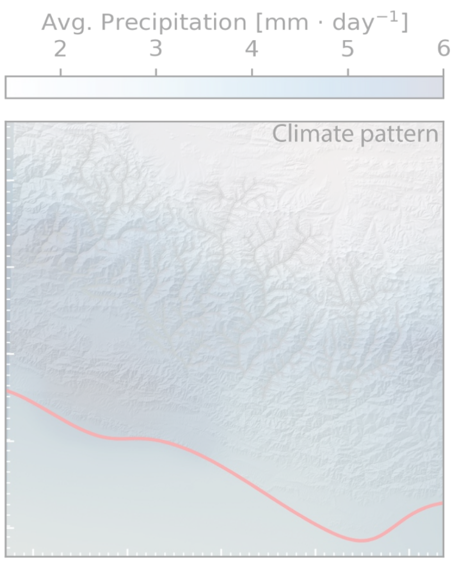


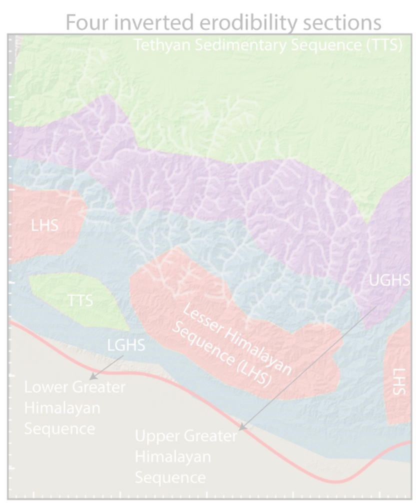
Oryan et al., in review

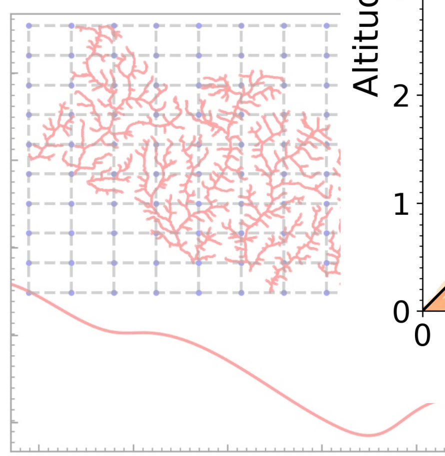
INVERTING HIMALAYAS USING $\chi_{u,k}$ TRANSFORMATION

1. Download a DEM and compute drainage area corrected for climate.
2. Map the spatial distribution of major lithological sections for piecewise rock erodibility values.
3. Describe 2D uplift surface using interpolating B-spline functions extending across the river network.
4. Invert for uplift and erodibility values minimizing $\chi_{u,k}$.





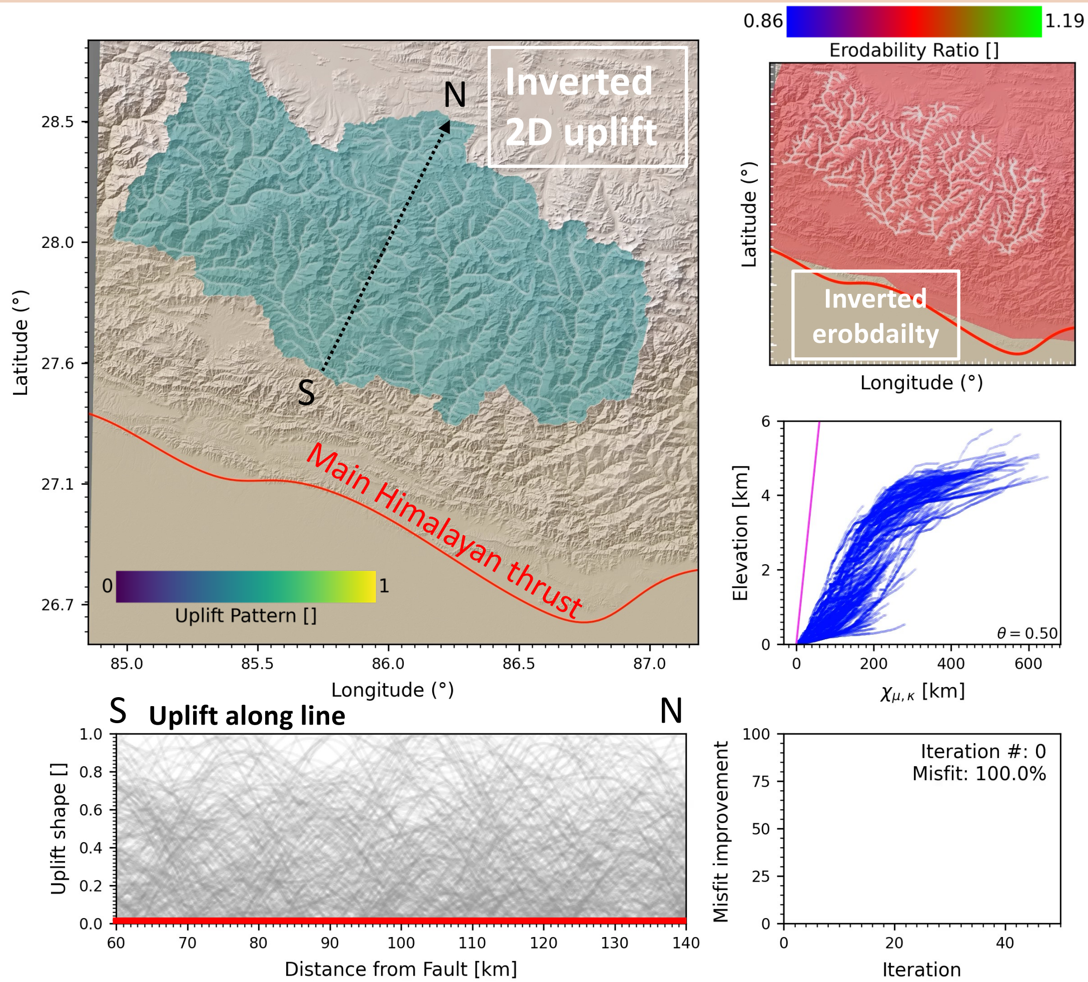


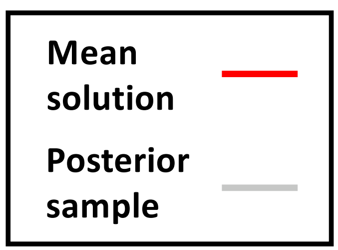


Oryan et al., in review

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

- Inversion of 120,000 river nodes spanning 18,000km^2 using Bayesian Quasi-Newton inversion method.
- Inverting for 144 parameters describing the uplift pattern and 4 erodibility values that best linearizes river profiles in $\chi_{u,k}$ space.





