Exploring Delta Morphodynamics Using the CSDMS BMI to Couple Fluvial and Coastal Processes

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Duke NICHOLAS SCHOOL OF THE ENVIRONMENT

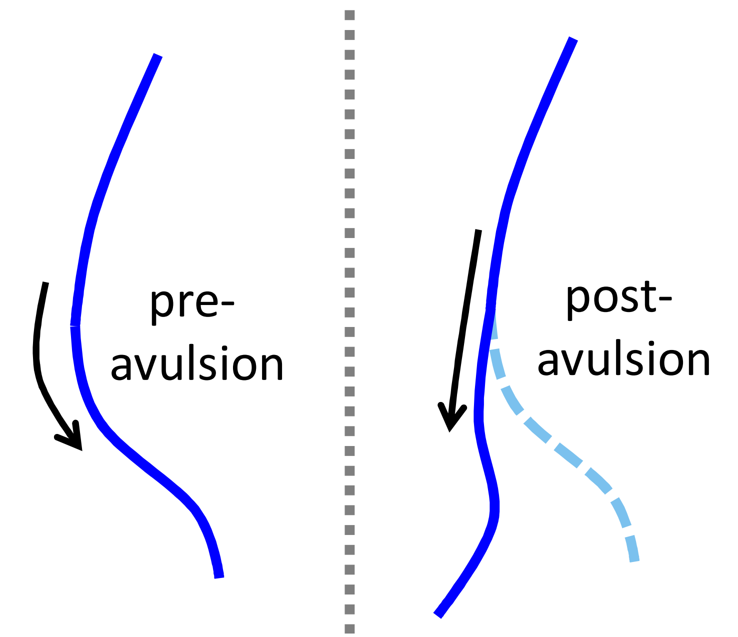
CSDMS

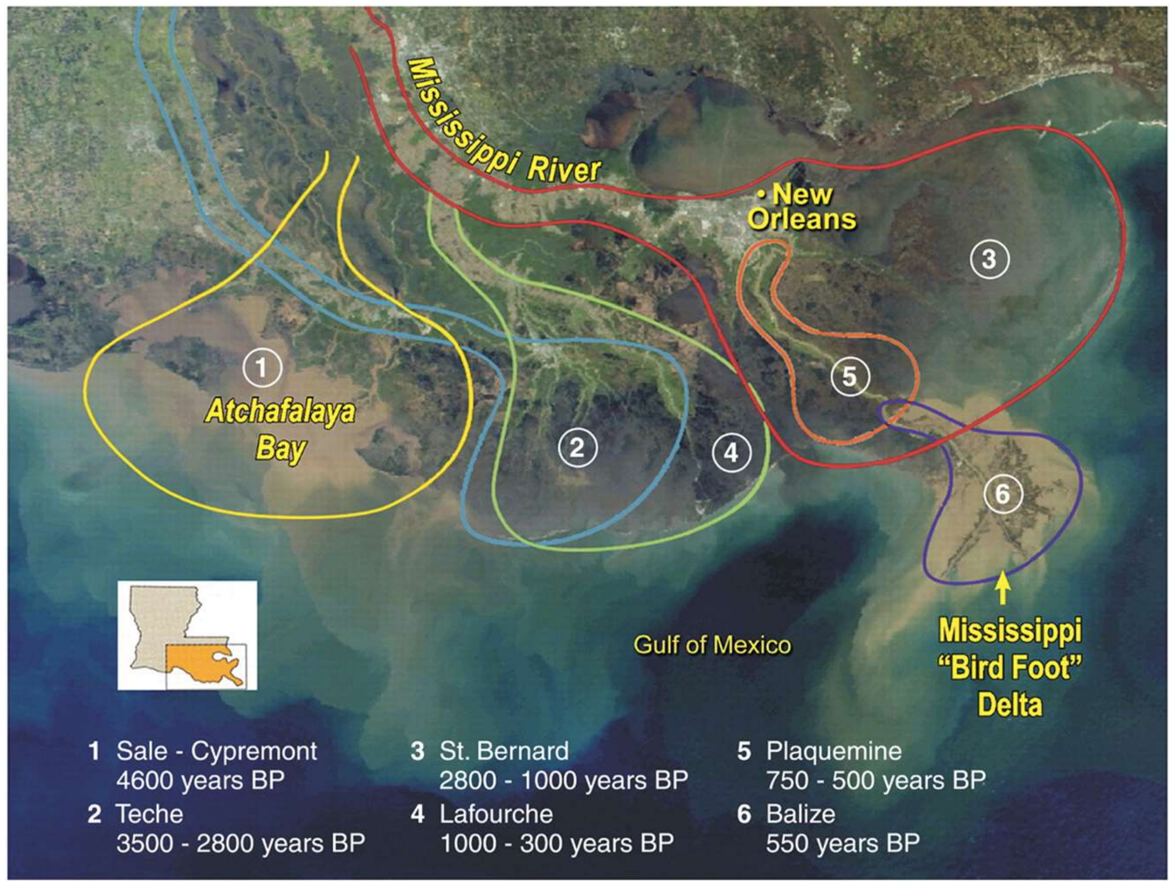
Why Deltas?

- Densely populated
  - 25% of world's population
  - large cities
- Agriculture & resources (e.g., oil, gas, groundwater)
- Transportation and trade
- Anthropogenic influence (e.g., climate, land-use change)
- Increasingly vulnerable

