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Tidal flat morphodynamics: a synthesis

Carl T. Friedrichs
Virginia Institute of Marine Science

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Tidal Flat Morphodynamics: A Synthesis

Carl Friedrichs

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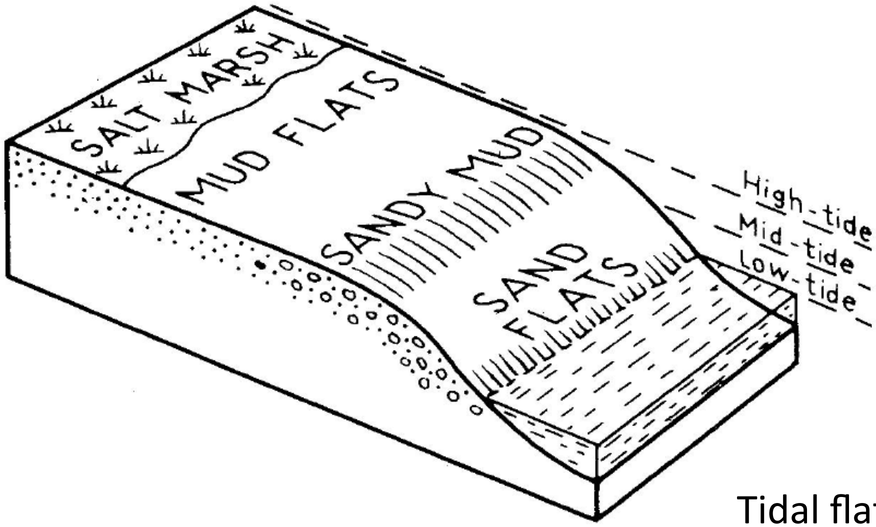
Main Points

1) On tidal flats, sediment (especially mud) moves toward areas of weaker energy.
2) Tides usually move sediment landward; waves usually move sediment seaward.
3) Tides and/or deposition favor a convex upward profile; waves and/or erosion favor a concave upward profile.
4) South San Francisco Bay provides a case study supporting these trends.

Photo of Jade Bay tidal flats, Germany (spring tide range 3.8 m)
by D. Schwen, http://commons.wikimedia.org

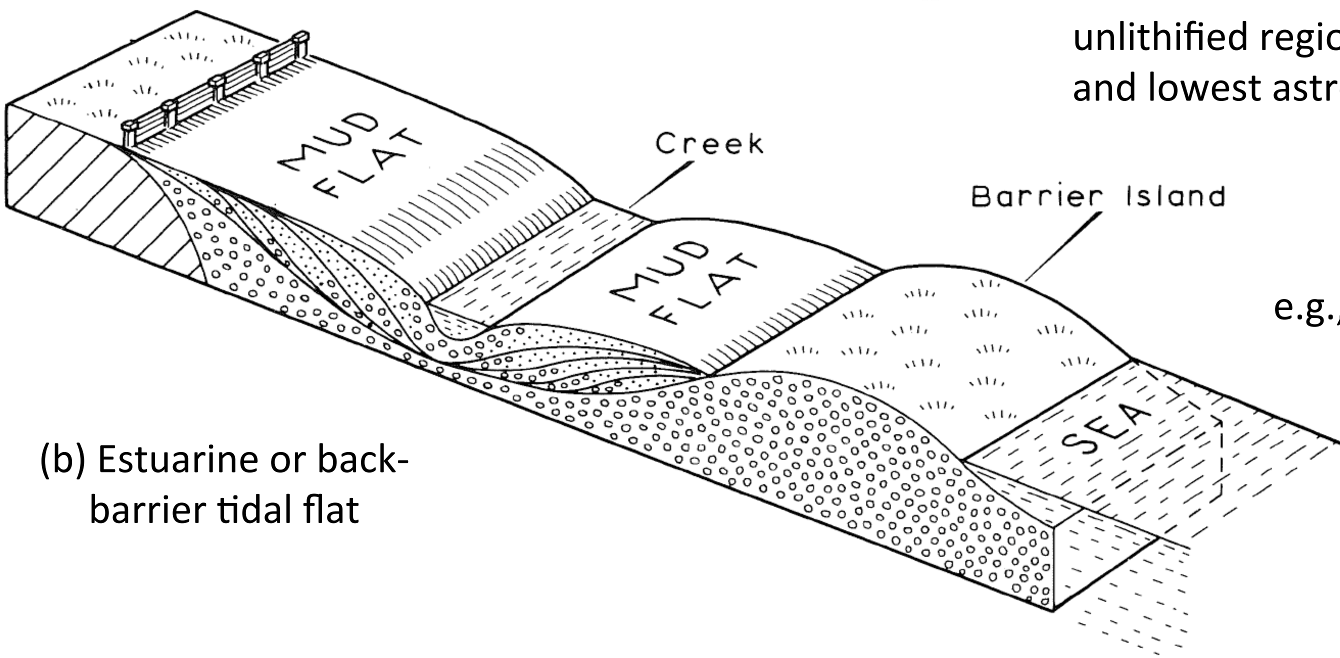
Tidal Flat Definition and General Properties

(a) Open coast tidal flat



e.g., Yangtze mouth

Tidal flat = low relief, unvegetated, unlithified region between highest and lowest astronomical tide.



e.g., Dutch Wadden Sea

(b) Estuarine or back-barrier tidal flat

(Sketches from Pethick, 1984)

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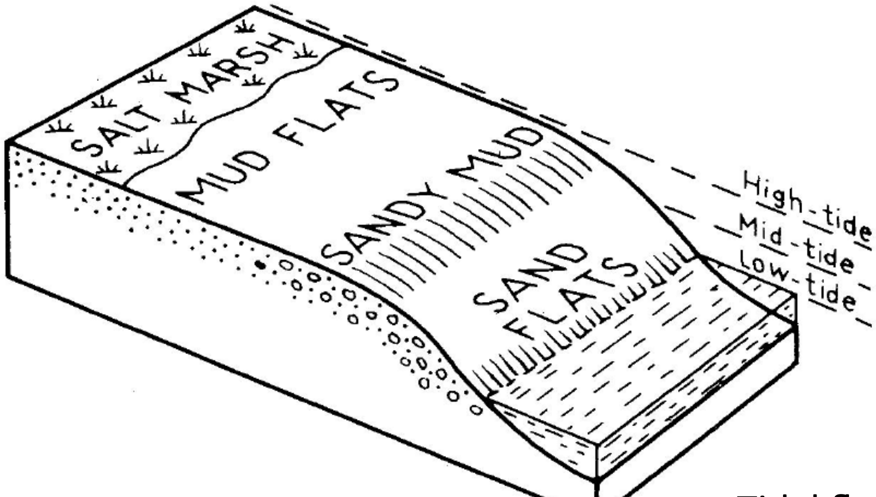

Note there are no complex creeks or bedforms on these simplistic flats.