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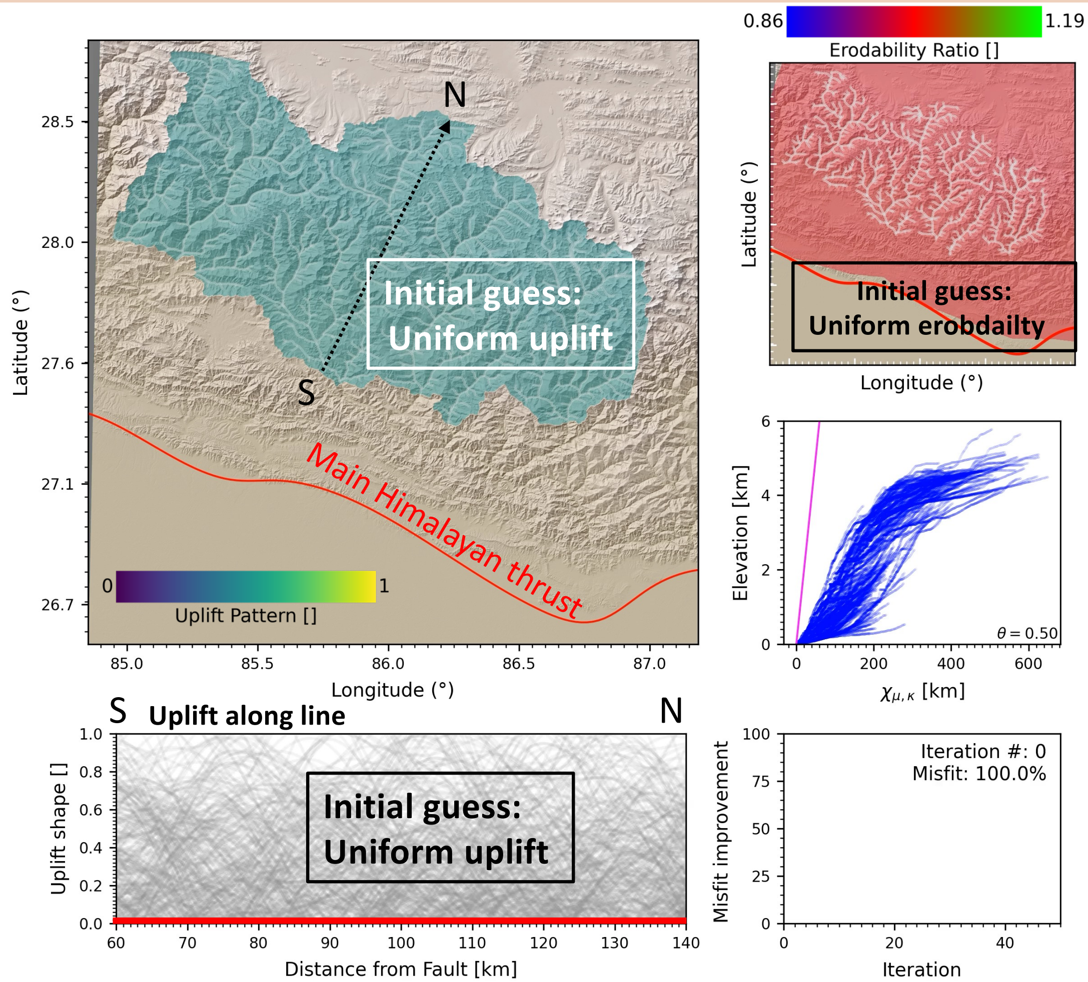

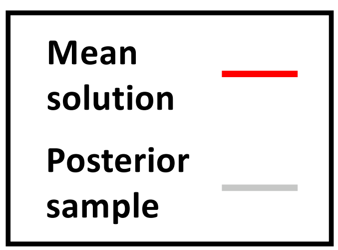

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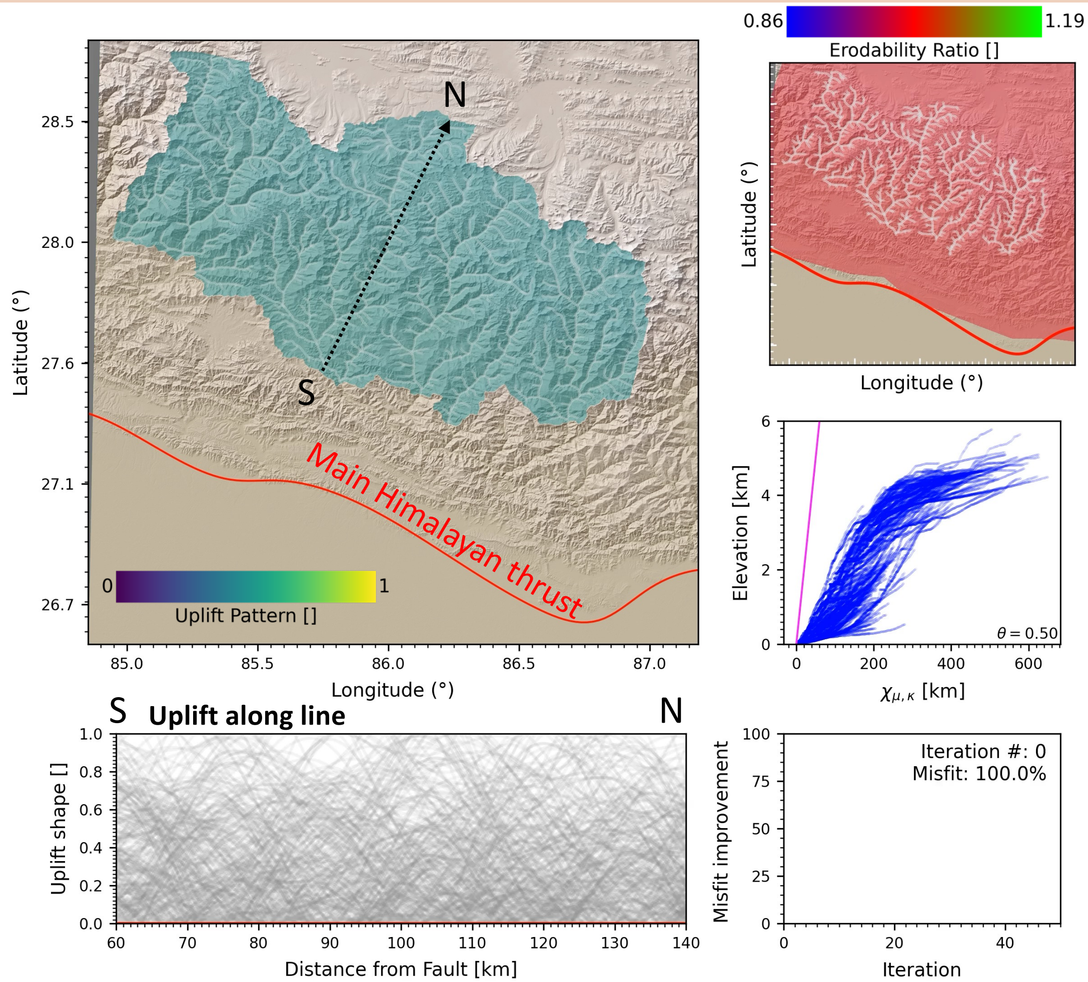


