Morphodynamics of Barrier-Inlet Systems: The Battle between Waves and Tide

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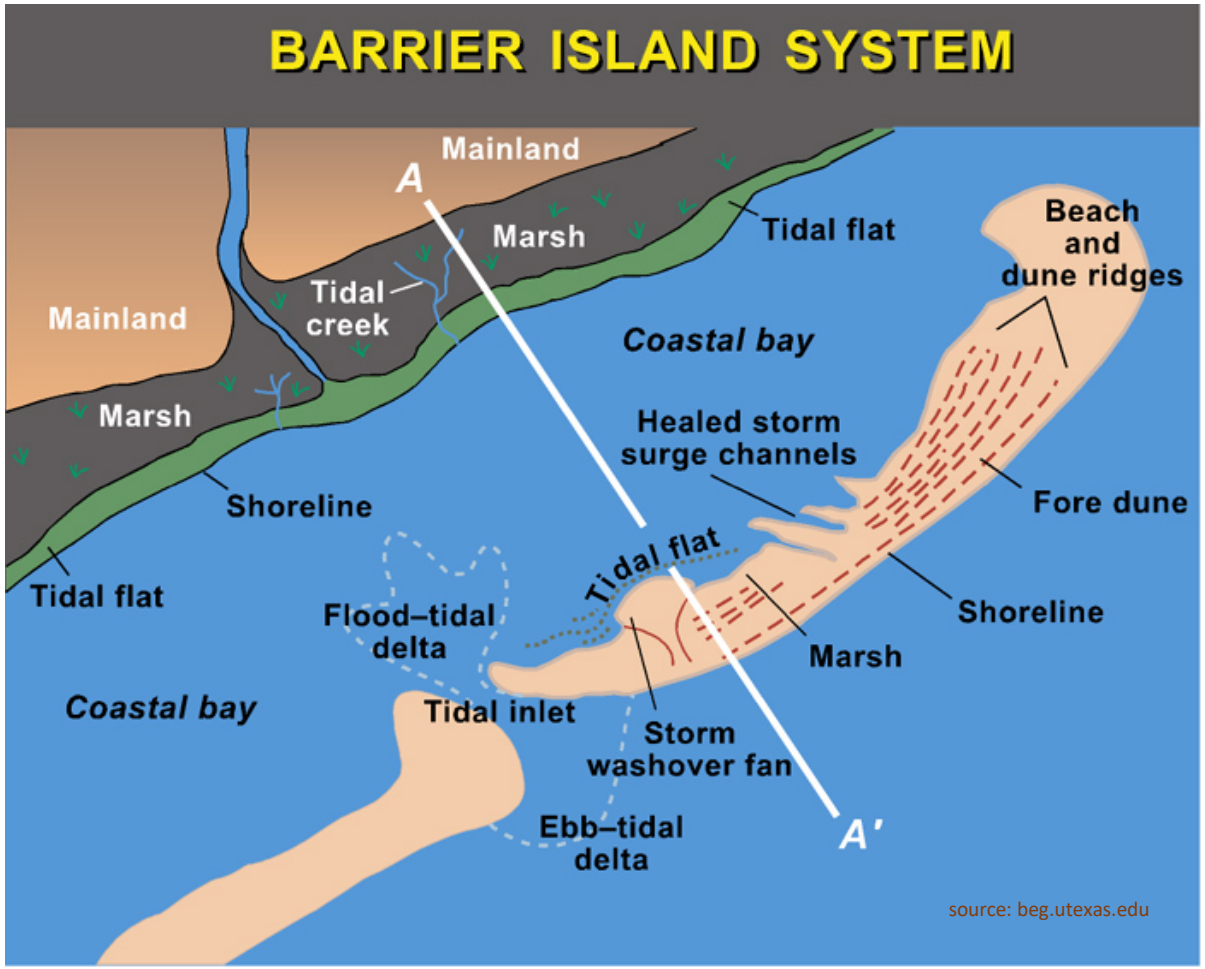
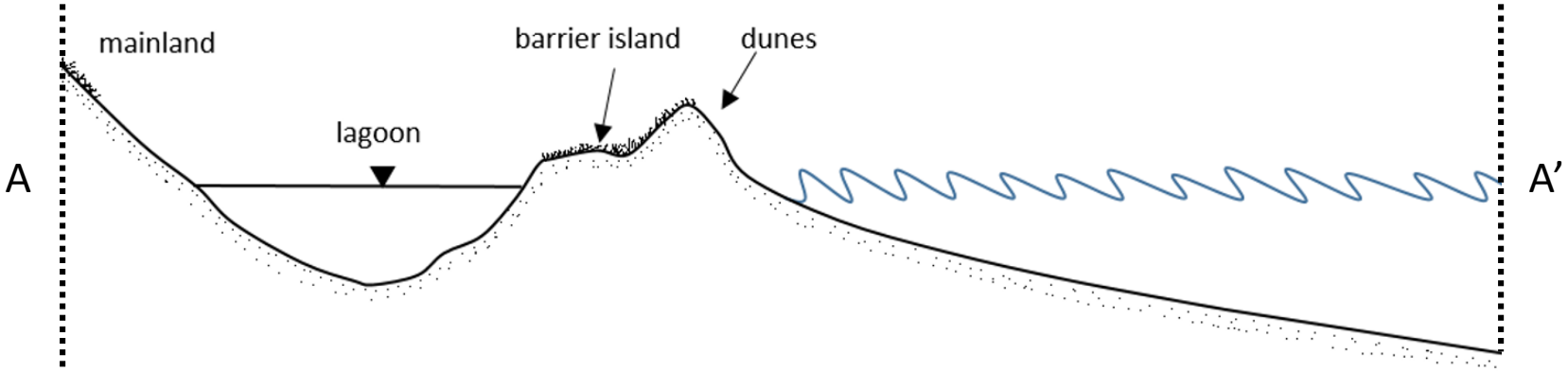


- Geomorphic features:
  - barrier island
  - tidal inlets
  - back-barrier lagoon
  - flood/ebb tidal deltas



Decadal dynamics of barrier-inlet system:

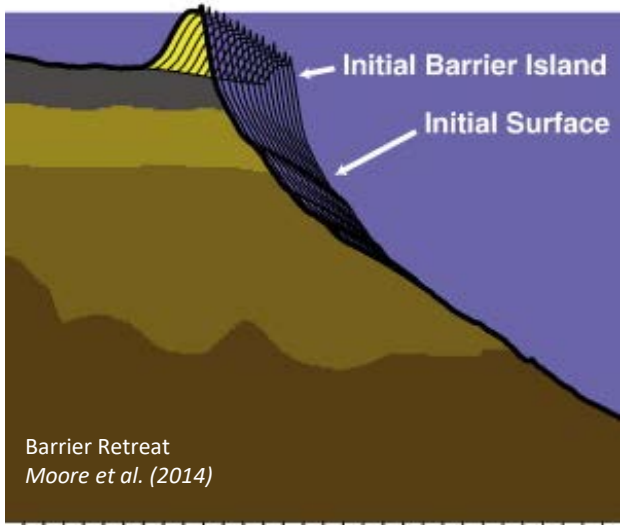
Year 1984 - 2016

- Rapid morphological evolution over time.
- Controlling factors:
  - Tides
  - Waves
  - River discharge
  - Geology
  - Sea level rise