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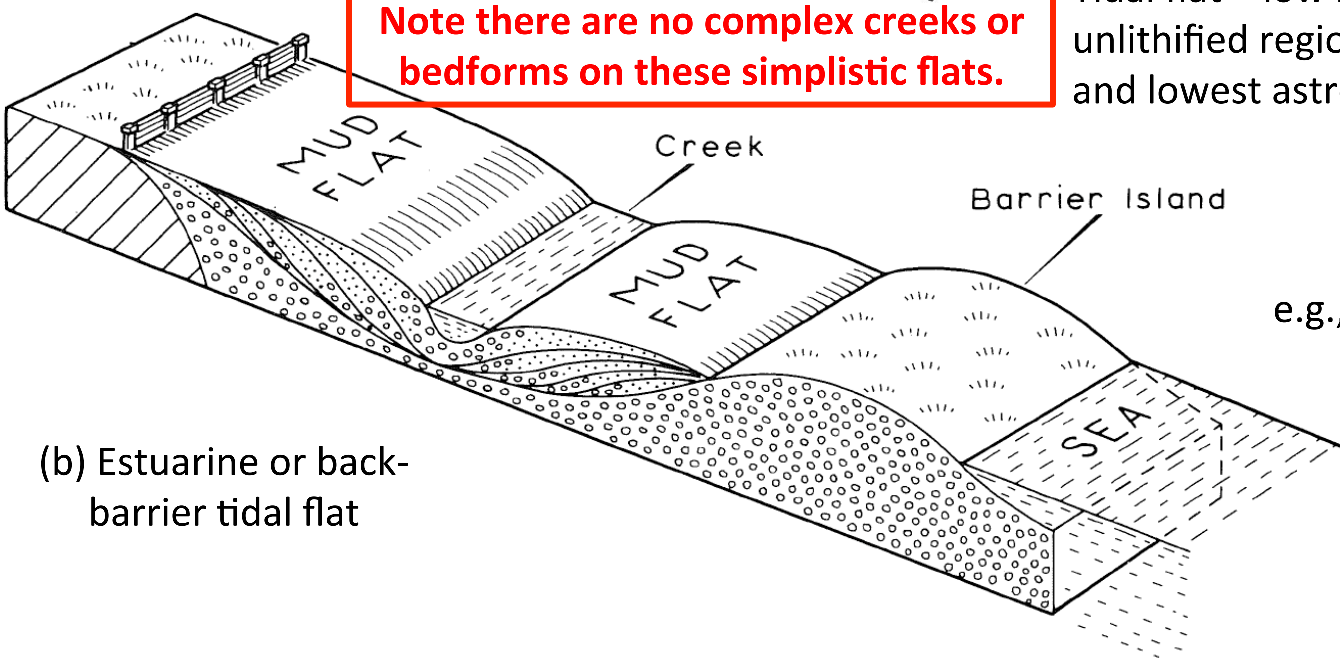

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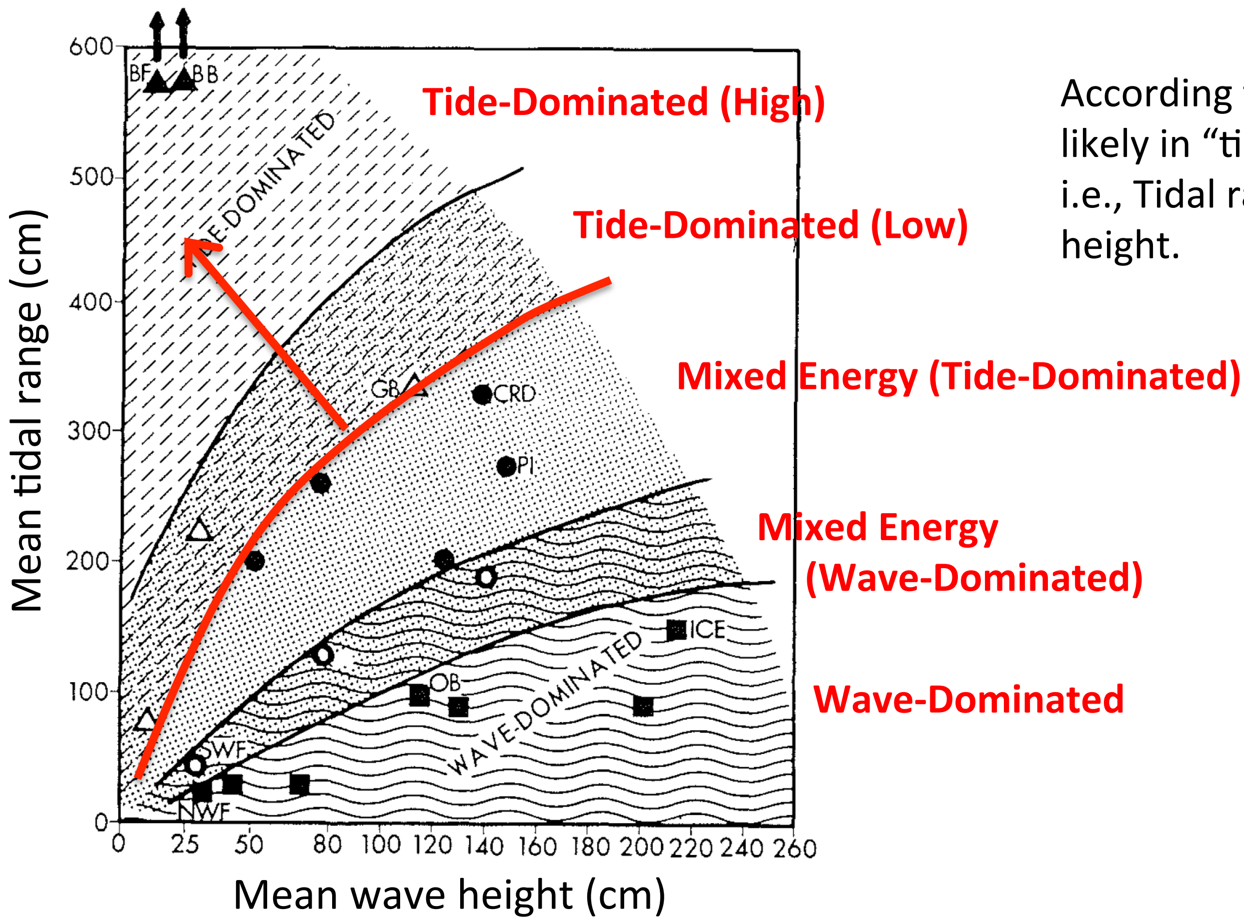
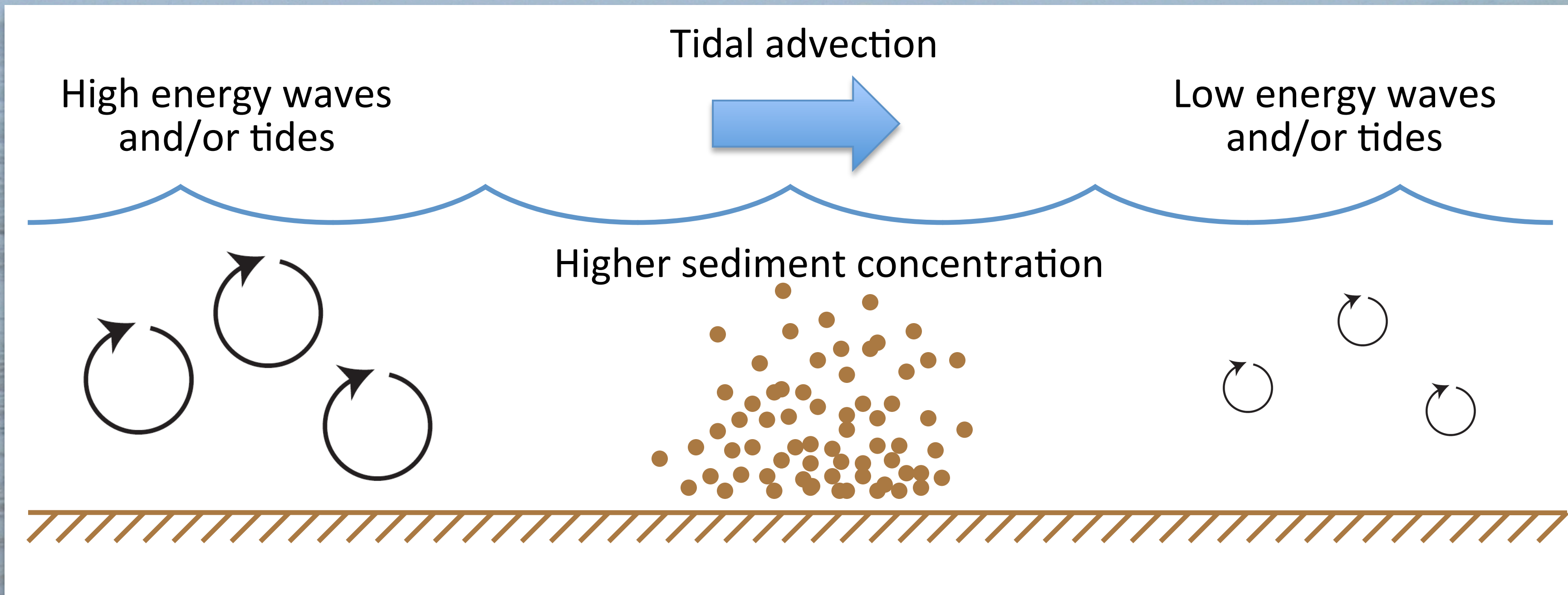
(Sketches from Pethick, 1984)

Where do tidal flats occur?

