Coupling shoreline and fluvial processes

Andrew Ashton

WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

Two-way coupling between Coastline and Fluvial Dynamics!

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Towards
Coupling shoreline and fluvial processes

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1930

coauthors and acknowledgments

Eric Hutton

Albert Kettner

Irina Overeem

Liviu Giosan

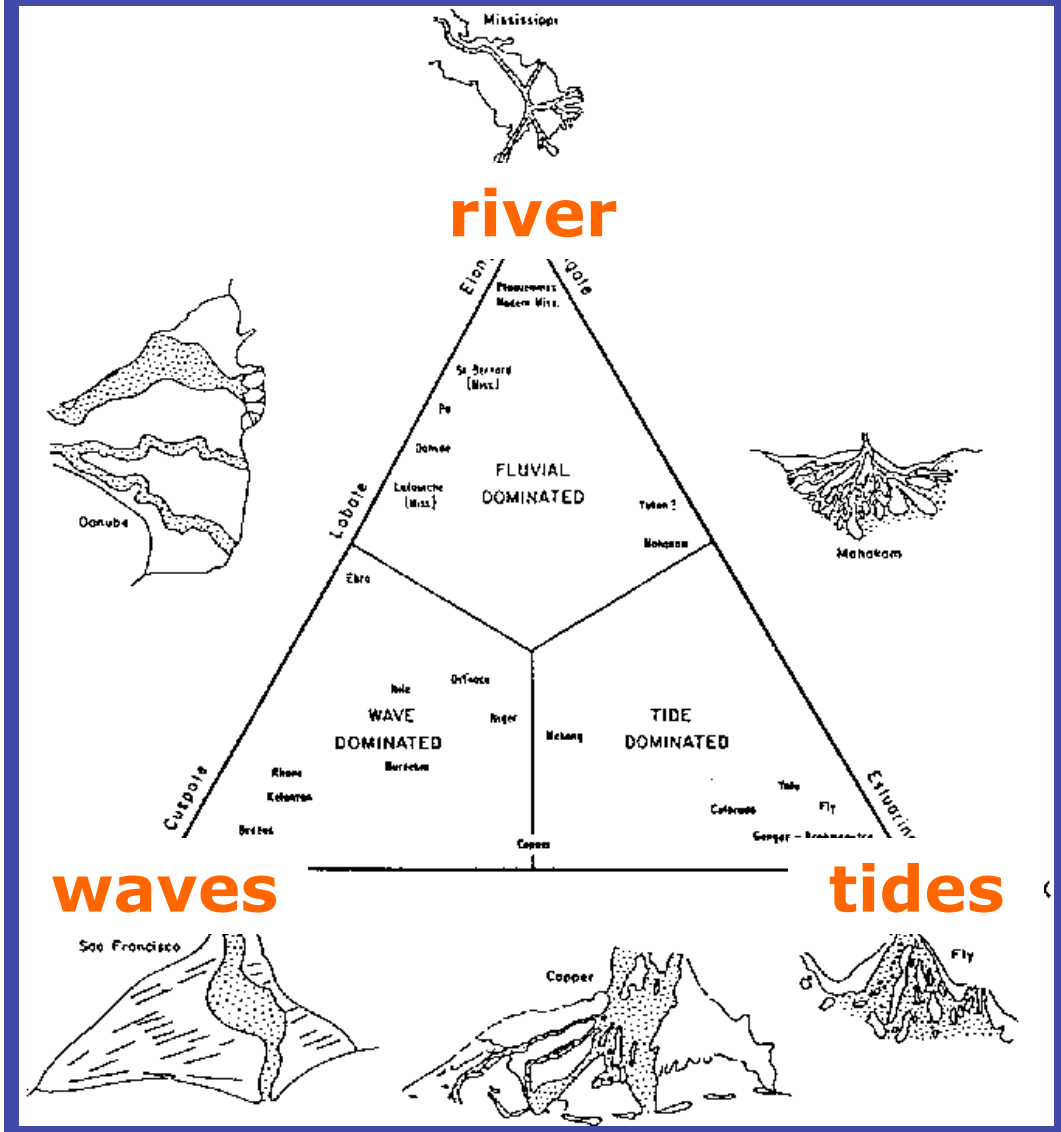
Brad Murray

Doug Jerolmack

GLD

ExxonMobil

wave-influenced deltas

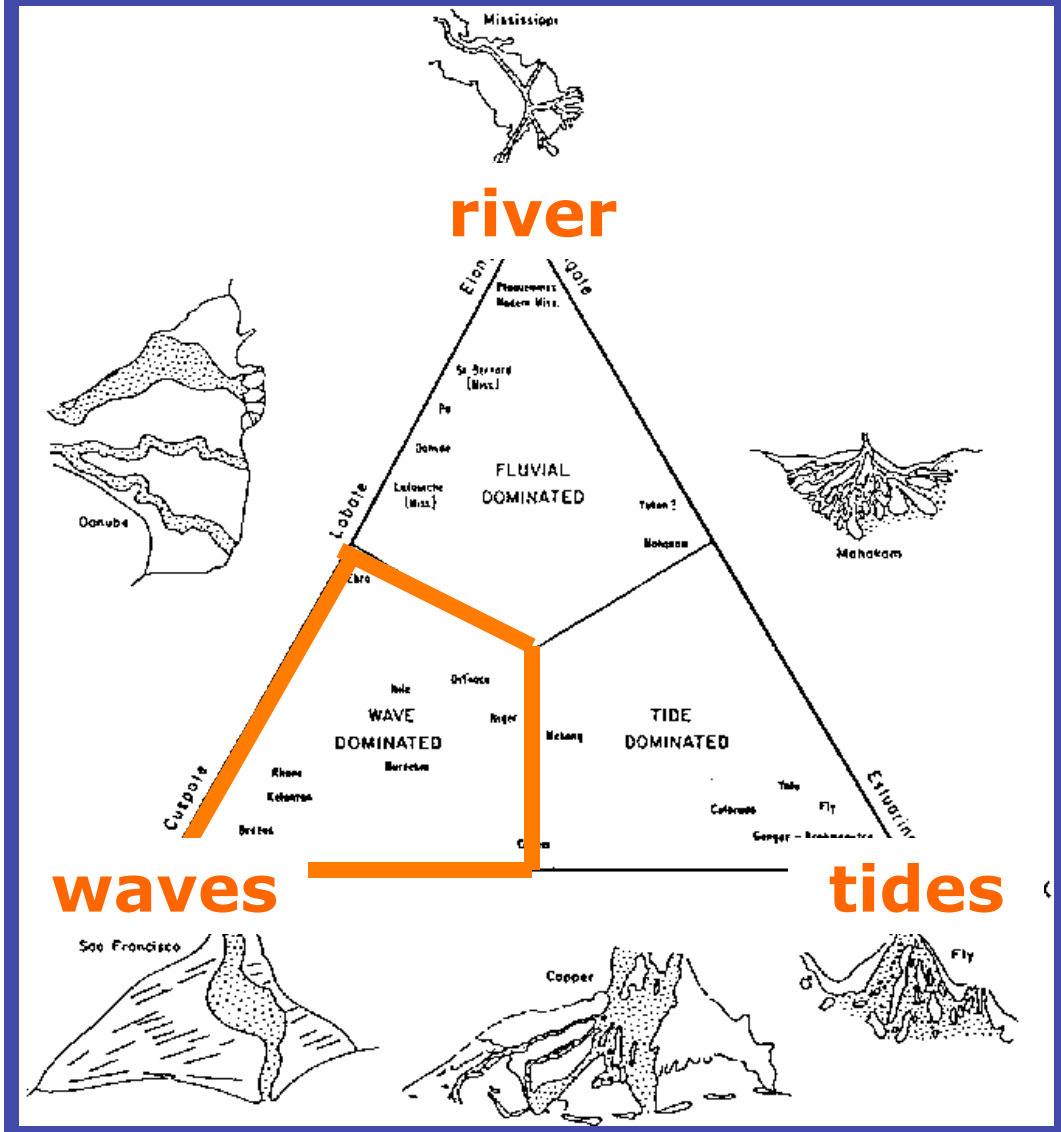


Galloway, 1975

Rosetta Lobe, Nile Delta, Egypt

Arno River Delta, Italy

wave-influenced deltas



Galloway, 1975

Rosetta Lobe, Nile Delta, Egypt

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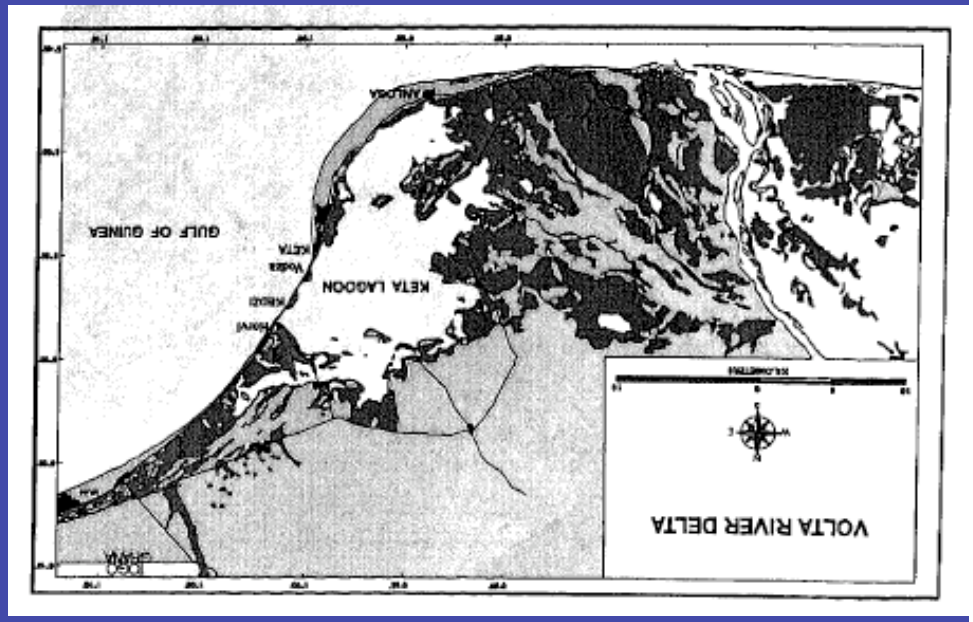
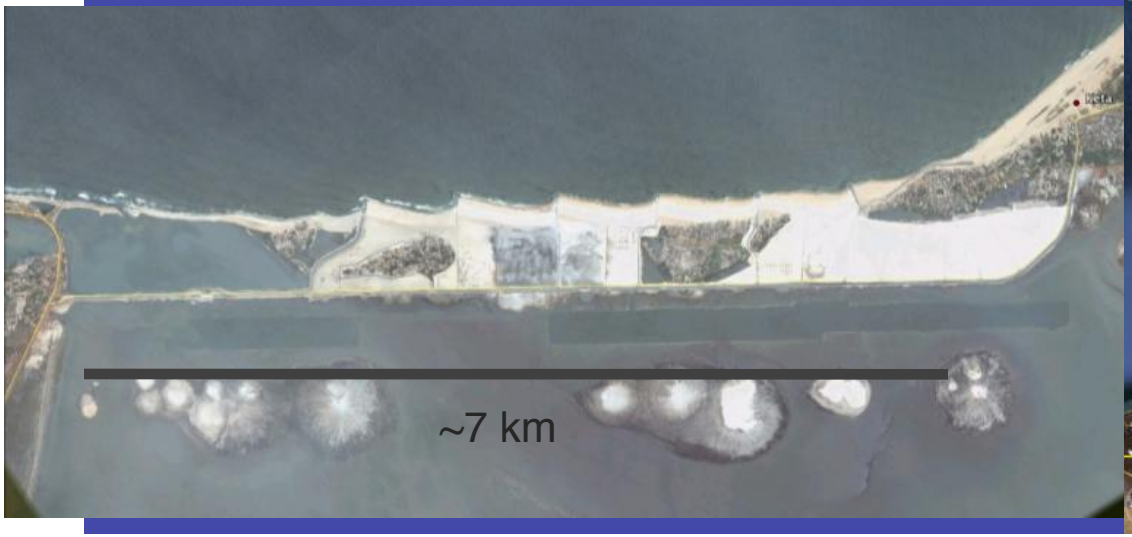
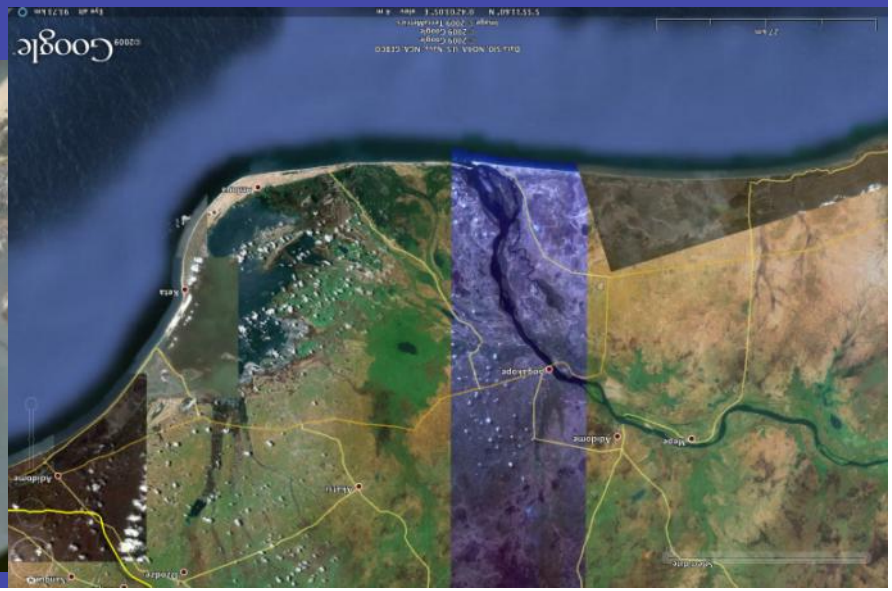
Volta Delta

- Western 1/3 of the coast
- Dense population, agriculture, wetlands, fishery
- Volta river dammed in1960's
  - 2nd largest reservoir by area
- 'Keta Sea Defense'
  - Completed ~2002
  - > 83,000,000 $US



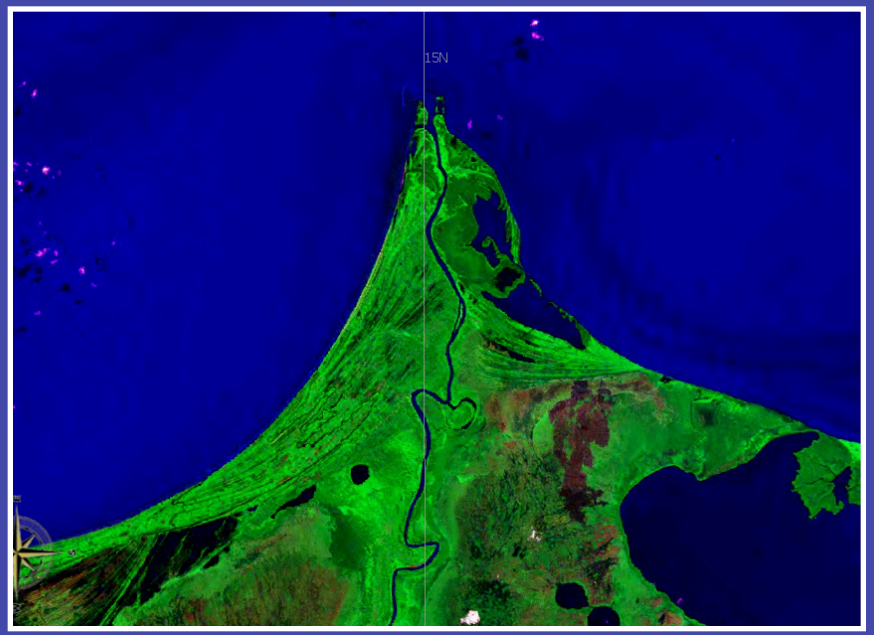
From Nairn et al., 1998



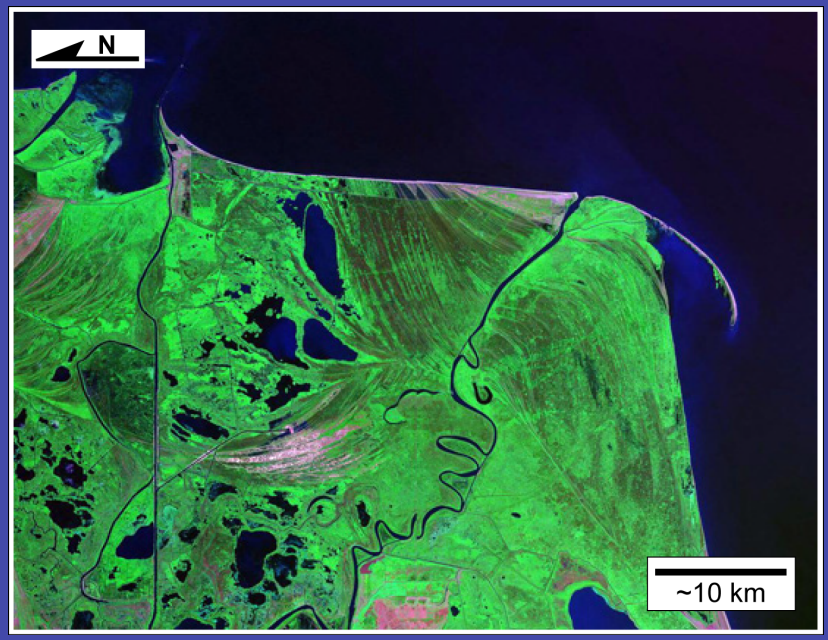


roadmap

1) Modeling shoreline evolution: CEM
2) Delta modeling results for constant fluvial input
3) The Ebro Delta: studying varying fluvial fluxes
4) Towards two way coupling of rivers and the coastline



Coco Delta, Nicaragua/Hondoras



Danube Delta, Romania

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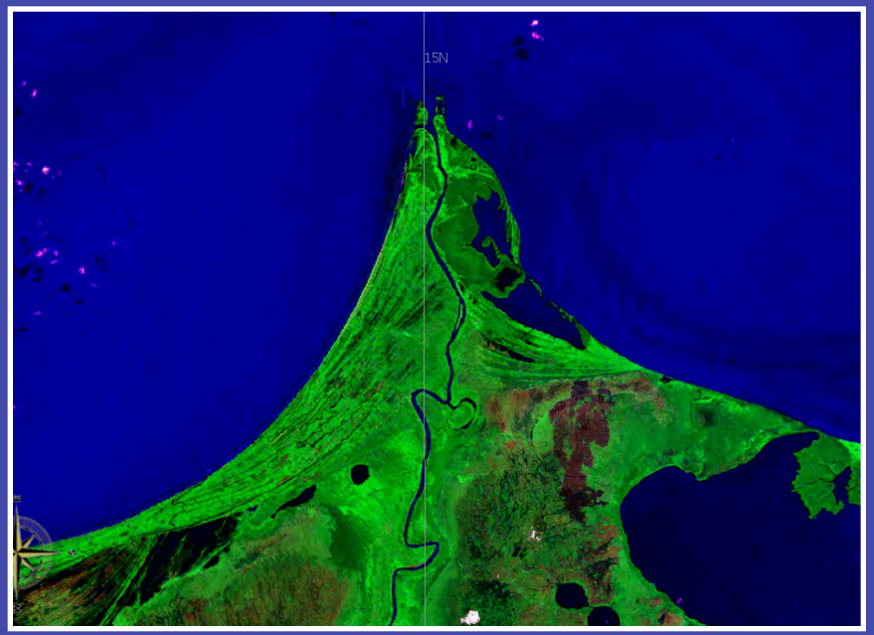