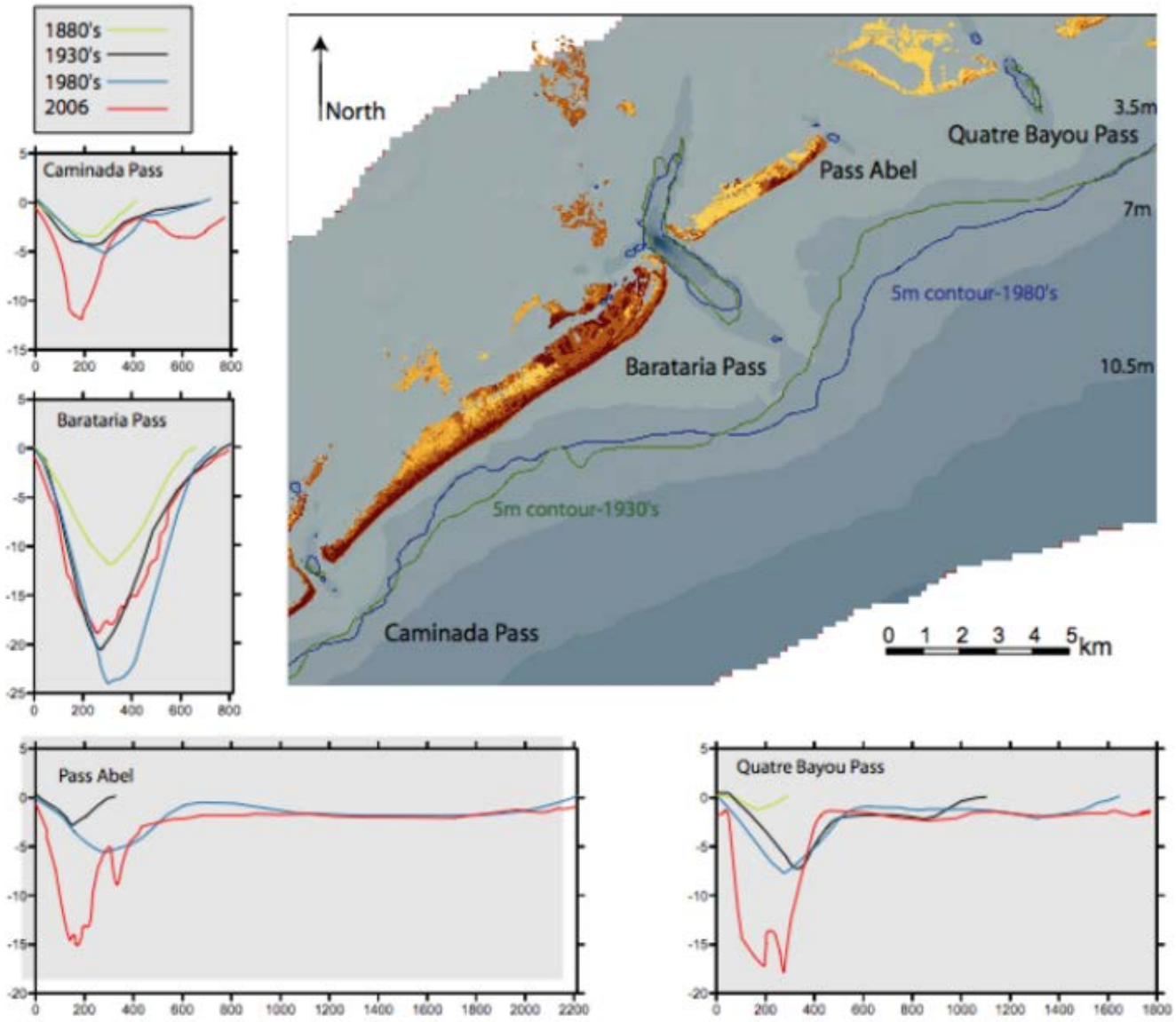
Barrier-inlet system evolution

- Inlet Dynamics
    - Evolution of Cross-sectional area
    - Multiple channel formation

- Barrier Dynamics
    - Barrier retreat due to sea level rise



Change of cross-sectional area of inlets over time.

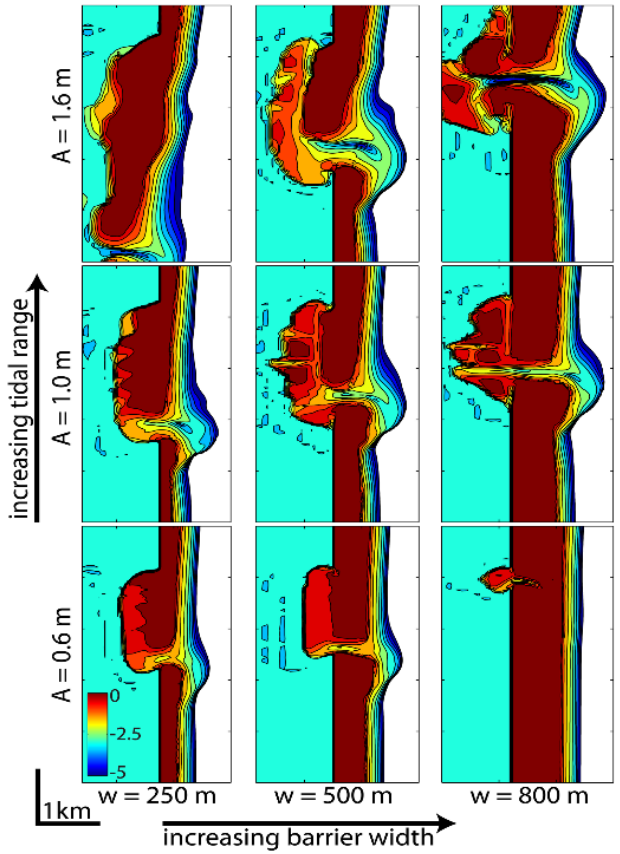


Fitzgerald et al. (2006)

Barataria Bay, Louisiana

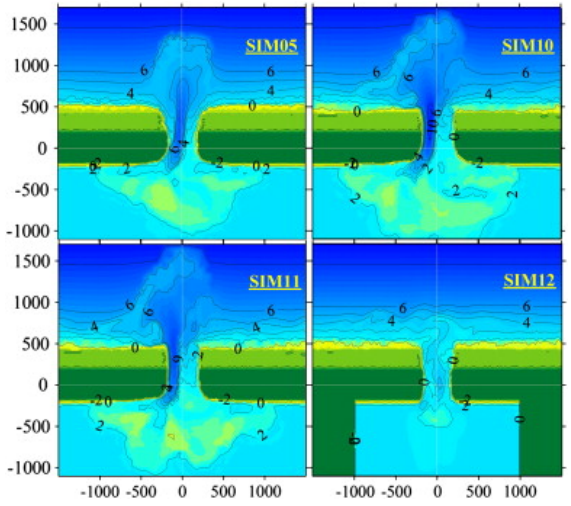
Numerical Modeling of Inlet-Flood/Ebb Delta System

Barrier width and tidal range
(7 years)



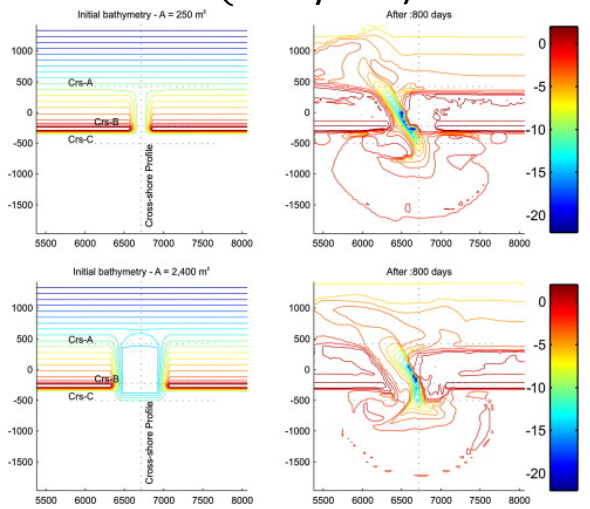
(Nienhuis & Ashton 2016)

2D model, tides and waves
(≈ 3 years)