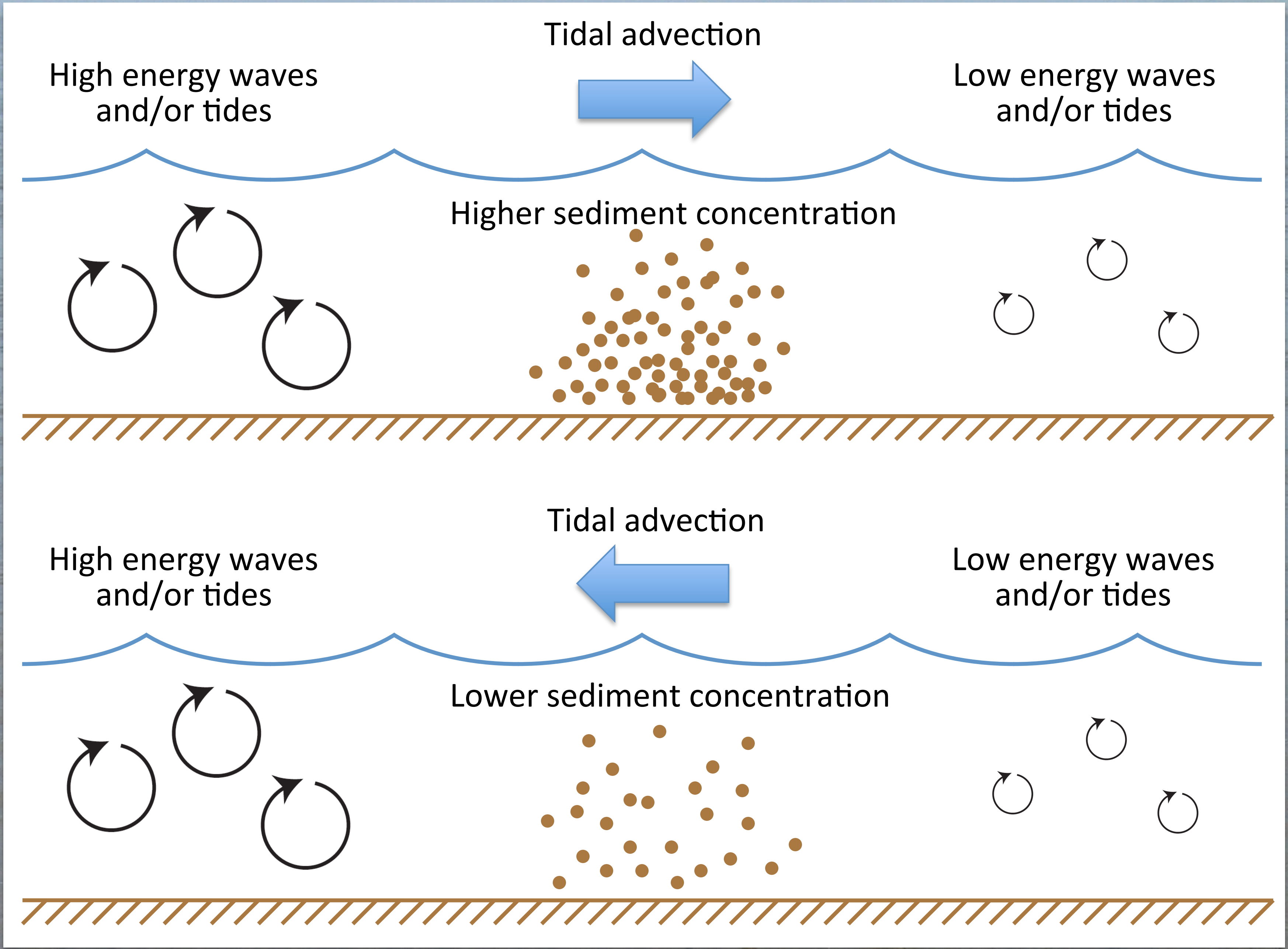


According to Hayes (1979), flats are likely in "tide-dominated" conditions, i.e., Tidal range > ~ 2 to 3 times wave height.

What moves sediment across flats?

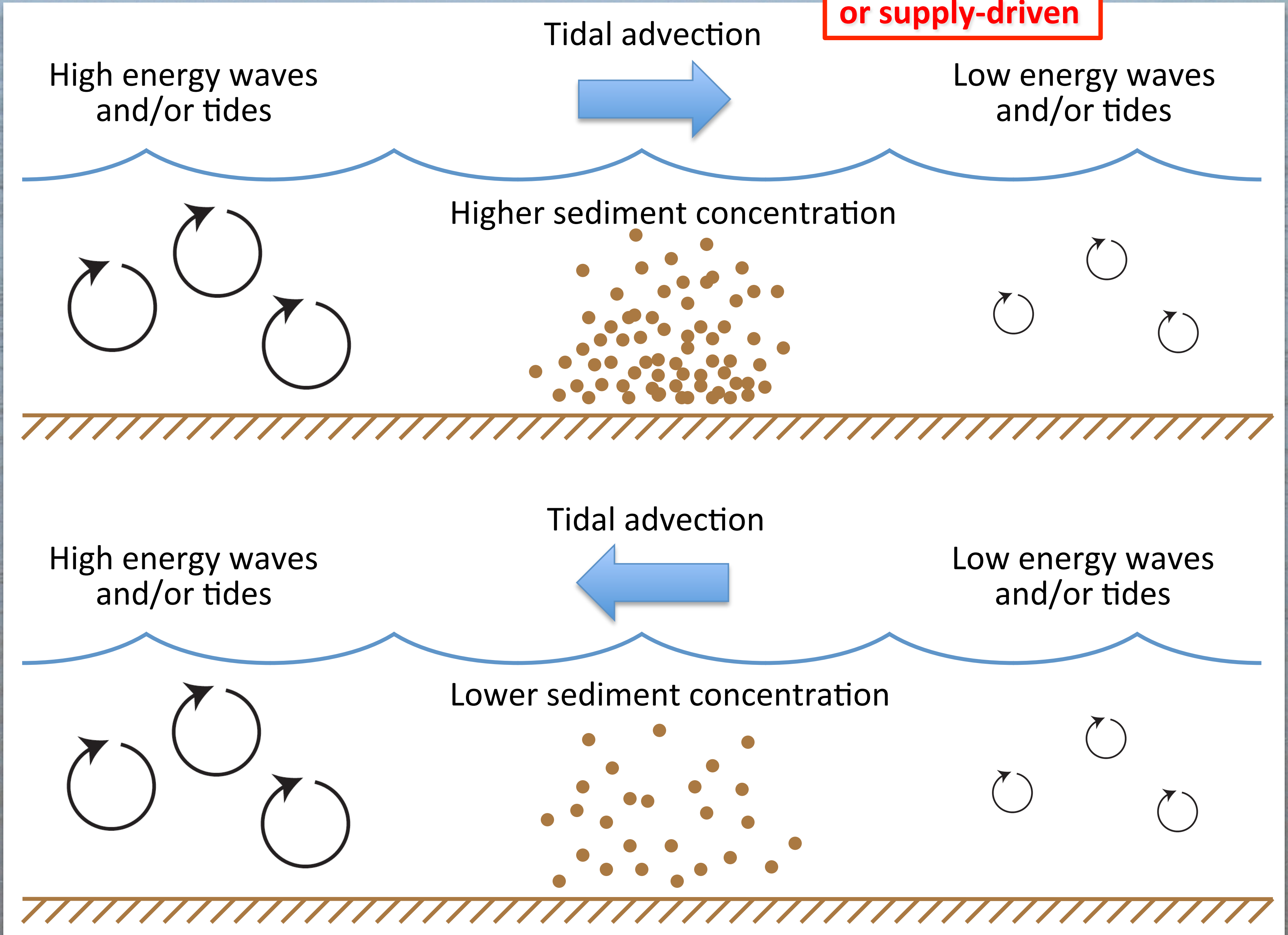


What moves sediment across flats? Ans: Tides plus energy-driven concentration gradients



What moves sediment across flats? Ans: Tides plus energy-driven concentration gradients