River Channel Avulsions

- Dictates location of sediment delivery to coast
- Sets delta lobe size

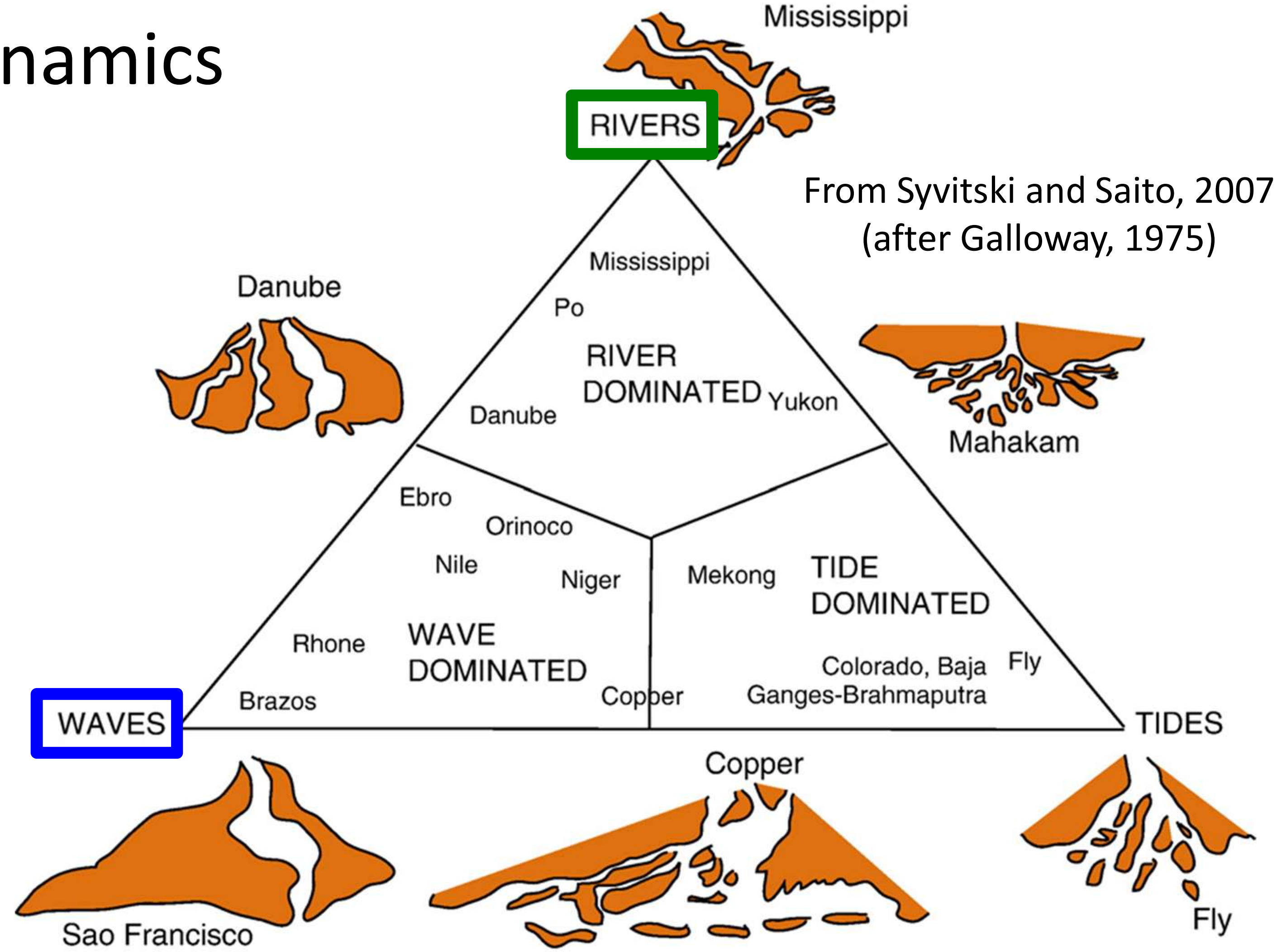




http://sustainindiana.org/2015/02/22/mississippi-delta-river-engineering/

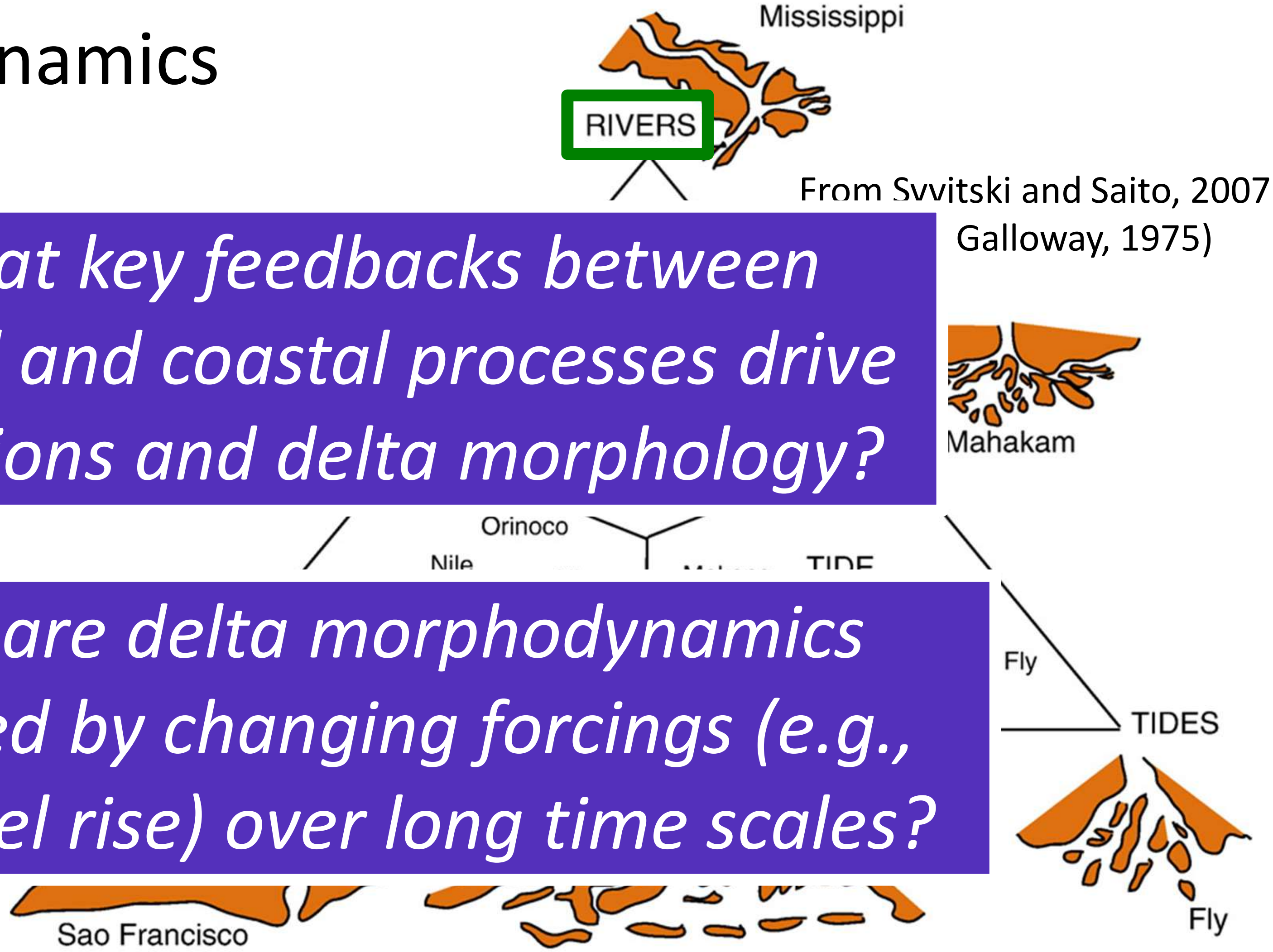
Delta morphodynamics influenced by:

- –Rivers
- –Tides
- –Waves
- –Grain size
- –Subsidence
- –Humans



Delta morphodynamics influenced by:

- –River
- –Tides
- –Wave
- –Gra
- –Sub
- –Hur

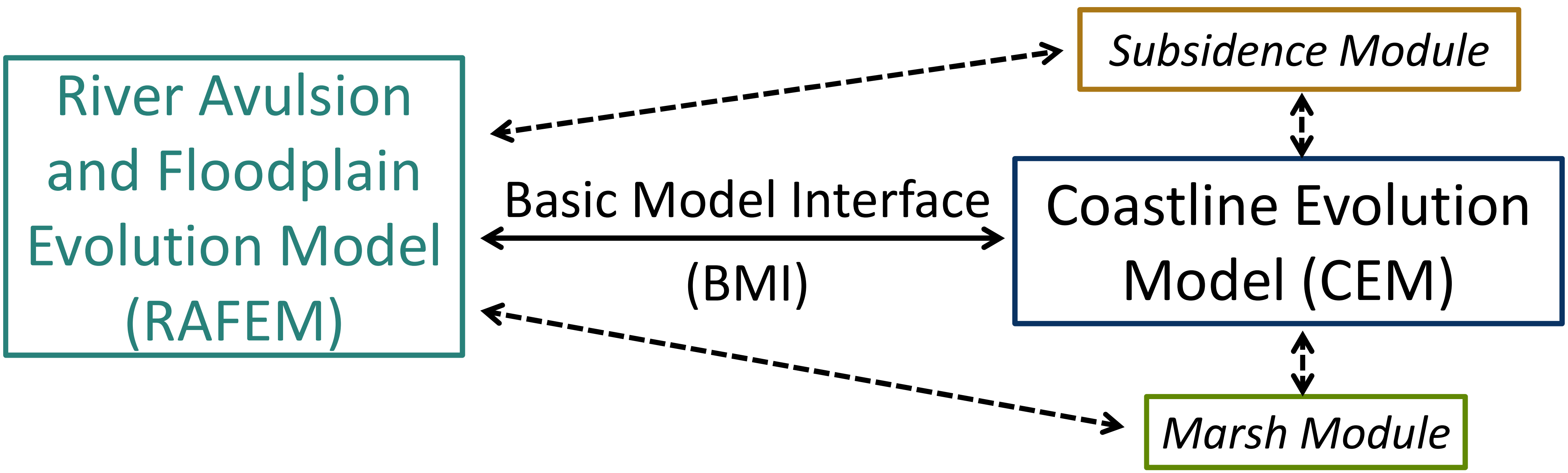


What key feedbacks between fluvial and coastal processes drive avulsions and delta morphology?

