Coupled Modeling of River and Coastal Processes: New Insights about Delta Morphodynamics, Avulsions, and Autogenic Sediment Flux Variability

Duke NICHOLAS SCHOOL OF THE ENVIRONMENT

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CSDMS COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

Motivation & Research Questions

- Deltas are flat & fertile → densely populated
- Important for agriculture, resources, and transportation
- Inhabitants increasingly susceptible to natural disasters
- Humans have:
  - Decreased sediment supply (e.g. dams)
  - Altered river course (e.g. channelization, levees)
- Relative sea-level rise rate (SLRR) increases → aggradation & backfilling increase (morphodynamic backwater) → avulsions assumed to be more frequent

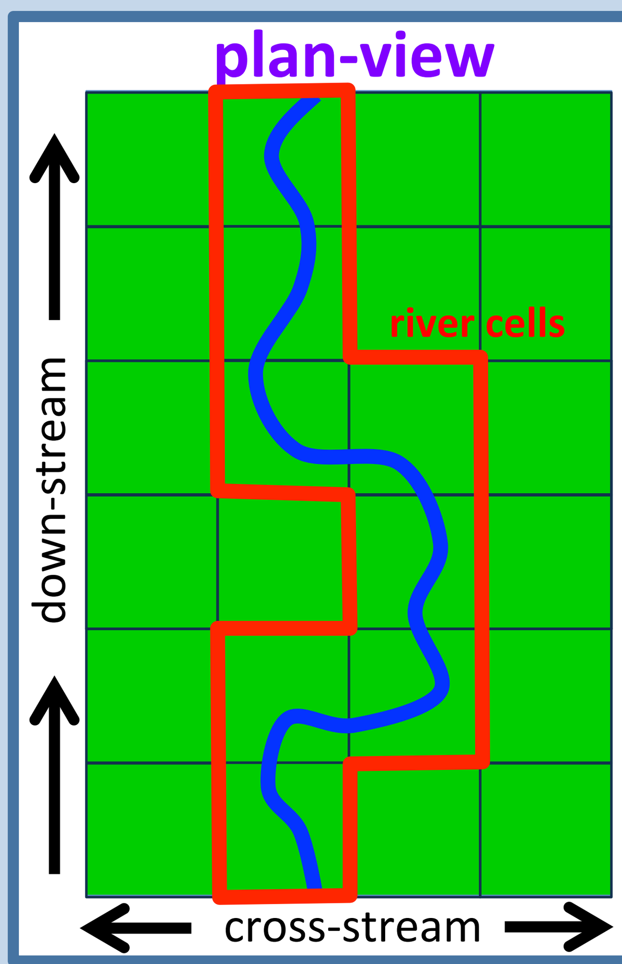
What key feedbacks between fluvial and coastal processes drive avulsions and delta morphology?

How are delta morphodynamics affected by changing forcings (e.g., sea-level rise) over long time scales?

New Delta Evolution Model

- Need to link both fluvial, deltaic, and coastal systems over multi-avulsion and lobe-building timescales
- Based on couplings using the Community Surface Dynamics Modeling System framework (Basic Model Interface)
- Generalized & scale invariant
- Capable of simulating large space & time scales

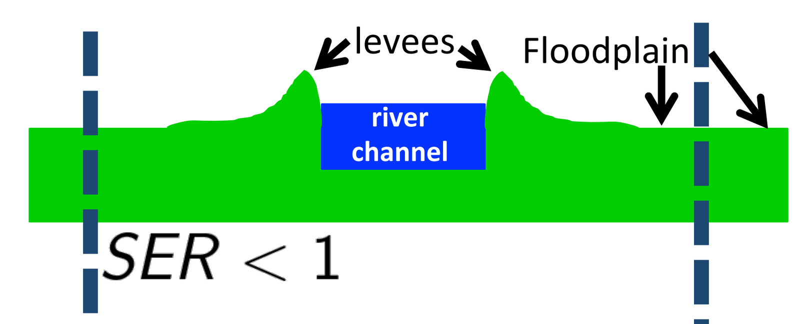
River Avulsion and Floodplain Evolution Model (RAFEM) ↔ **CSDMS Basic Model Interface** ↔ Coastline Evolution Model (CEM)