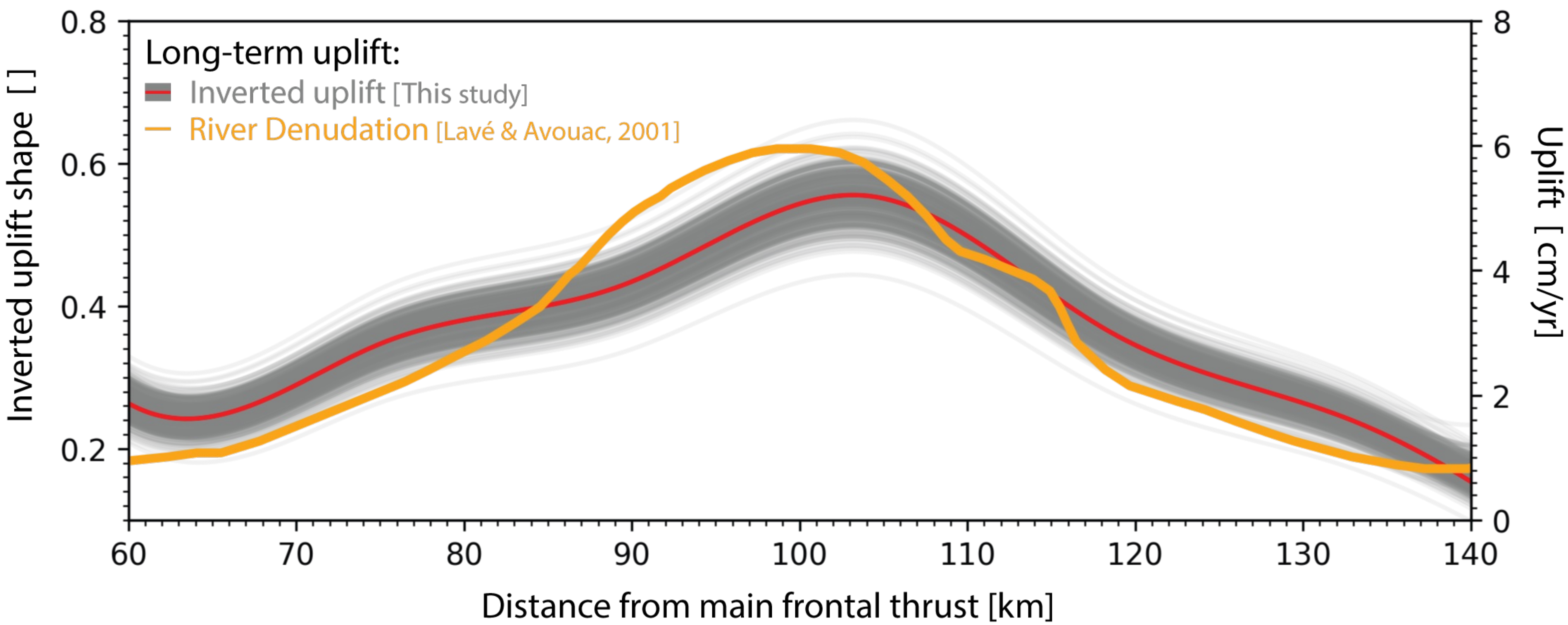
Mean solution

Posterior sample

Oryan et al., in review

RETRIEVED UPLIFT PATTERN RESEMBLE PREVIOUS ESTIMATES

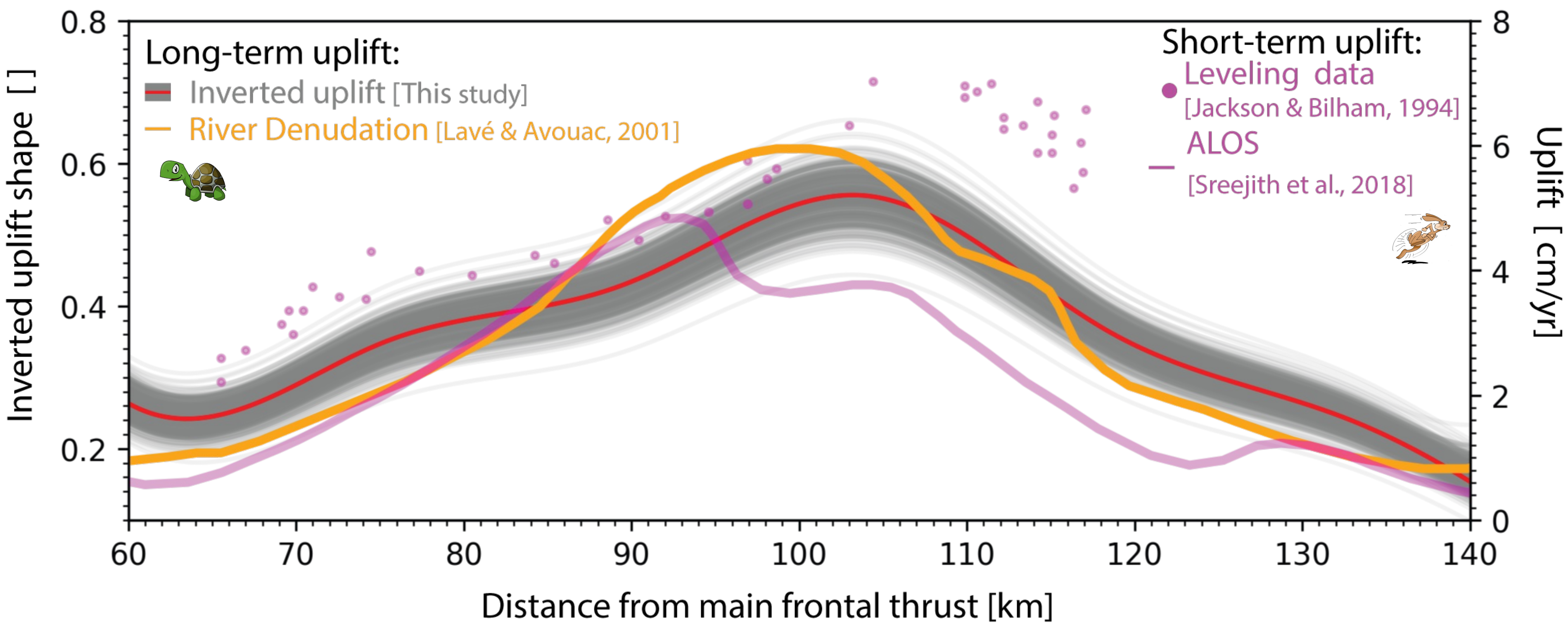
- Inferred long-term uplift matches denudation rates.



Oryan et al., in review

RETRIEVED UPLIFT PATTERN RESEMBLE PREVIOUS ESTIMATES

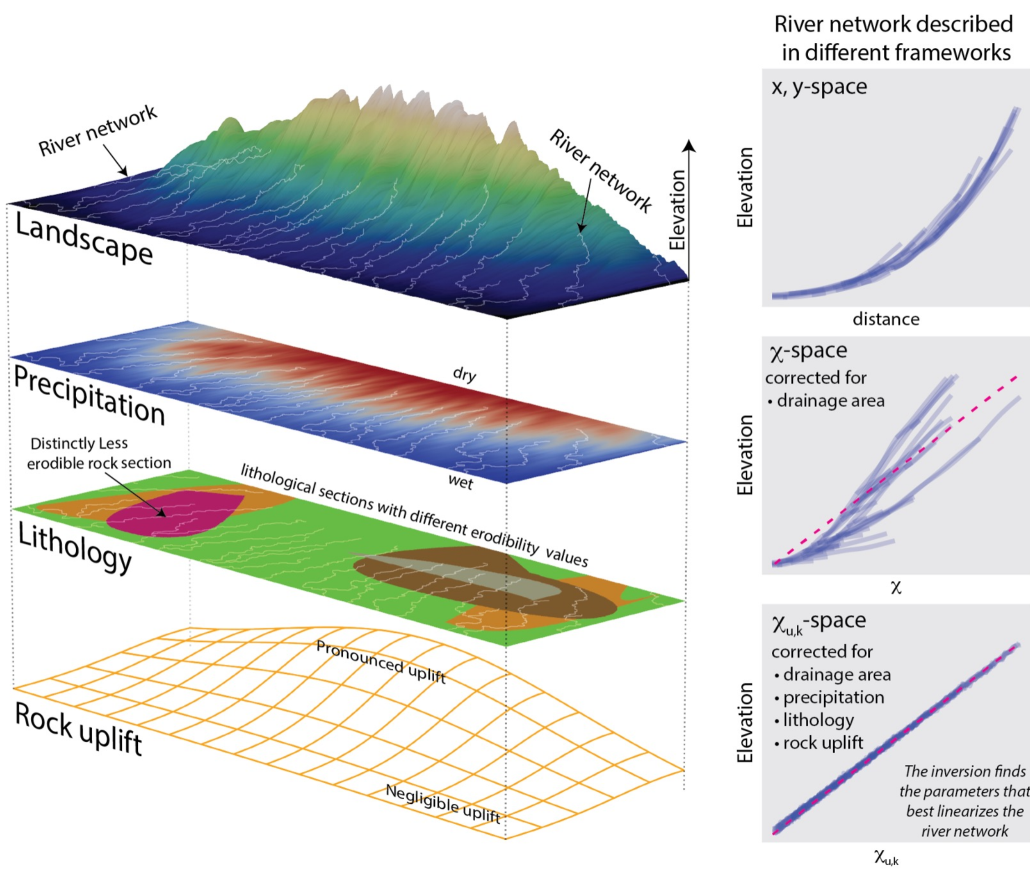
- Inferred long-term uplift matches denudation rates.
- Uplift shape is comparable with shape of short term interseismic uplift.