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

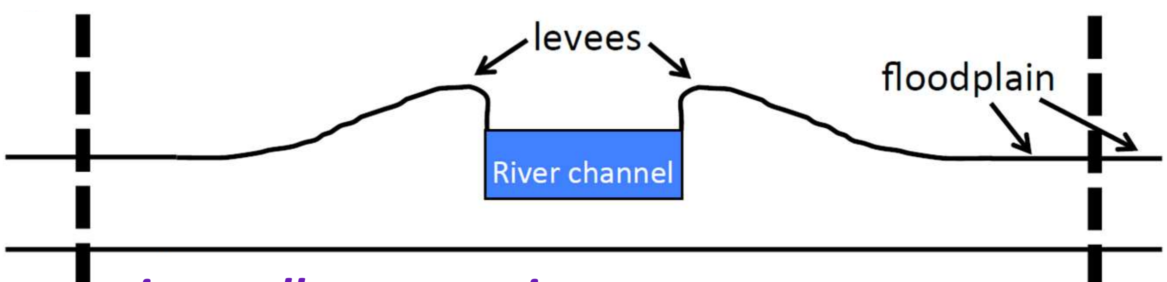
New Delta Evolution Model

- Large spatial scales & long time scales
- Generalized & scale invariant
- Based on couplings using the CSDMS BMI



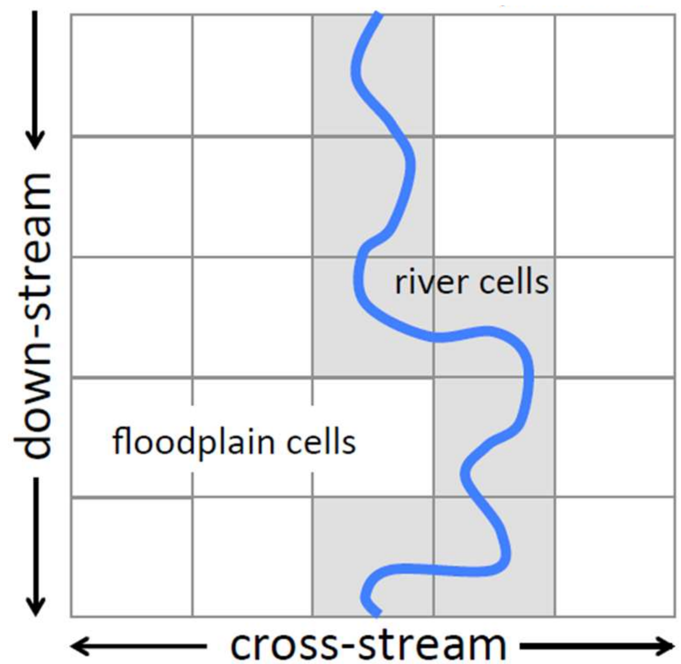
River Avulsion and Floodplain Evolution Model (RAFEM)

- Cell width >> channel width
- Steepest-descent river course (Jerolmack and Paola, 2007)
- Diffusion of river profile (Paola et al., 1992; Paola 2000)
- Subsidence (here, uniform)
- New land behind shoreline = marsh (maintains elevation)
- Sea-level rise related erosion (Wolinsky and Murray, 2009)



river cell cross section

plan view

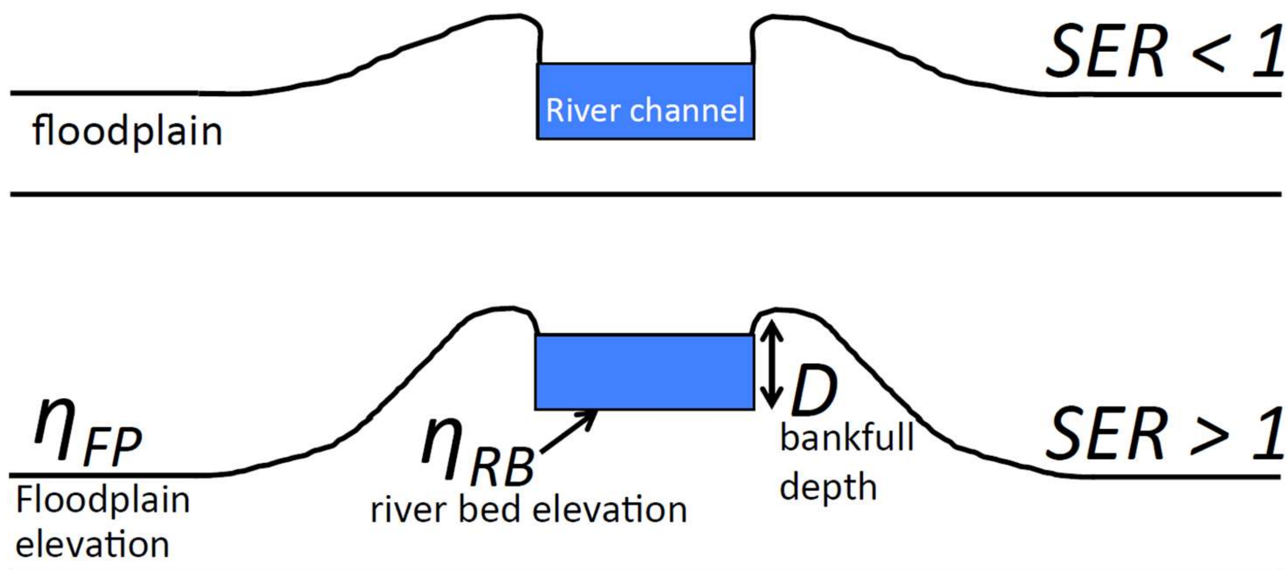


Ratliff, Hutton, and Murray, 2018 *JGR-ES*

Avulsions in RAFEM

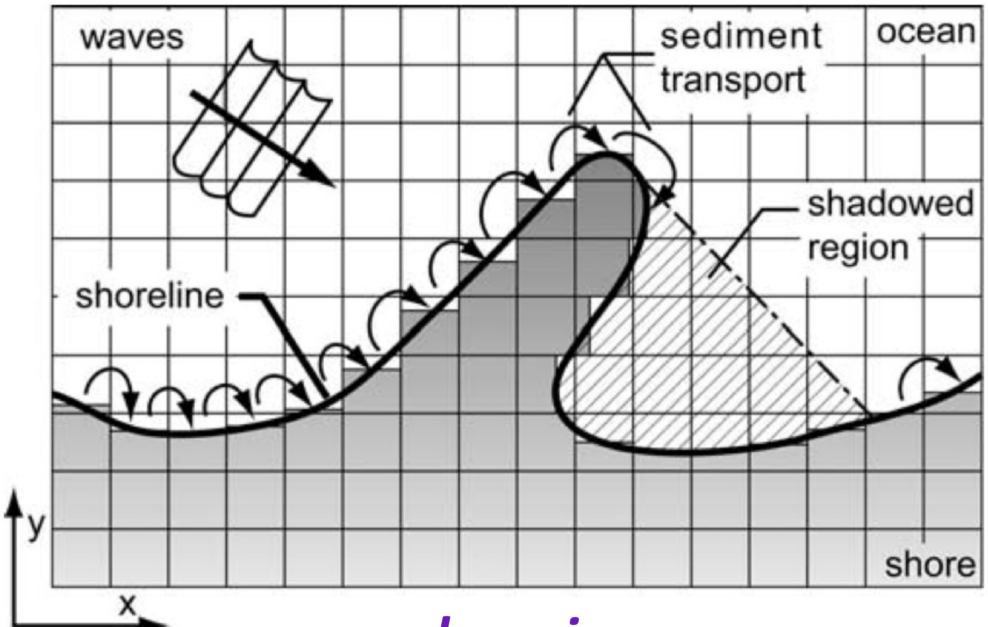
- River aggrades; becomes 'perched' above floodplain
- **Triggered by normalized super-elevation ratio** (Heller and Paola, 1996; Mohrig et al., 2000)
- **Avulsion successful if shorter (& steeper) new path** (Slingerland and Smith, 2004; Hoyal and Sheets, 2009)
- **Unsuccessful avulsion →** crevasse splay

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



Ratliff, Hutton, and Murray, 2018 *JGR-ES*

Coastline Evolution Model (CEM)

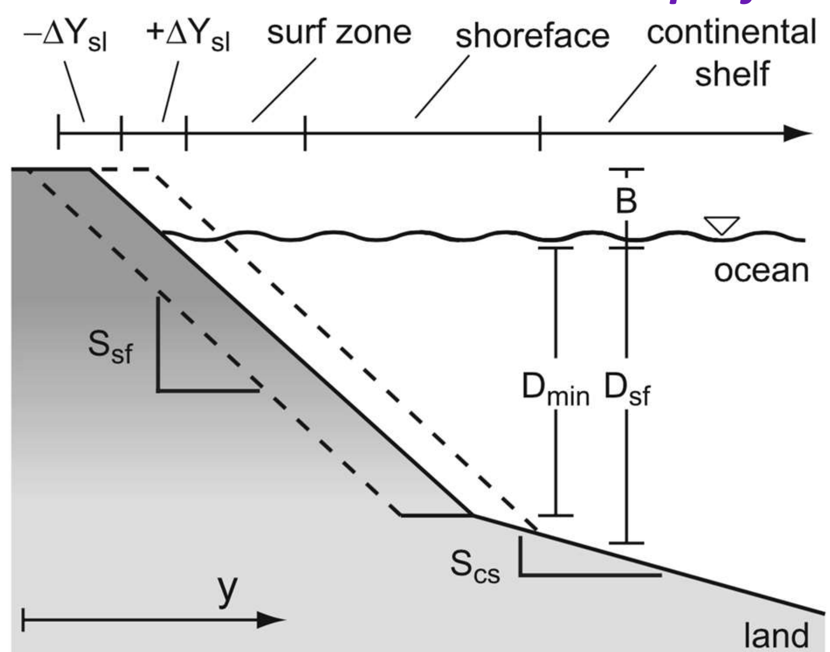


plan-view

Wave climate:

- A (0-1): Asymmetry
- U (0-1): Diffusivity

cross-shore profile

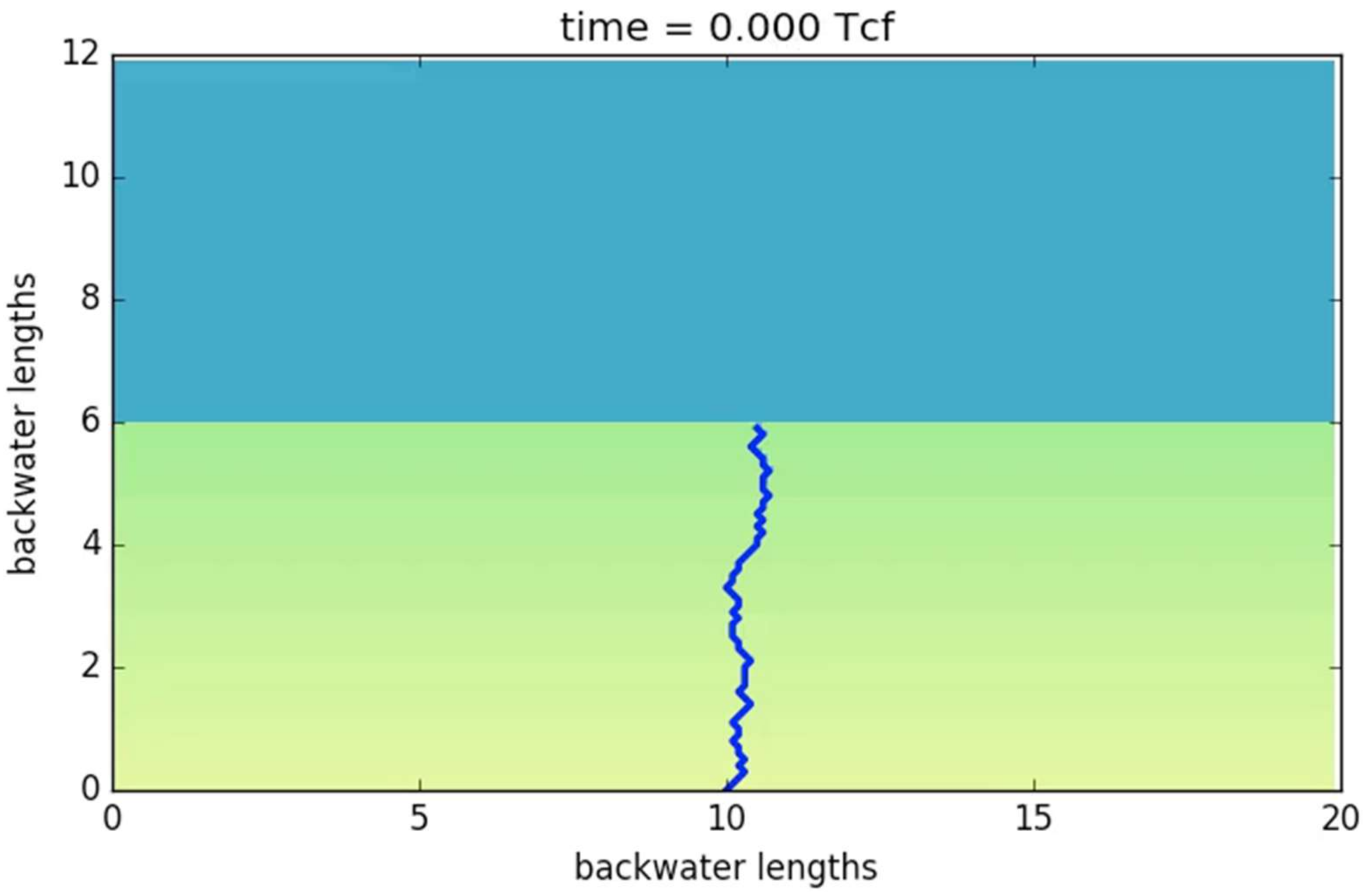


Ashton and Murray, 2006

- Conserves nearshore sediment
- Alongshore sediment transport
- Gradients → erosion & accretion
- Wave climate & shadowing

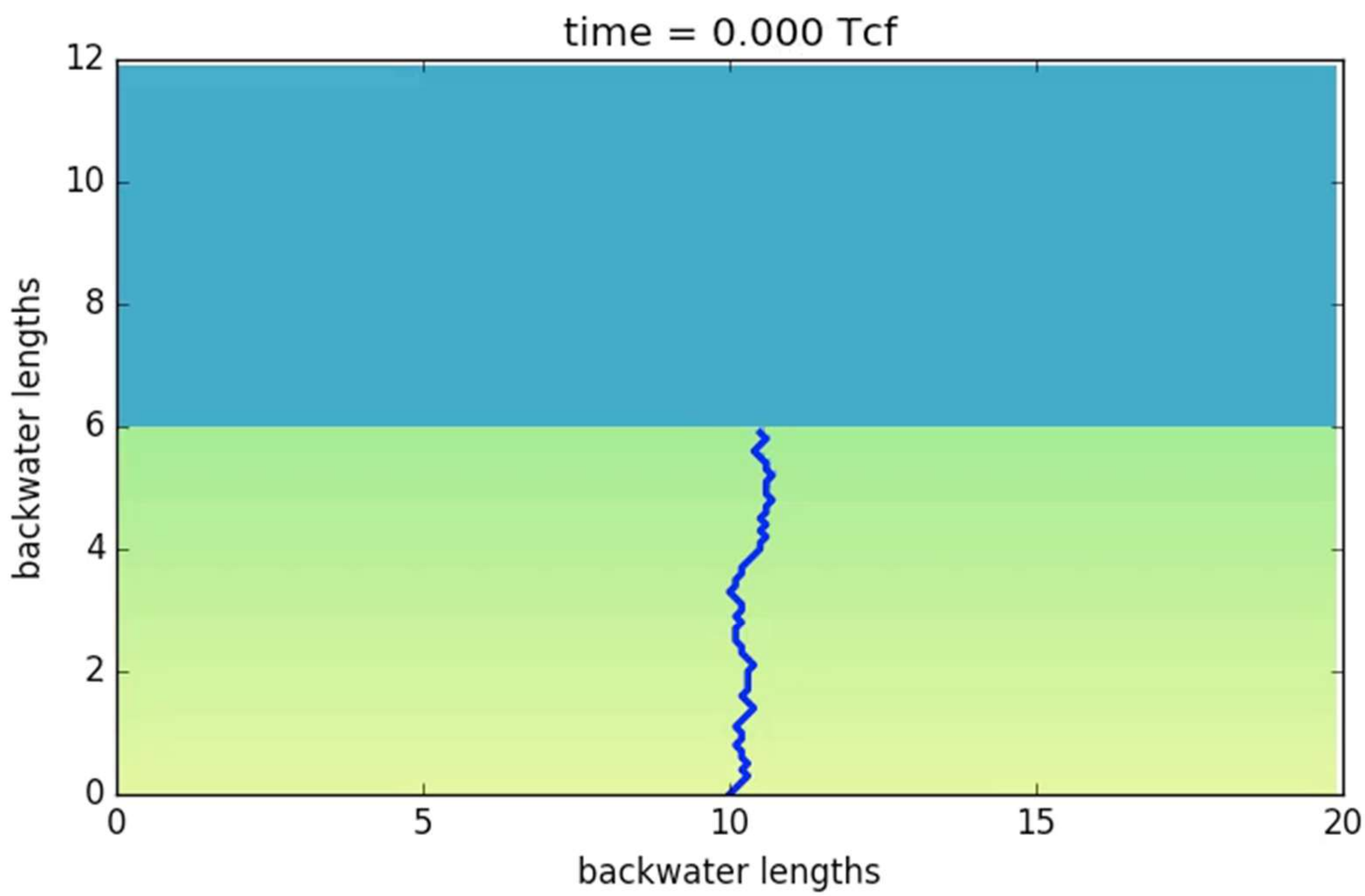
WH* = 0.1, A = 0.5, U = 0.3
No sea-level rise