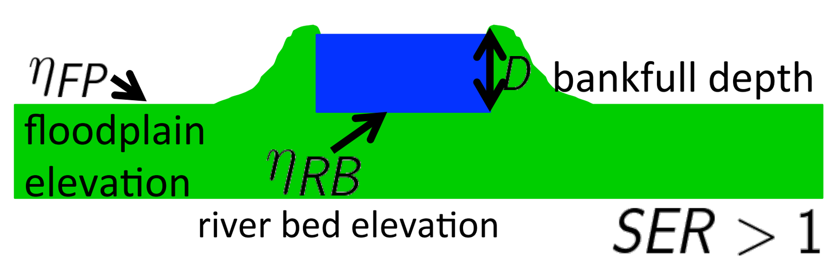
River Avulsion and Floodplain Evolution Model (RAFEM)

- **Cell width >> channel width**
- **Steepest-descent methodology** (following Jerolmack and Paola, 2007)
- **Diffusion of river profile** (Paola et al., 1992; Paola 2000)
- **River avulsions** triggered by **normalized super-elevation ratio (SER)** (Mohrig et al., 2000), **unsuccessful if not shorter** than previous path
- **Floodplain deposition** = crevasse splay (after 'failed' avulsion; steepest path longer than current course)

cell cross-section

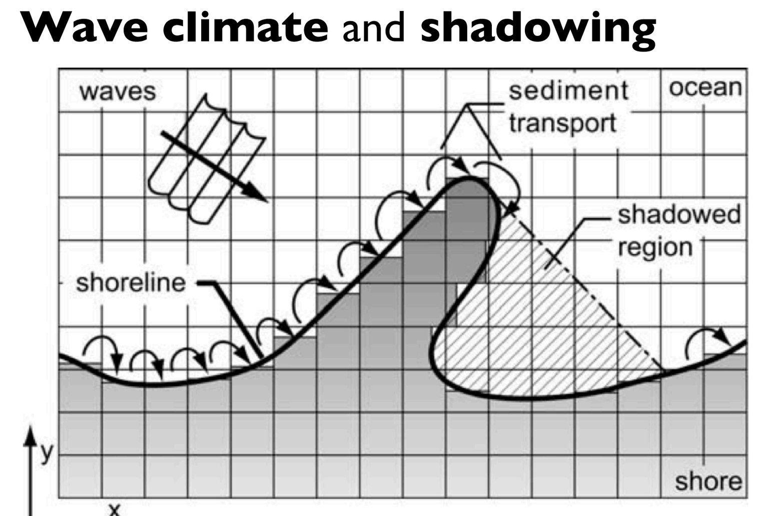


$$SER = \frac{(\eta_{RB} + D) - \eta_{FP}}{D}$$



Coastline Evolution Model (CEM)