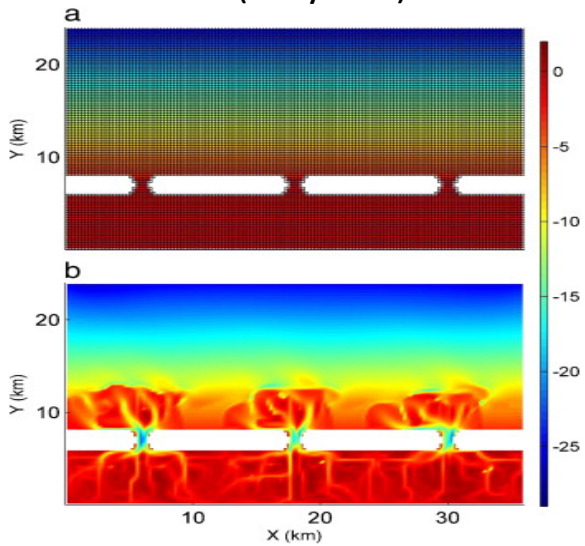
(Nahon, et al., 2012)

Tidal inlets towards equilibrium
(≈ 2 years)



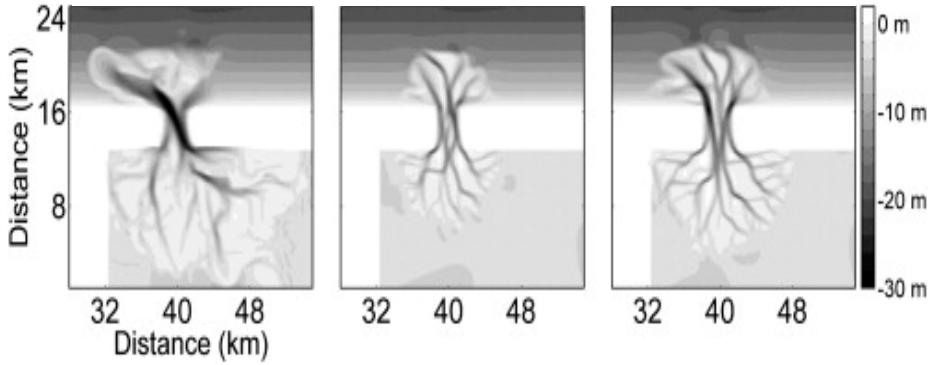
(Tran, et al., 2012)

Multiple inlet-barrier system
(60 years)



(Yu, et al., 2014)

Different transport formula
(> 50 years)

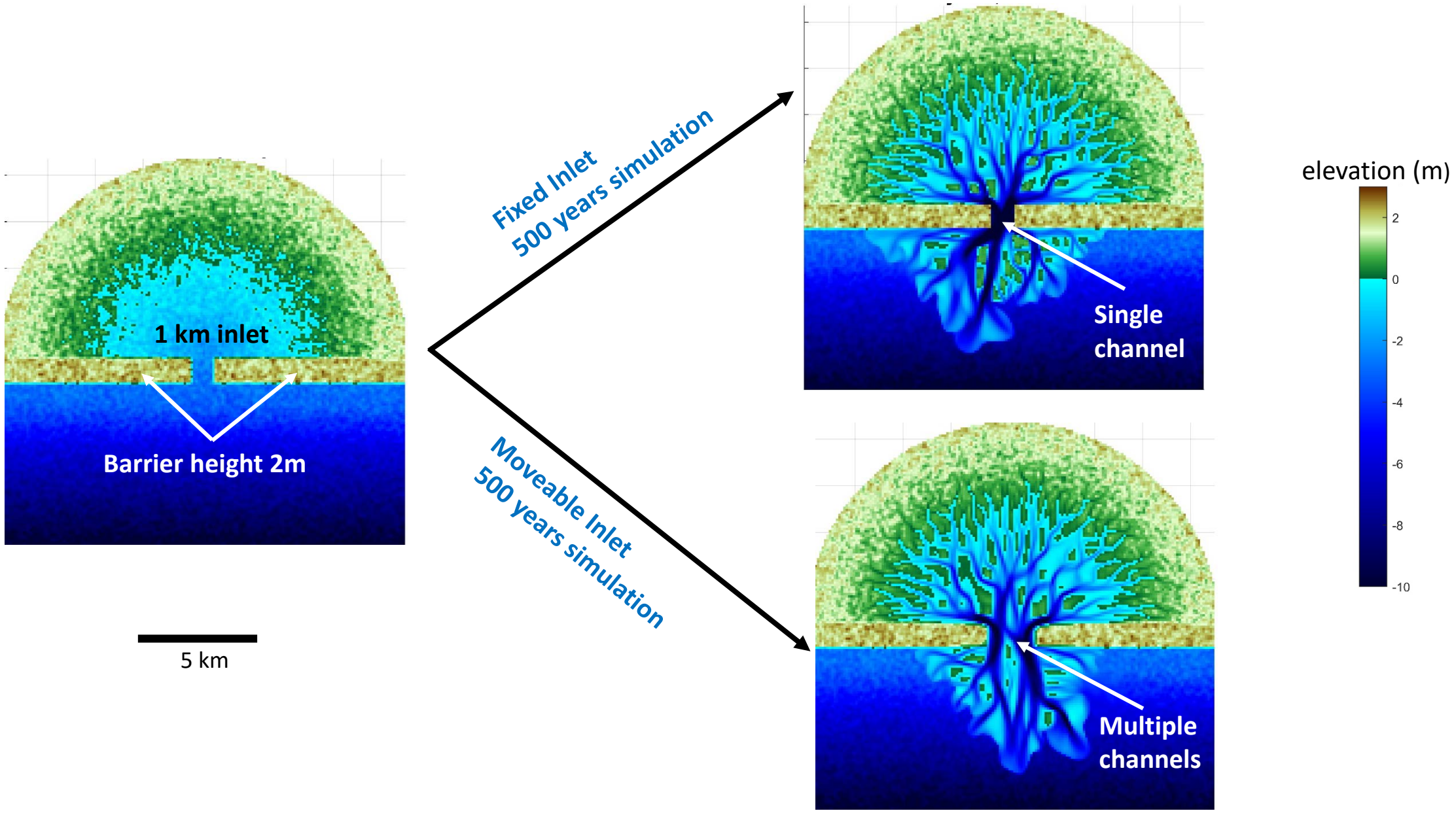


(Dissanayake, et al., 2009)

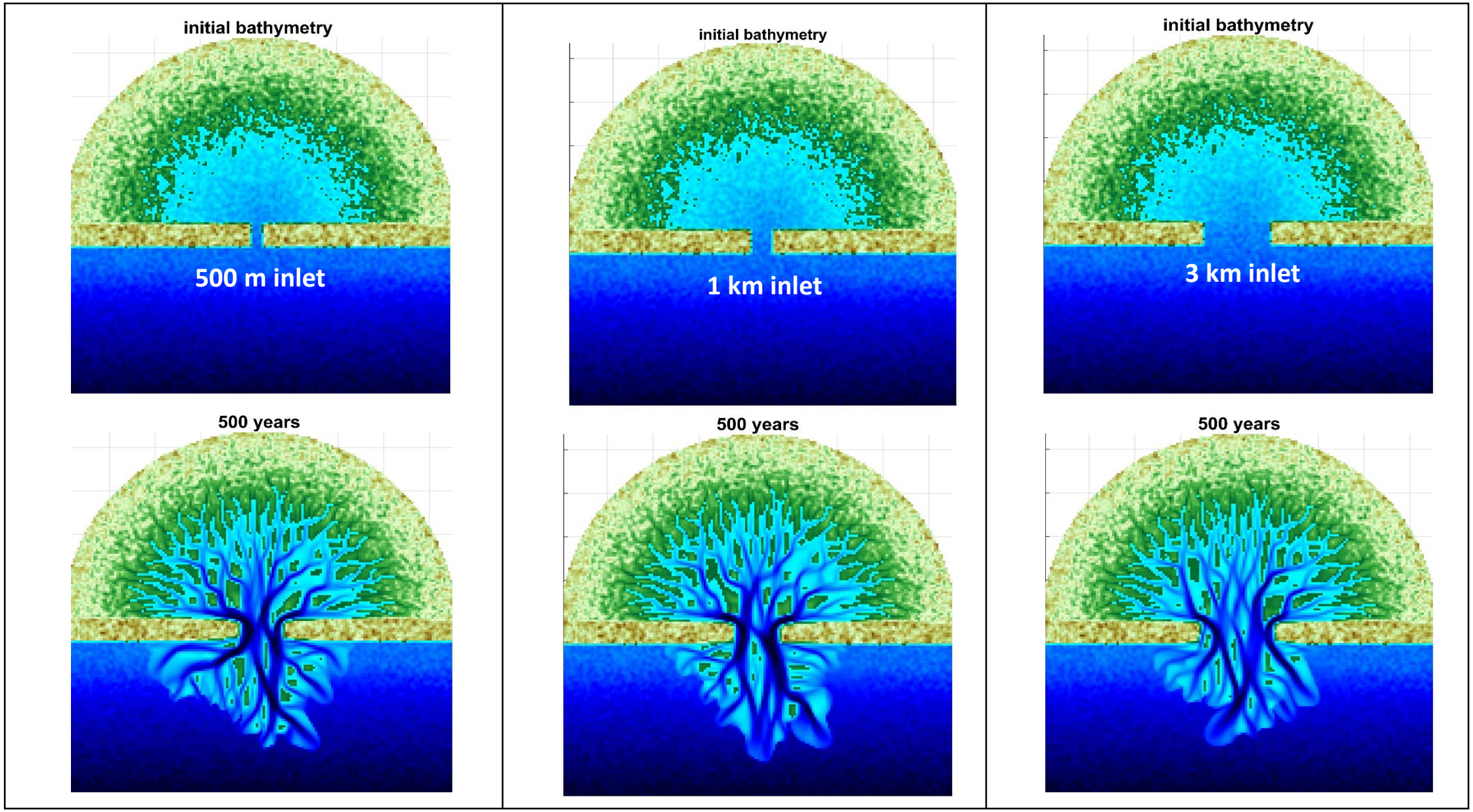
Inlet Evolution: what is left to understand?