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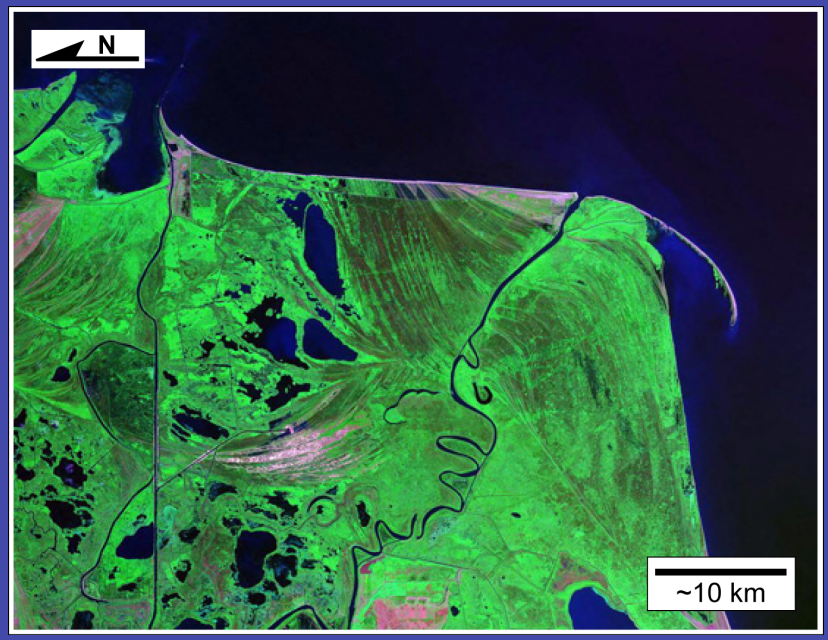
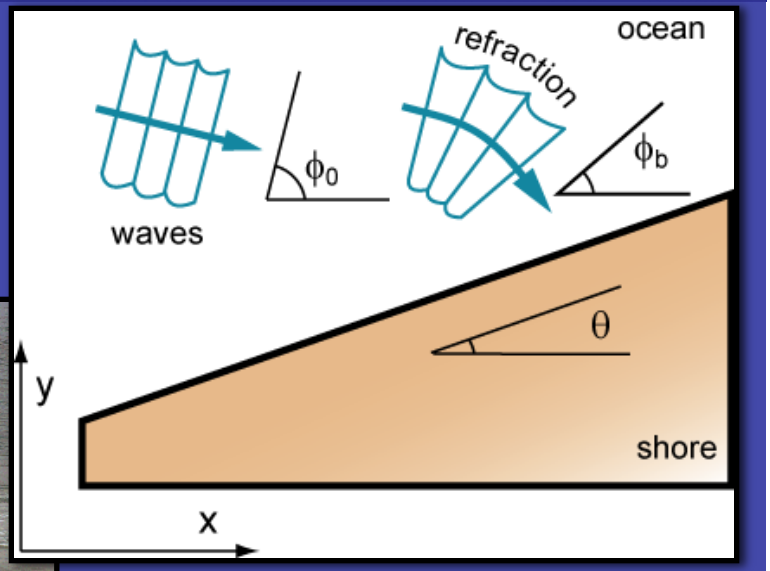


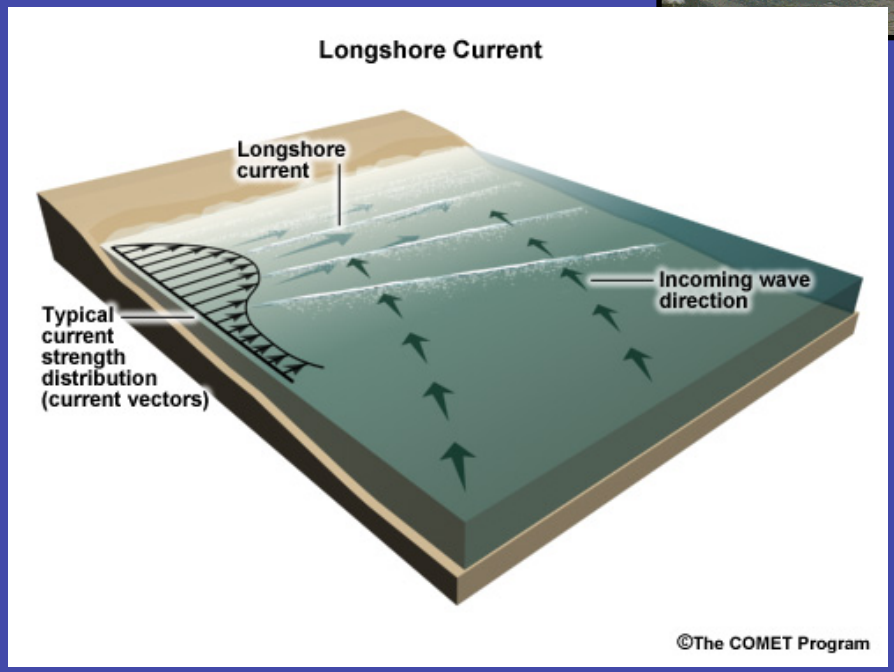
Danube Delta, Romania

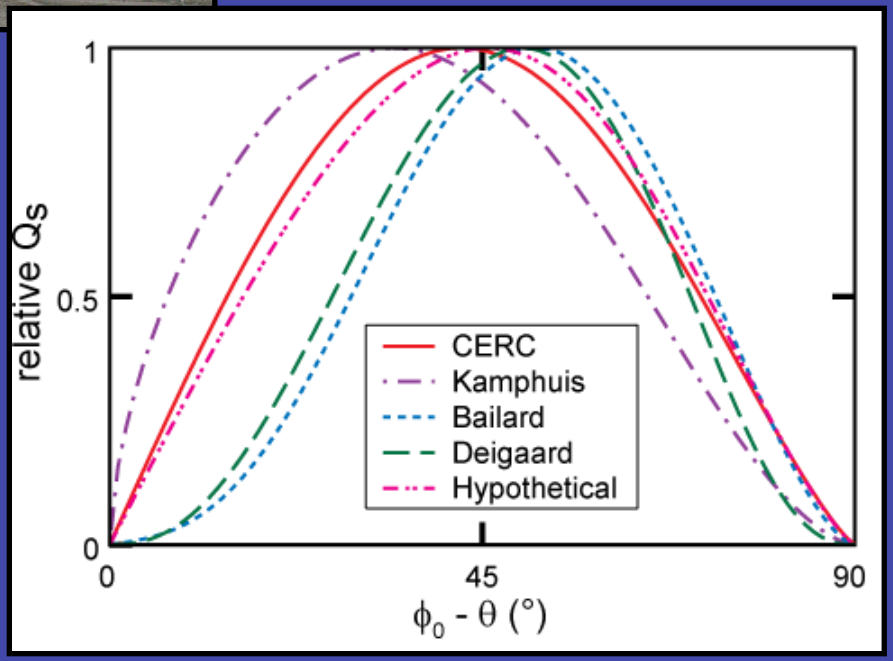
alongshore sediment transport

- breaking-wave-driven alongshore sediment transport (within the surf zone) is highly dependent on wave angle
- maximizing angle:

  ~45 degrees



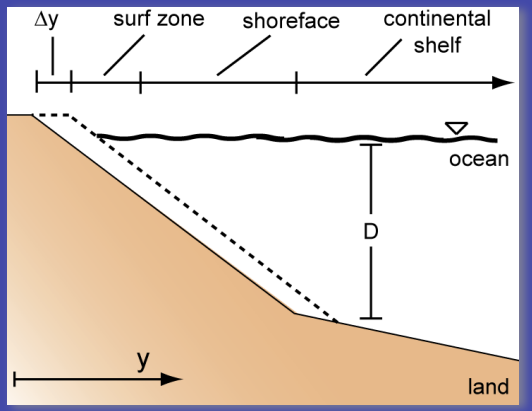




traditional approach

- combining the conservation of mass:

$$\frac{dy}{dt} = -\frac{1}{D}\frac{dQ_s}{dx}$$



- with the small angle approximation

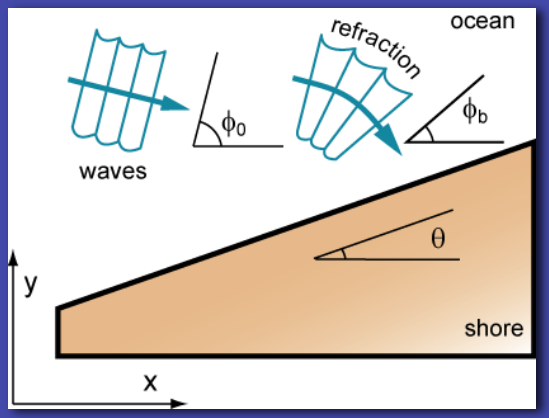
$$Q_s = K H_b^{5/2} \cos(\phi_b - \theta) \sin(\phi_b - \theta)$$

$$Q_s = K H_b^{5/2} \qquad (1) \qquad dy / dx$$

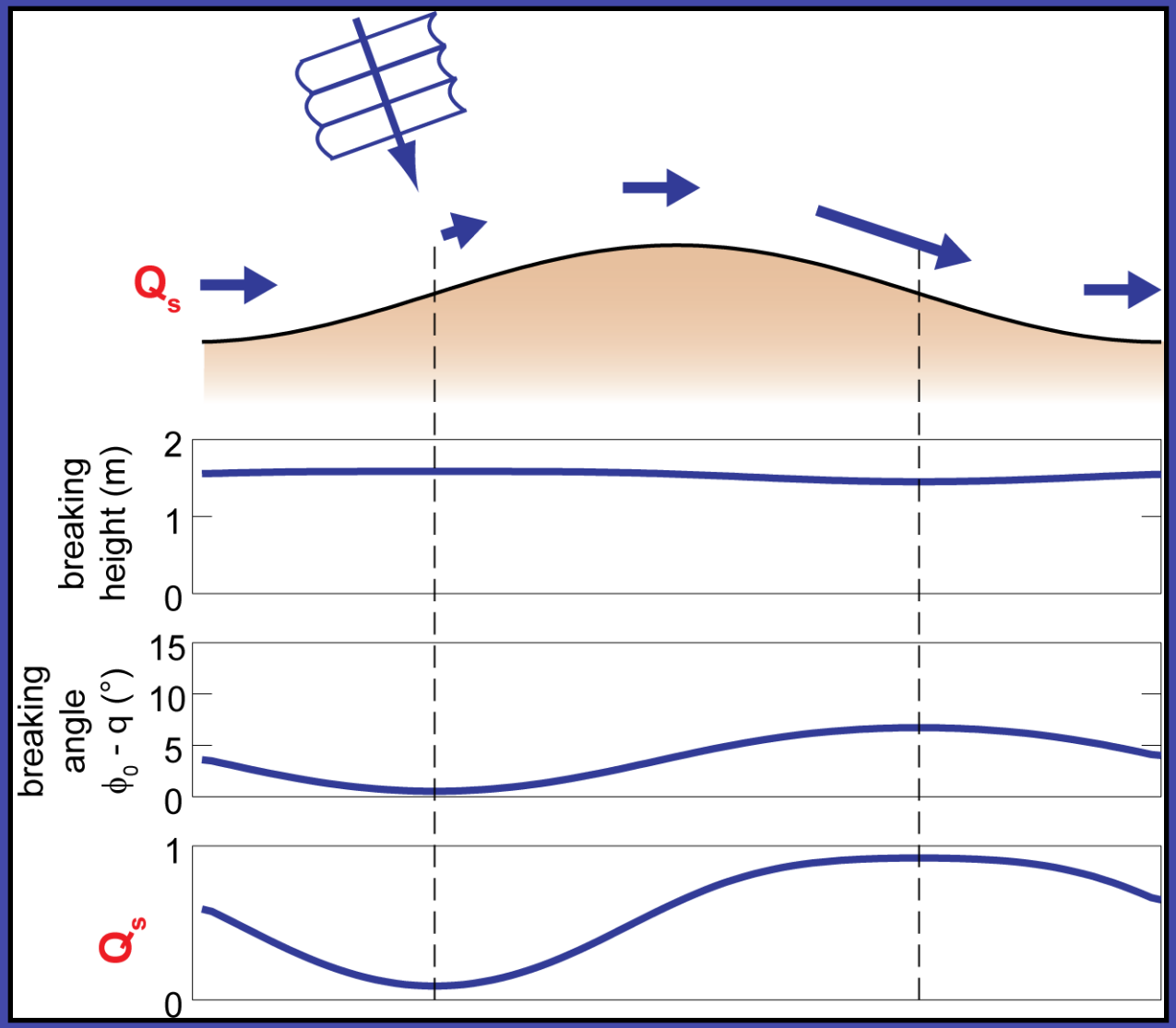
- generates a shoreline evolution equation:

$$\frac{dy}{dt} = -\frac{K}{D} H_b^{\frac{5}{2}} \frac{d^2 y}{dx^2}$$

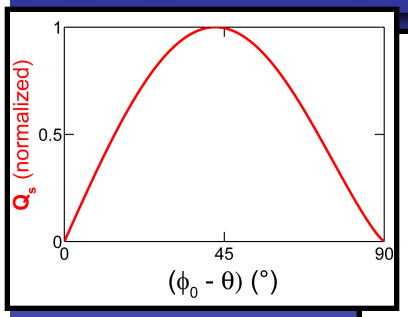
(classic diffusion equation)

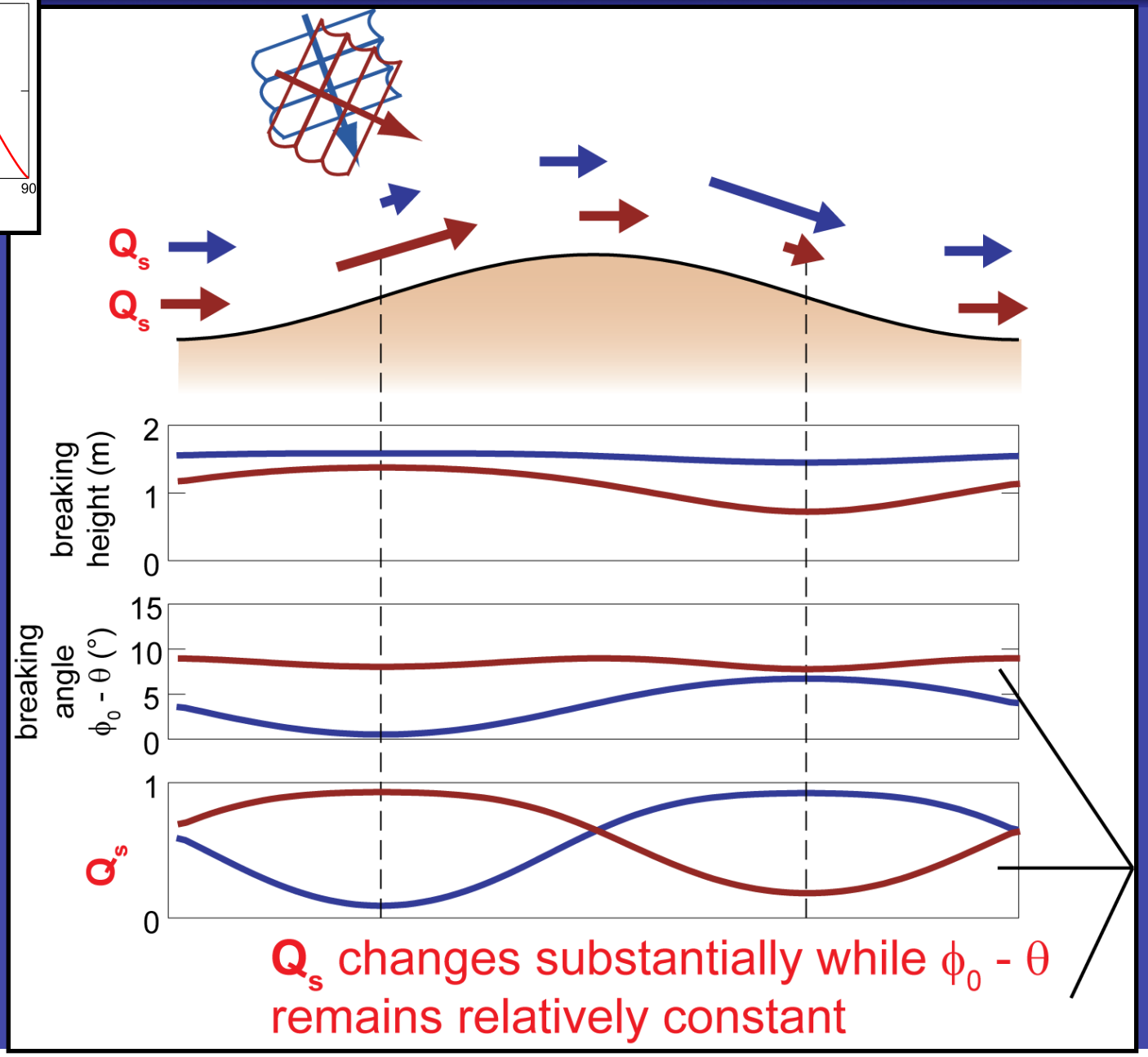


low-angle waves



high-angle waves

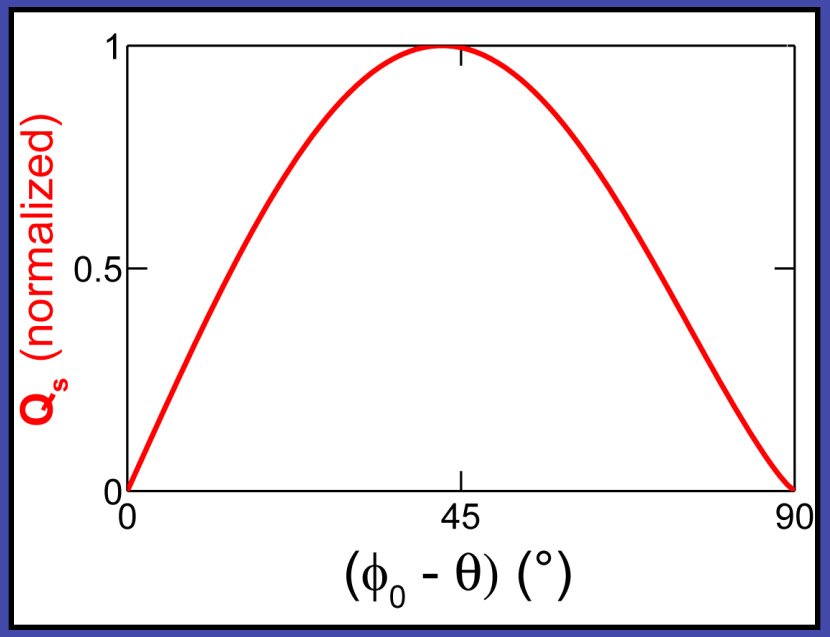


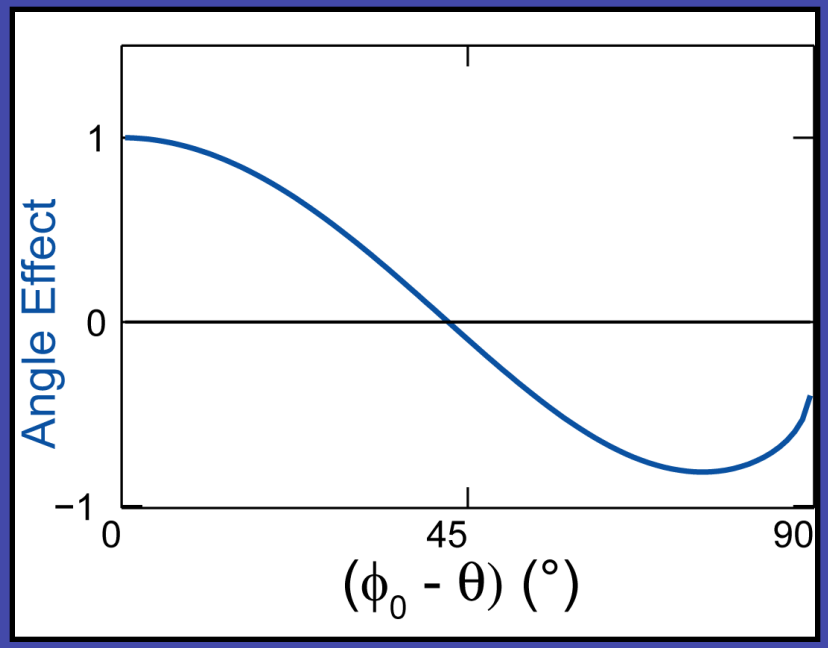


angle-dependent shoreline diffusivity

$$\frac{dy}{dt} = K\ E\ Ang\ \frac{d^2y}{dx^2}$$

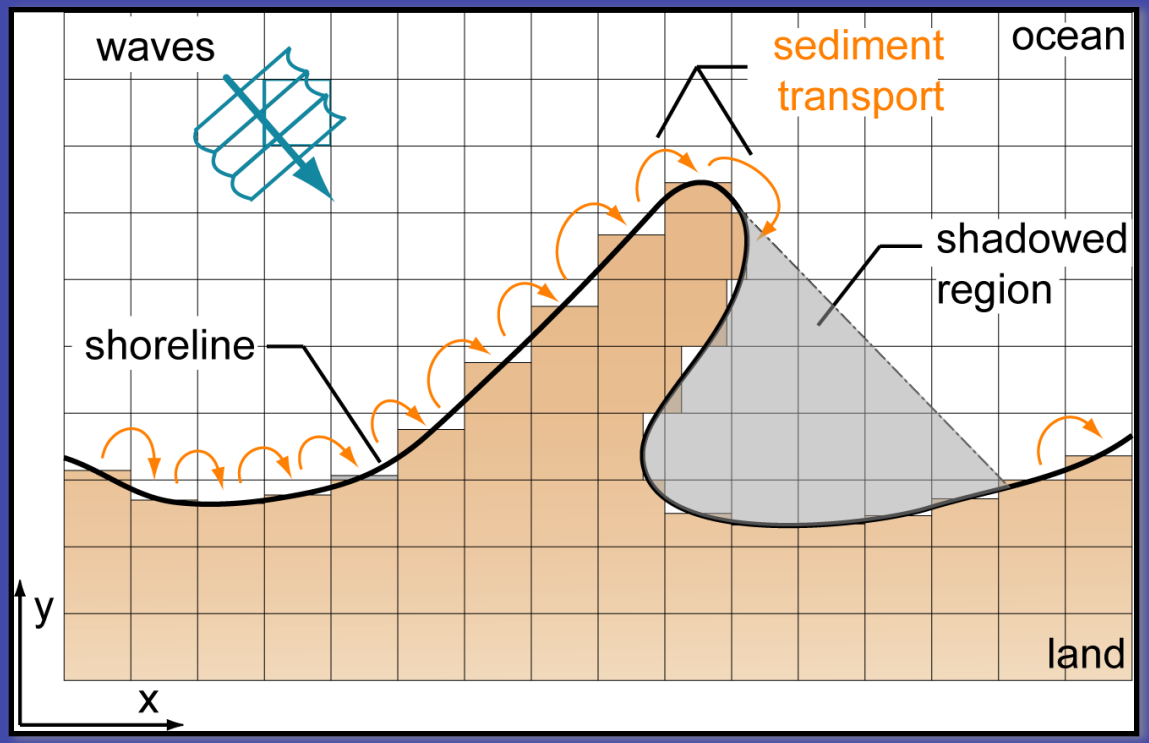
- K: 'Proportionality Constant'
- E: 'Energy' or Wave Height Contribution
- Ang: Wave Angle Effect on Diffusivity