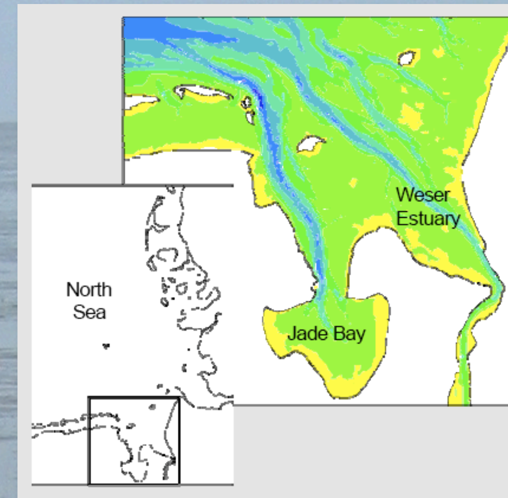
or supply-driven

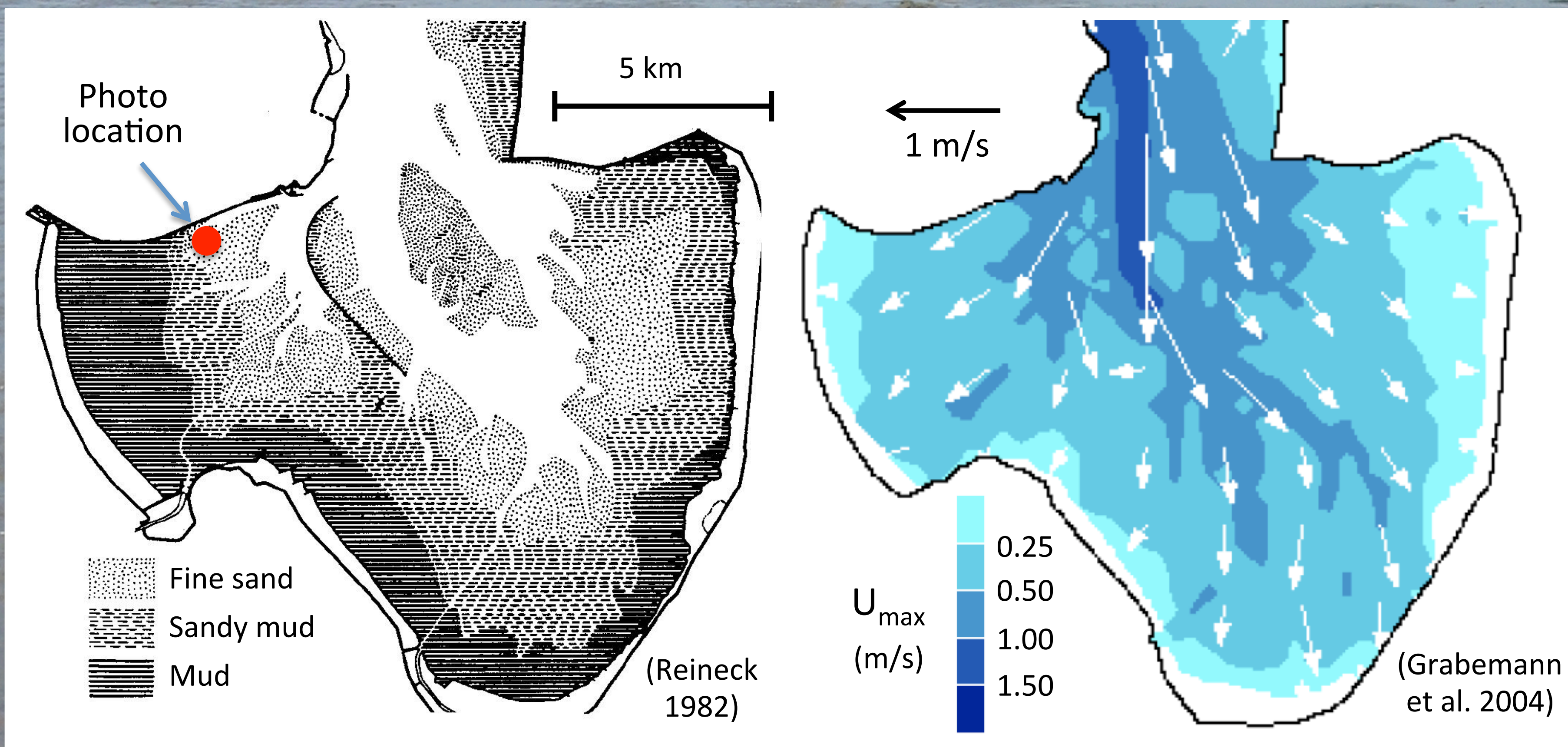


Typical sediment grain size and tidal velocity pattern across tidal flats:

Mud is concentrated near high water line where tidal velocities are lowest.

Ex. Jade Bay, German Bight, mean tide range 3.7 m; Spring tide range 3.9 m.





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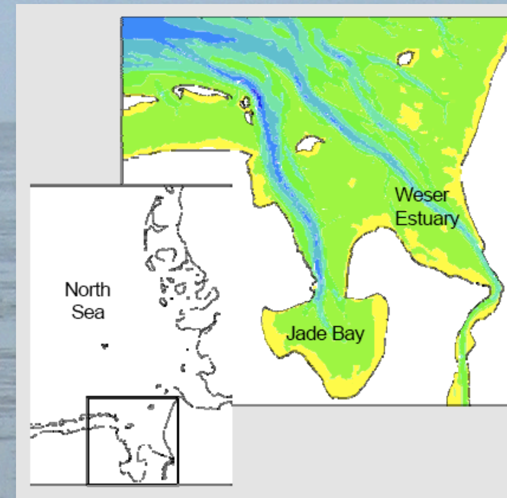