- Long term evolution of Inlets
    - What causes the inlet to widen?
    - Will the system eventually reach the equilibrium configuration irrespective of the initial geometry?

Modeling with Delft3D: Fixed and moveable barrier with one inlet (Tidal Range 2 m)



Modeling with Delft3D: Variation of the (moveable) inlet width



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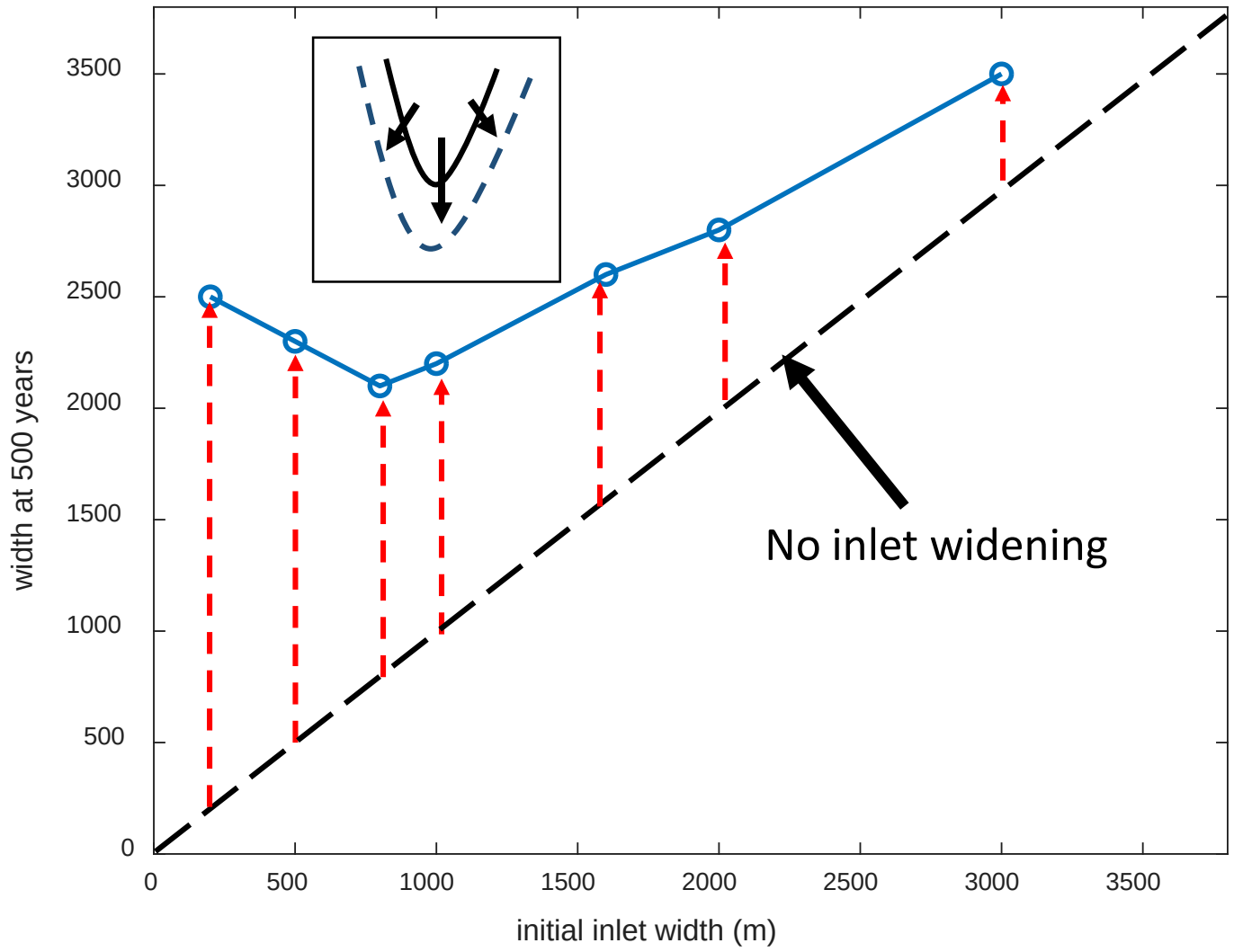
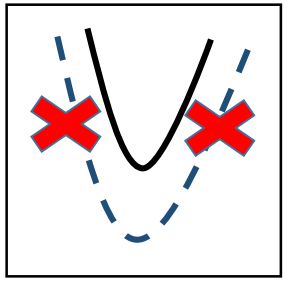
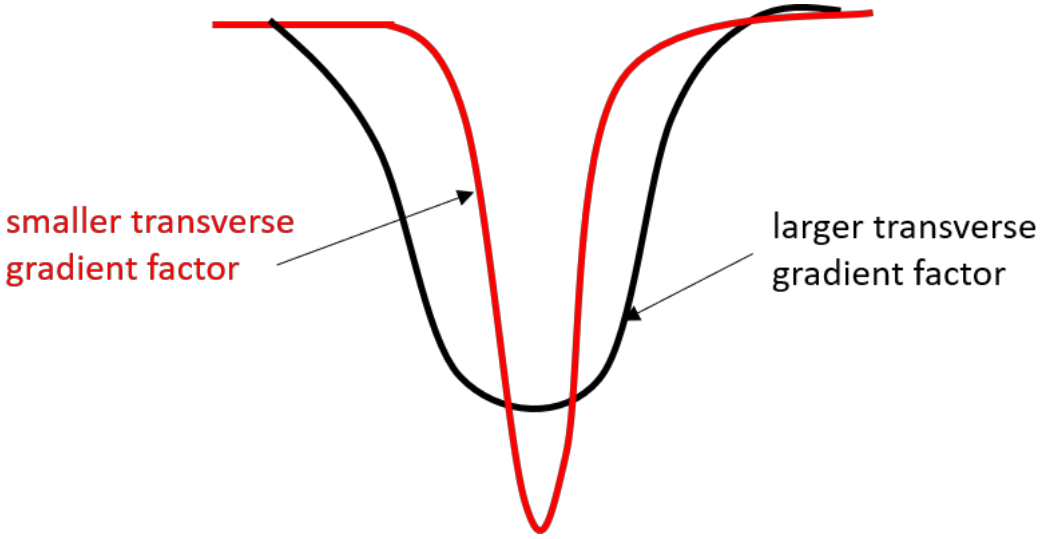