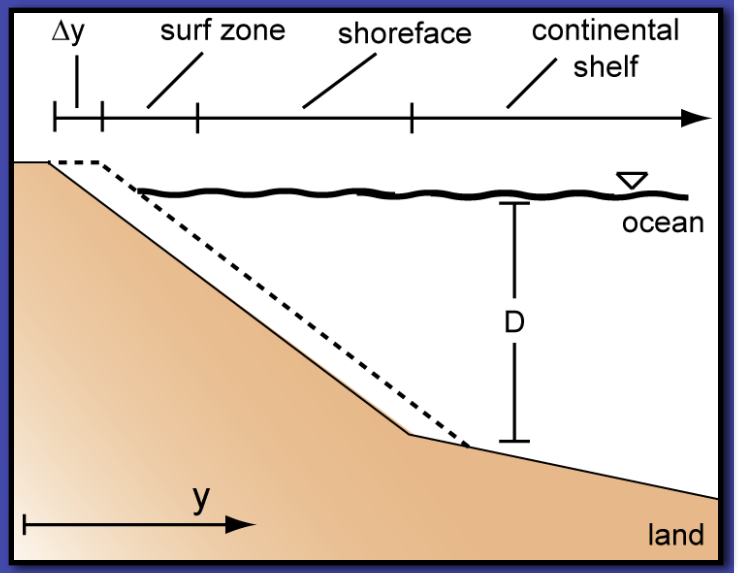


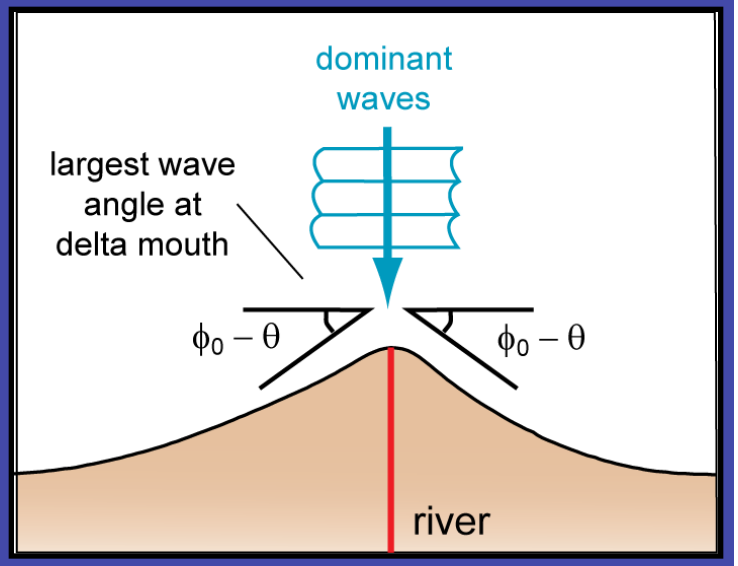


numerical model: ‘CEM’

- ‘Coastline Evolution Model’
- discretizes the plan-view domain
- tracks one contour line – the shoreline
- simple wave refraction
- *Ashton and Murray, JGR-ES 2006*

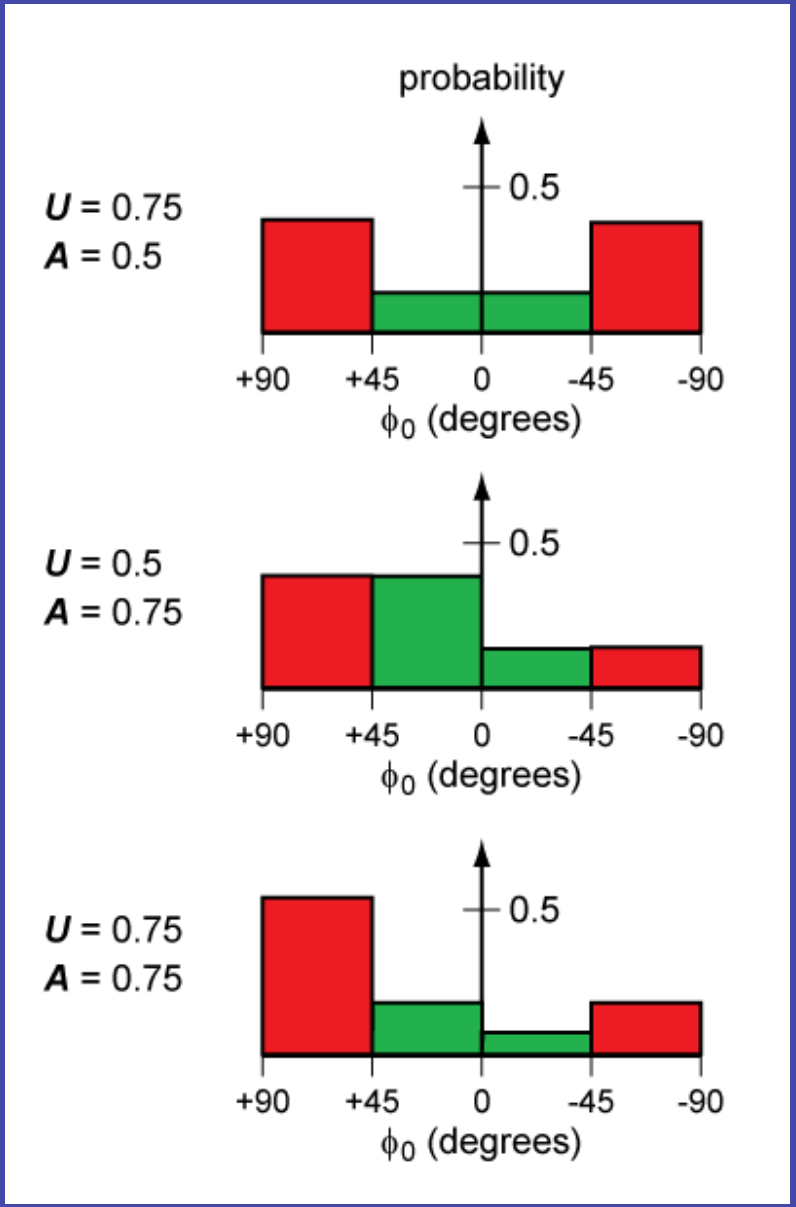




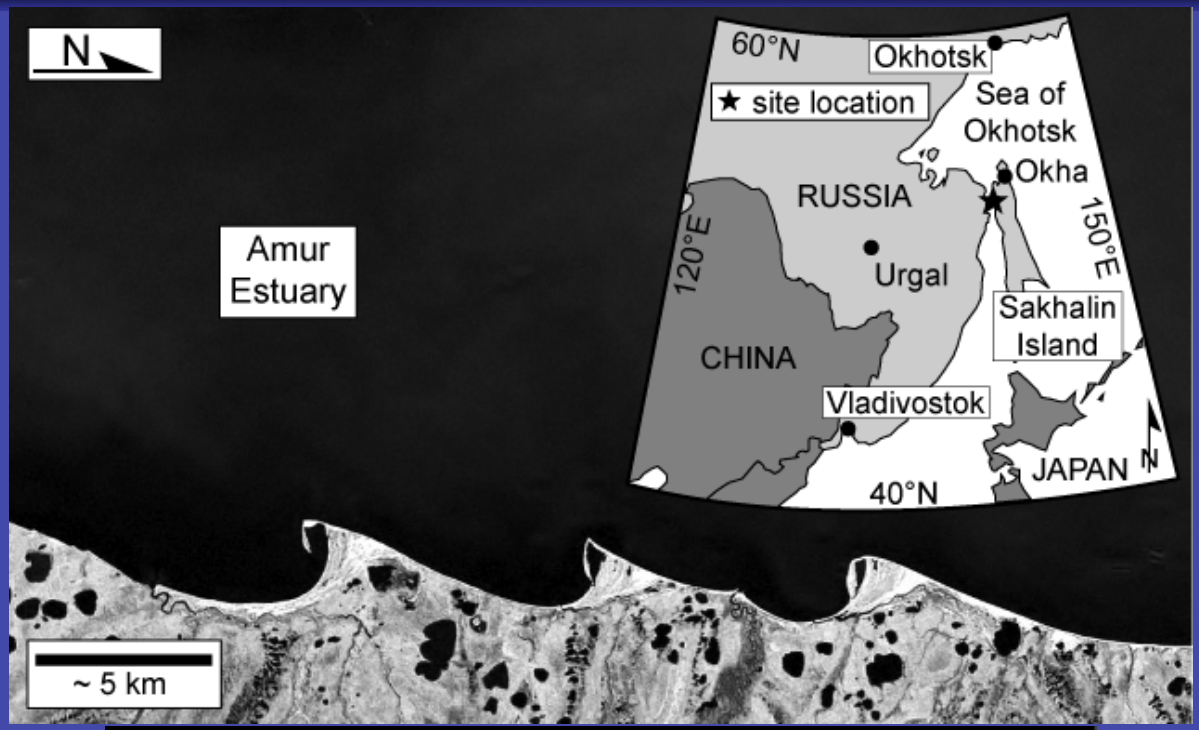


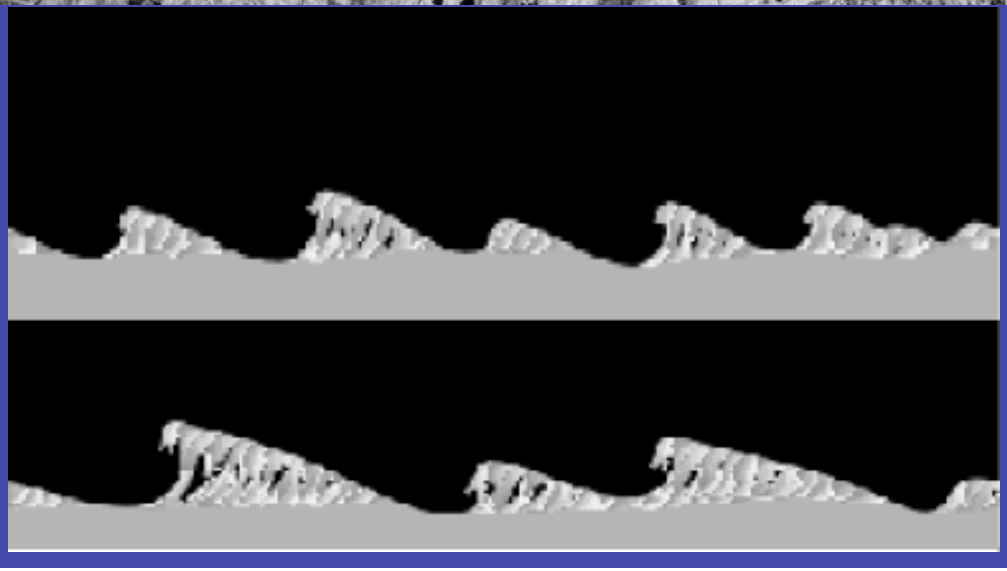
waves from all angles

- random distribution of waves selected from PDF
- controlled by:
  - ***U*** = proportion of high-angle, 'unstable' waves
  - *A* = asymmetry (proportion of waves approaching from left, driving alongshore sediment transport to the right)



shoreline self-organization

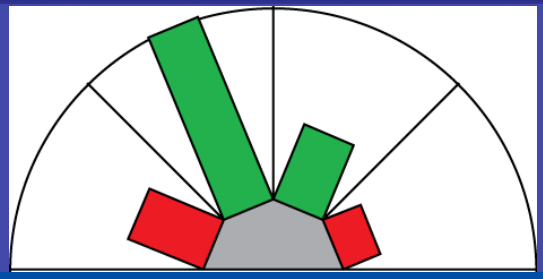




Ashton et al., Nature 2001

Ashton and Murray, JGR-ES 2006

simulated low-angle spits



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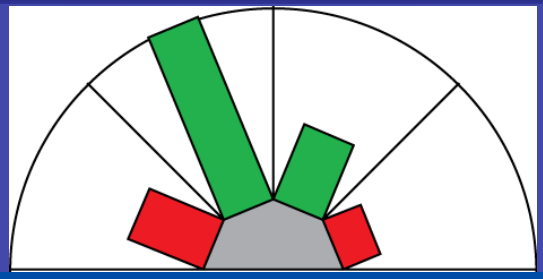

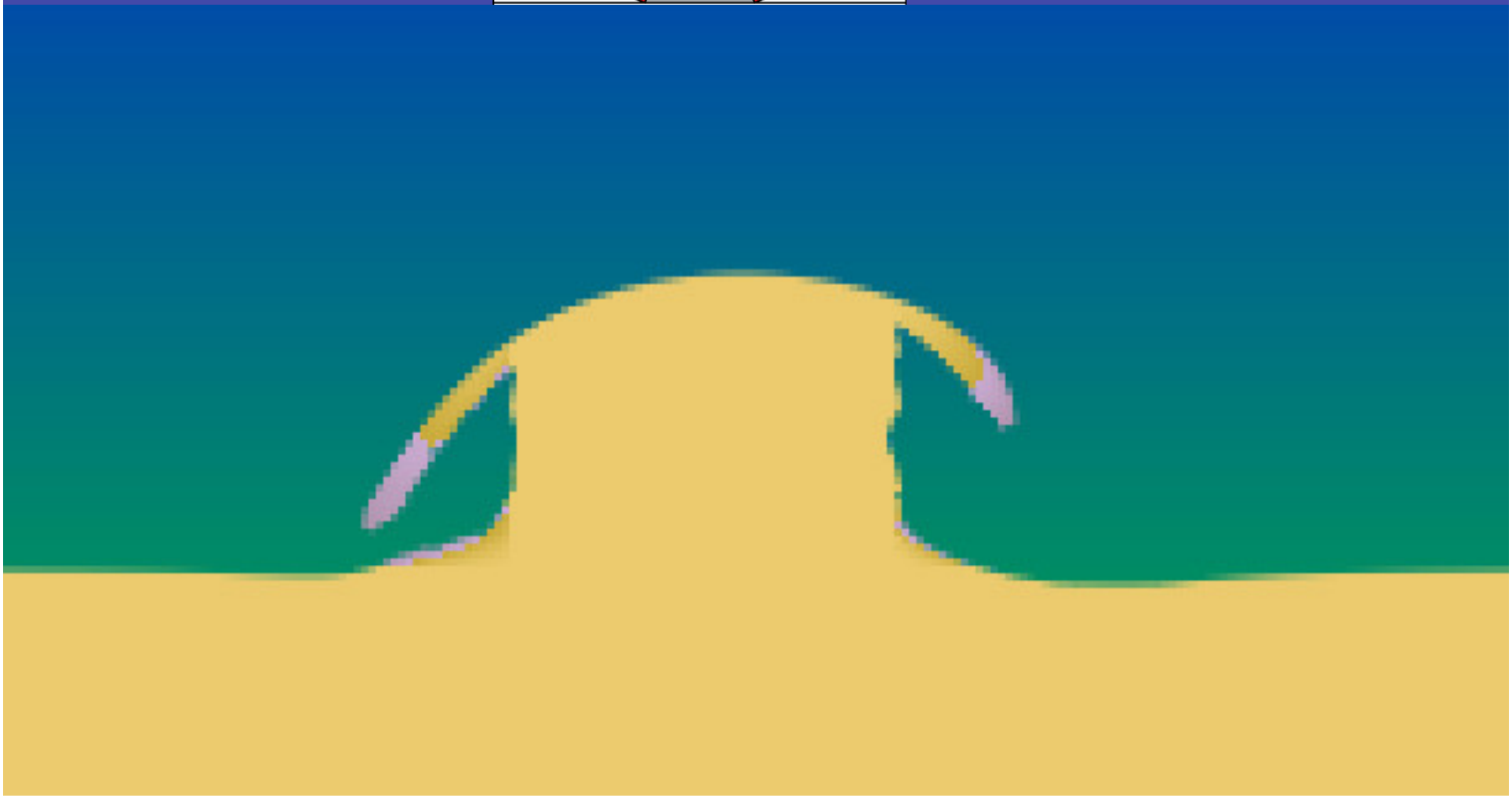

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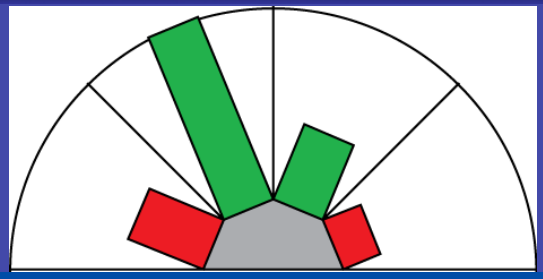