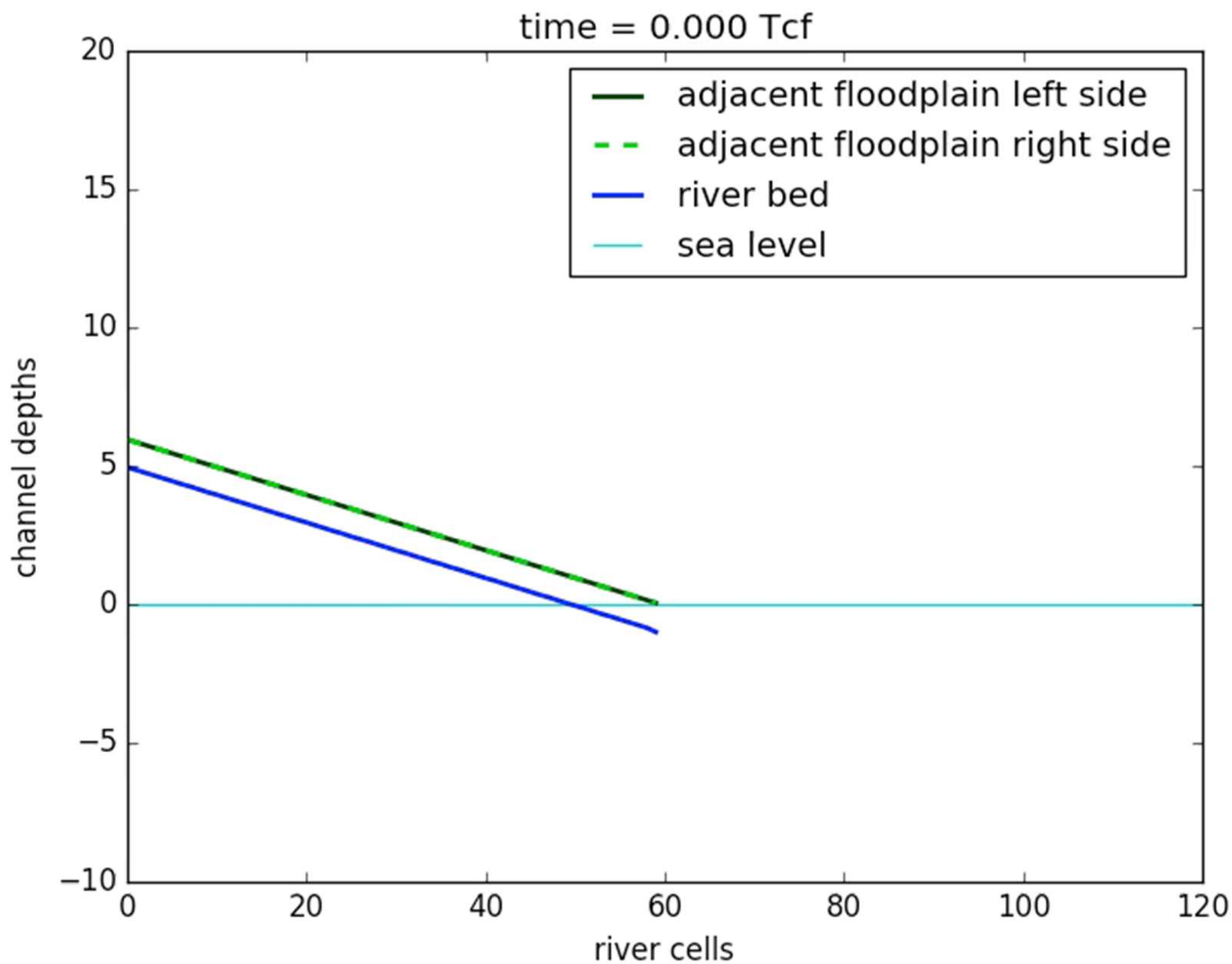
backwater length = channel depth / slope



WH* = 0.3, A = 0.5, U = 0.3
No sea-level rise

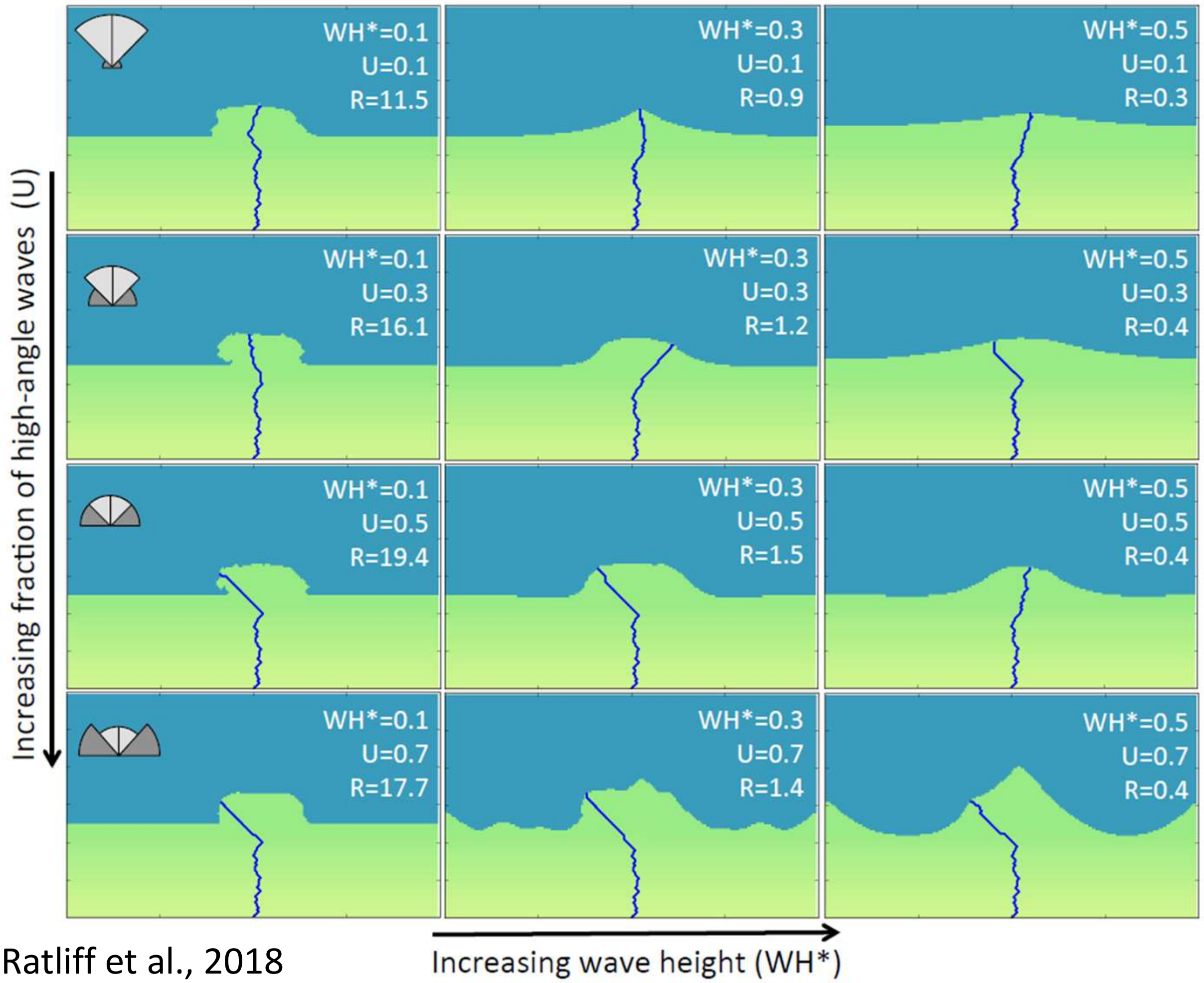
backwater length = channel depth / slope