Oryan et al., in review

KEY POINTS SO FAR

- Inversion in $\chi_{u,k}$ space 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.

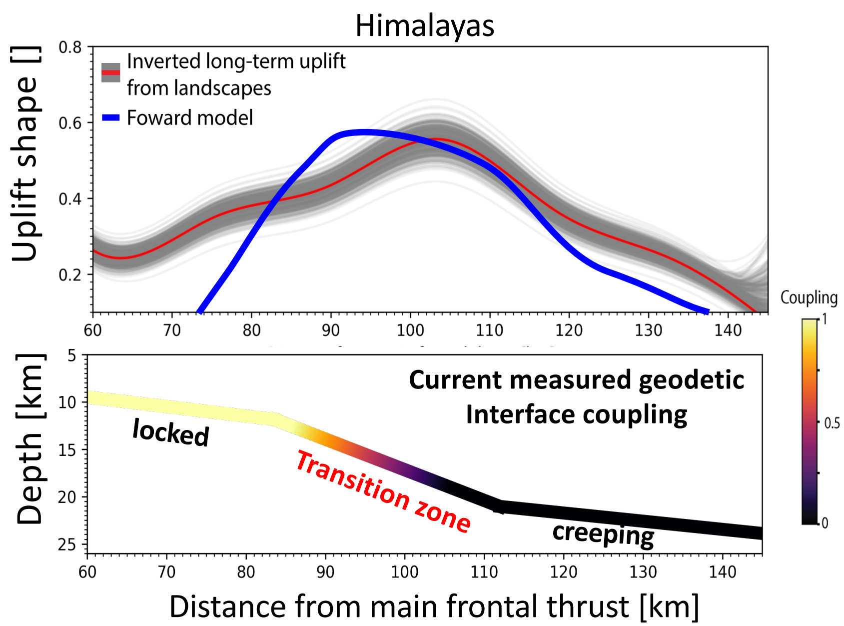


Section 4 – Research Program at the University of Oregon

UNIVERSITY
OF OREGON

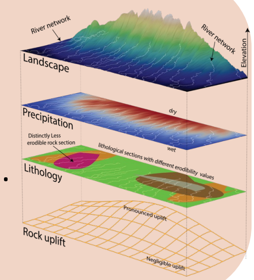
INVERTING LANDSCAPES FOR PERSISTENT PLATE LOCKING

- My group will use the frameworks described in sections 2 and 3 to **invert forearc landscapes for long-term megathrust coupling.**



Observational data

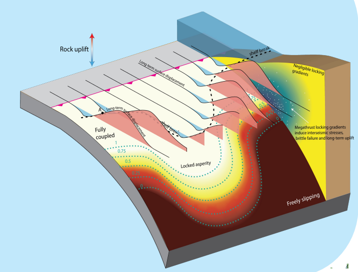
Inferring Long-Term Tectonic Uplift from Bayesian Inversion of Landscapes [Oryan et al. in review]



Landscape ⇨ Long-term Uplift

Forward model

Fingerprints of Megathrust Locking in Subduction Landscapes [Oryan et al.,2024]



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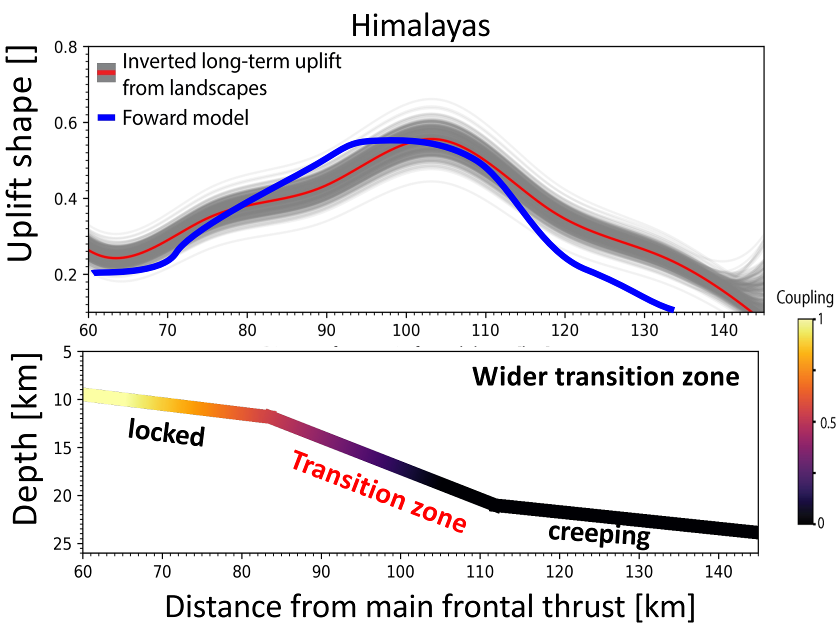

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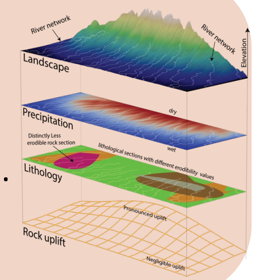

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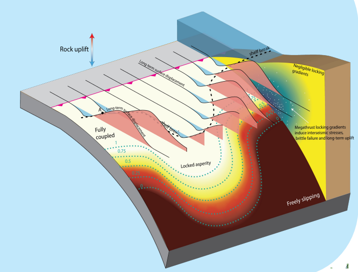

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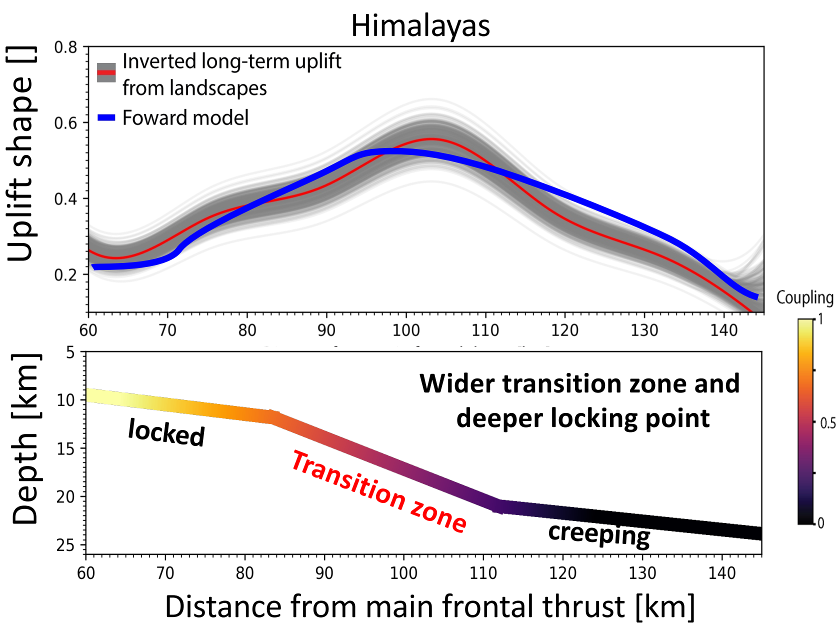