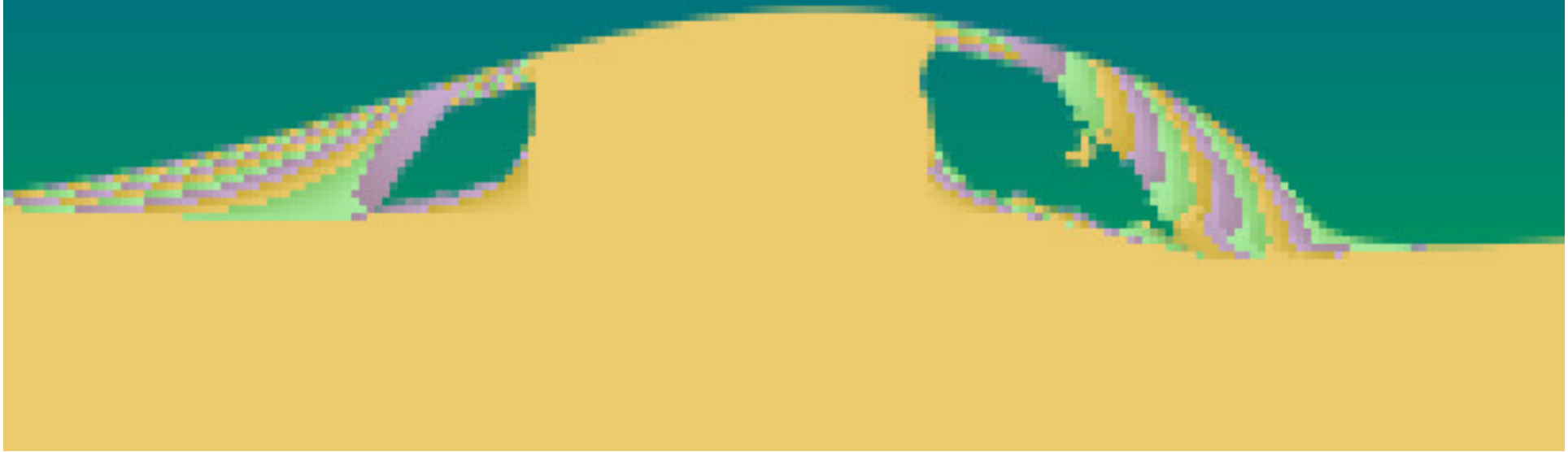

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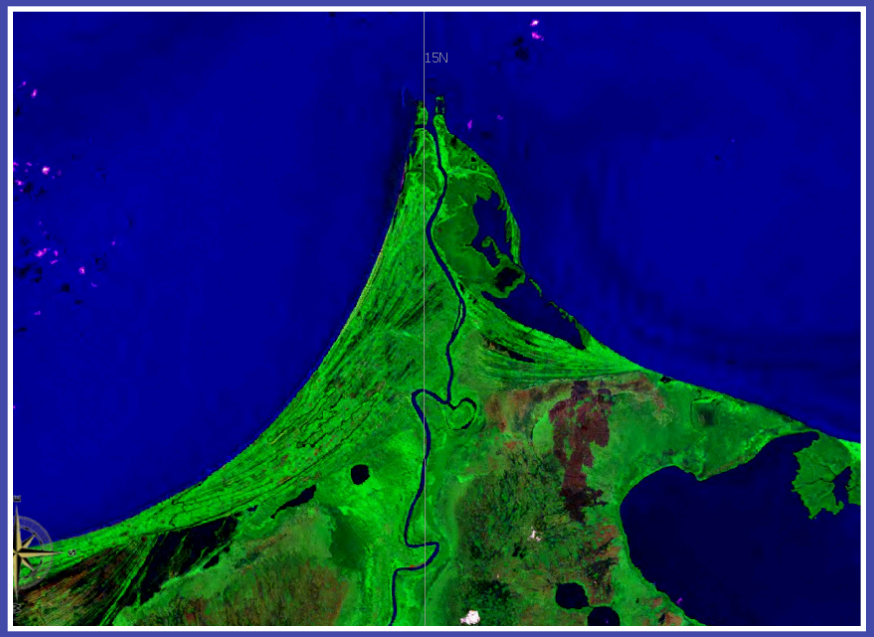
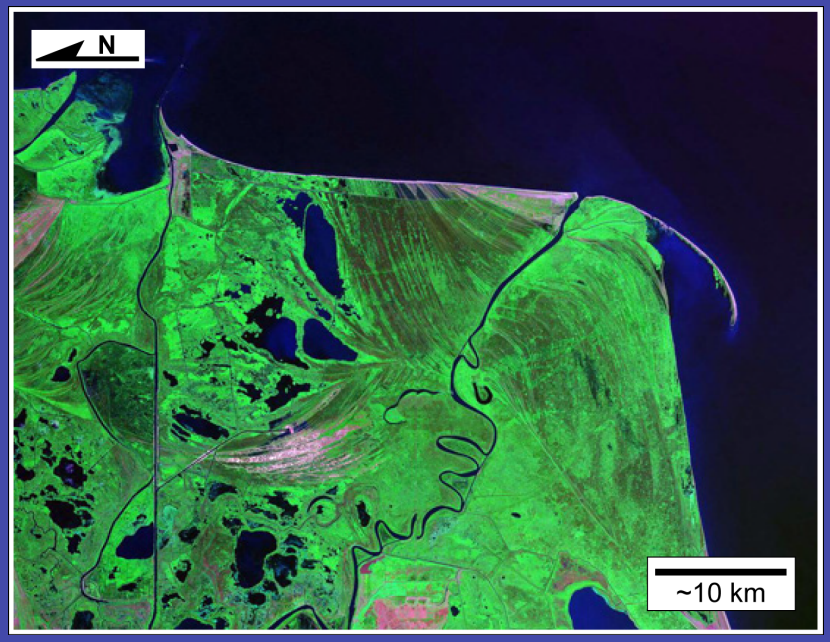
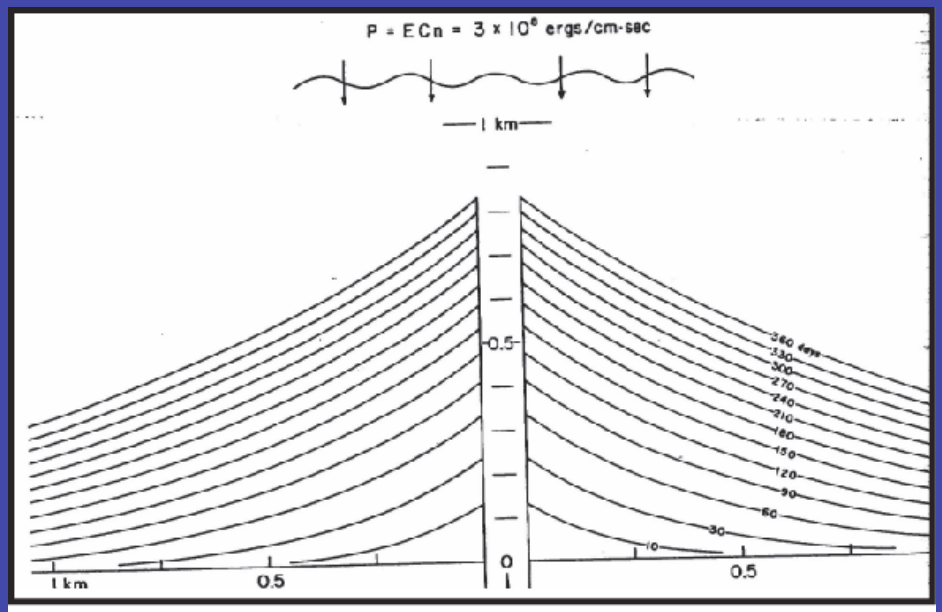


Coco Delta, Nicaragua/Hondoras

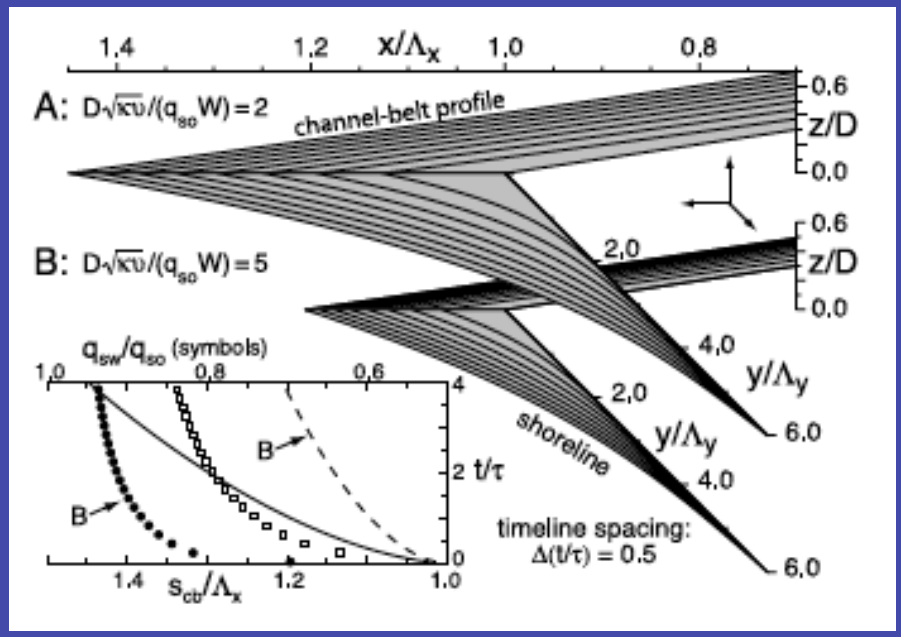


Danube Delta, Romania

deltas: previous modeling



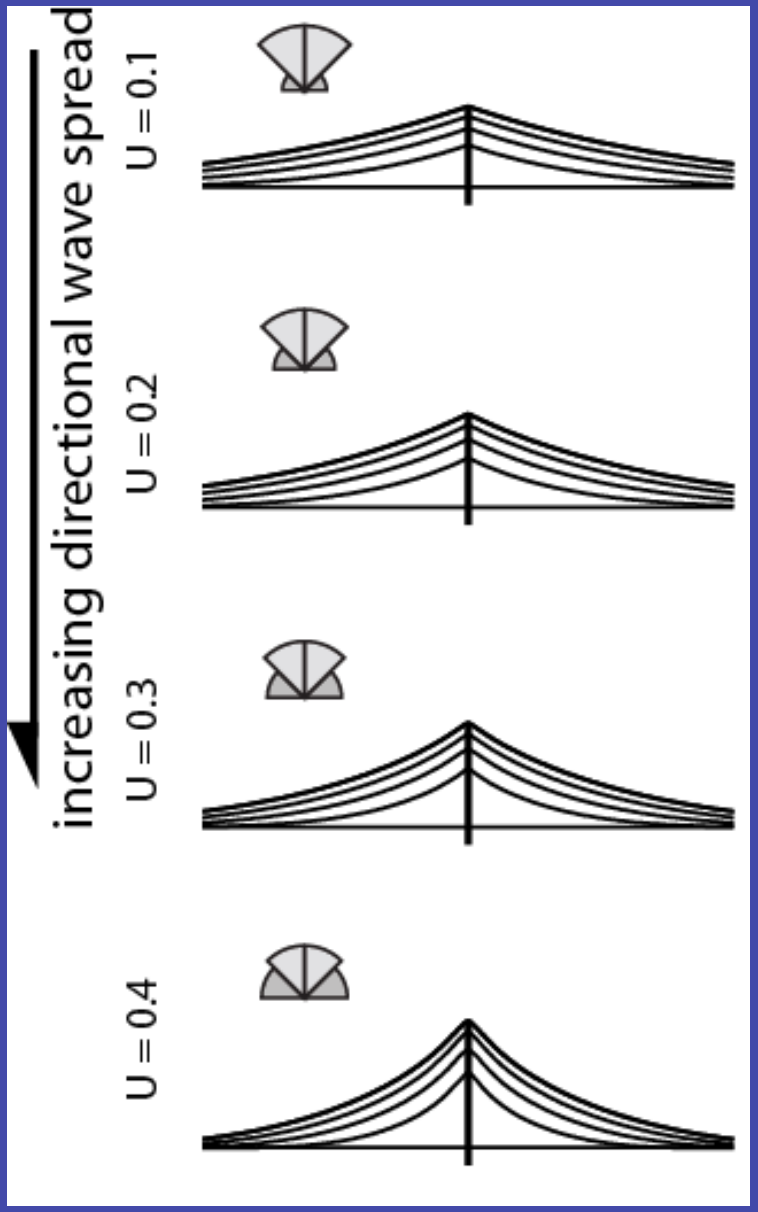
(Komar 1973, GSA Bull)

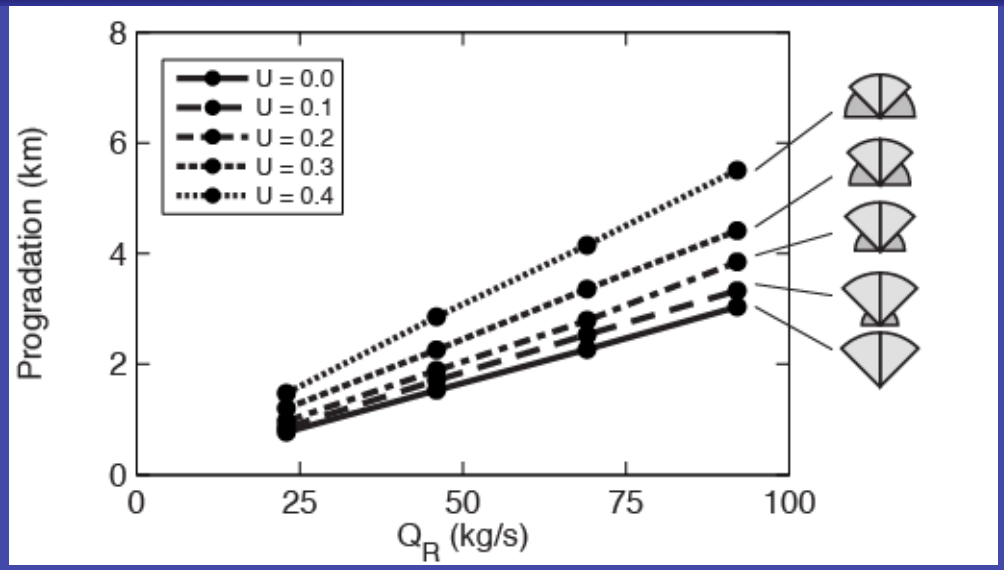


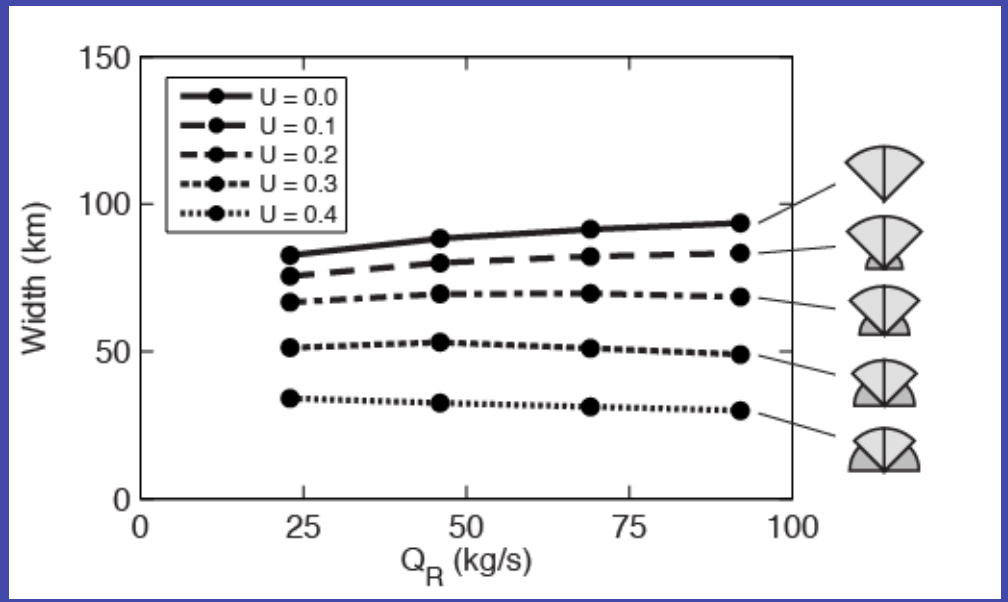
Swenson, GRL 2005

- often linear diffusion equation is used
- numerical modeling (with waves approaching from very ‘low’ angles) supports diffusion concept