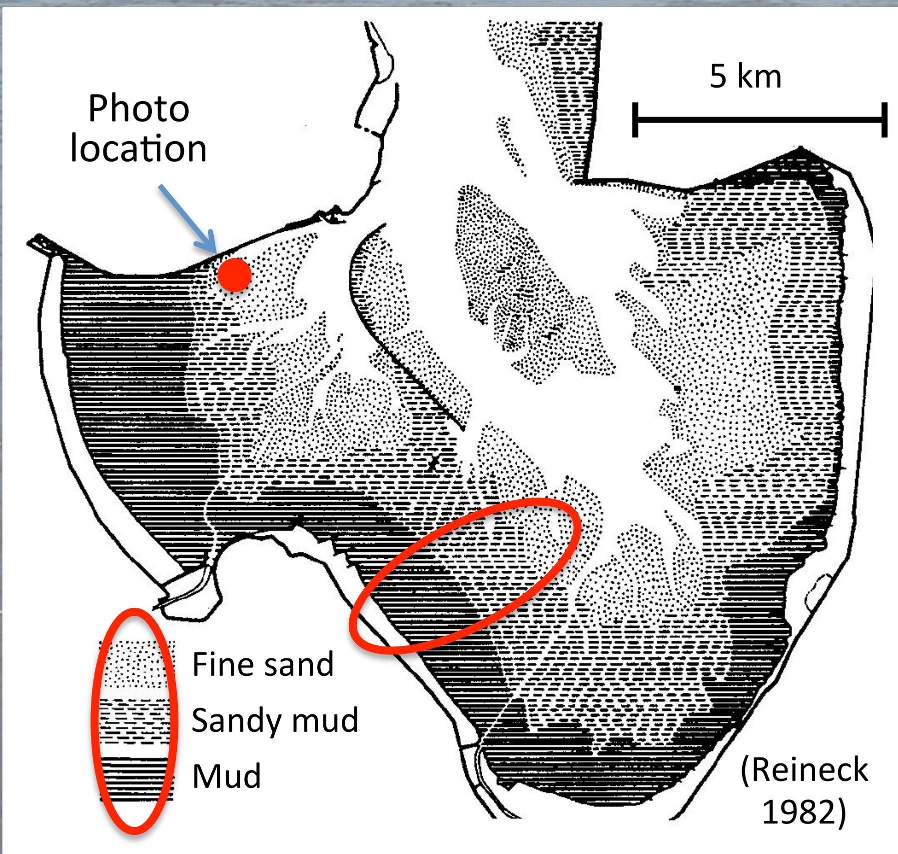

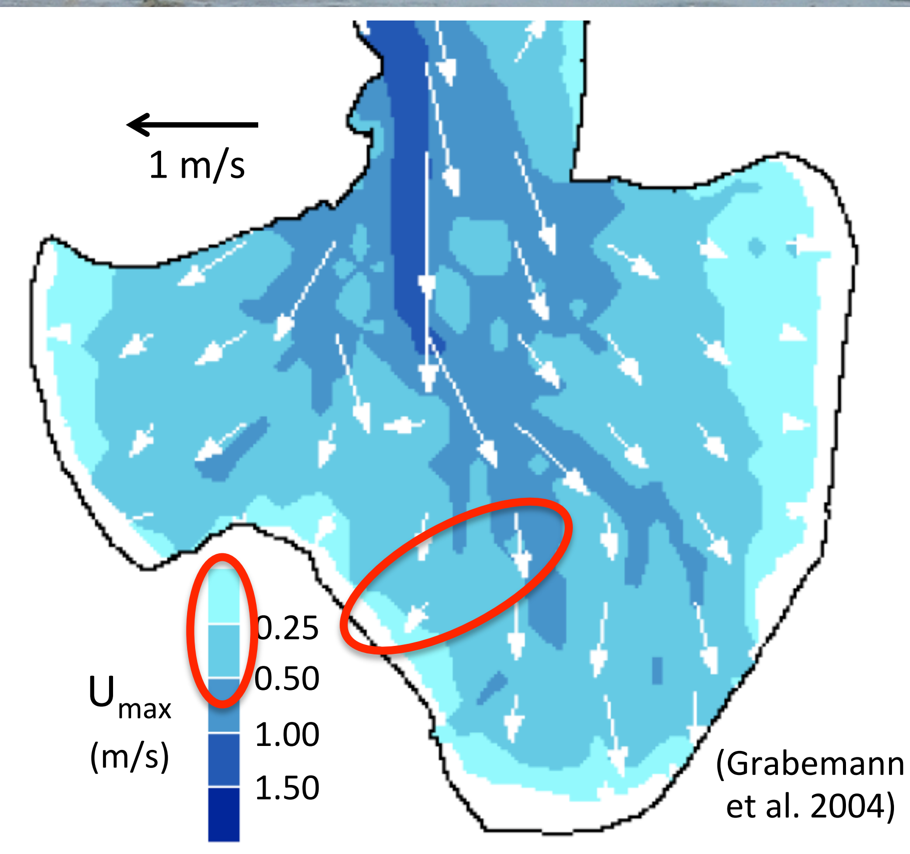

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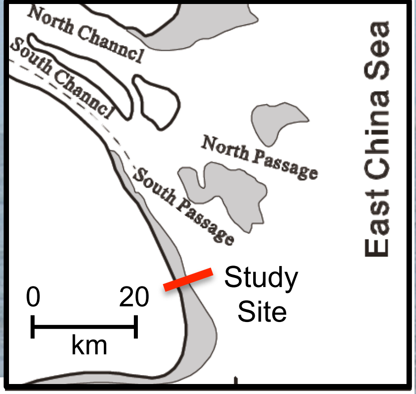
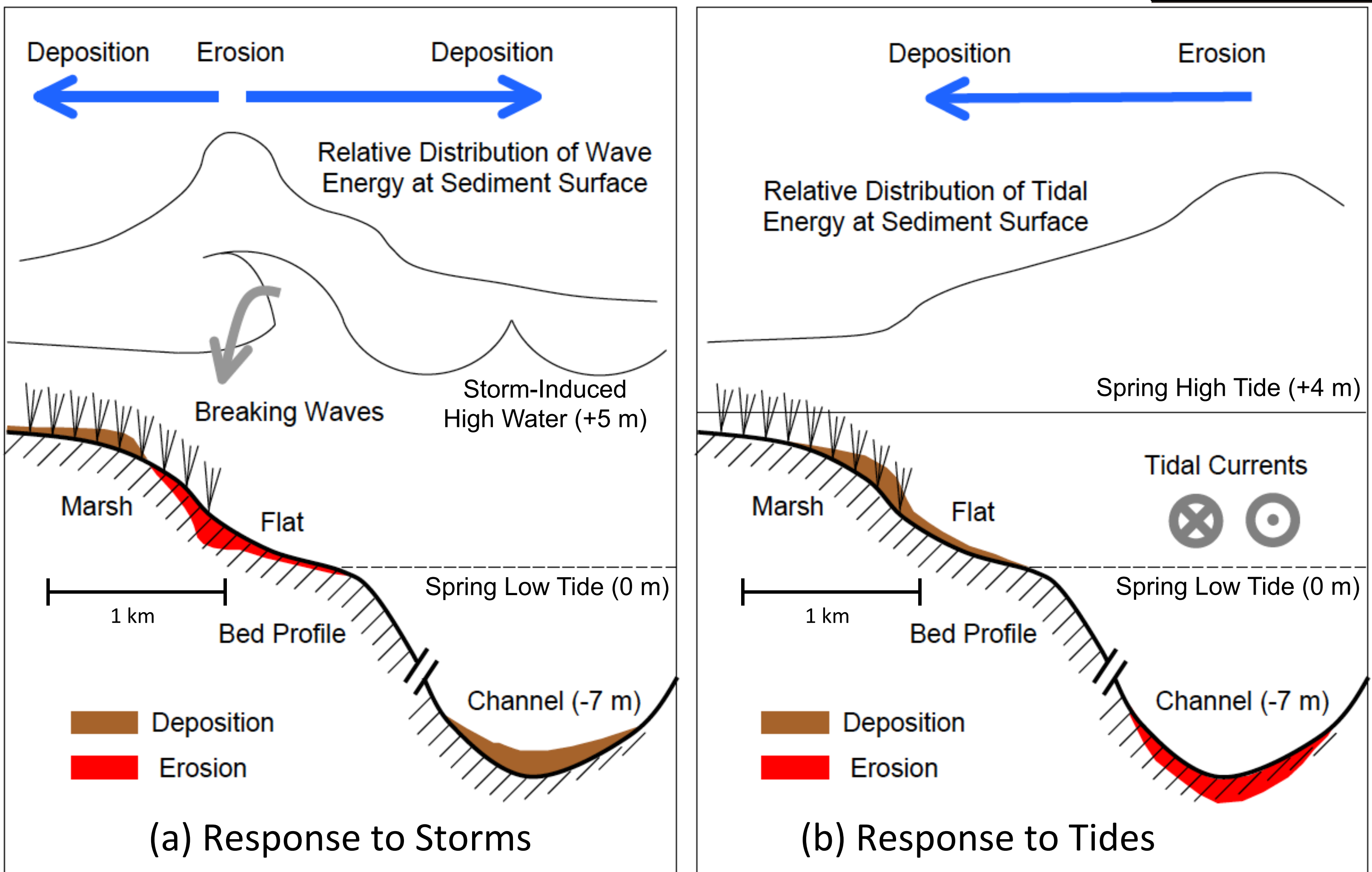
Following energy gradients: Storms move sediment from flat to sub-tidal channel; Tides move sediment from sub-tidal channel to flat

Ex. Conceptual model for flats at Yangtze River mouth (mean range 2.7 m; spring 4.0 m)

(Yang, Friedrichs et al. 2003)