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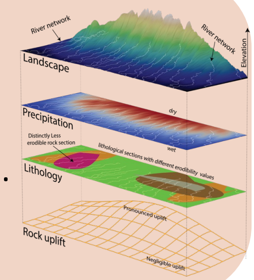

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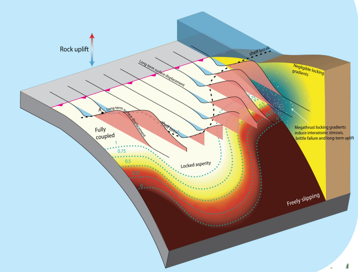

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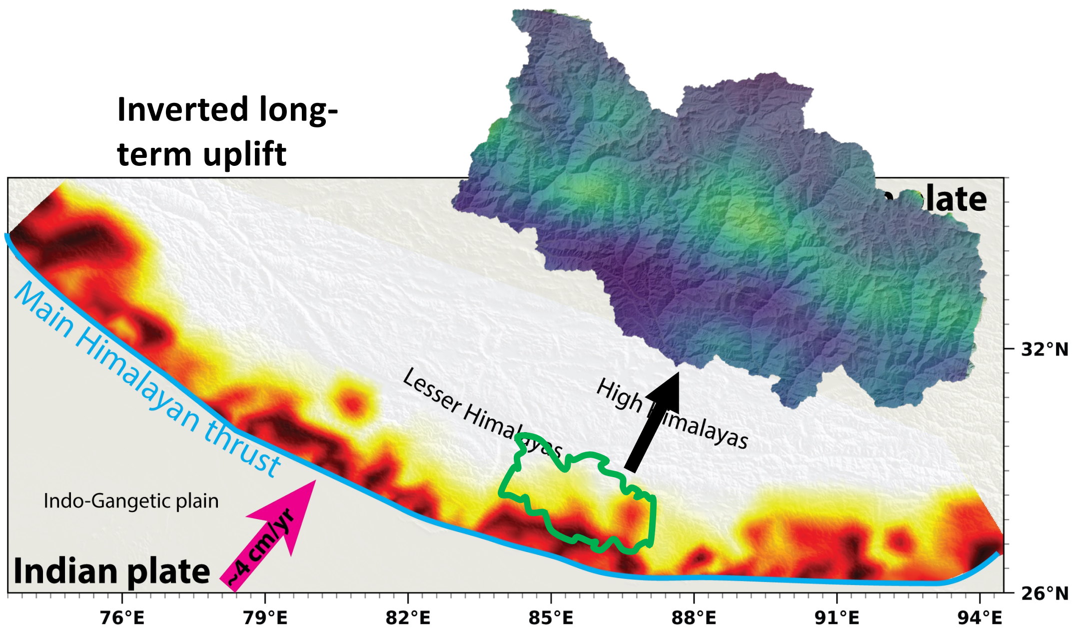
Inverted long-term uplift



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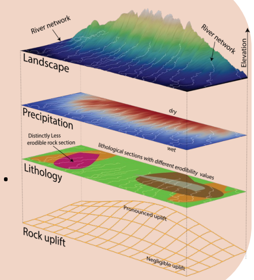

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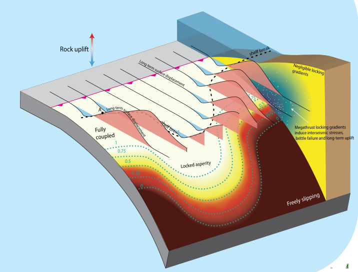

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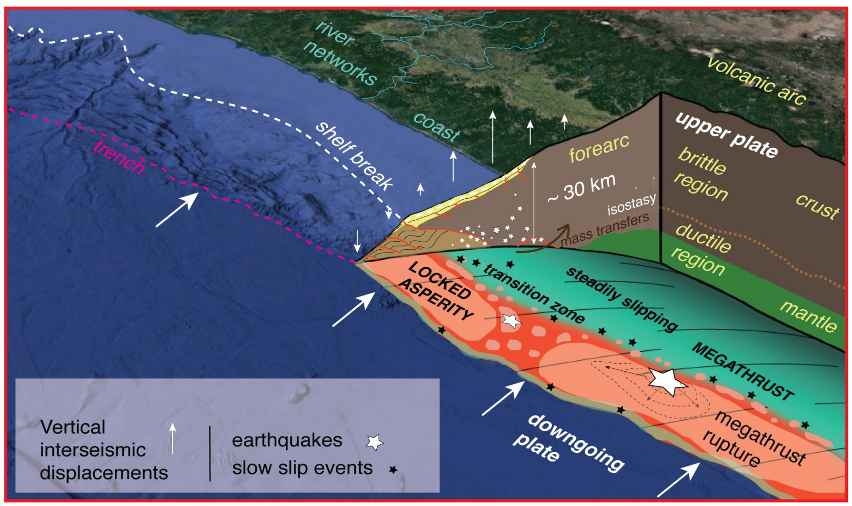

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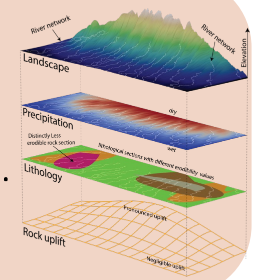

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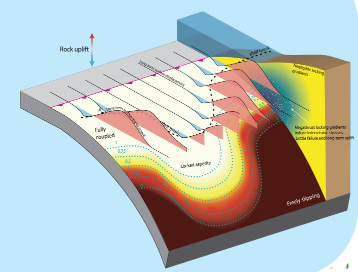

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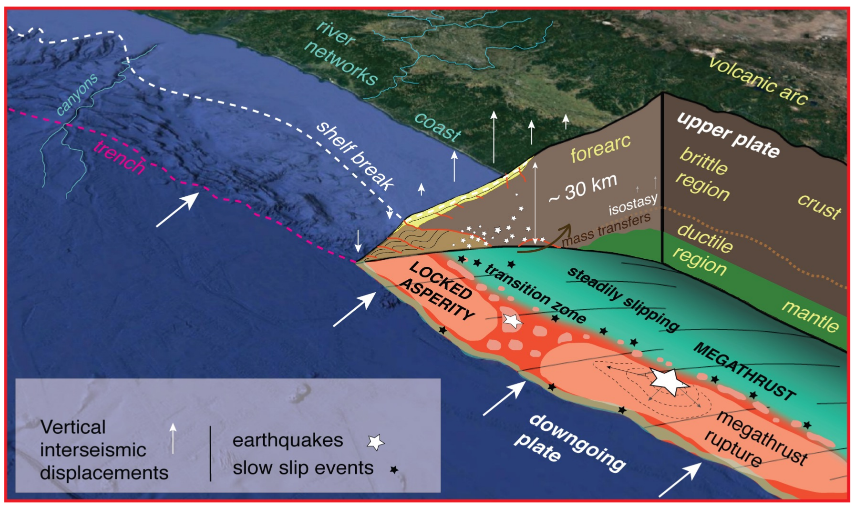
INVERTING LANDSCAPES FOR PERSISTENT PLATE LOCKING

- My group will use the frameworks described in sections 2 and 3 to **invert forearc landscapes for long-term megathrust coupling.**
- We will strive to expand our observational record and use **submarine canyons**.