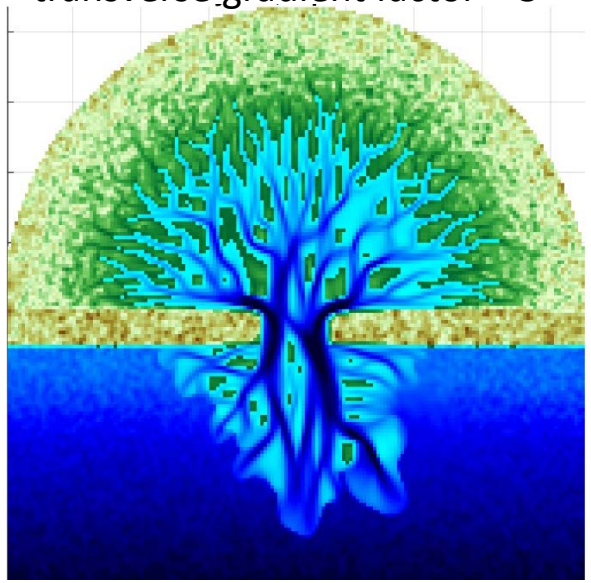


Equilibrium condition

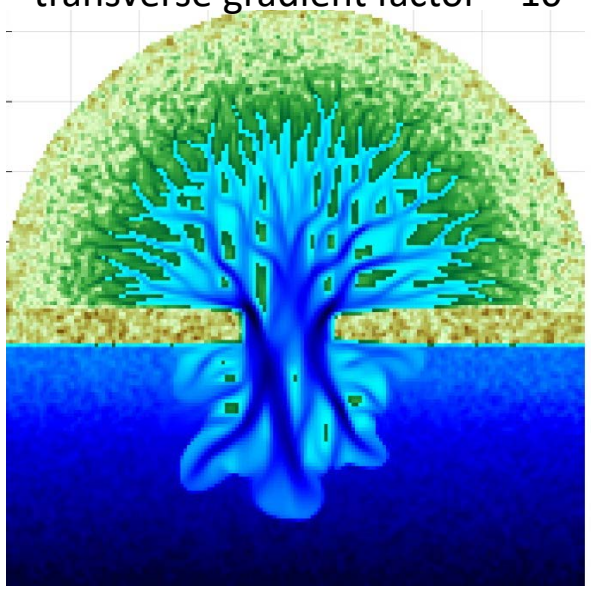
Modeling with Delft3D: Variation of transverse bed gradient factor



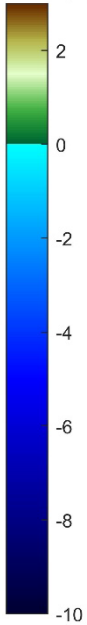
transverse gradient factor = 5



transverse gradient factor = 10

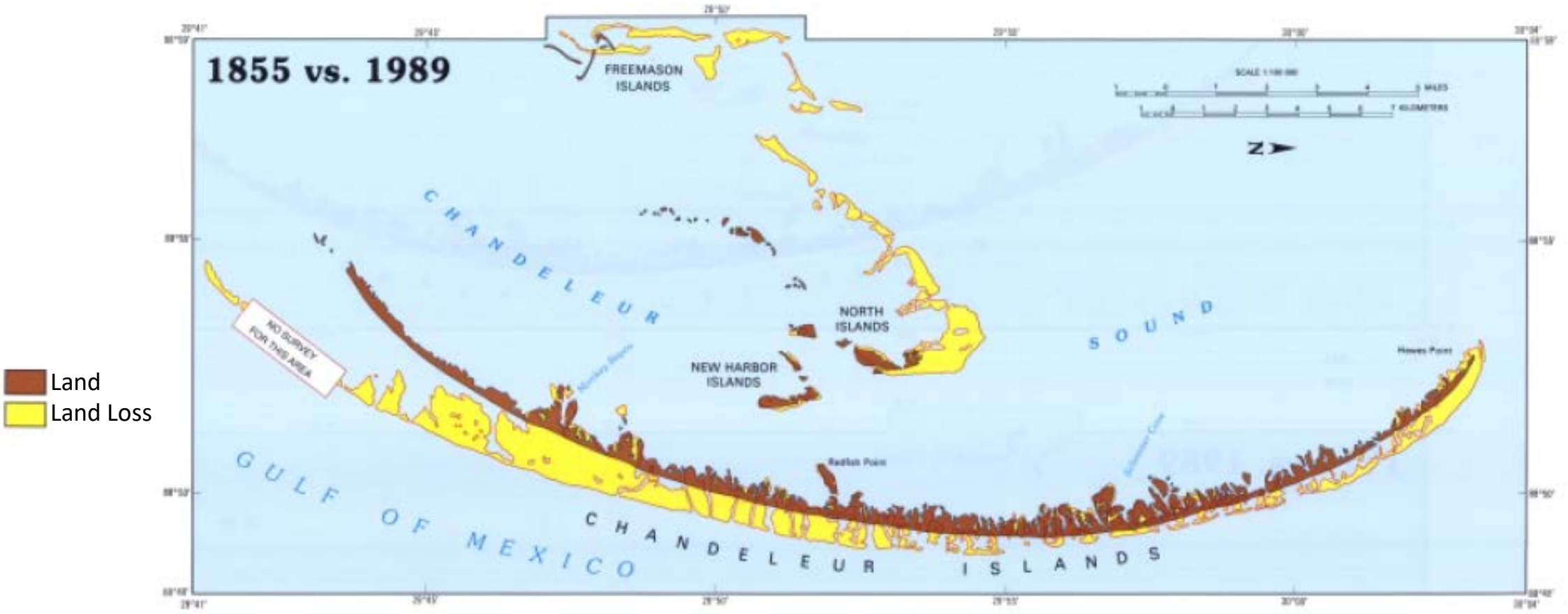


elevation (m)



5 km

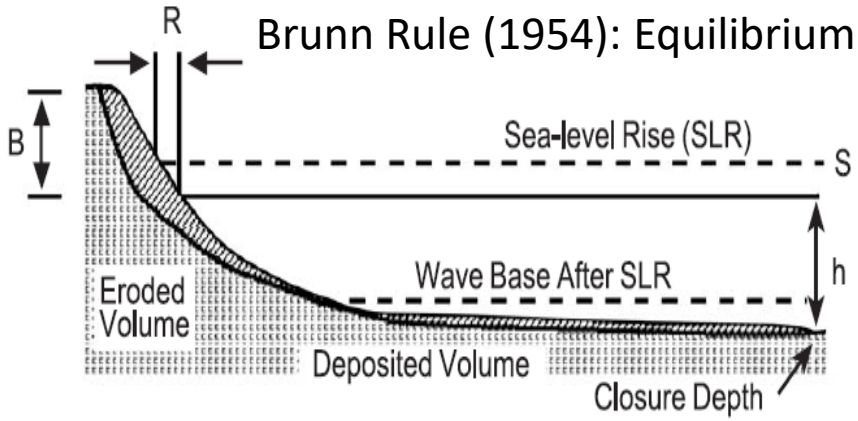
Retrogradation of Chandeleur Island, Louisiana



http://www.coast2050.gov/reports/barrieratlas.htm

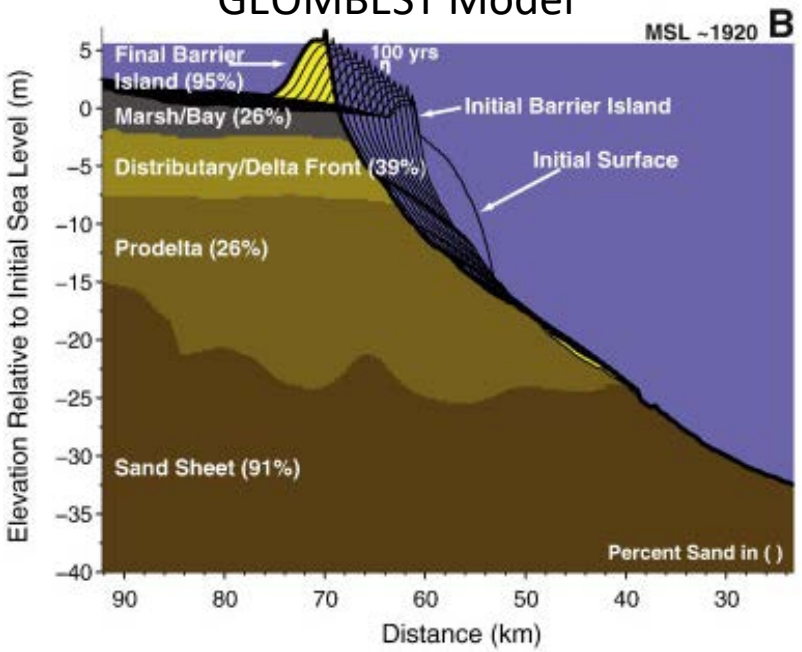
Numerical Modeling of Barrier Retreat with SLR