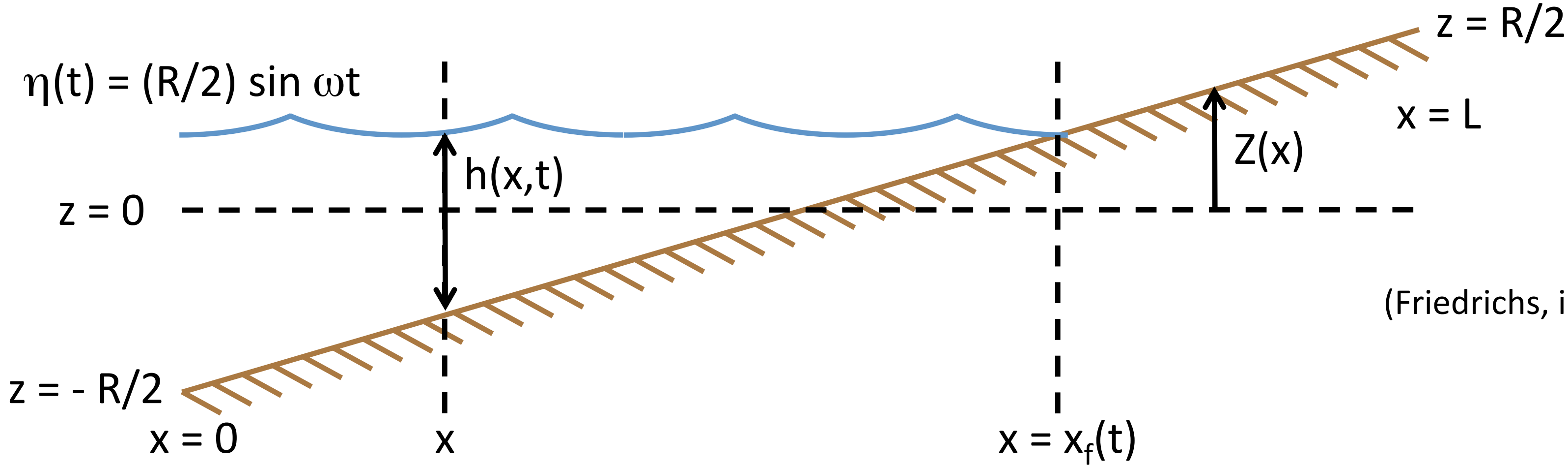




(a) Response to Storms

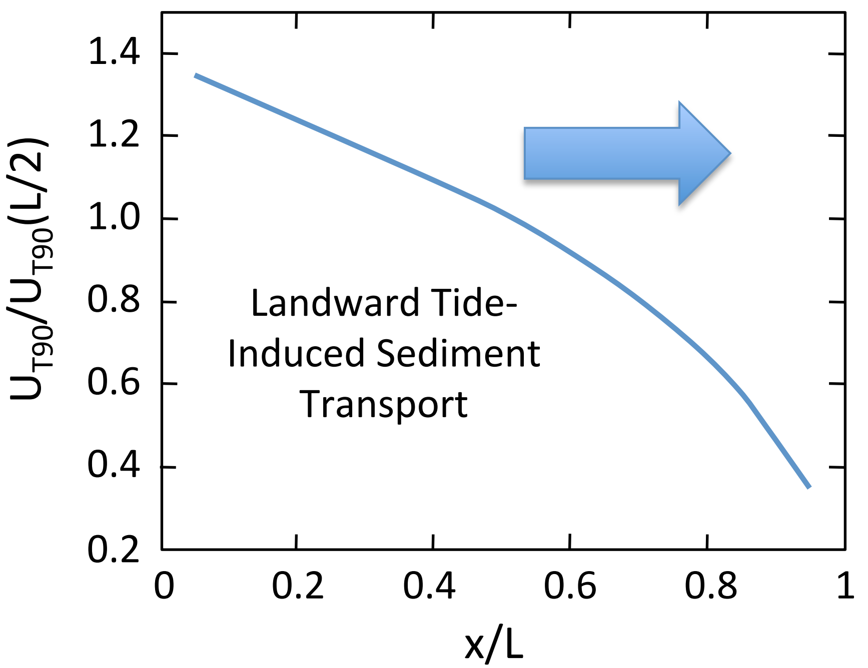
(b) Response to Tides

Maximum tide and wave orbital velocity distribution across a linearly sloping flat:



(Friedrichs, in press)