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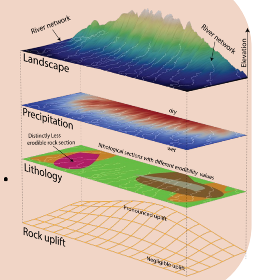

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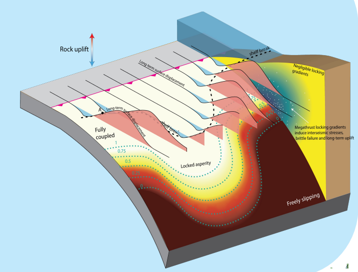
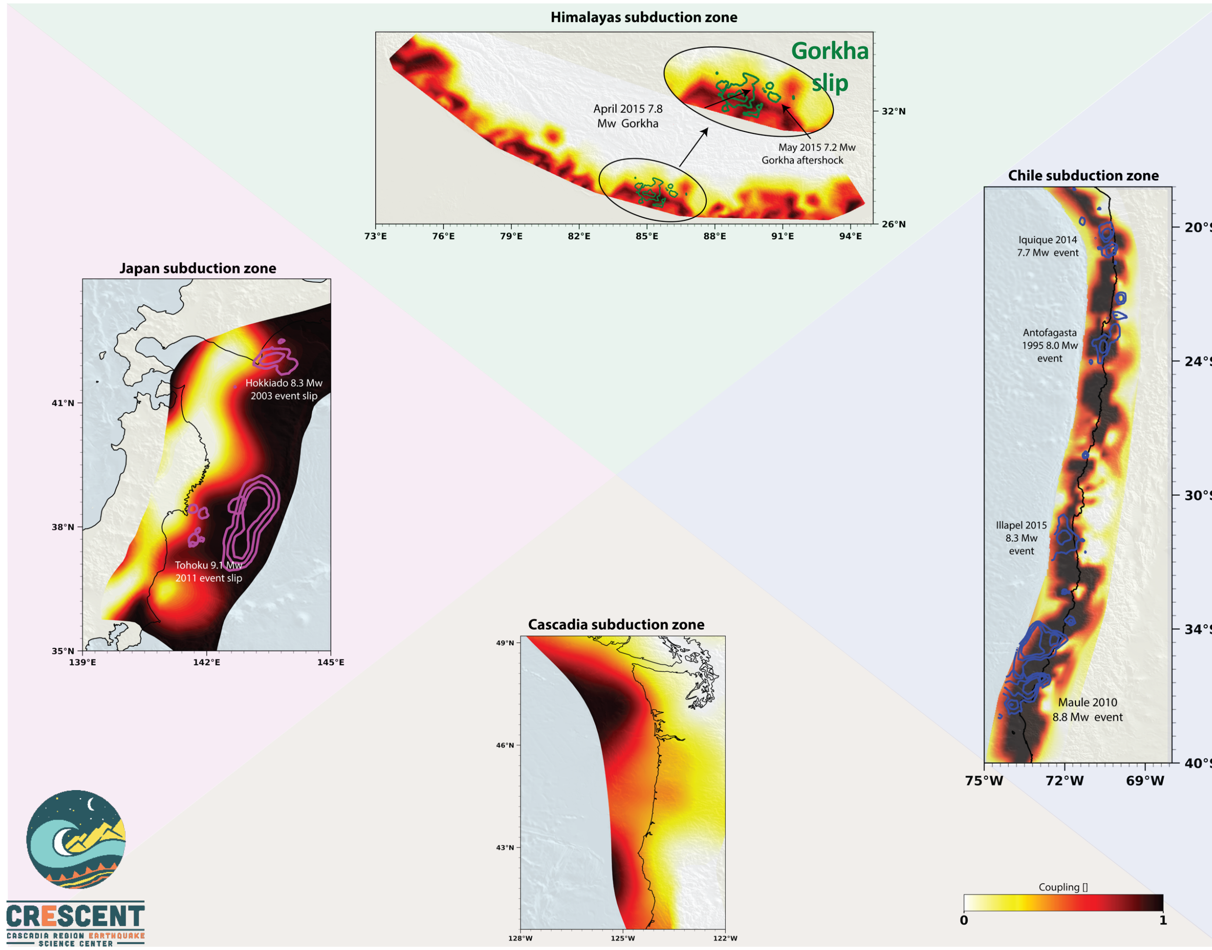


Coupling → Long-term Uplift

UNIFYING MEGATHRUSTS FAULTS USING OPTIMAL TRANSPORT AND MACHINE LEARNING TOOLS

- My group will use machine learning and optimal transport tools to compute geodetically and physically consistent geometric mappings between megathrusts.



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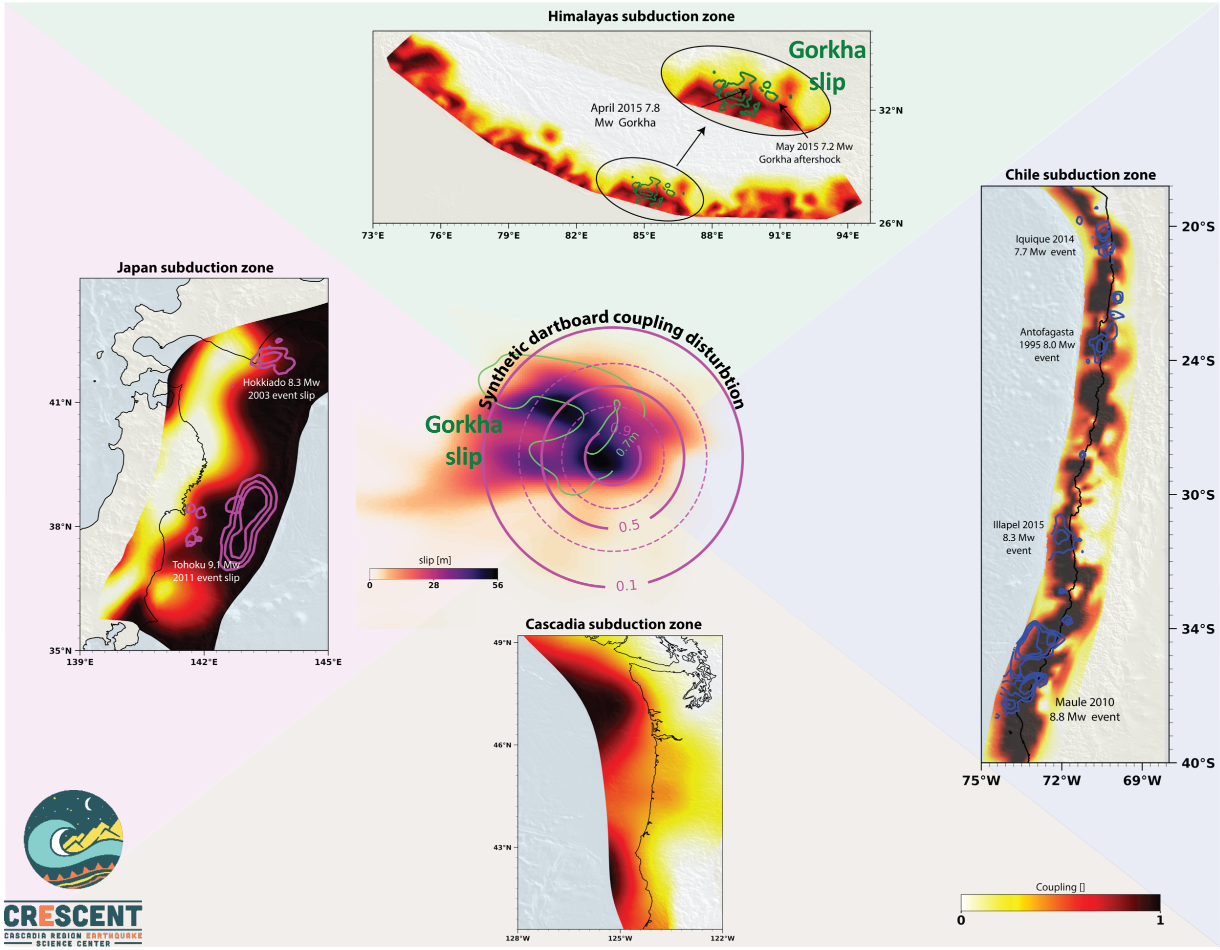