Brunn Rule (1954): Equilibrium Profile



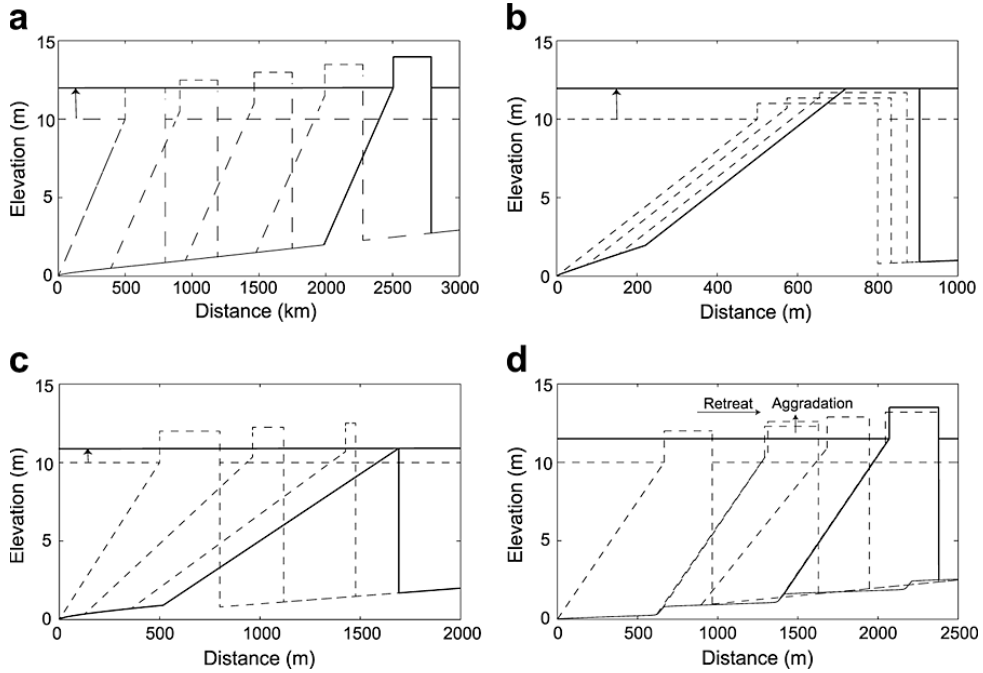
Collected from Cooper & Pilkey (2004)

GEOMBEST Model



Moore et al. (2014)

Rollover, Drowning and Discontinuous Retreat

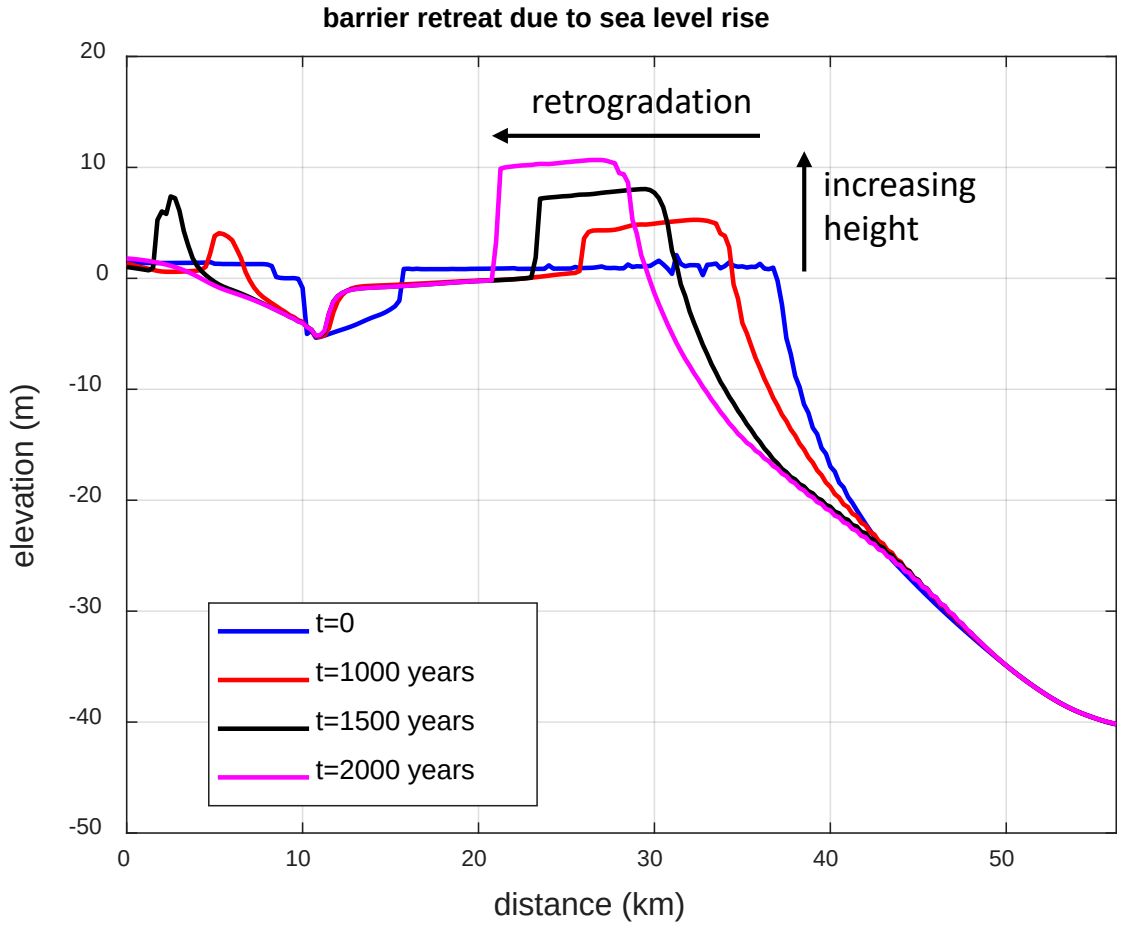


Lorenzo-Trueba & Ashton (2014)

Barrier Evolution

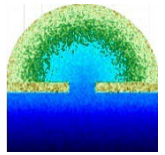
- Barrier retreat and sea level rise
    - How will the barriers retreat landward in 2-D?

Modeling with Delft3D: 1D Model (barrier retreat with SLR)



- Barrier tends to retreat landward due to sea level rise (retrogradation).