Spatial variation in tidal current magnitude



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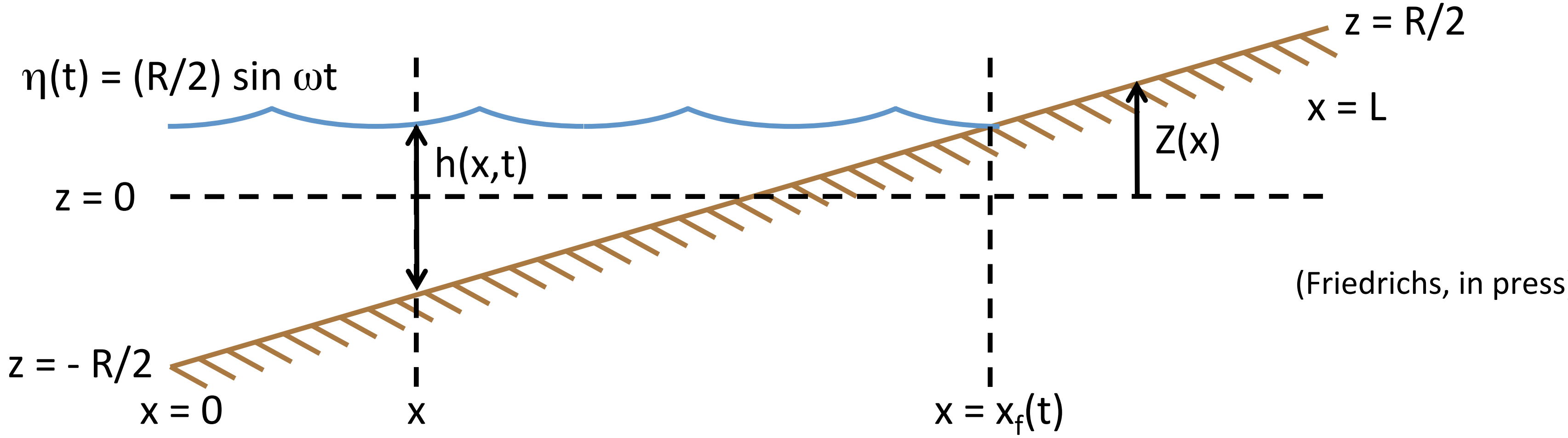
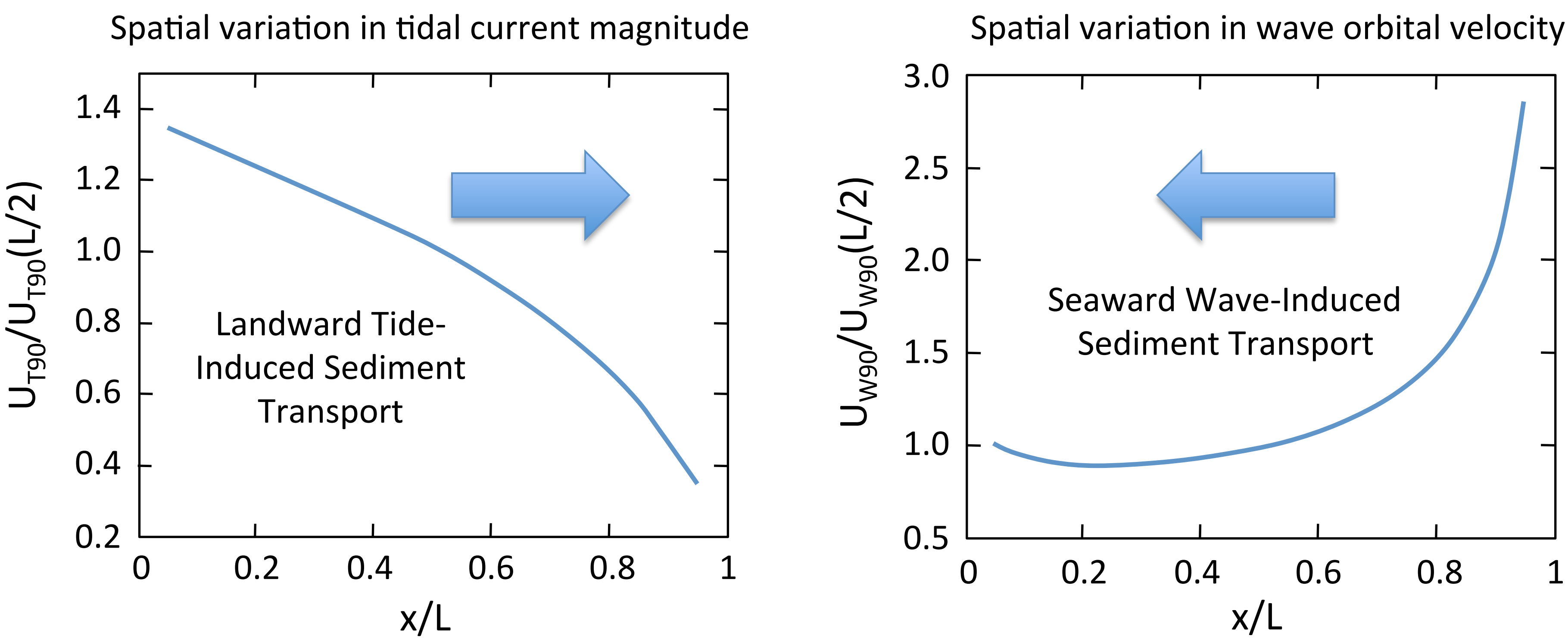
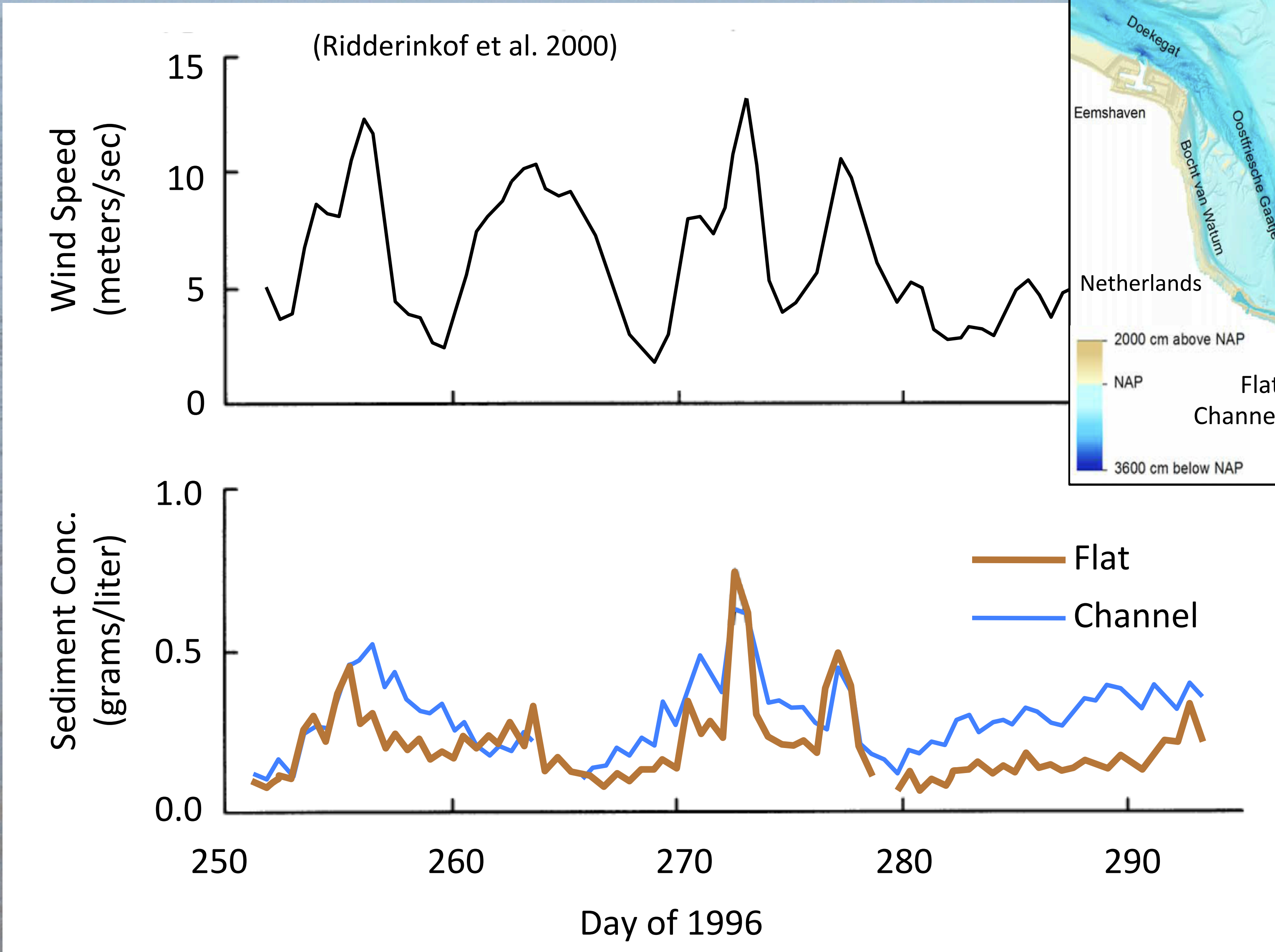
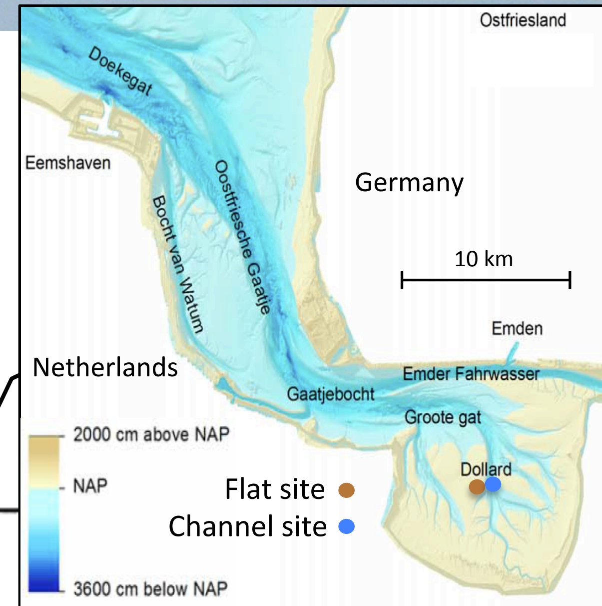




Wind events cause concentrations on flat to be higher than channel





(Hartsuiker et al. 2009)

Ems-Dollard estuary, The Netherlands, mean tidal range 3.2 m, spring range 3.4 m

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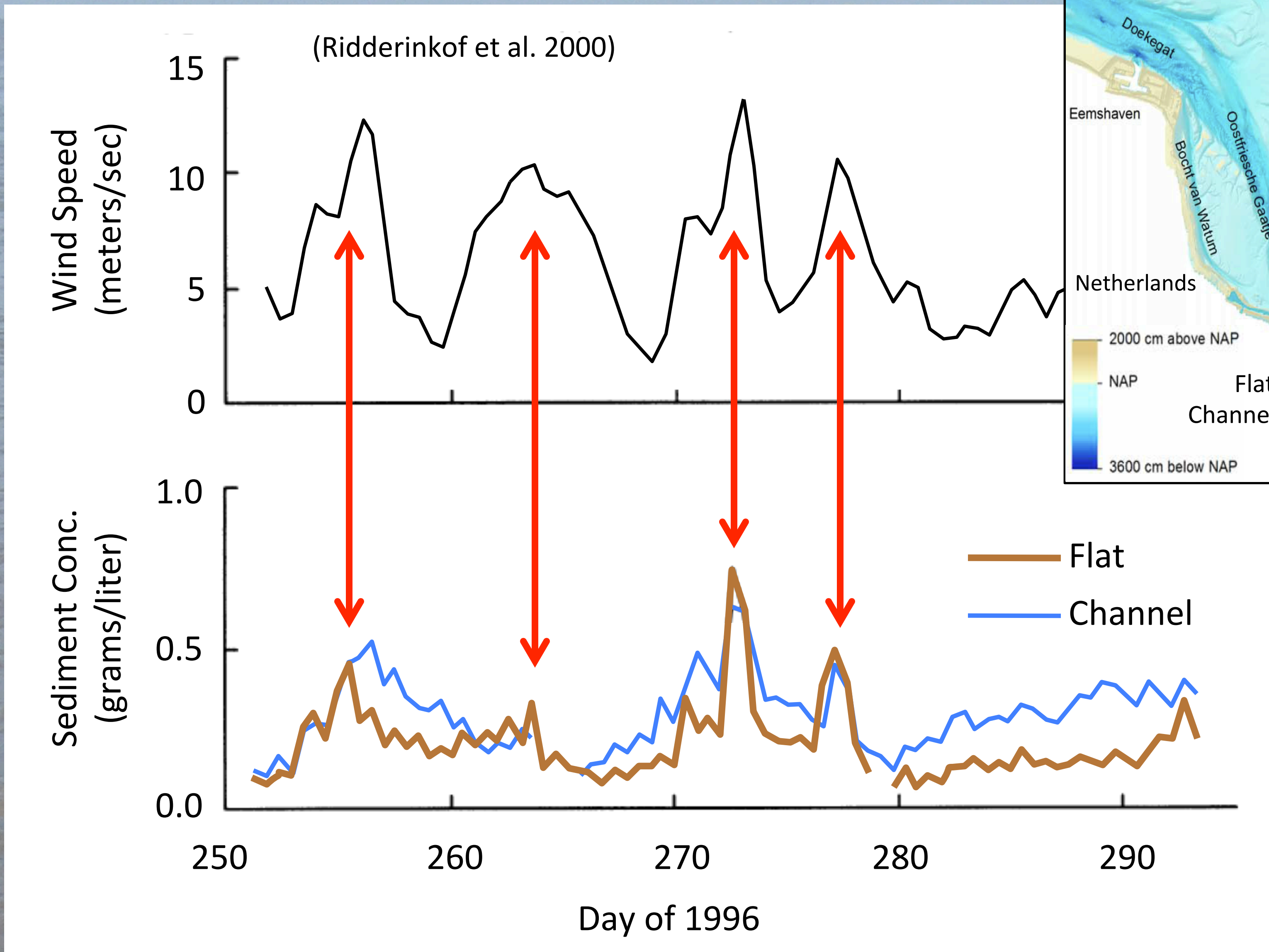