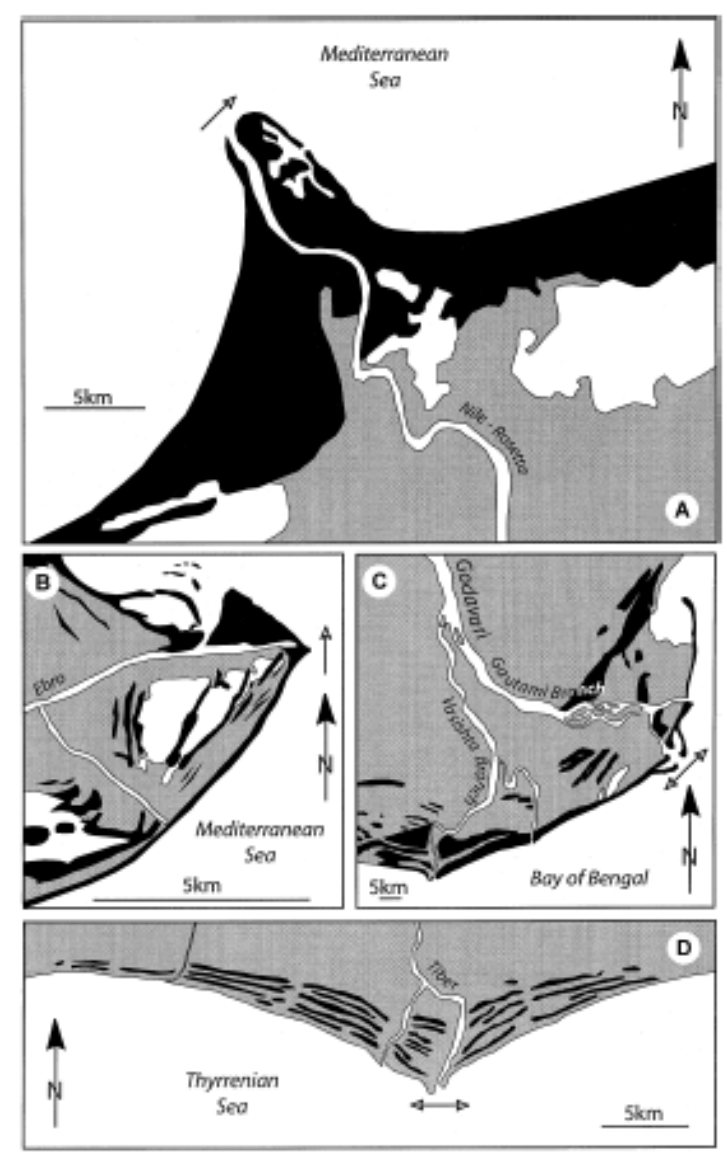
CEM results- symmetrical waves



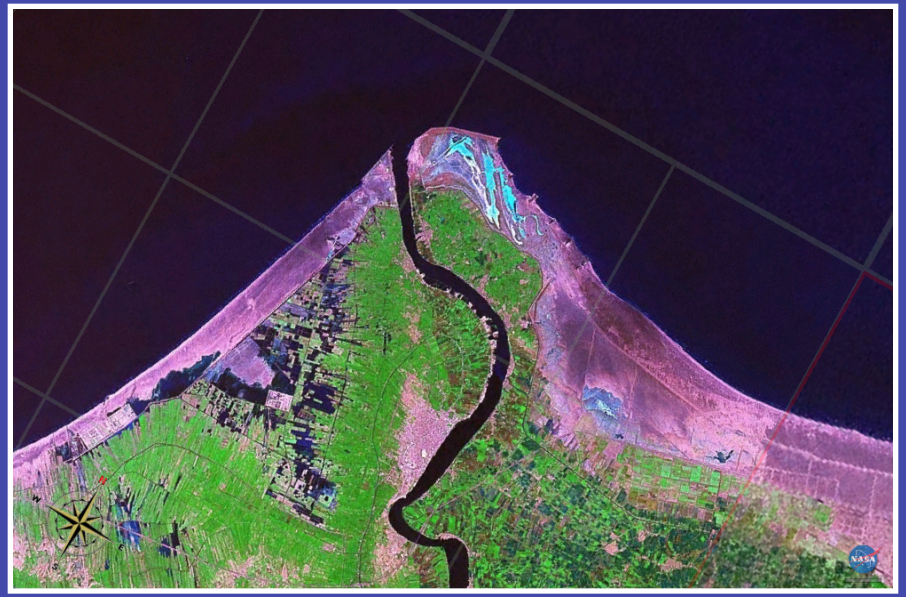




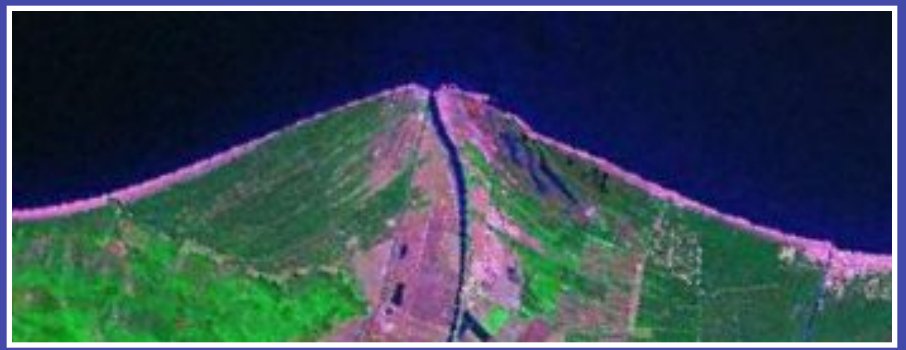
symmetrical wave-influenced deltas



Bhattacharya & Giosan, 2002

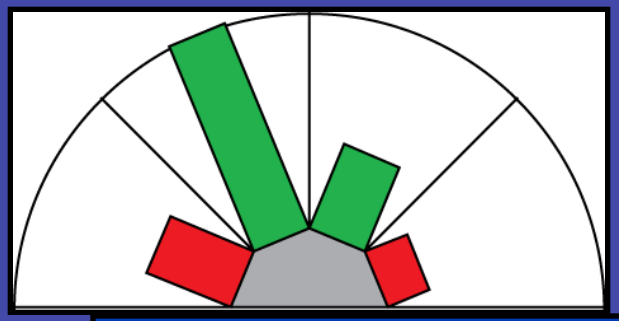


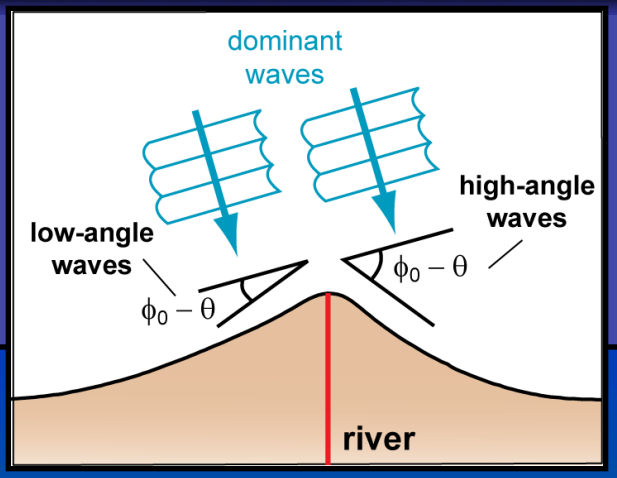
Rosetta Lobe, Nile Delta, Egypt

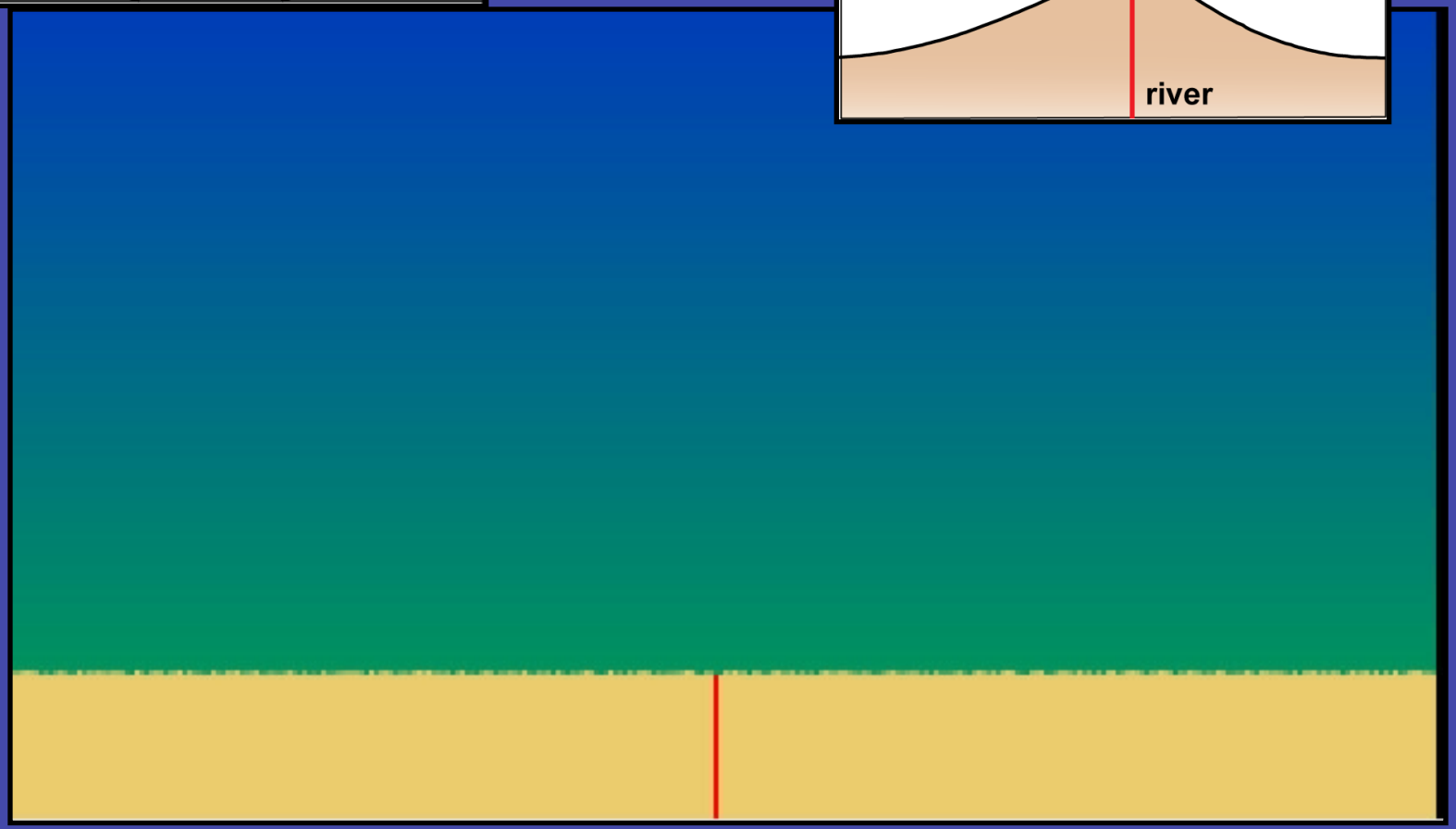


Arno River Delta, Italy

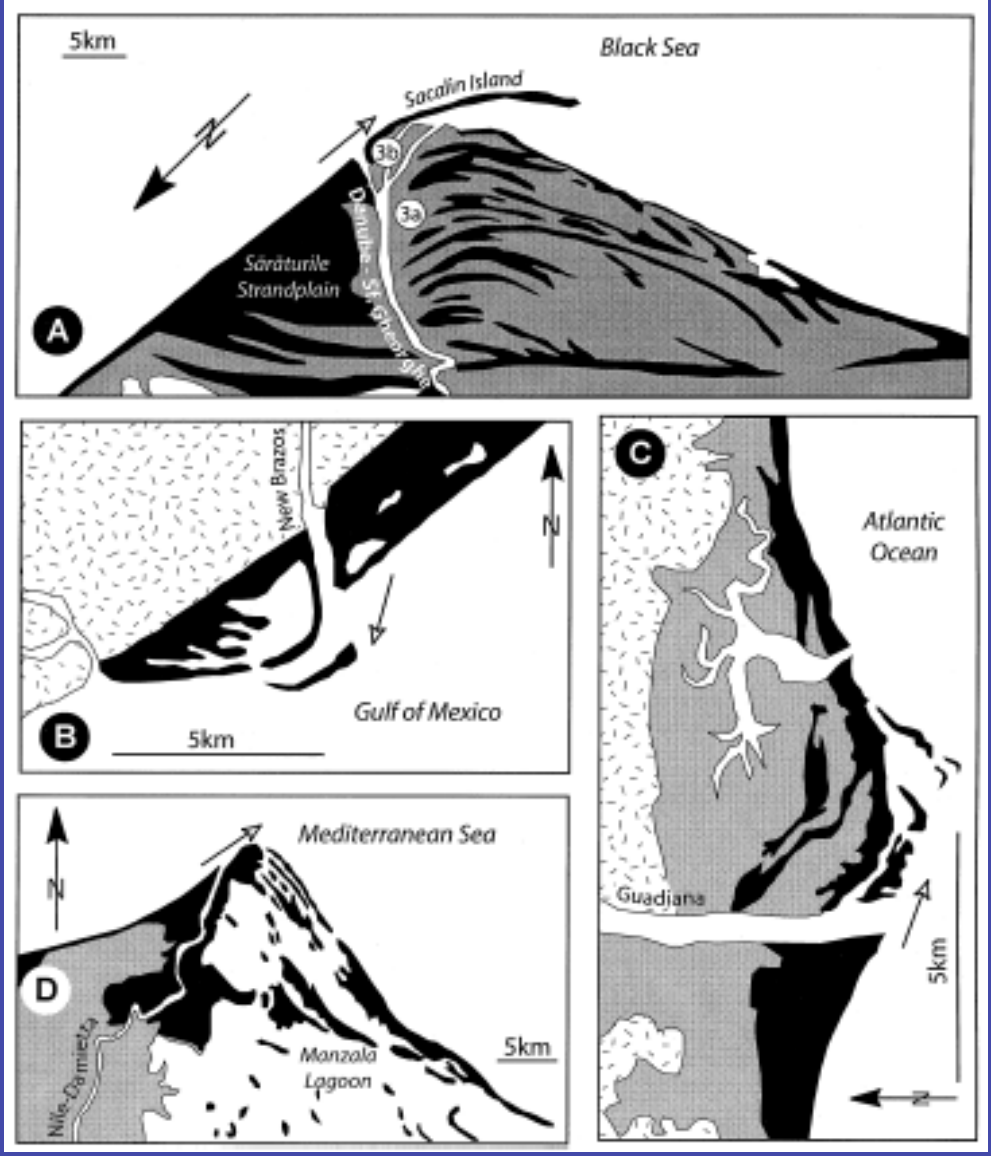
asymmetrical wave climate







asymmetrical wave-influenced deltas



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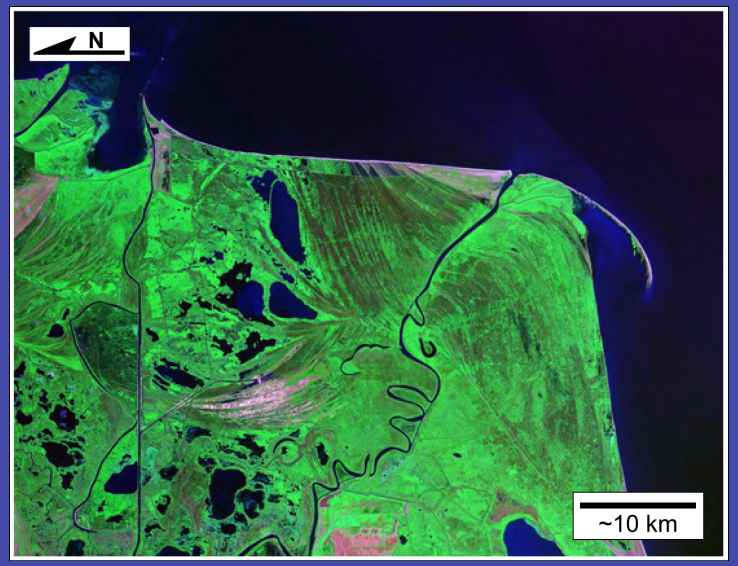
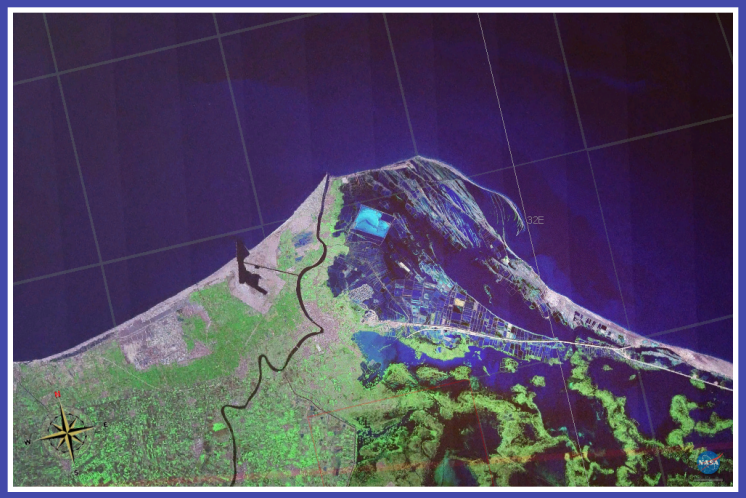
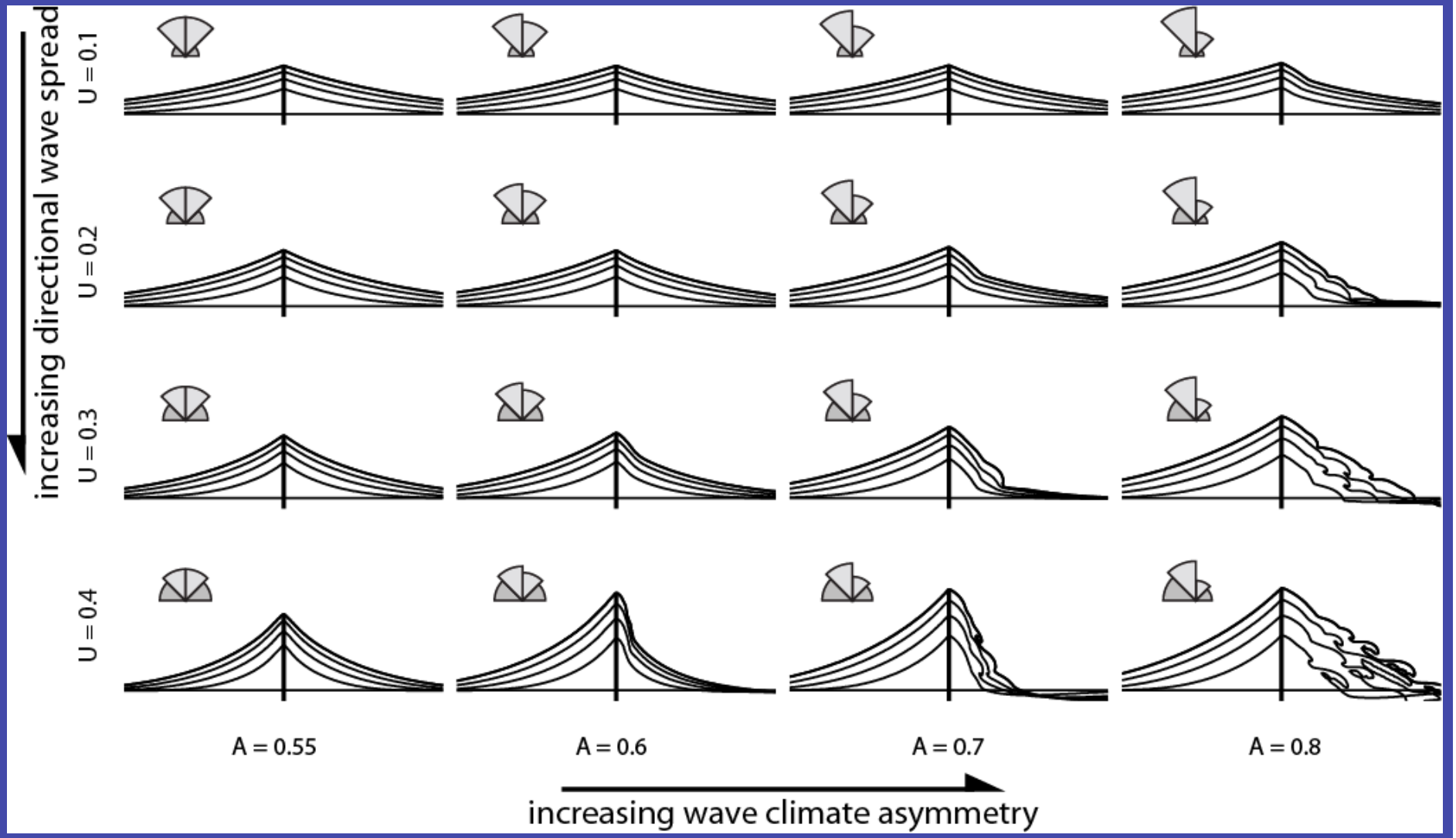