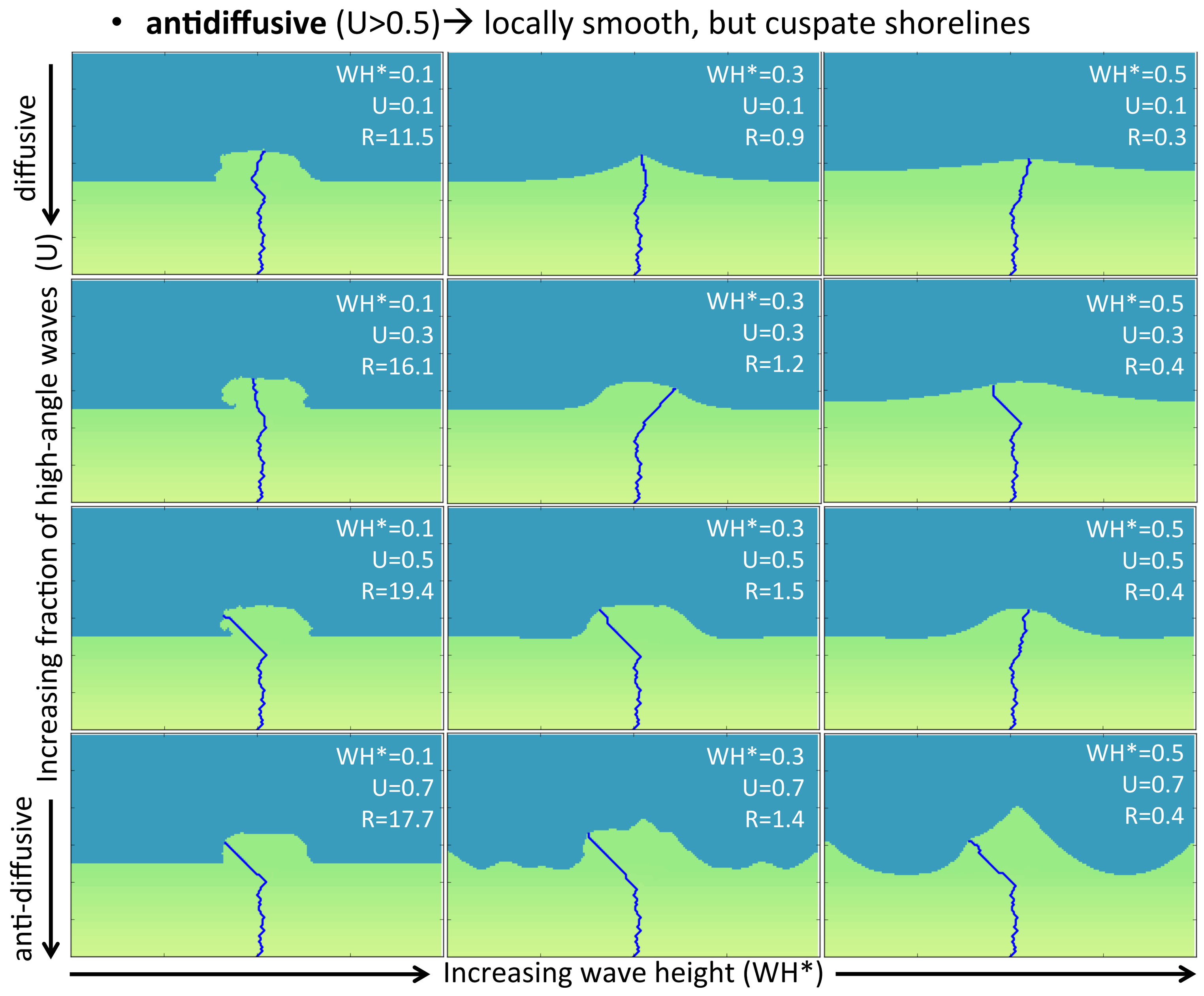
- Shoreline **erosion & accretion** driven by **alongshore sediment transport**
- **Conserves nearshore sediment**
- **Wave climate** and **shadowing**



Ashton and Murray, 2006

Wave climate diffusivity affects morphology

- **low wave height**: sign of wave climate diffusivity doesn't matter; waves too low to affect shape
- **higher wave height**: sign does matter, affects morphology & avulsion time scales
  - **diffusive** (U<0.5) → flat shorelines, progradation inhibited
  - **antidiffusive** (U>0.5)→ locally smooth, but cuspate shorelines



fluvial dominance ratio R expresses how quickly fluvial sand is delivered to shore vs. how quickly it is reworked by waves (Nienhuis et al., 2015):