Challenges to Model with Delft3D:

- (semi)fixed geometry 
- Computation time 

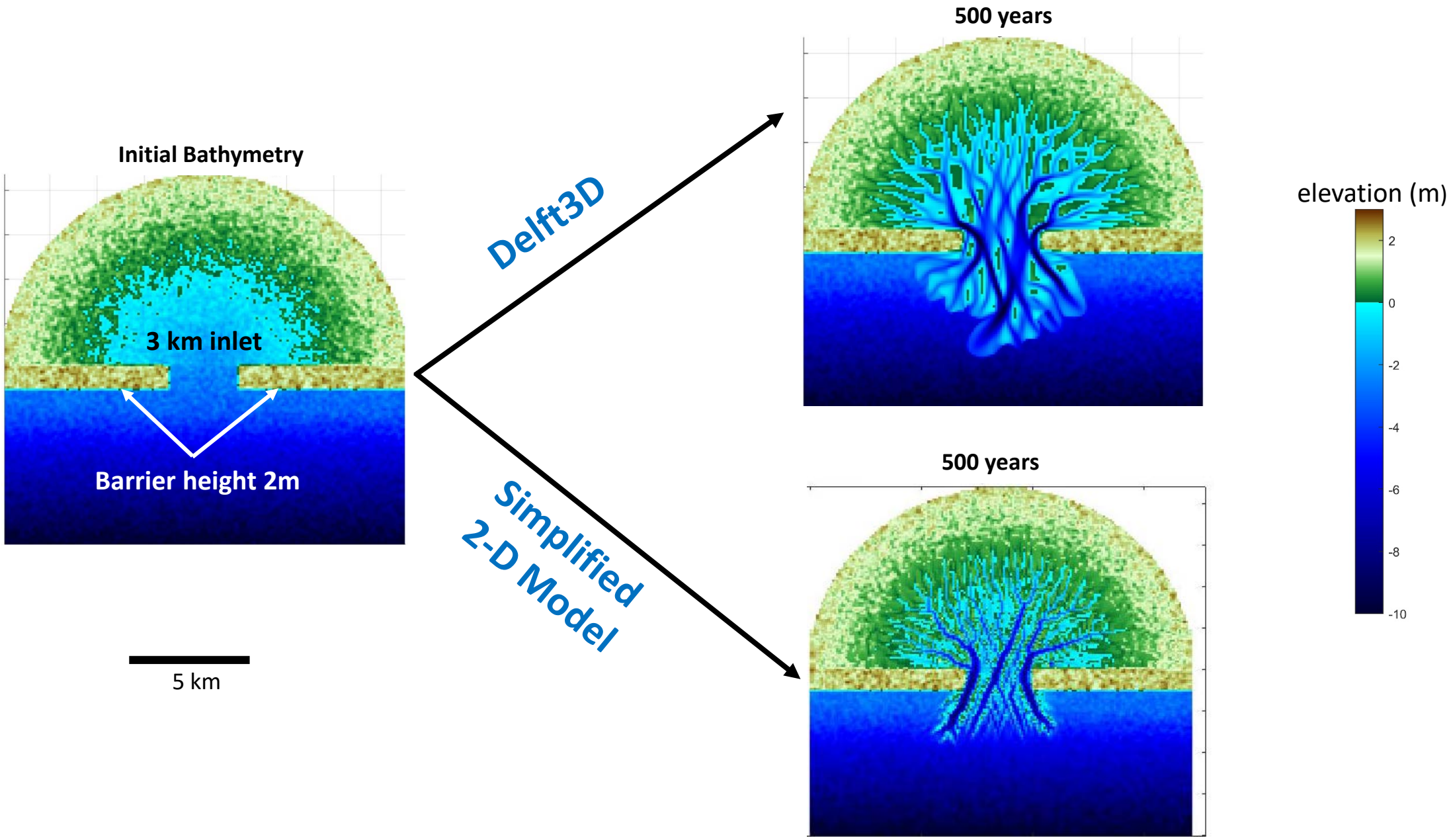
Different approach:

- Simplified 2D model
- Tide averaged model to investigate long-term effect

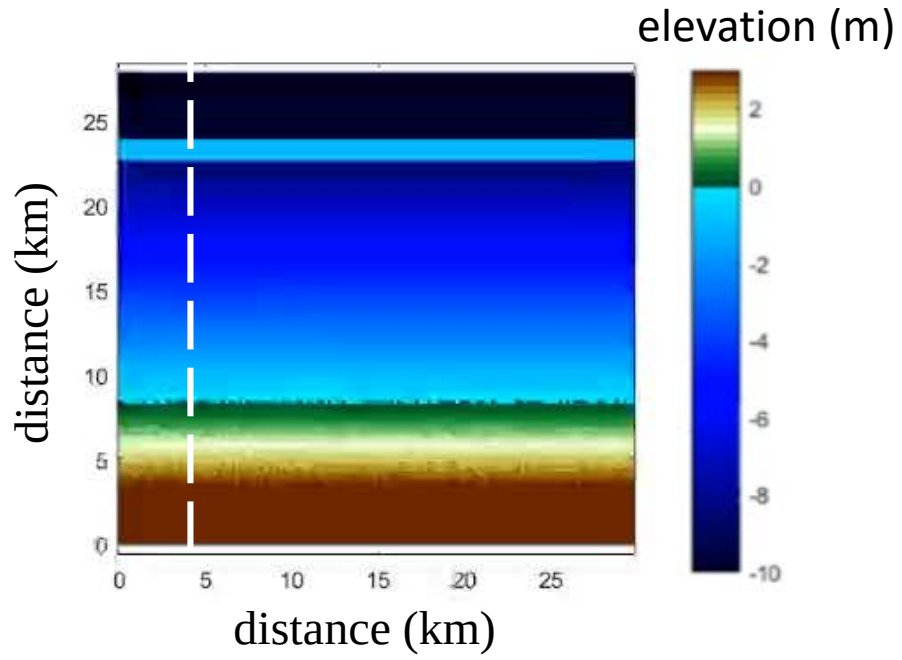
Simplified 2-D Model

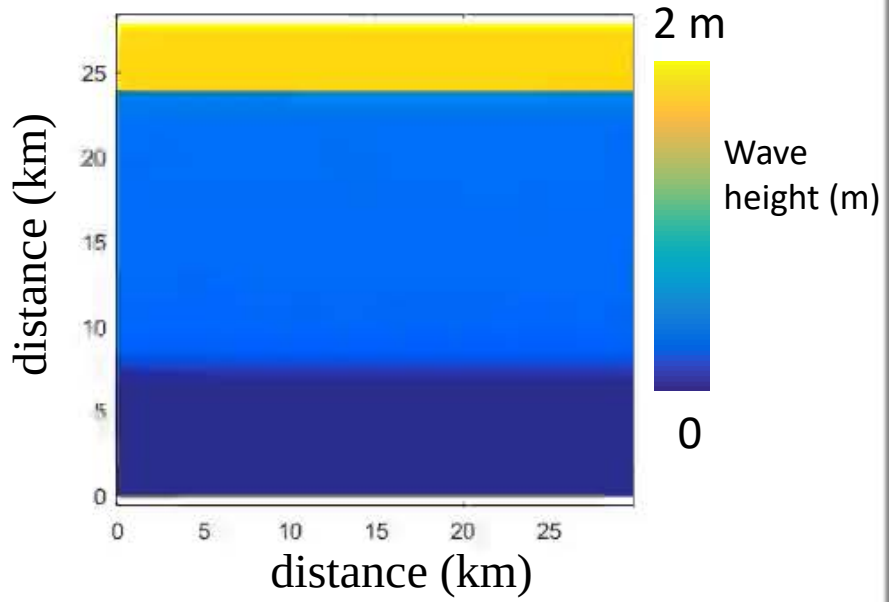
- Swell Waves: Spectral waves (similar to SWAN model)
- Sea Waves: Fetch & wind speed and direction
- Bed Morphodynamics
  - Tide & Surge: Current Induced erosion, tidal dispersion
  - Wave driven onshore, downslope and longshore components