Danube Delta, Romania

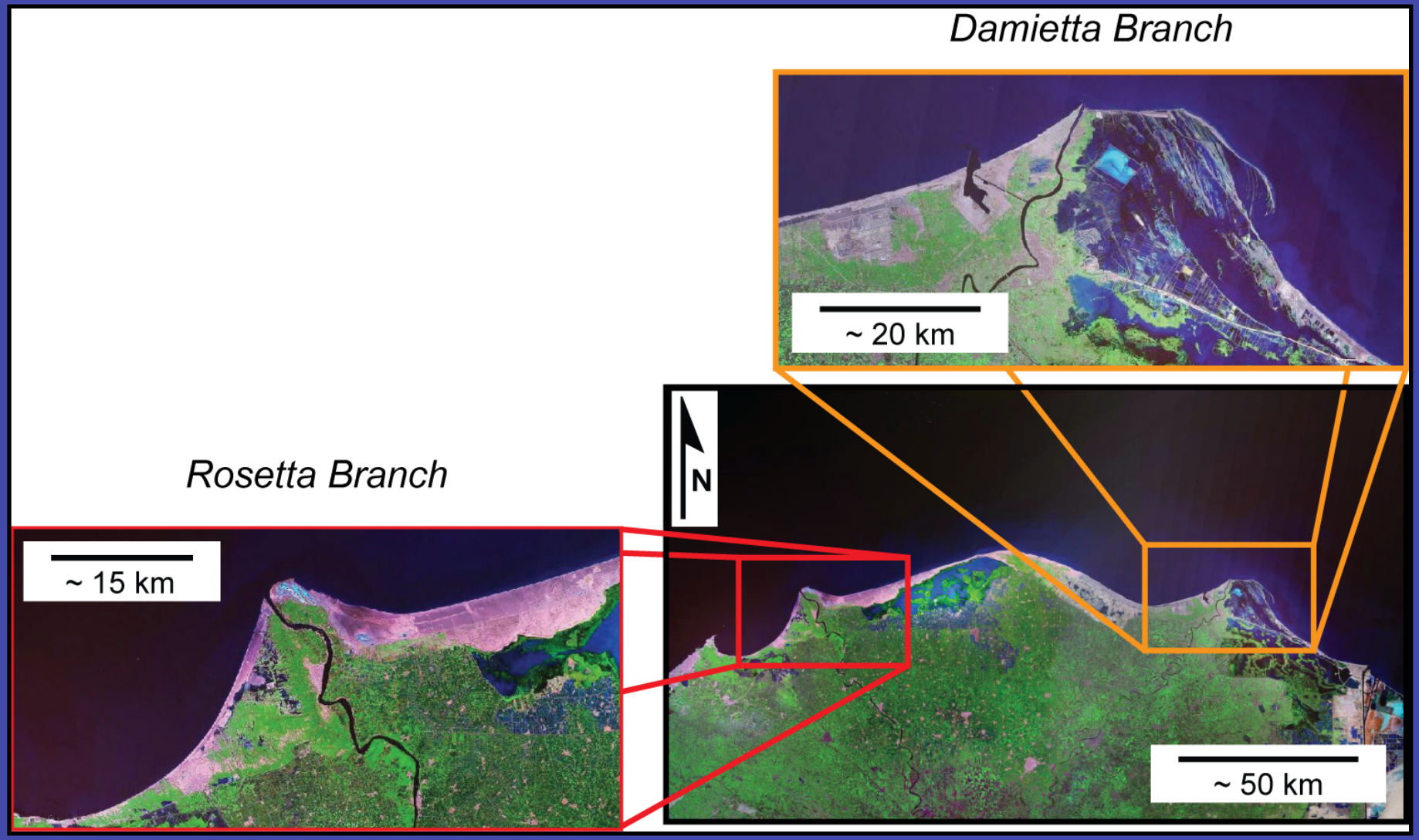


Damietta Lobe, Nile Delta, Egypt

delta morphologies with asymmetry



hypothesis test – Nile Delta



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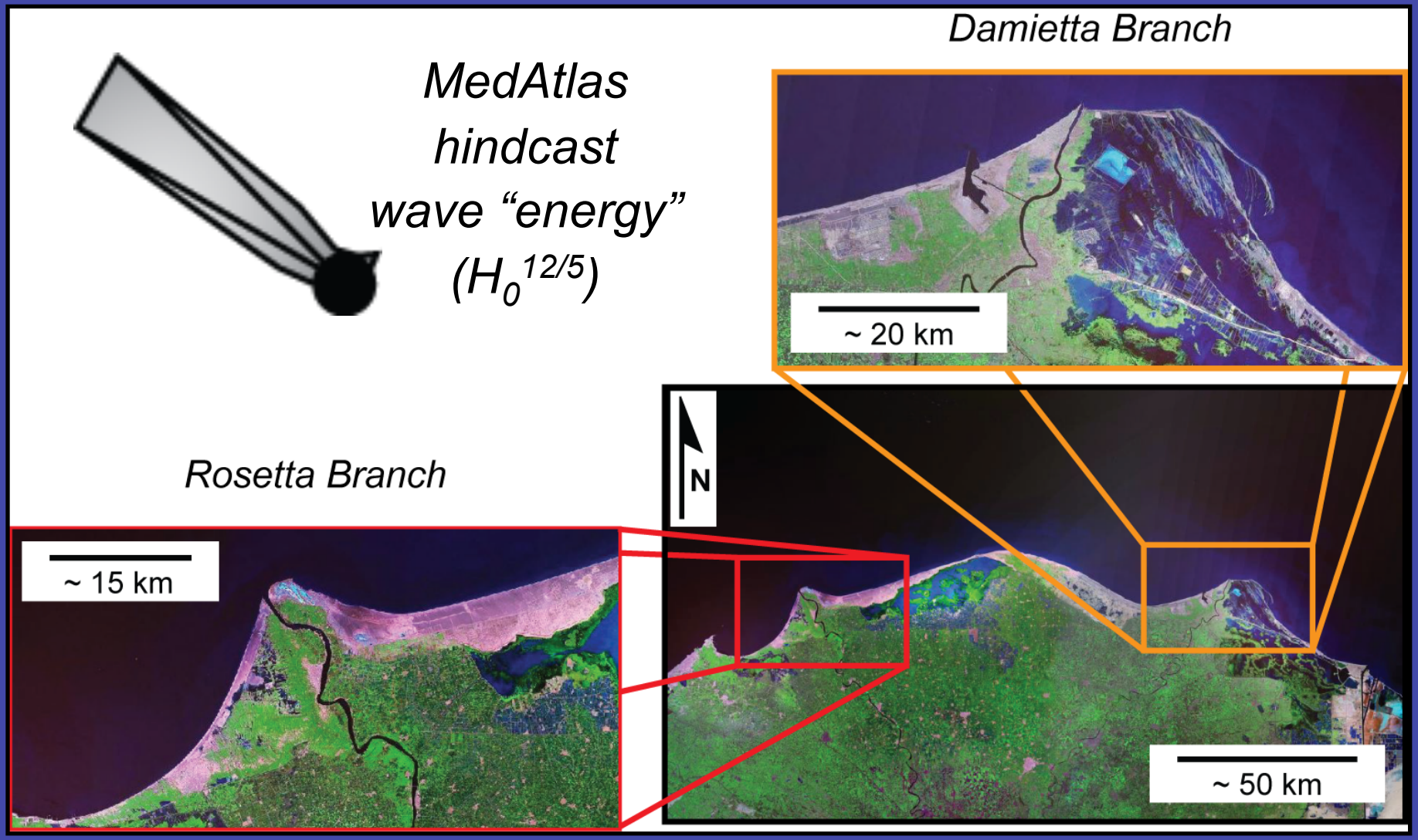
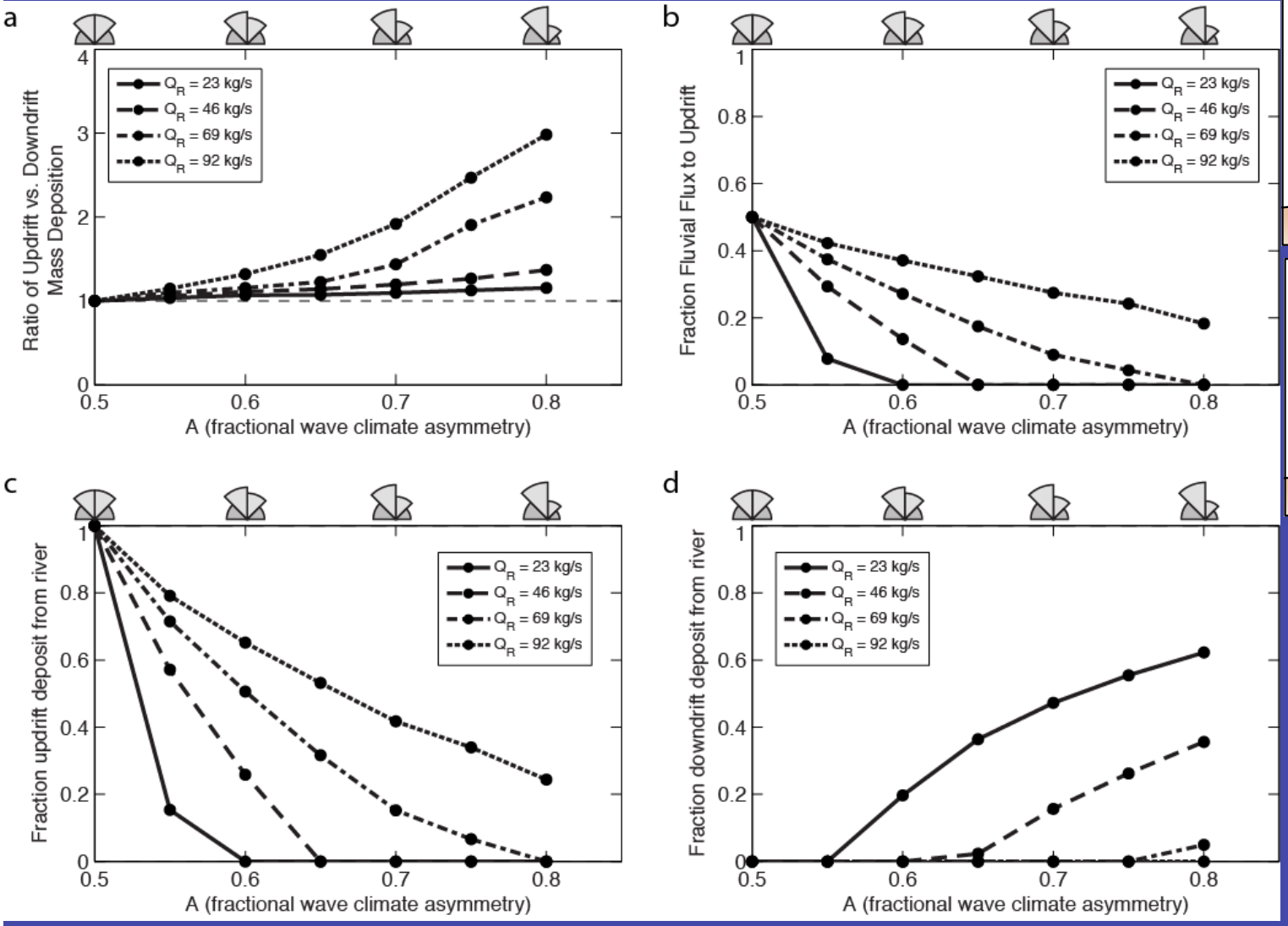
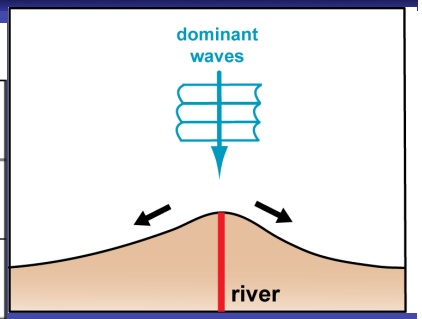
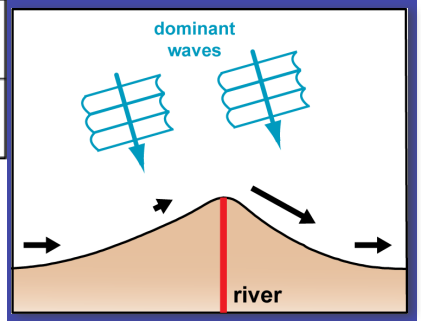


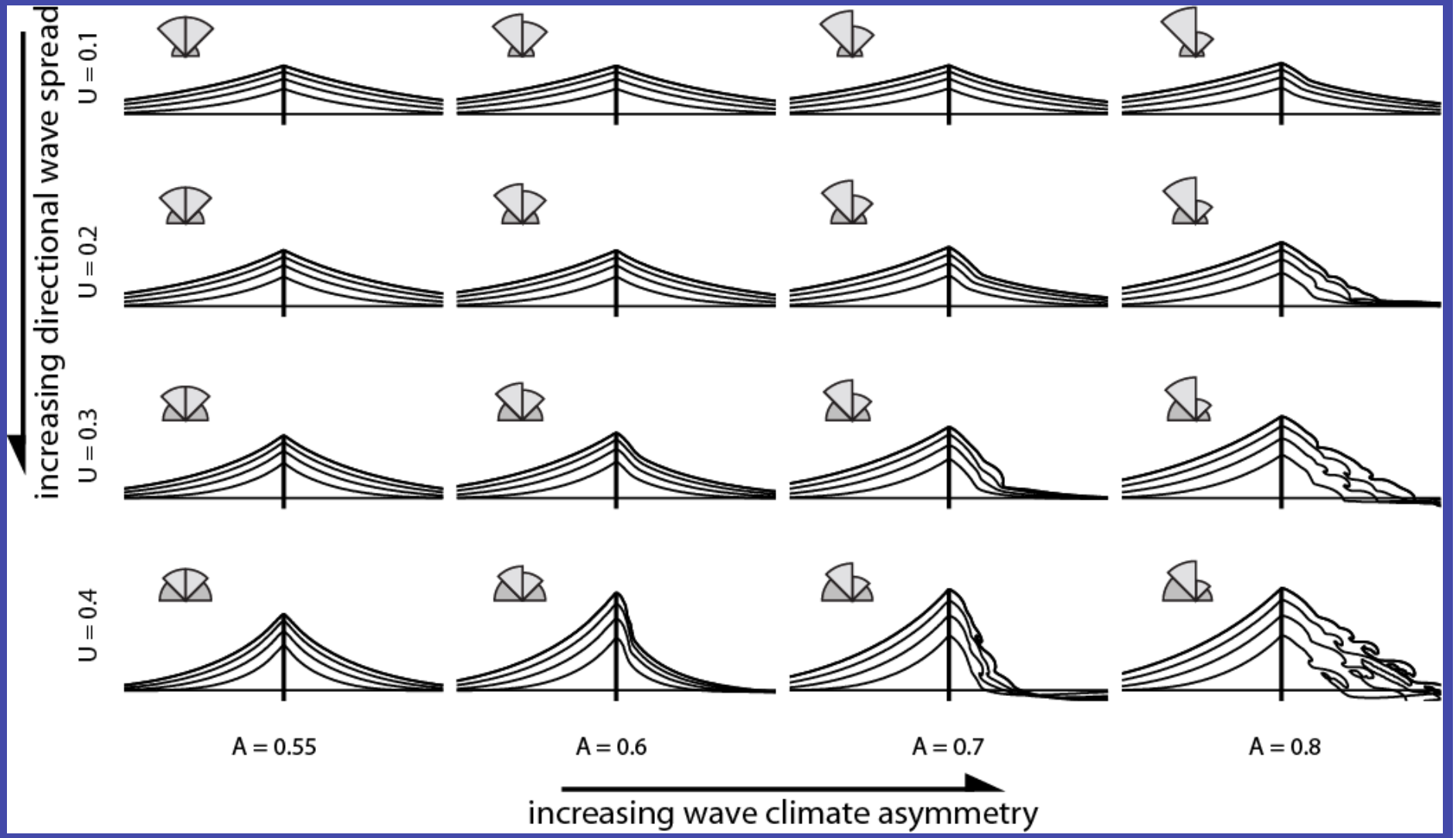
statistics of sediment distribution







delta morphologies with asymmetry



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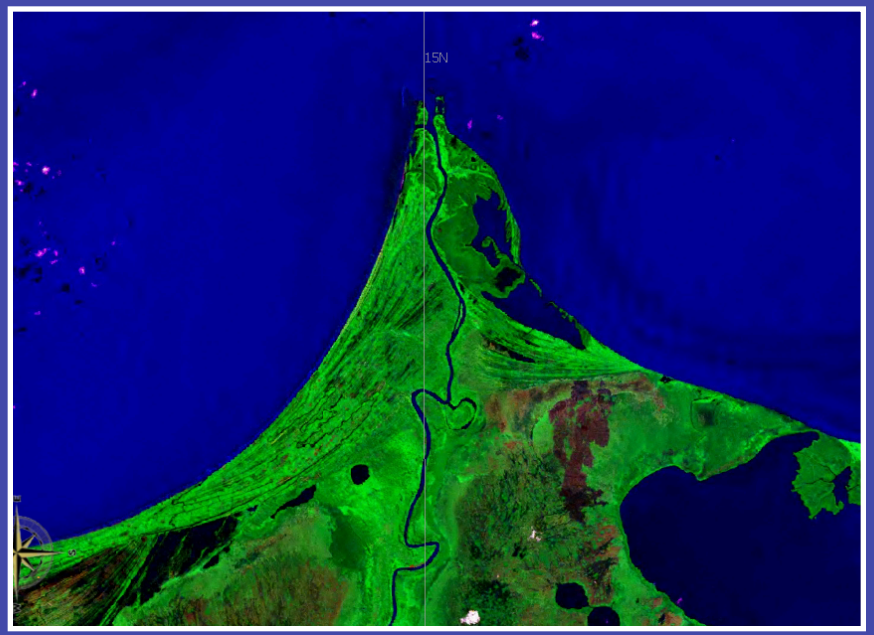
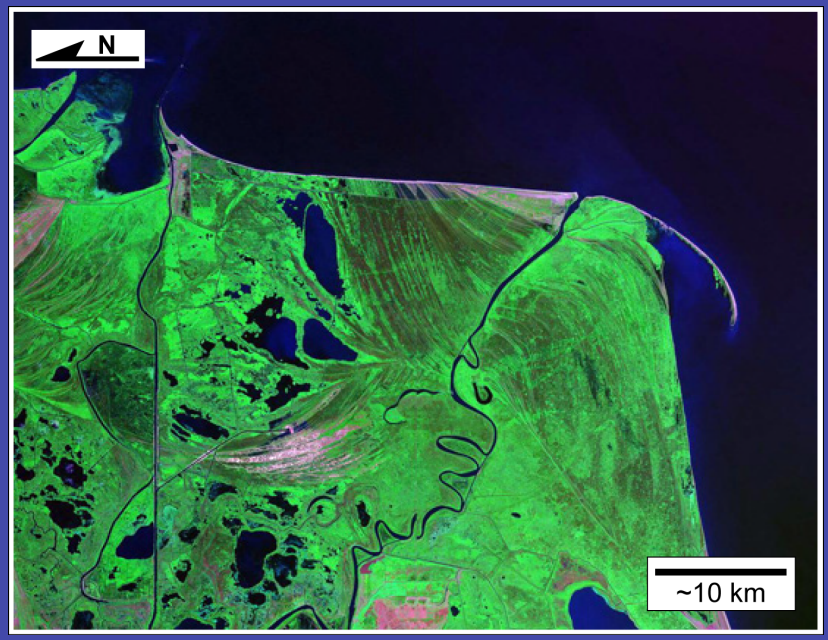


Coco Delta, Nicaragua/Hondoras



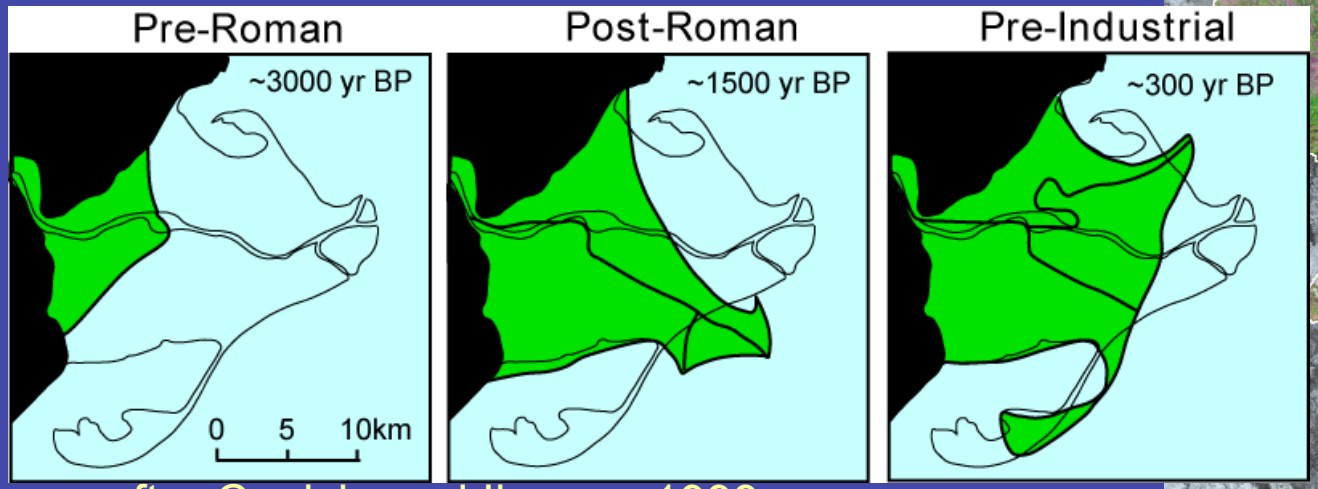
Danube Delta, Romania

Ebro Delta, Spain

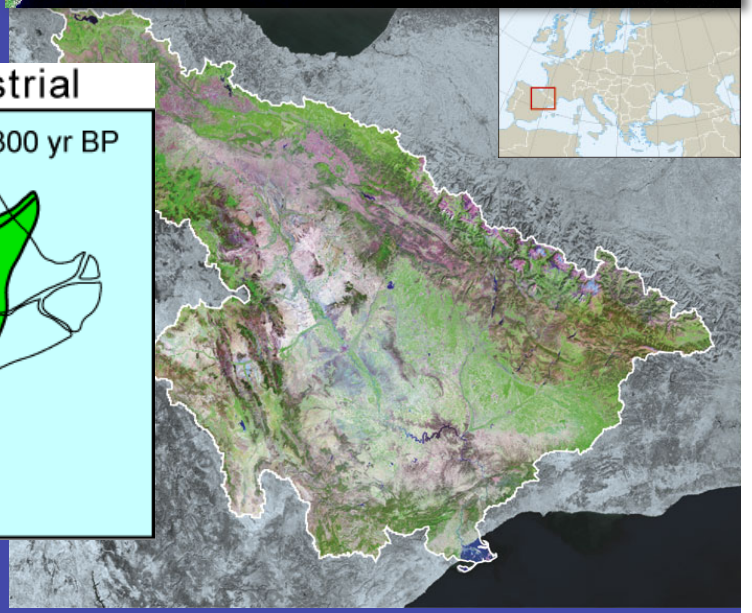
Brief history:

- small cuspate delta ca. 3000 yr BP

  (no more recent dates)
- apparent rapid extension as agriculture/land use expands
- currently erosionally dominated due to damming



after Canicio and Ibanez, 1999



approach

approach

approach

- develop agent-based coupled penguin behavioral model

approach

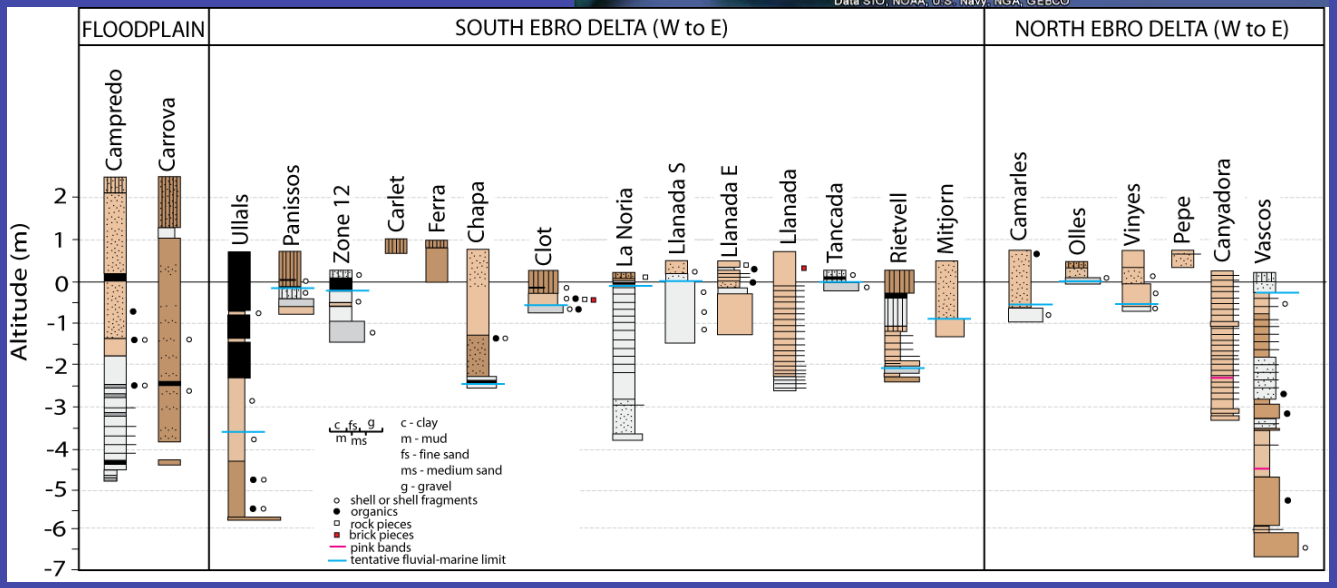
Can we quantify the human impact on the evolution of the Ebro Delta?