$$R = \frac{Q_r}{Q_{s,max}}$$

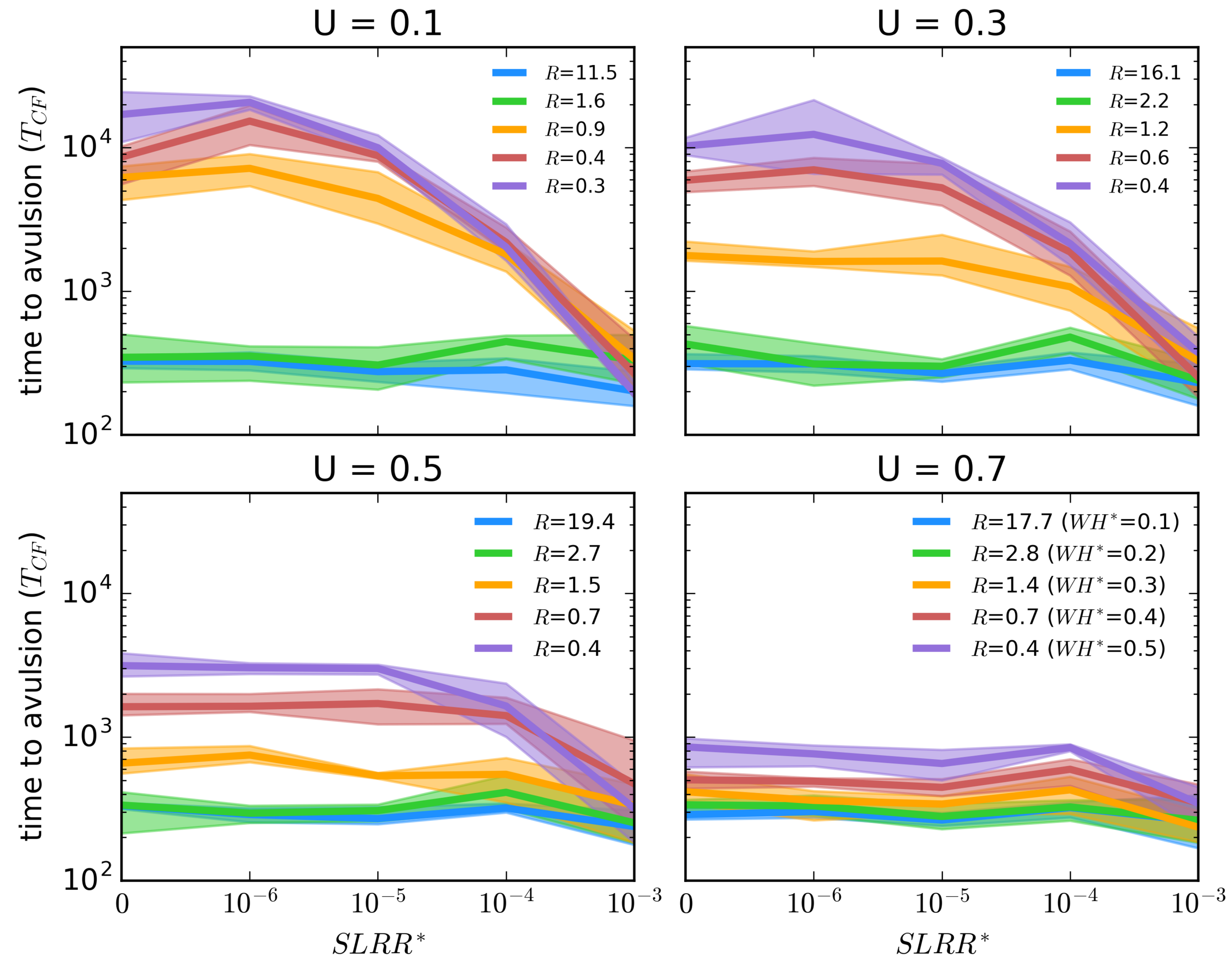
R > 1: river-dominated

R < 1: wave-dominated

Avulsion time scales

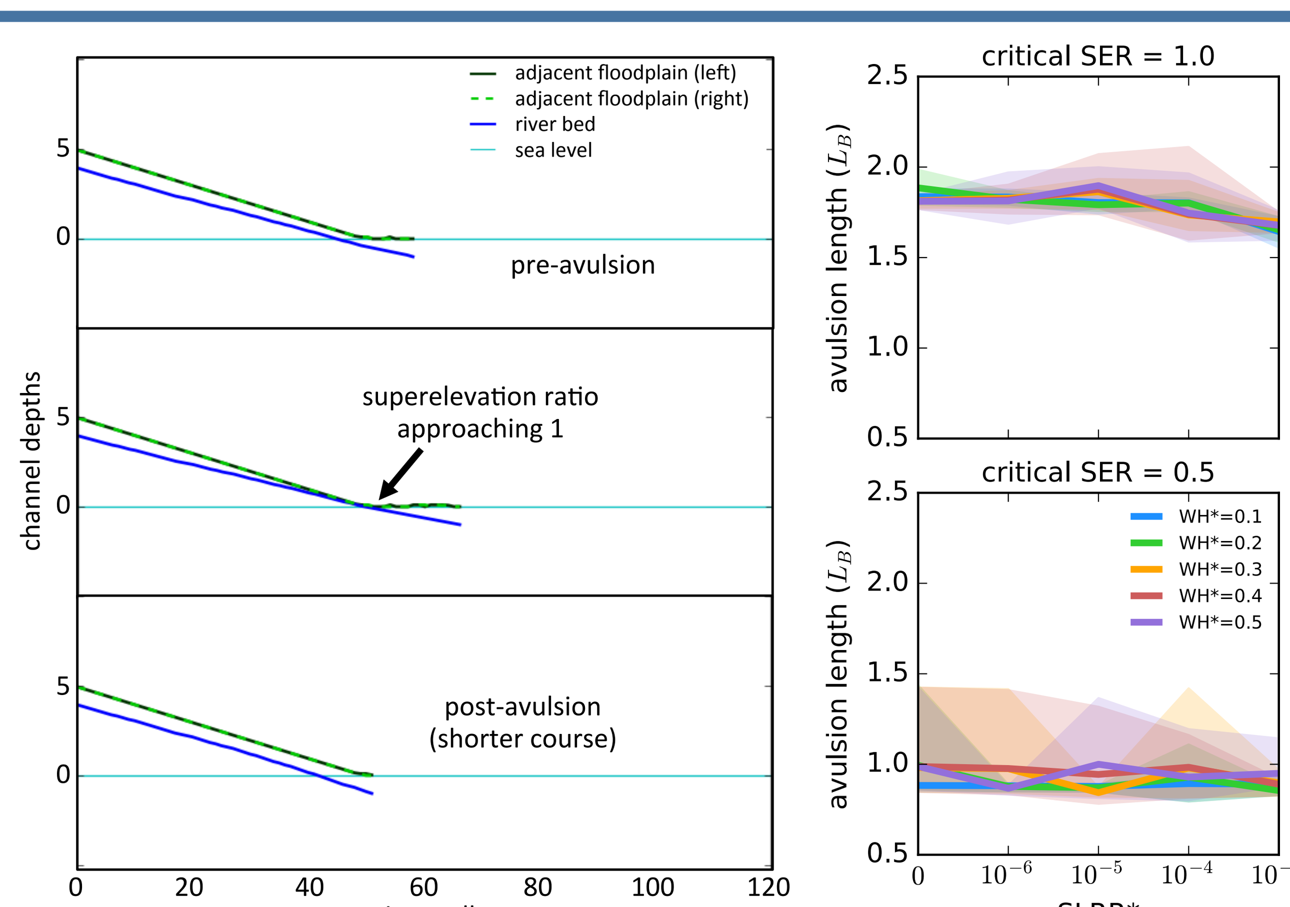
- **diffusively wave-dominated**: progradation slow, avulsions take longer to occur
- **river-dominated or U>0.5**: progradation not inhibited, avulsions happen quickly
- **Increasing SLRR* only decreases avulsion time scales for wave-diffused deltas!**