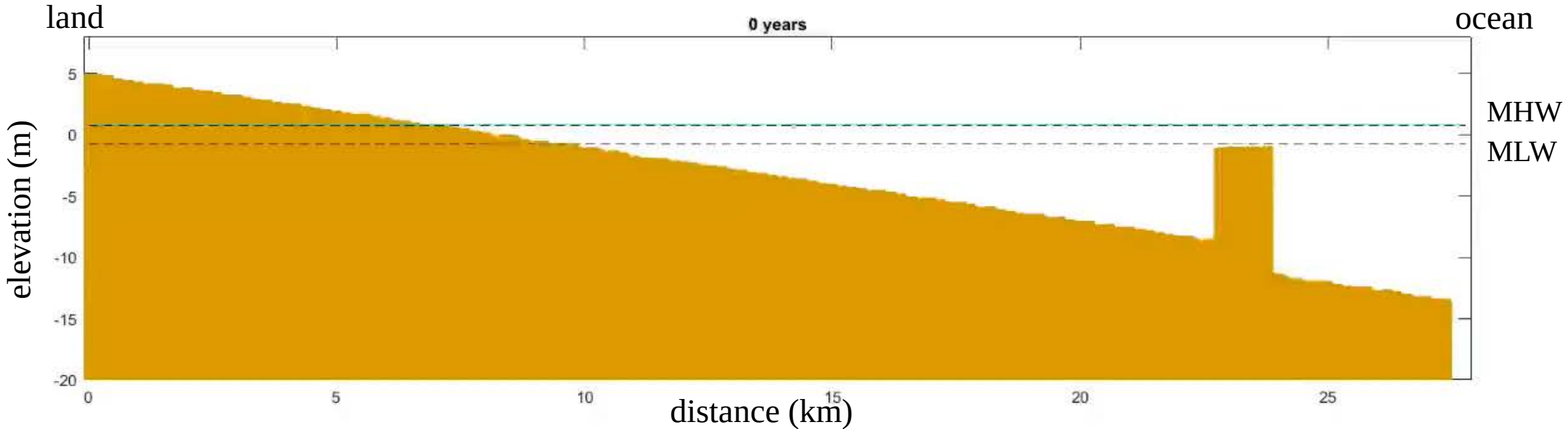
Comparison of Results: Delft3D vs Simplified 2D Model



tides (range=1.5m) + multidirectional swells + surges + sea waves

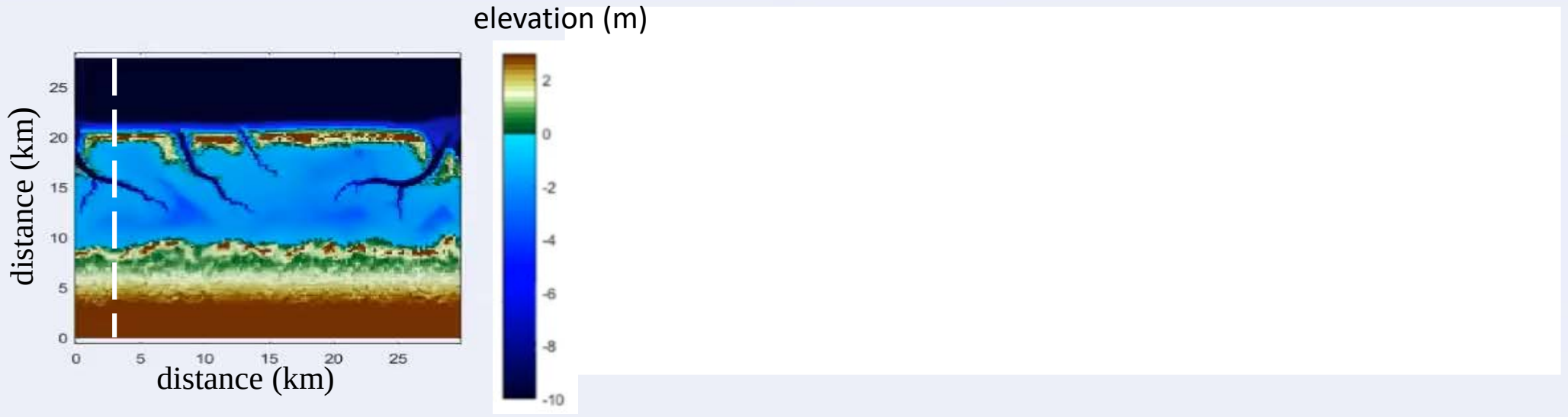


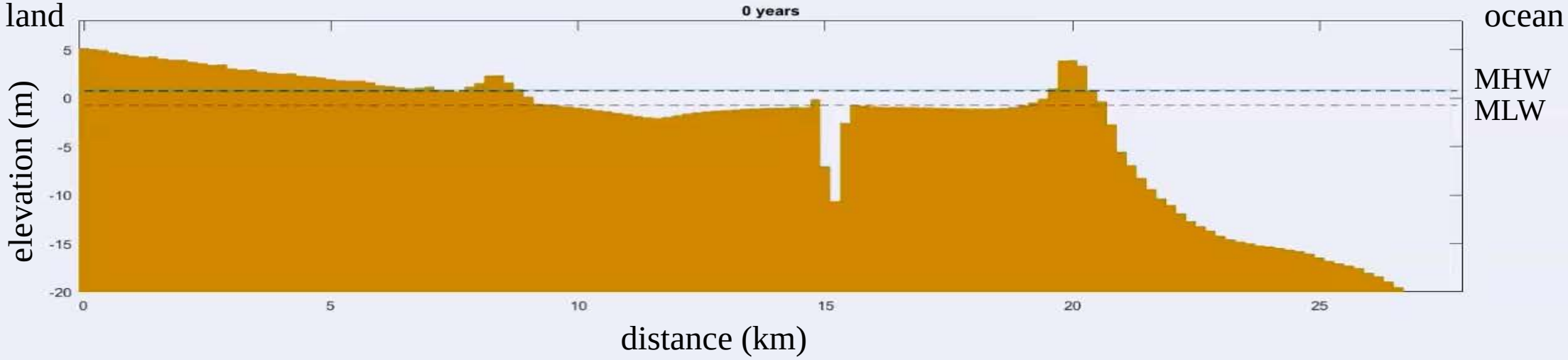




Focus on barrier systems with little mud and marshes (example: Wadden Sea, The Netherlands)

From “equilibrium” + SLR (2 mm/yr)





Conclusion

Delft3D Simulations:

- Inlet widening and deepening
- Formation of multiple channels with moveable inlet
- Equilibrium inlet width

Simplified 2-D Model:

- Simple 2D model: good agreement with delft3D
- Flexible and fast
- Allows self-organization of the system

Future Plan

- Compare the model with data (i.e. barrier geometry and stratigraphy)
- Incorporate more processes: mud and marshes

Questions?

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Simplified 2-D Model

Di Silvio et al (2010)

Friction dominated hydrodynamics

$$U_{x|y} = \frac{h^{4/3}}{U_o}\frac{1}{n^2}\frac{\partial \eta}{\partial x|y}$$

$$\frac{\partial (hU_x)}{\partial x} + \frac{\partial \left(hU_y\right)}{\partial y} = \frac{\min(d, r_{eq})}{T/2}$$

Tide input

Sea level
Tidal range
Surge

Bed elevation

Total water prism

Effective water depth

fetch

Wind speed and direction

Tide & Surge flow

SeaWaves

Current-induced erosion

Wave-induced erosion

$$\frac{\partial \left(K_x h\frac{\partial c}{\partial x} + V_x hc\right)}{\partial x} + \frac{\partial \left(K_y h\frac{\partial c}{\partial y} + V_y hc\right)}{\partial y} = E - D = w_s(c_{eq} - c)$$

Di Silvio et al (2010)

Sediment transport (c_{eq} + Dispersion) → Erosion - Deposition

Van Rijn (2007)

$$\frac{\partial z}{\partial t}\rho_{bulk} = \underbrace{(D - E) + \nabla \cdot \boldsymbol{S}}_{current\ driven} + \underbrace{\nabla \cdot \boldsymbol{W}}_{wave\ driven}$$

Bed morphodynamics

- **D-E** *Cayocca (2001)*
- **Downslope by currents**
- **Downslope by waves**
- **Along-wave (onshore and longshore)**

Mase (2001)

Swell Waves

Swell height and direction

Energetics-based model
(Bowen, 1980; Ortiz and Ashton, 2016)