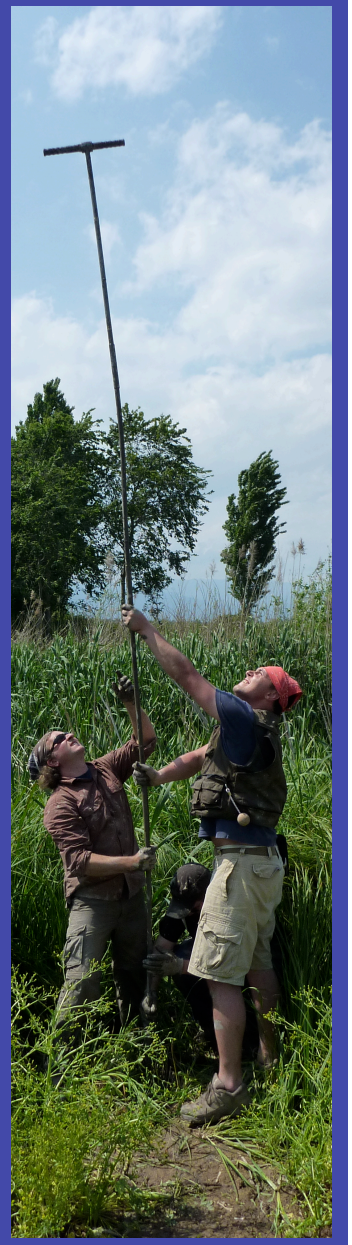
1) field investigations to date/interpret evolution
2) fluvial modeling to capture climate and anthropogenic effect
3) coastline modeling to investigate morphologic evolution

   -- coupling of 2) and 3) through CSDMS framework --

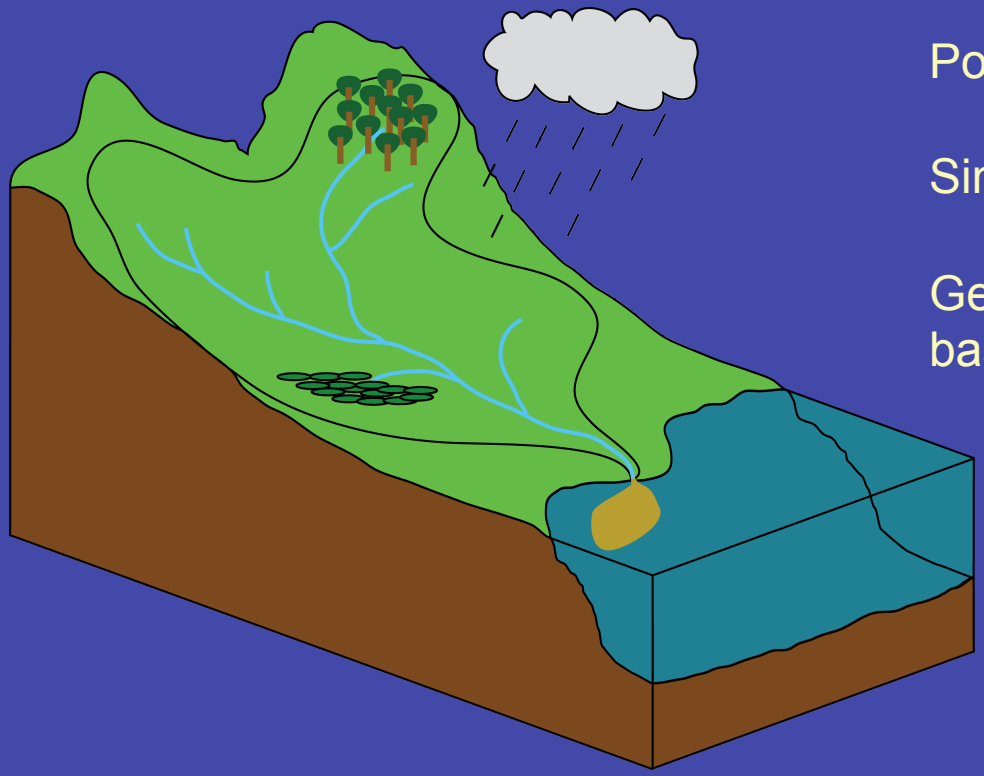
field data collection

- coring May 2010
- sites on delta to date evolution
- floodplain sites to understand flooding regime
- dates not back yet





HydroTrend Model



Climate driven hydrological transport model

Point source model

Simulates daily water and sediment load

Generic model; not specific to a certain river basin; no 'tuning' needed to apply

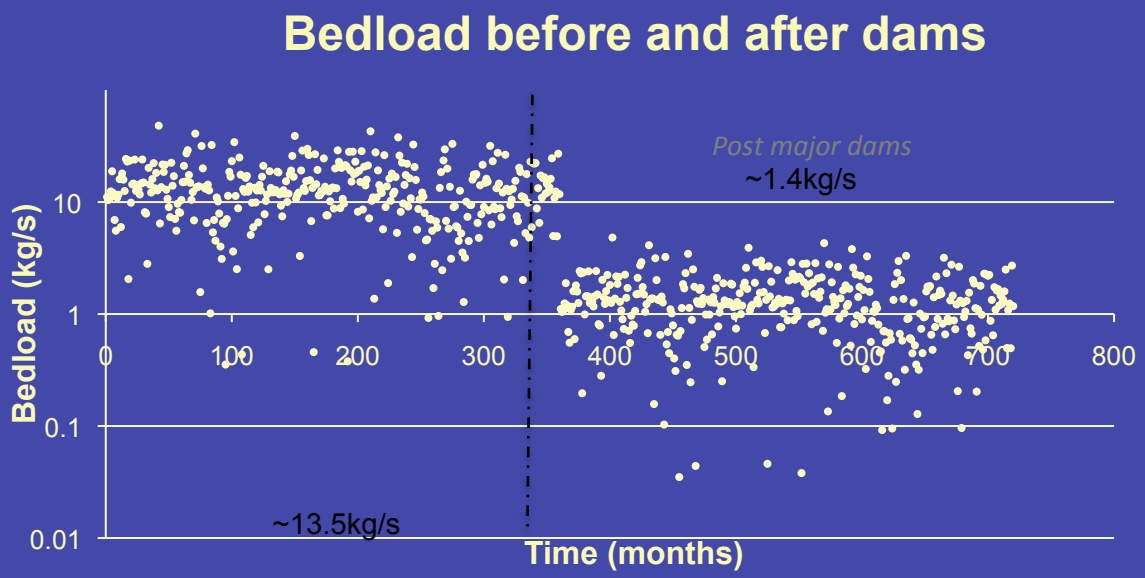
Qs = BQART

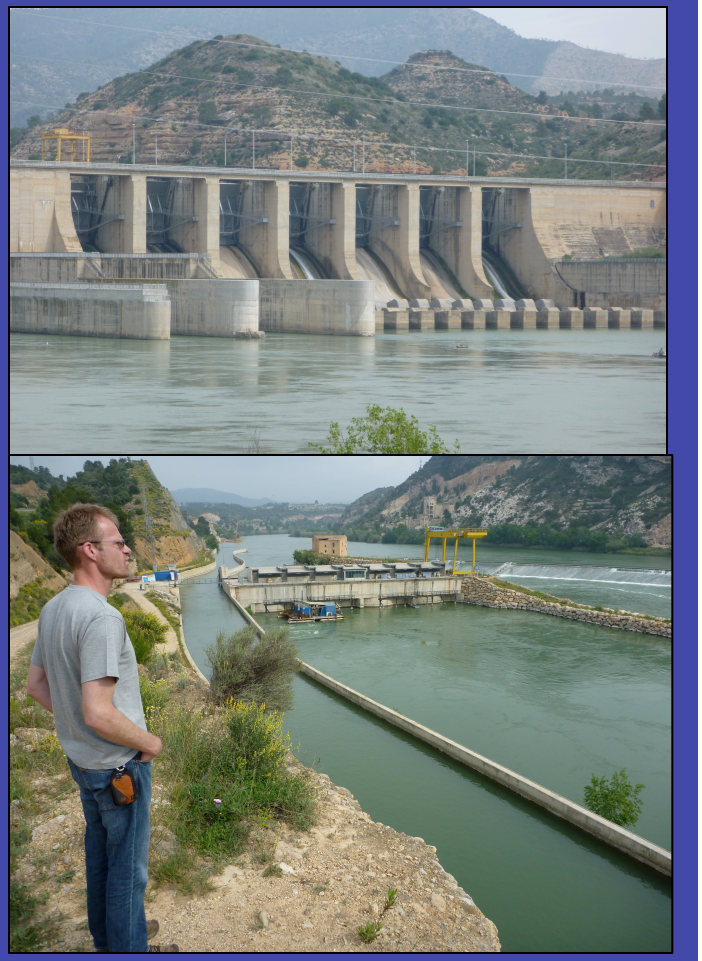
- B (Lithology, Anthropogenic, Trapping efficiency, Glaciers)
- Q (Water discharge)
- A (Area)
- R (Relief)
- T (Temperature)

Kettner and Syvitski, Computers & Geosc., 2008

Syvitski & Milliman, Journal of Geology, 2007

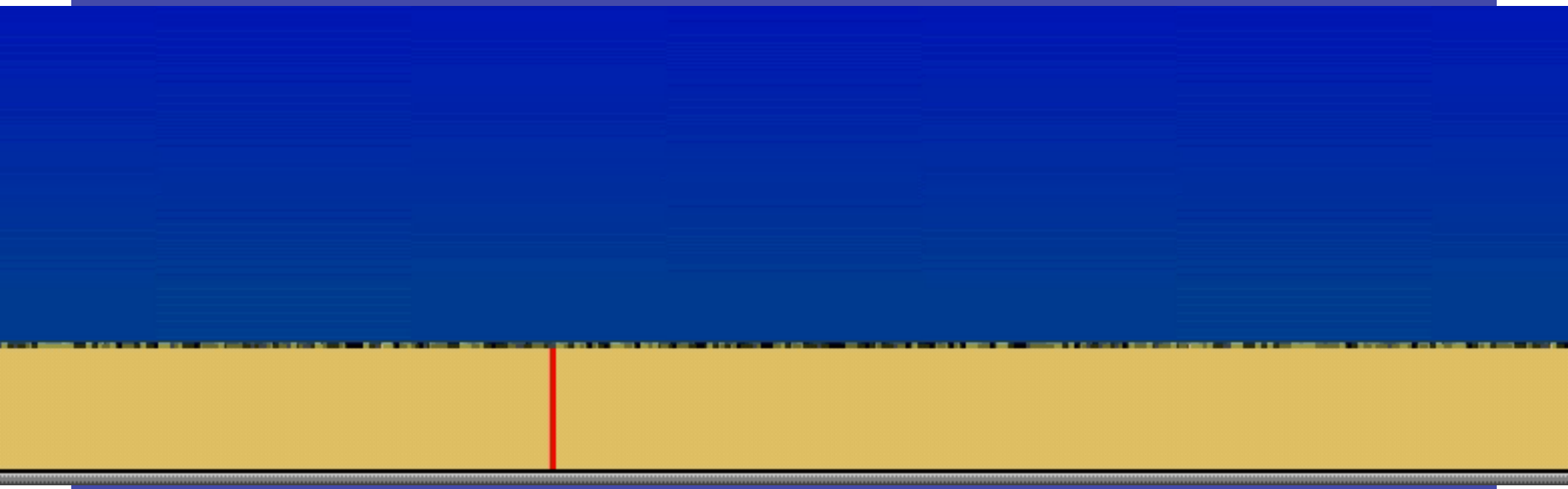
preliminary HydroTrend results



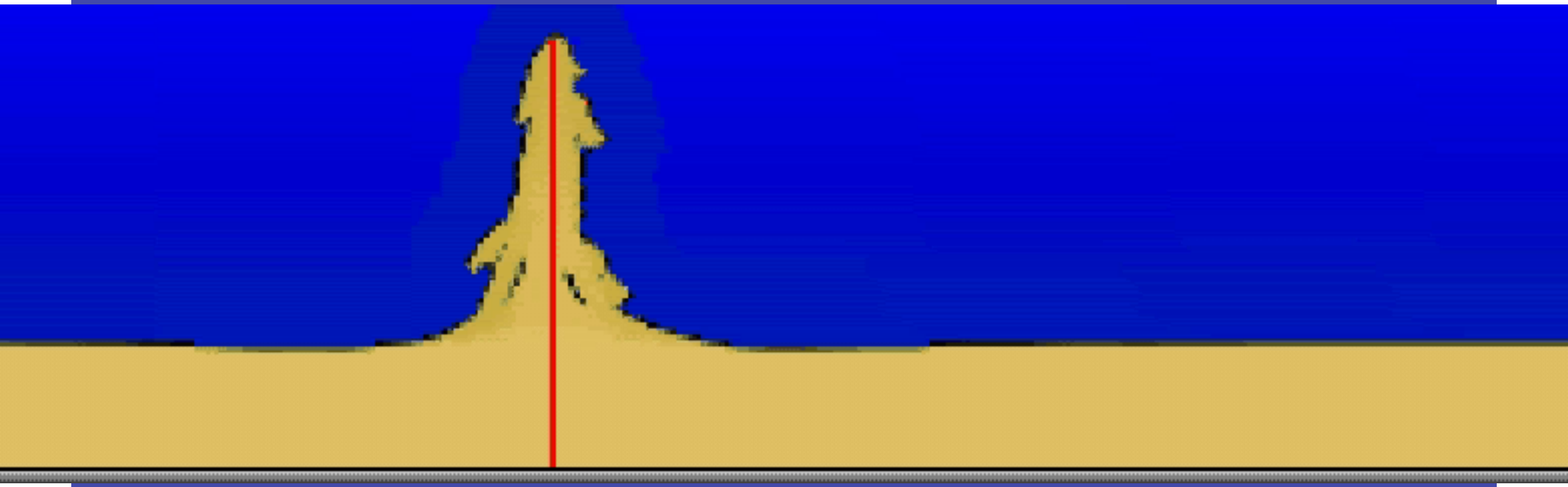


The emplacement of reservoirs in the main stream of the Ebro River during the 50-60's enhanced the wet rice farm practices that increased the evapo-transpiration; reducing the water discharge by ~ **35**% at the outlet.

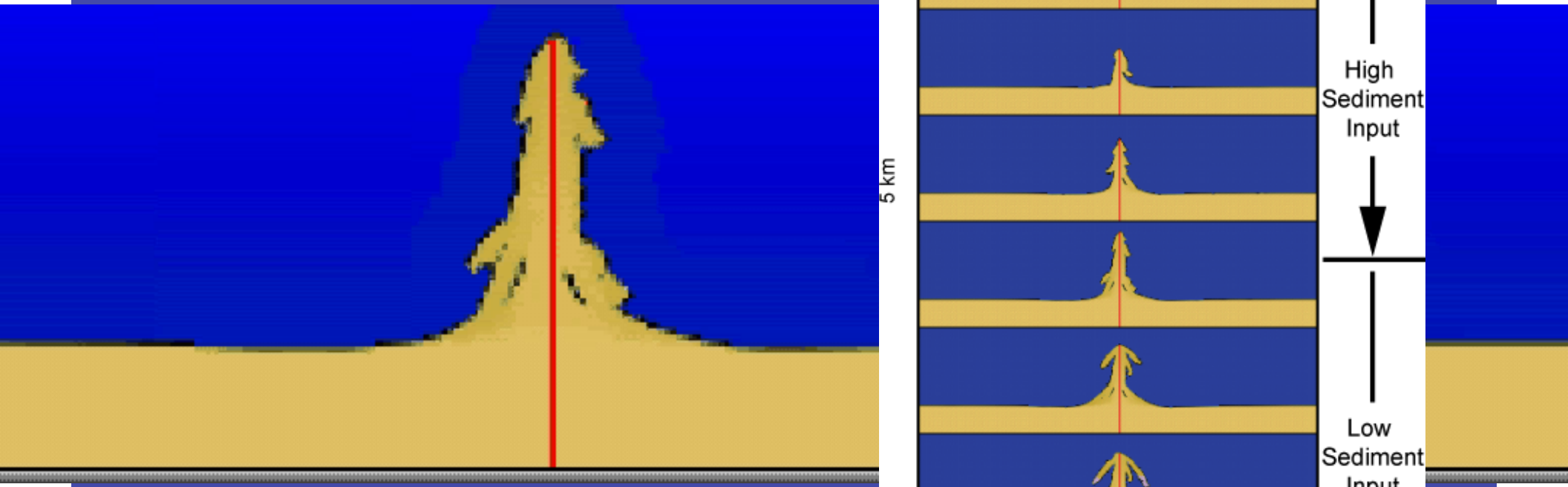
sediment reduction and shoreline evolution



sediment reduction and shoreline evolution

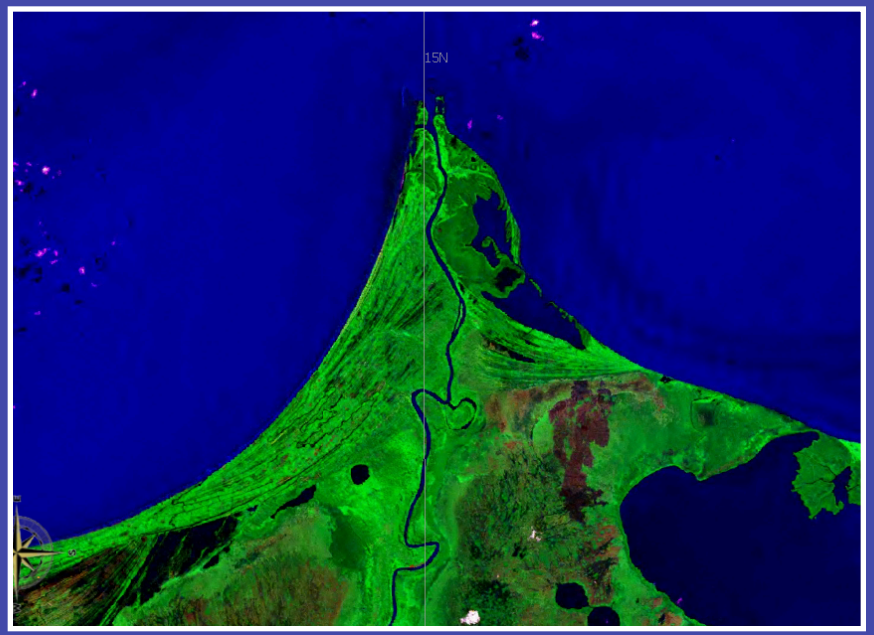


sediment reduction and shoreline evolution



roadmap

1) Modeling shoreline evolution: CEM
2) Delta modeling results for constant fluvial input
3) The Ebro Delta: studying varying fluvial fluxes
4) Towards two way coupling of rivers and the coastline



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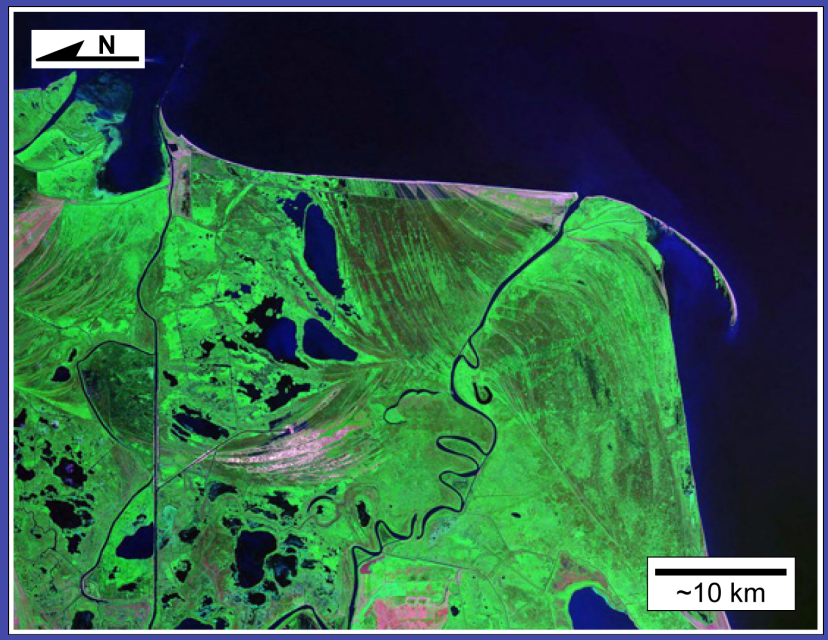
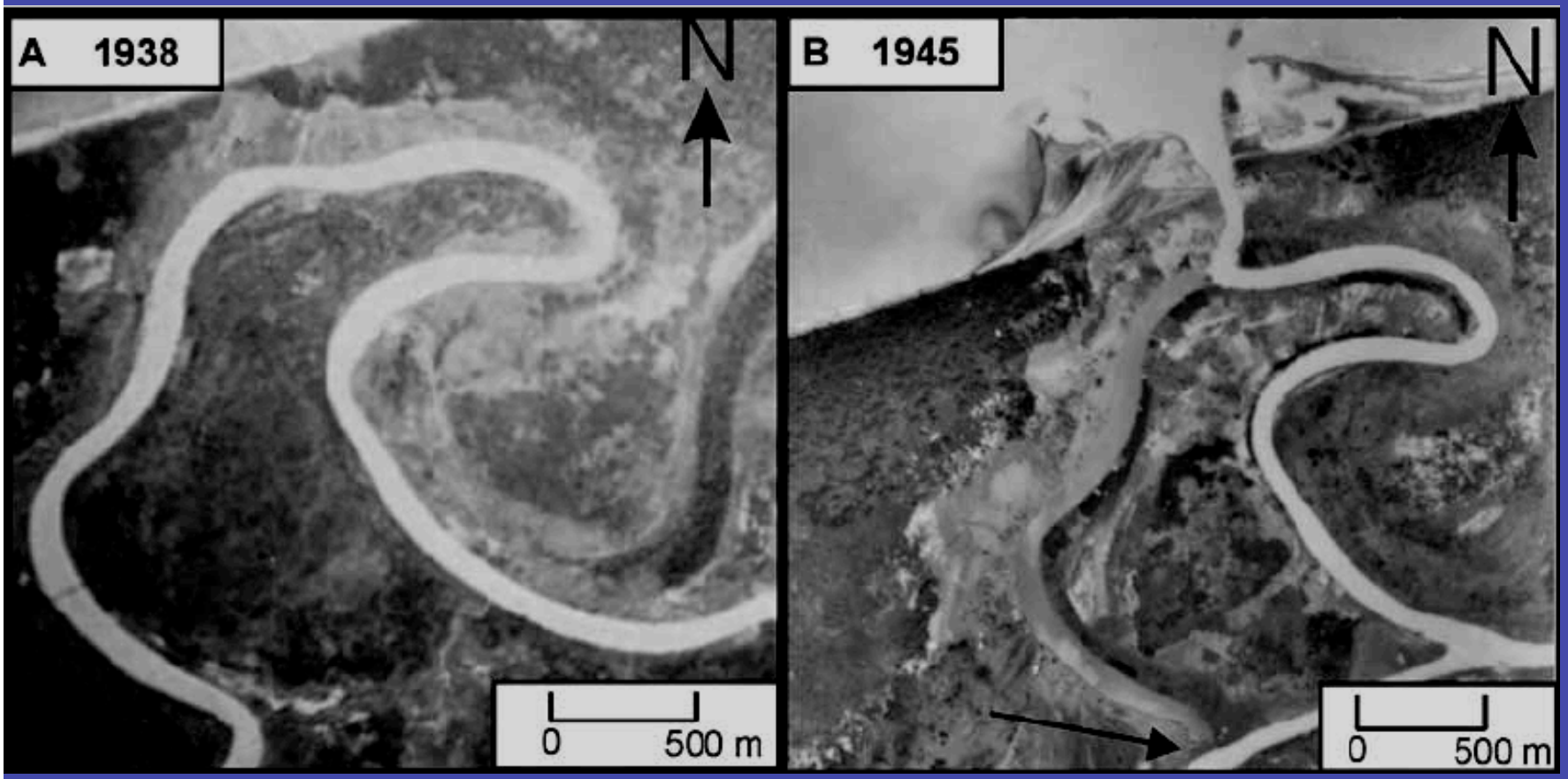