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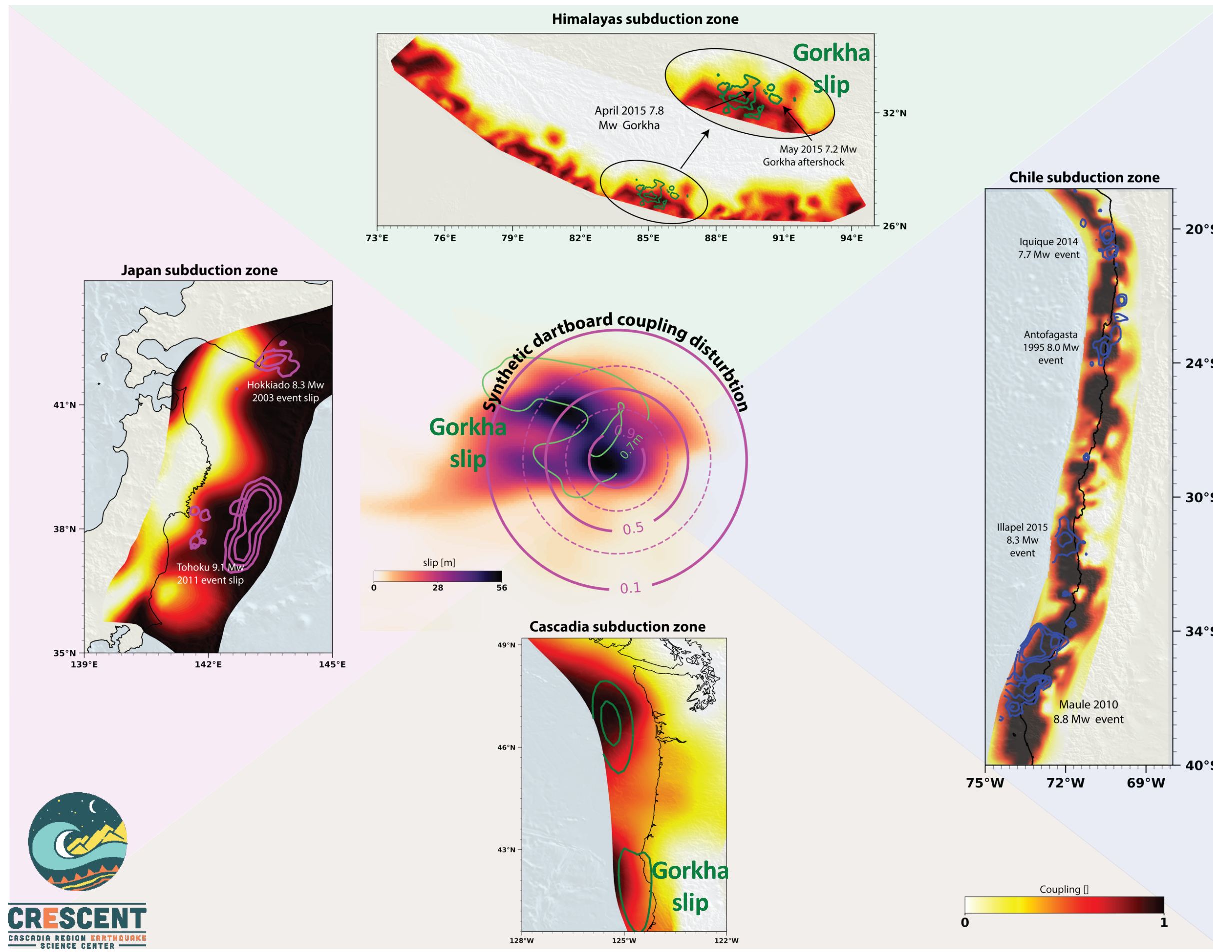
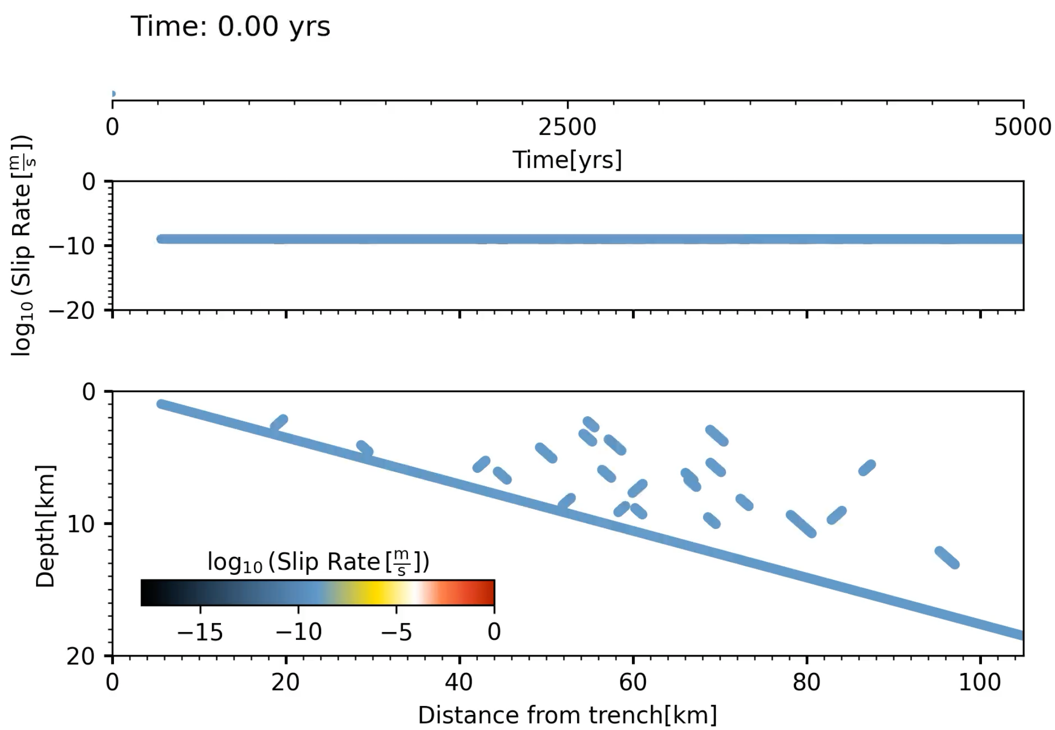
- This approach will **extend our seismo-geodetic observational** record several-fold and allow us to assess seismic hazard more robustly.