Critical
SER = 1

Wave climate dictates delta morphology



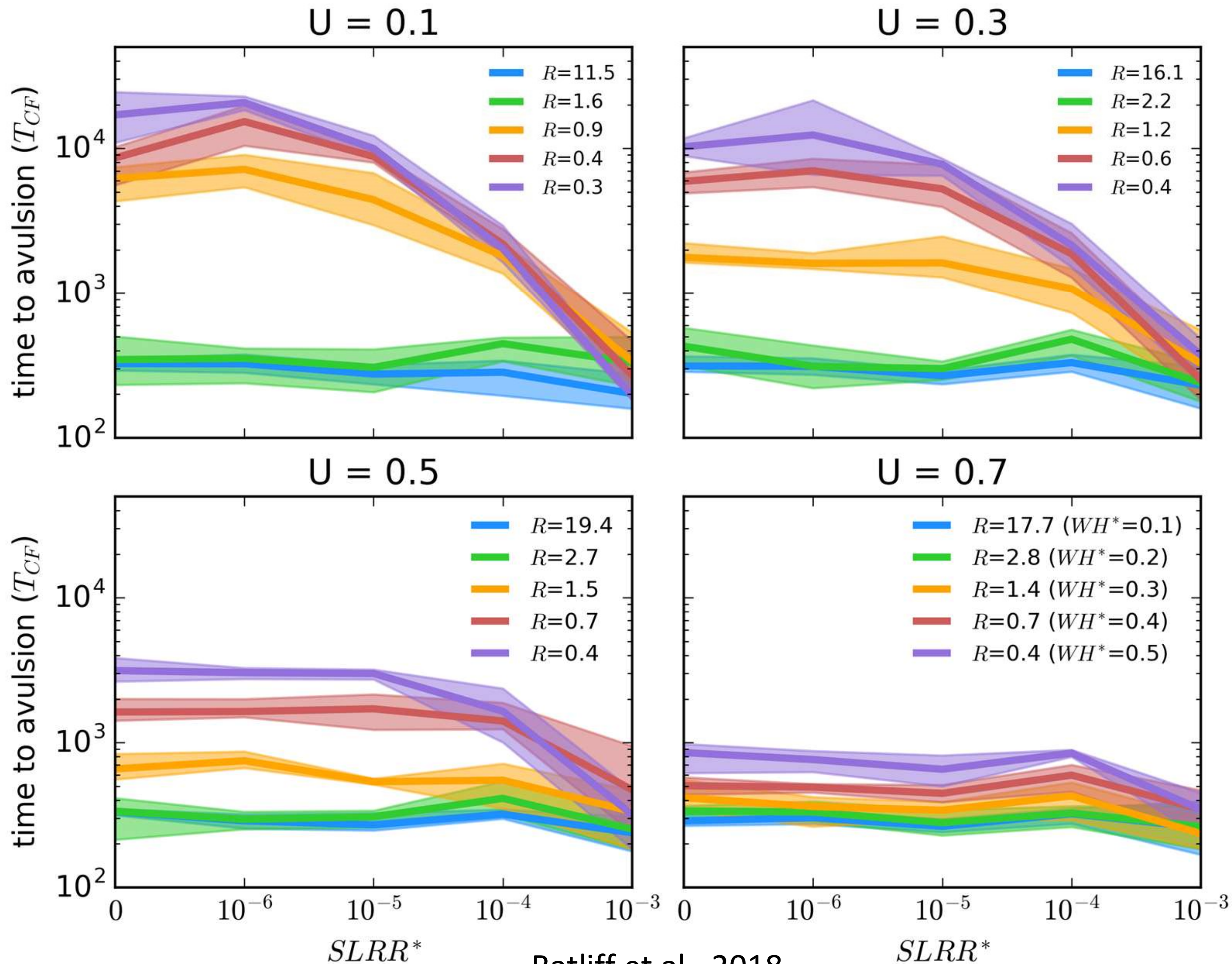
Ratliff et al., 2018

fluvial dominance ratio (Nienhuis et al., 2015):

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

Small WH* → Waves have little effect on shape

Large WH* →
- U < 0.5: flattening
- U > 0.5: cuspate



Ratliff et al., 2018

Avulsion Time Scales

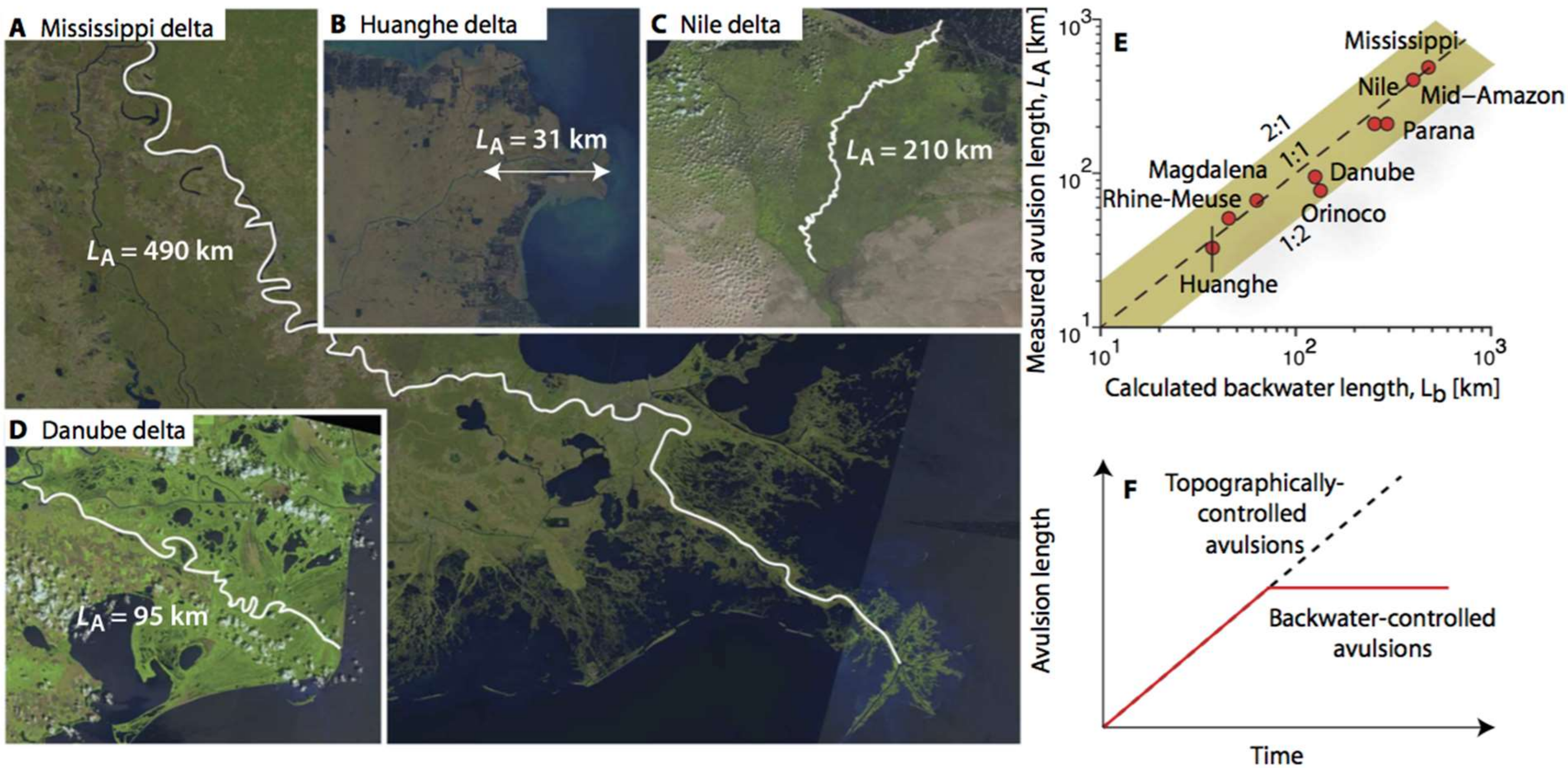
Bigger waves:

- Smaller U → avulsions take longer because river progradation inhibited
- Bigger U → avulsions occur more quickly

Smaller waves: wave climate diffusivity not as important

Higher SLRR* accelerates avulsions for diffusively wave dominated deltas, *but not for R > 1 or R < 1 with bigger U*