Danube Delta, Romania

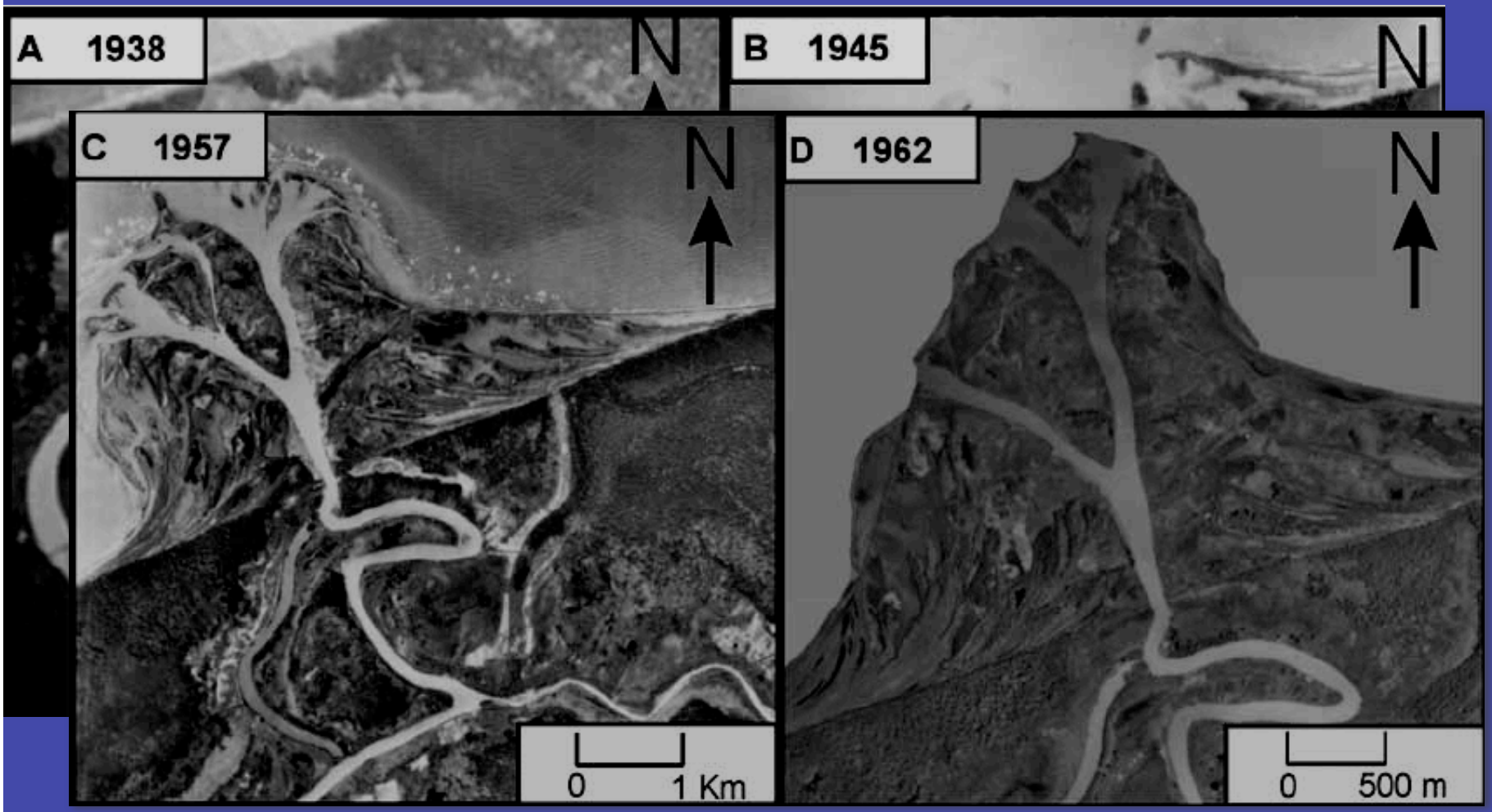
Tinajones Delta, Colombia

Tinajones historical evolution



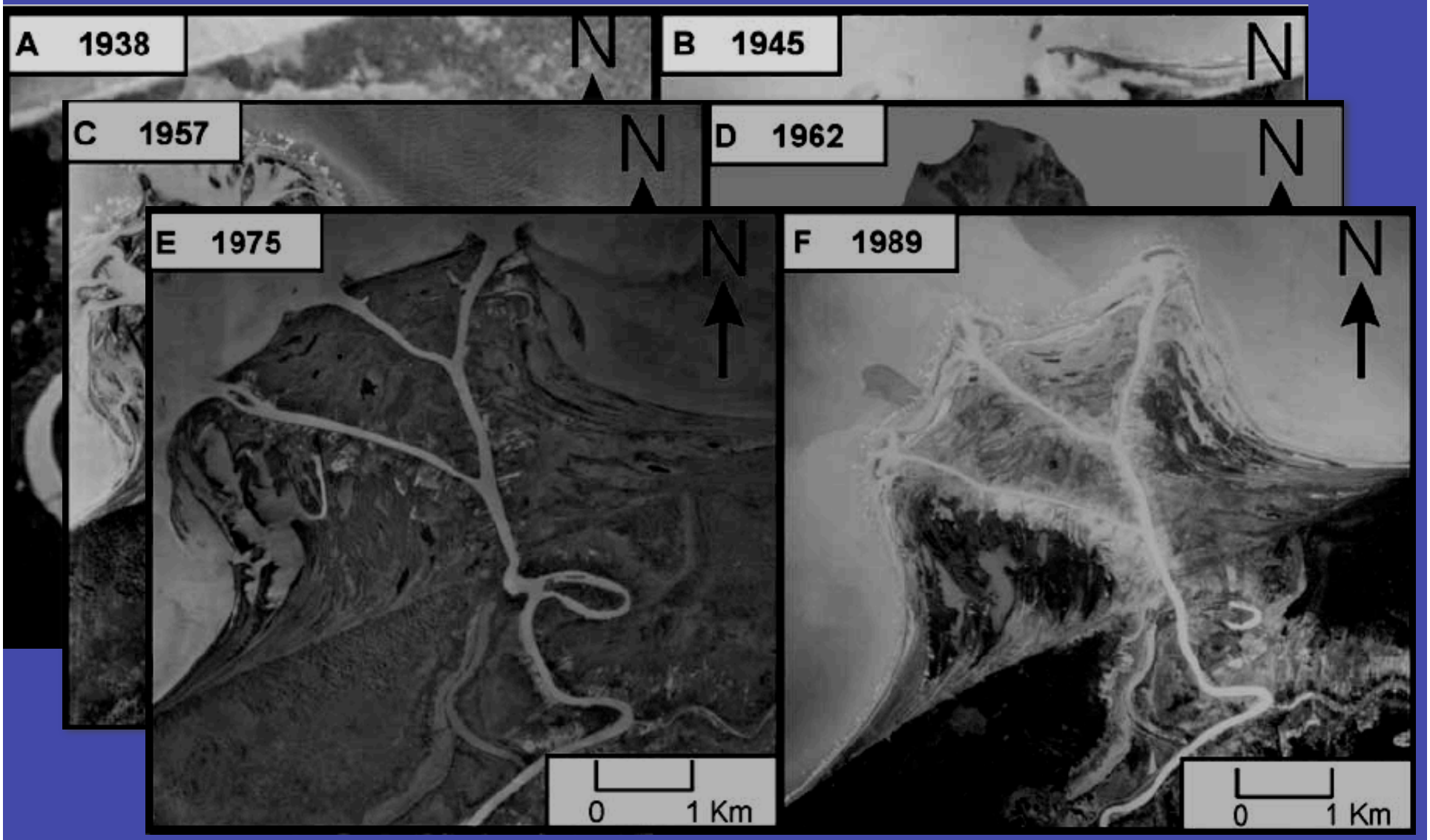
from *Suarez, Journal of South American Earth Sciences 16, 2004*

Tinajones historical evolution



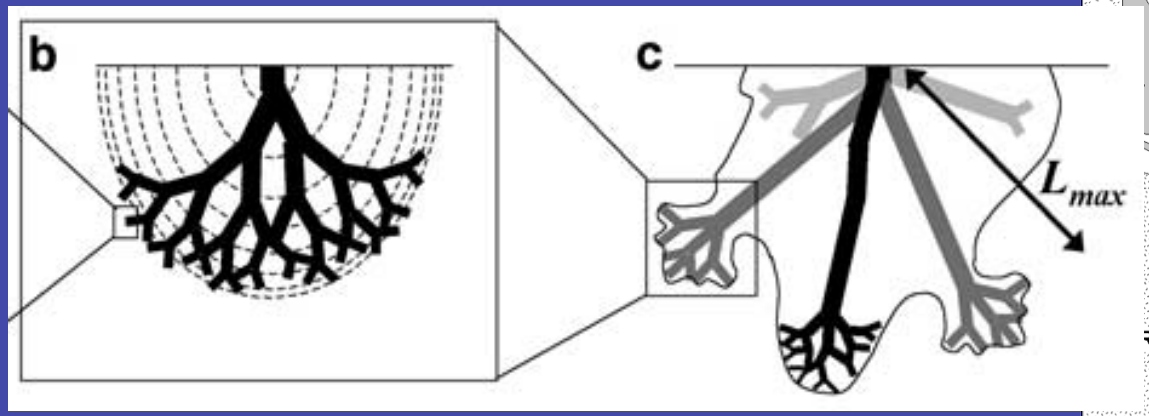
from *Suarez, Journal of South American Earth Sciences 16, 2004*

Tinajones historical evolution

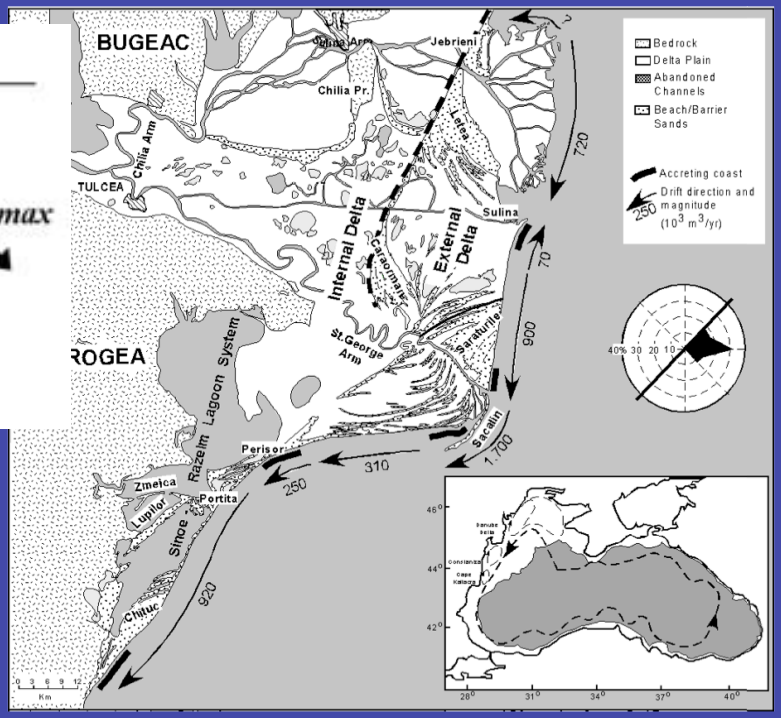


from *Suarez, Journal of South American Earth Sciences 16, 2004*

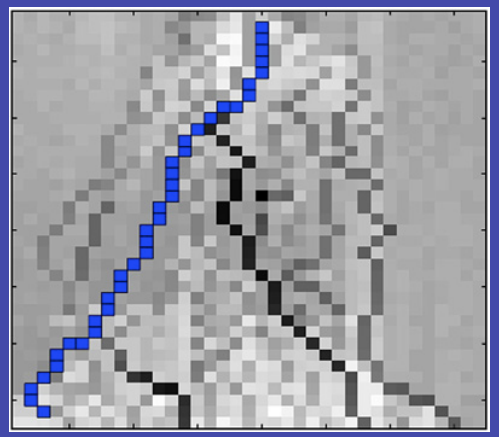
feedbacks and avulsions with waves



Jerolmack and Swenson, GRL 2007



- Scientific questions:
  - How do the feedbacks affect delta morphology?
  - Does interconnection through littoral transport affect the characteristic timescales of evolution/avulsion?
  - Does asymmetrical evolution affect the characteristics of avulsion?



Jerolmack and Paola, Geomorphology 2007

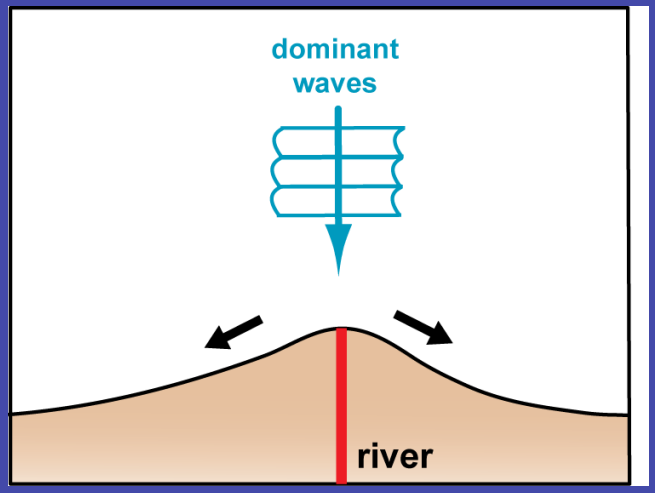
two-way coupling through CMT

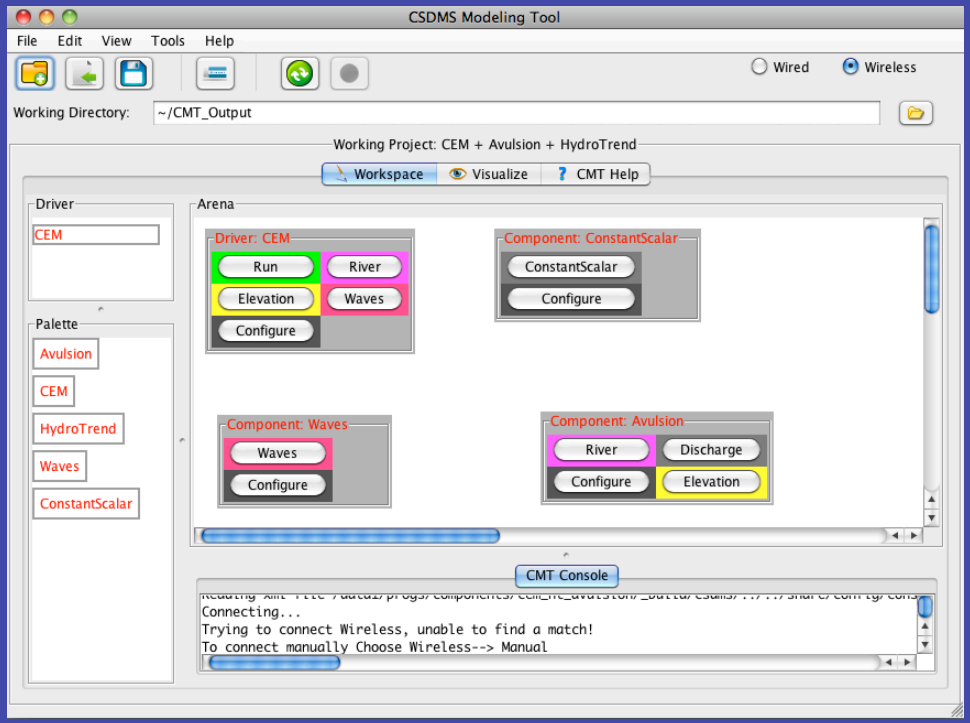
- flexible ‘avulsion’ component to implement different fluvial flux and routing schemes
  - fixed direction (several rivers)
  - migrating river
  - geometric ‘bifurcation’ rules
  - dynamic upstream avulsion
- simple feedback:

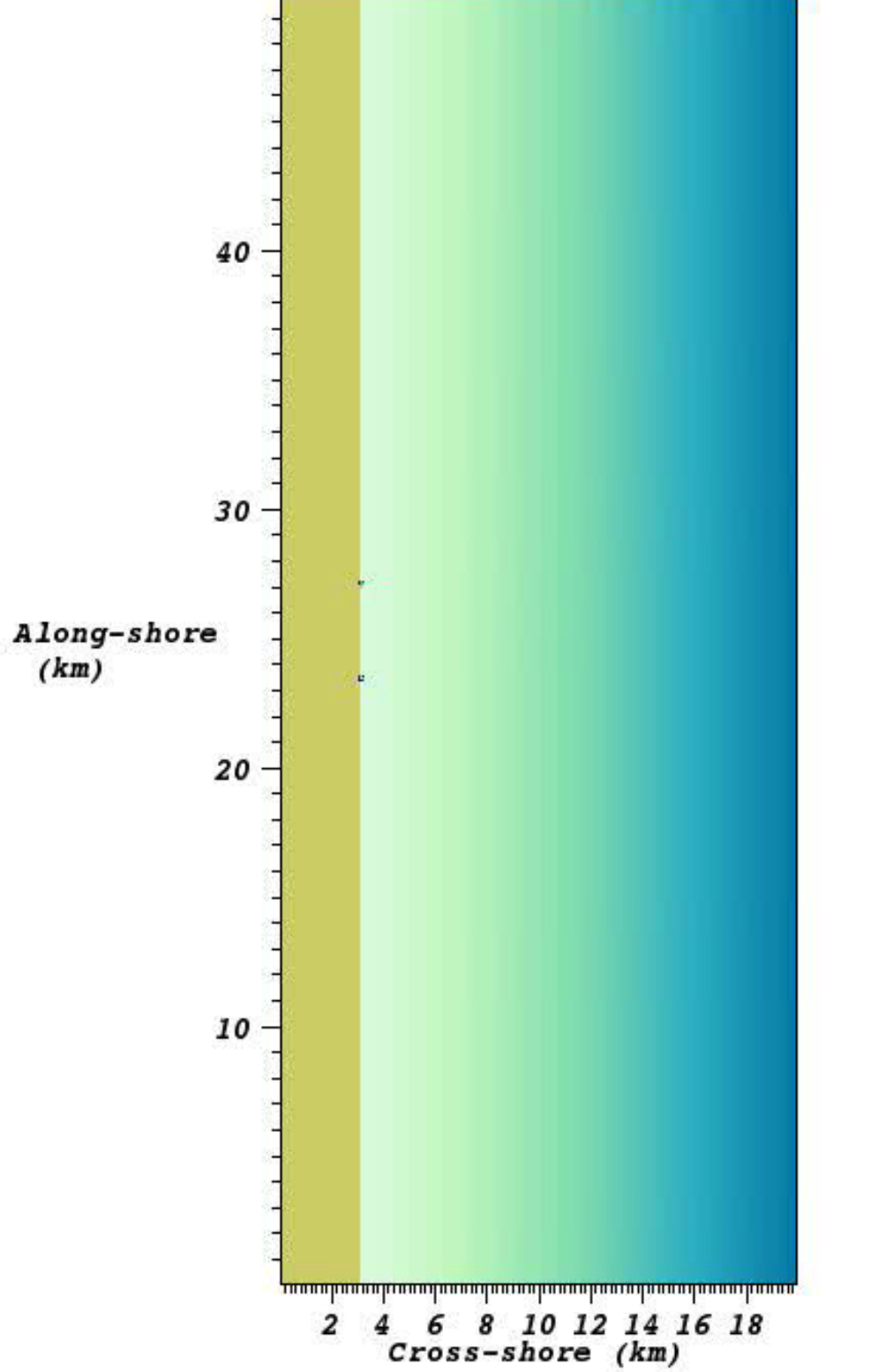
  $Q_b = a\,S^b$, where

  slope S ~ river length

  b > 1 (non-linear)
  - just a first try!







Day = 0

summary

- waves and deltas are not boring
- wave angle distribution exerts a first-order control on growth rate and sediment distribution of these deltas
- integration through CSDMS is allowing investigation of scientific questions:
  - evolution of the Ebro Delta through one-way coupling
  - two-way feedbacks between the coastal and fluvial domains
- benefits from CSDMS
  - robust development framework allows progressive development
  - integration team
- thoughts for food
  - difficulty using CMT for model concept development

Volta Delta, Ghana