THE ENERGY BUGDET OF EARTHQUAKE CYCLES

- **Investigating Seismic Cycle Dynamics:** Using SEAS simulations, my group will explore how non-recoverable strain accumulation in the overriding plate impacts earthquake dynamics and the coseismic period.



Oryan et al., in prep.

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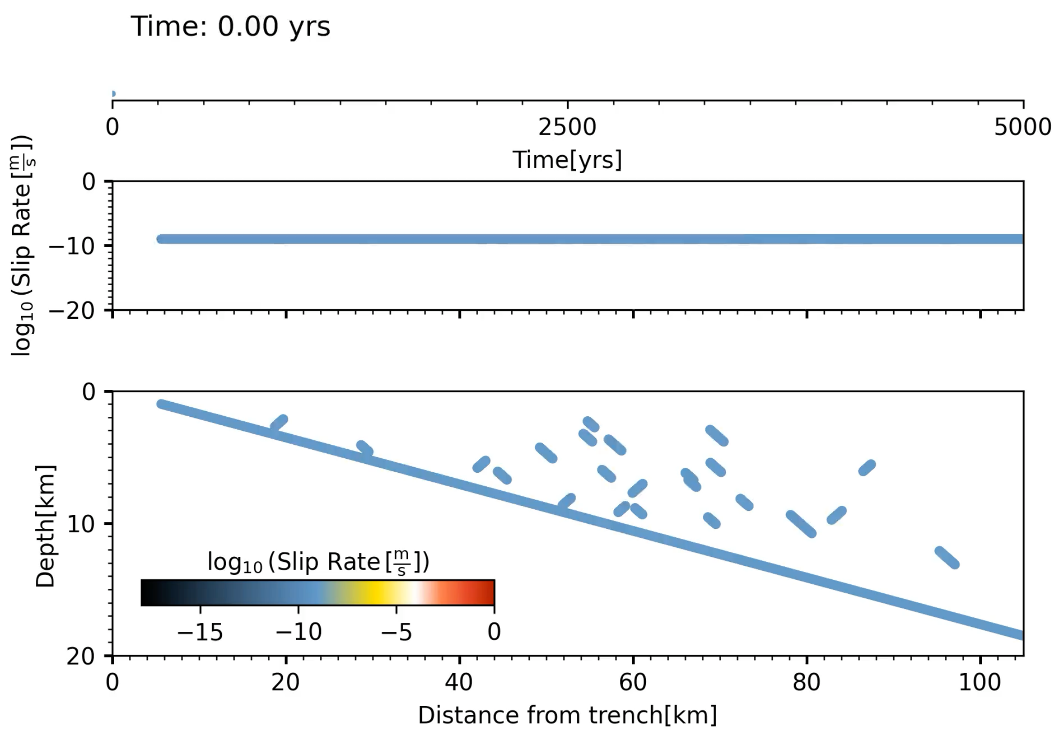
- **Unraveling Energy Distribution in Subduction Zones:** We will study the rheological properties that govern the balance between elastic deformation (fueling earthquakes) and inelastic strain (shaping subduction zone landscapes).



Oryan et al., in prep.

ACKNOWLEDGEMENTS

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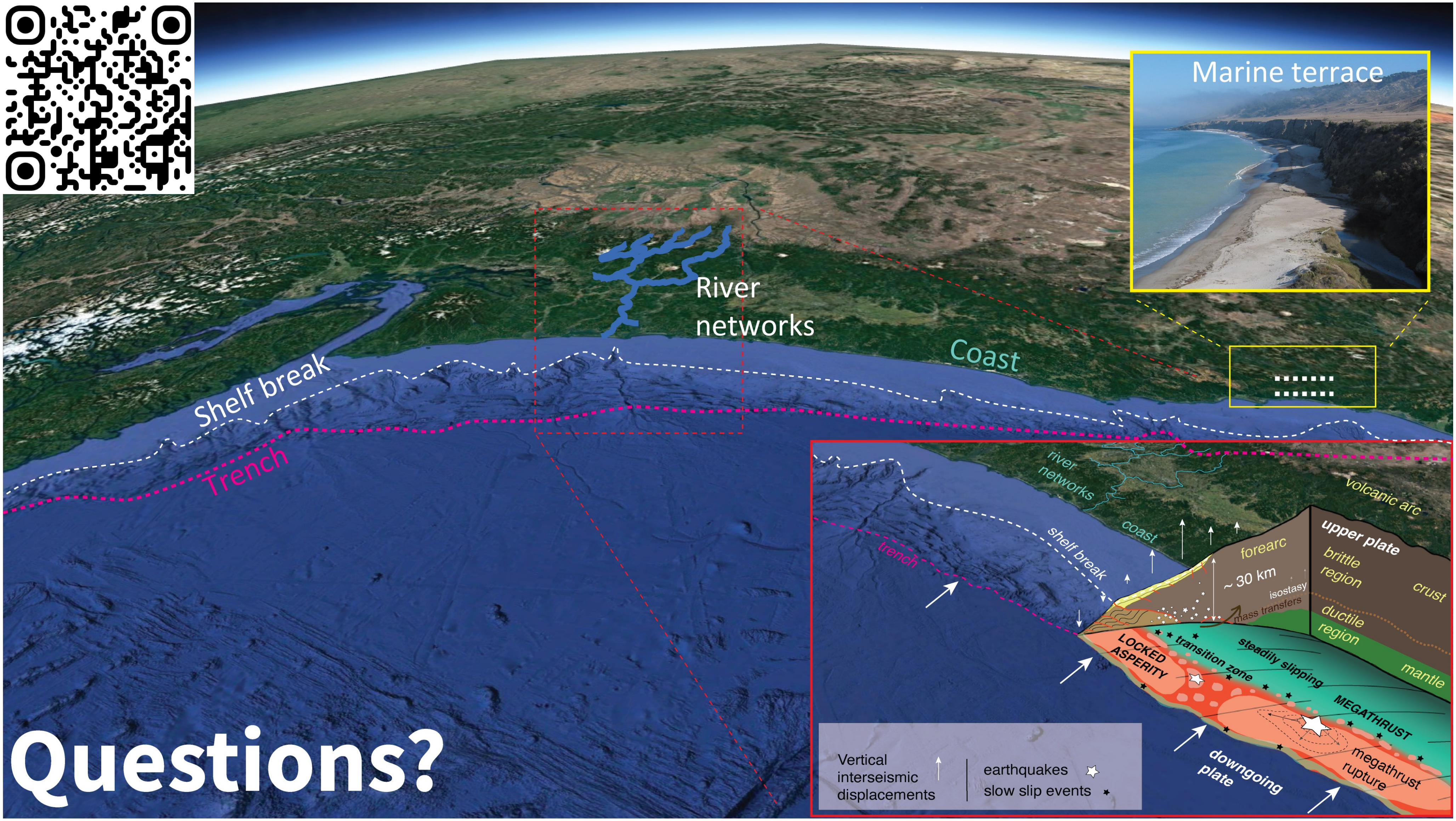
Lucile Bruhat
Luca Malatesta
Mike Steckler
Roger Buck
Romain Jolivet


Marine terrace
River networks
Coast
Shelf break
Trench
river networks
volcanic arc
coast
shelf break
trench
upper plate
forearc
brittle region
crust
~ 30 km
isostasy
mass transfers
ductile region
mantle
LOCKED ASPERITY
transition zone
steadily slipping
MEGATHRUST
megathrust rupture
downgoing plate
Vertical interseismic displacements
earthquakes
slow slip events
Questions?