Avulsion Length Scale

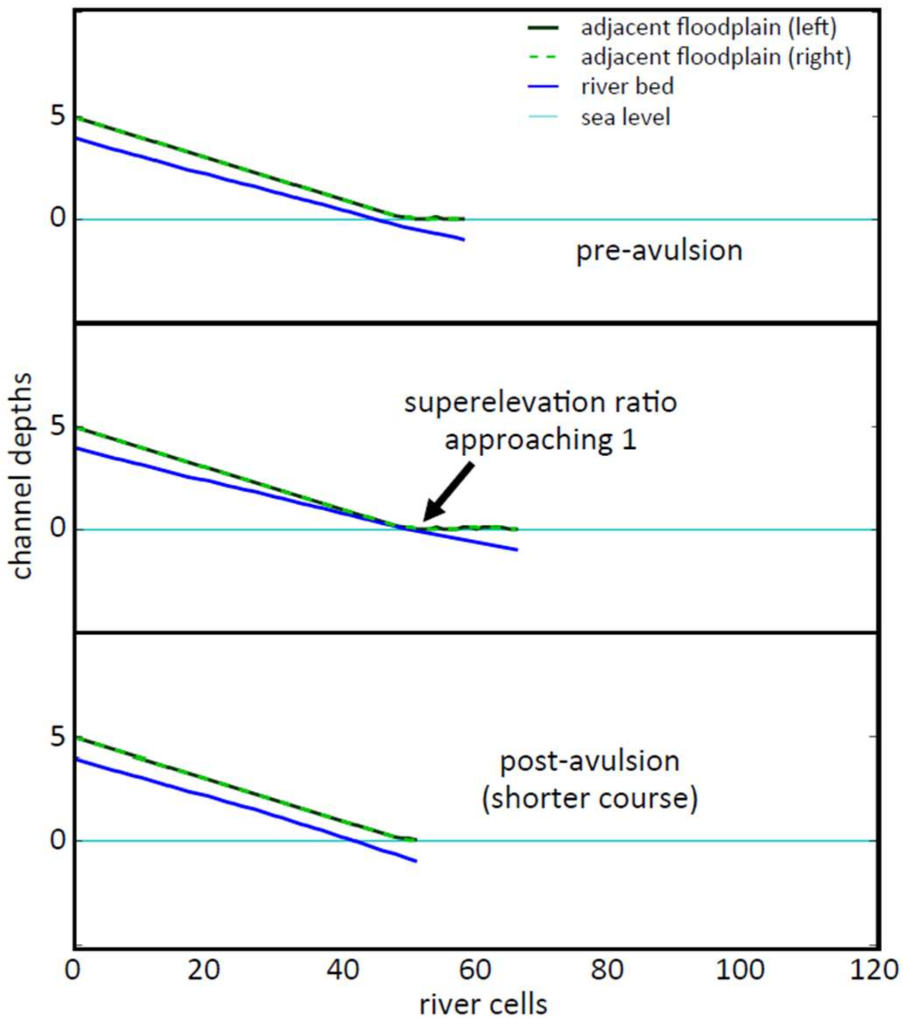


Ganti et al., 2016

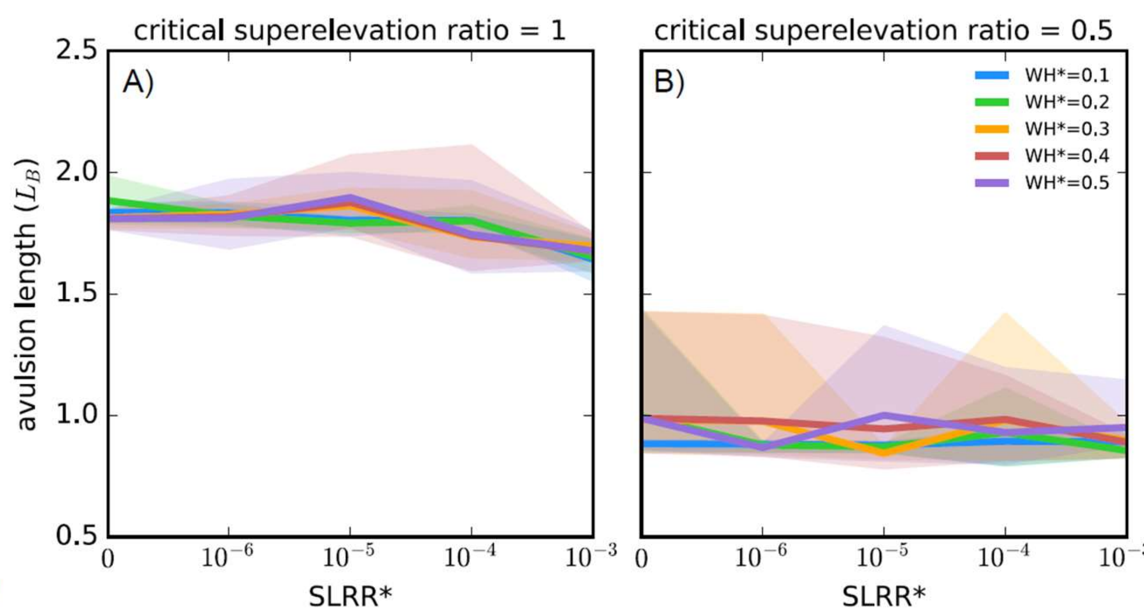
Most avulsions (in nature and lab) scale with backwater length

$L_B \approx$ channel depth / channel slope

RAFEM-CEM Avulsion Length Scale

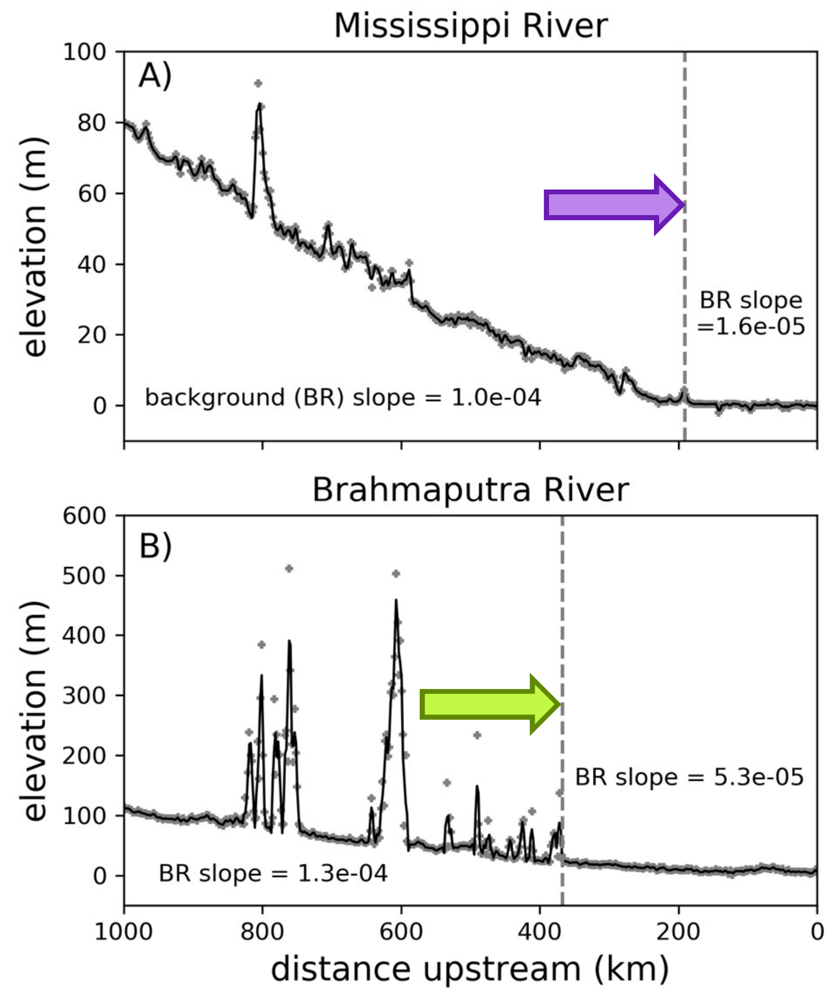


- River becomes superelevated most quickly at floodplain slope break
- *SER* sets preferred avulsion length, L_A
- Preferential L_A is geometrically-driven