→ In river-dominated or U>0.5 cases, lateral (transgressive) movement of shoreline counteracts base-level driven aggradation, no net affect on avulsion timing



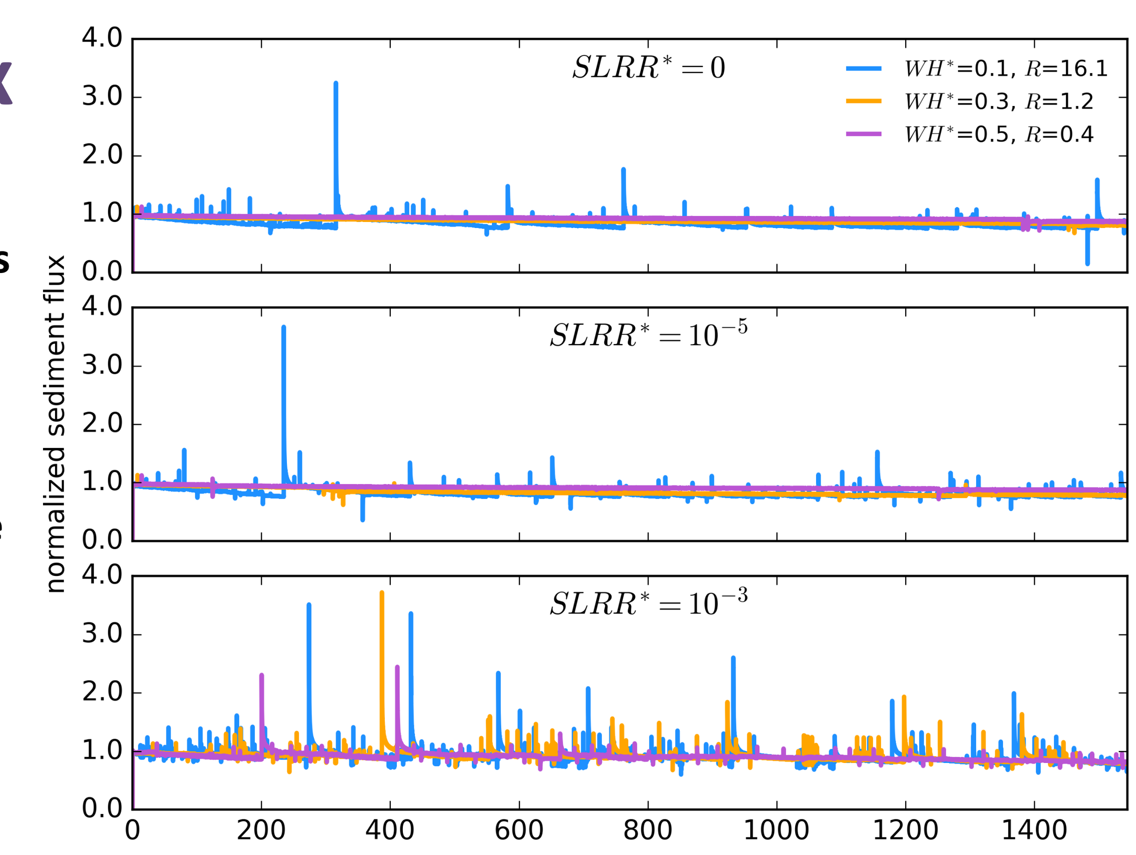
Avulsion length scale

- **Preferential length scale is a function of geometry** (not varying discharge)
- over long-term, **profile diffuses more rapidly than surrounding floodplain**, becomes super-elevated at terrestrial concavity
- **length scales with critical SER**, values scale well with lab and field data



Sediment flux variability

- **Peaks represent avulsions**
- **River-dominated**: larger cyclical peaks in flux
- **Wave-dominated**: less autogenic variability
- **Increasing SLRR* → more avulsions and variability for wave-diffused deltas** (b/c base-level driven aggradation causes avulsions to occur more frequently)



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Visit https://github.com/katmratliff or csdms.colorado.edu for code & more info.