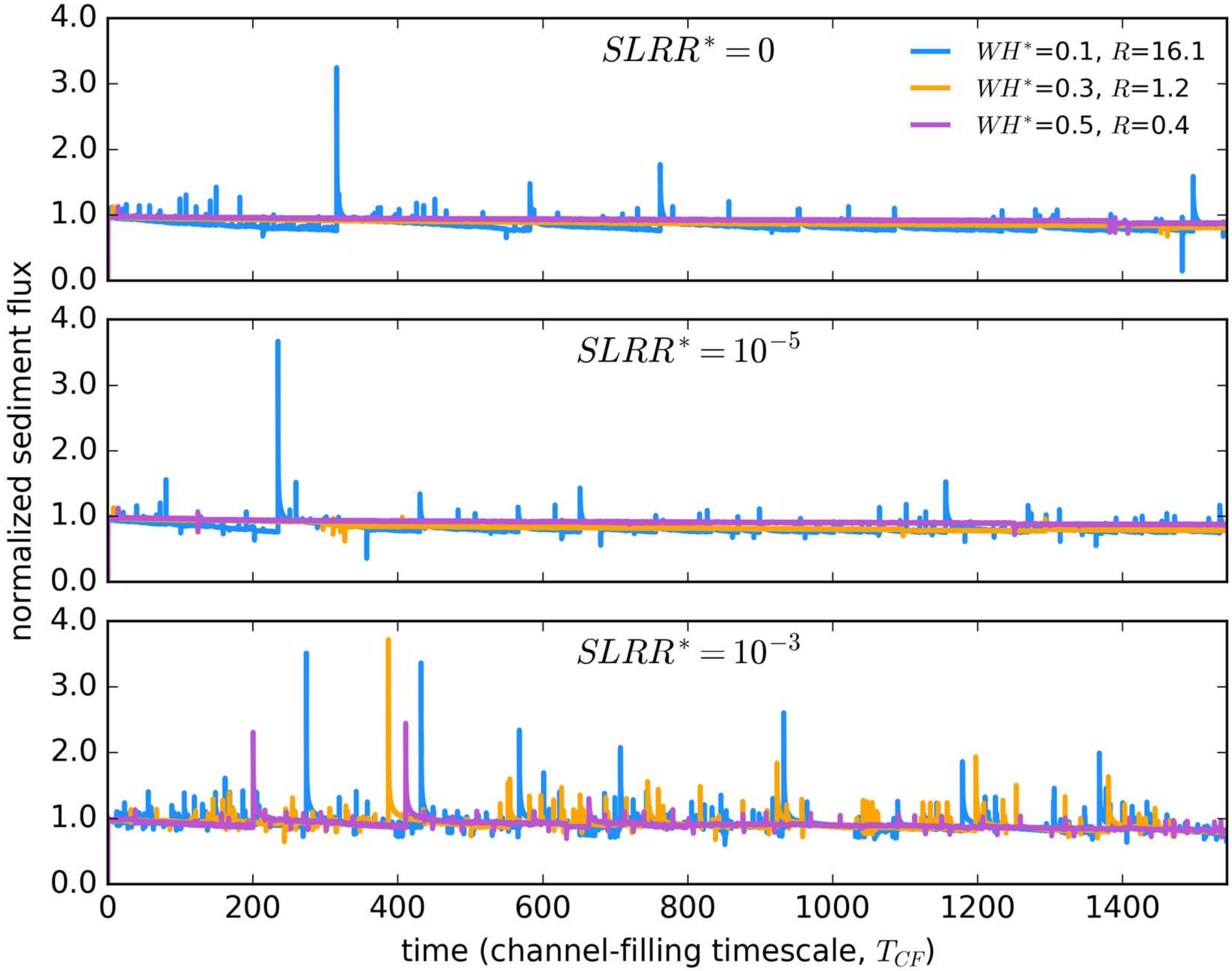
Is this geometry realistic?

- Extracted ‘distal’ floodplain elevation profiles from rivers (using 15km buffer)
- Recent major avulsions:
  - Lafourche avulsion site
  - Bengal Basin upper delta plain
- Floodplain slope upstream of avulsion node greater than downstream slope
  - Mississippi River: > 6x
  - Brahmaputra River: ~2.5x
- Floodplain diffuses more slowly than river profile? (like in RAFEM)

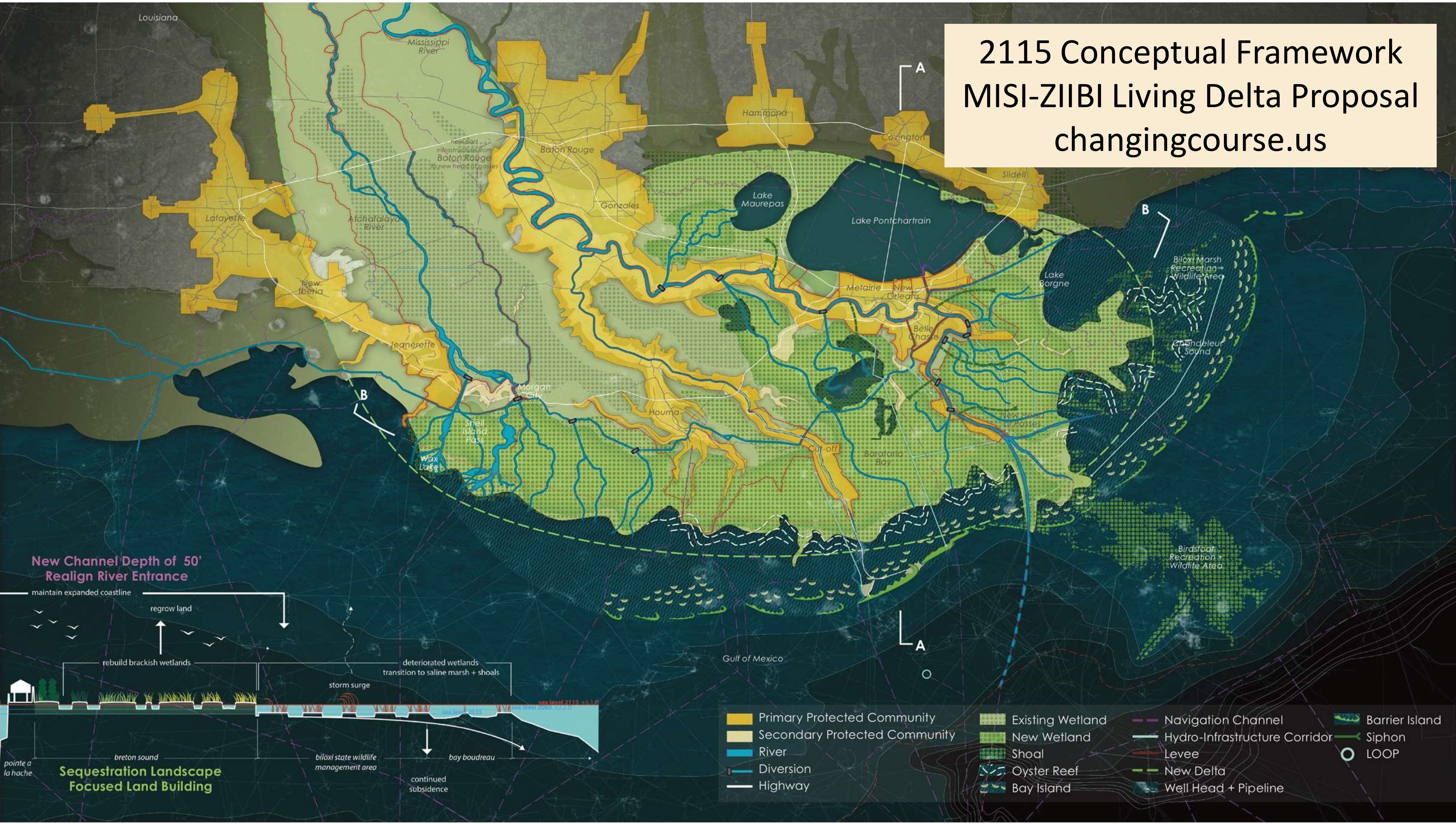


Autogenic Variability

- Steady external forcings
- Storage and release cycles drive sediment delivery to coast
- Impacts delta stratigraphy
- Management implications



2115 Conceptual Framework
MISI-ZIIBI Living Delta Proposal
changingcourse.us



Thank You

https://github.com/katmratliff/rafem

https://csdms.colorado.edu/wiki/Model:RAFEM

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