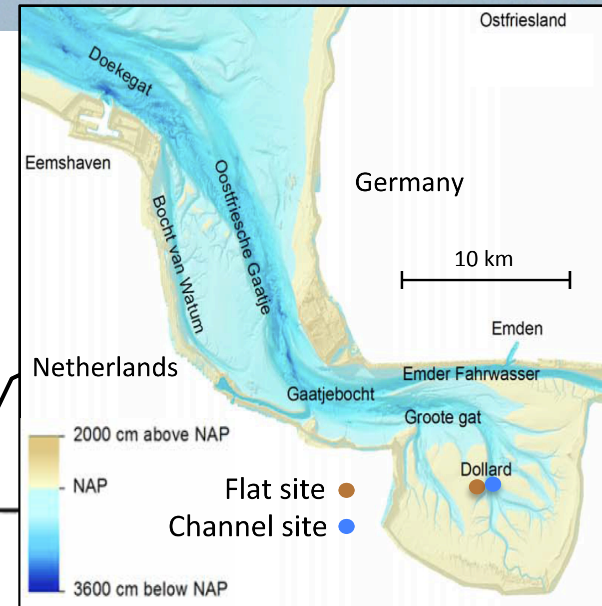

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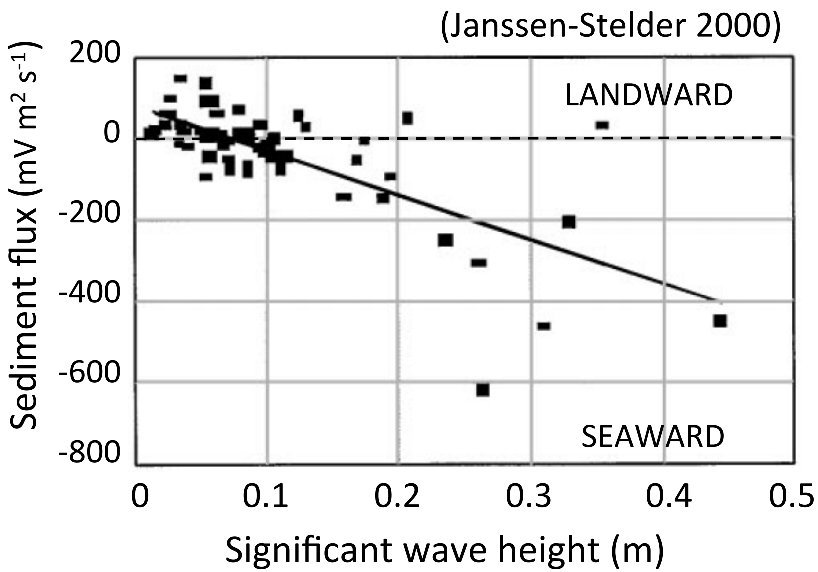
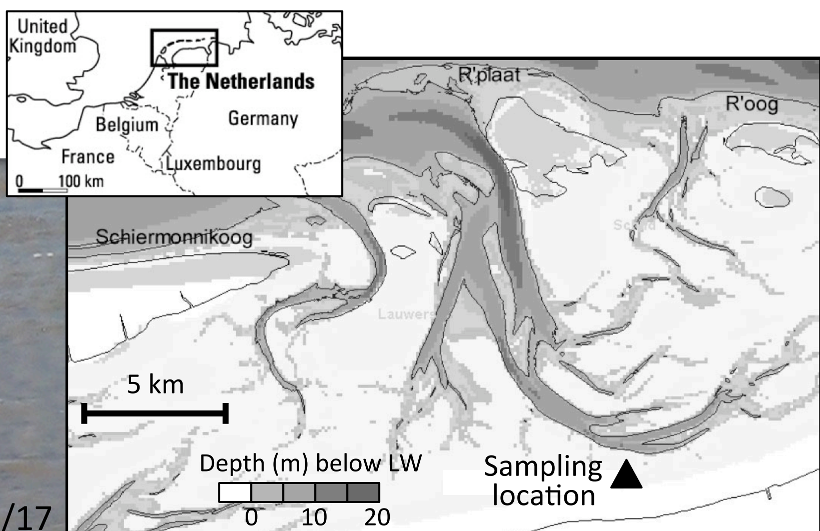
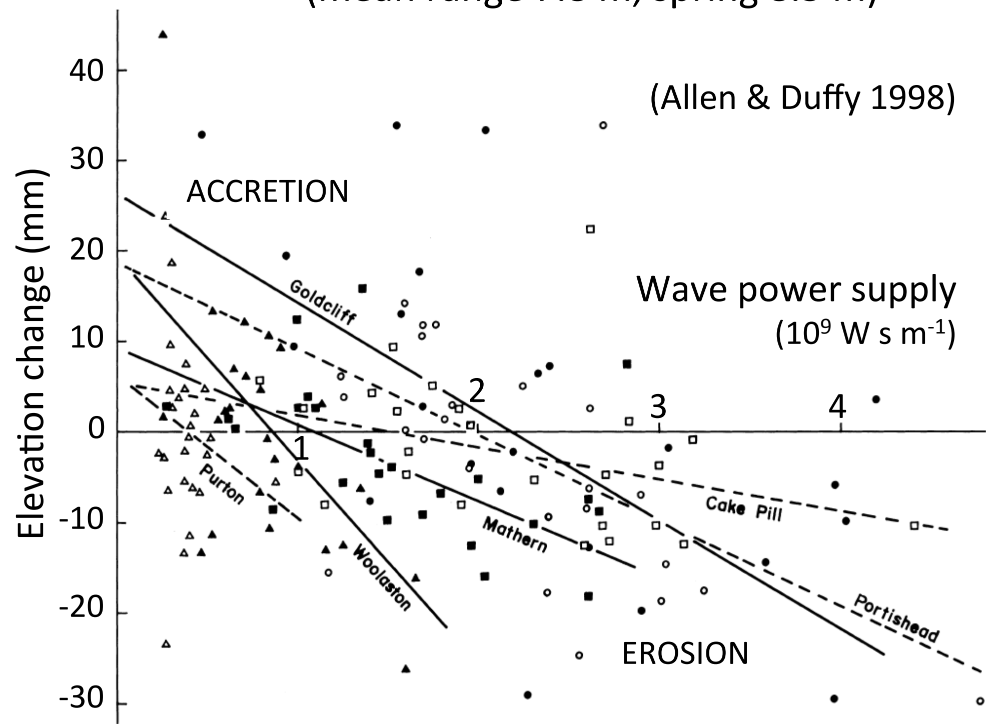
Larger waves tend to cause sediment export and tidal flat erosion

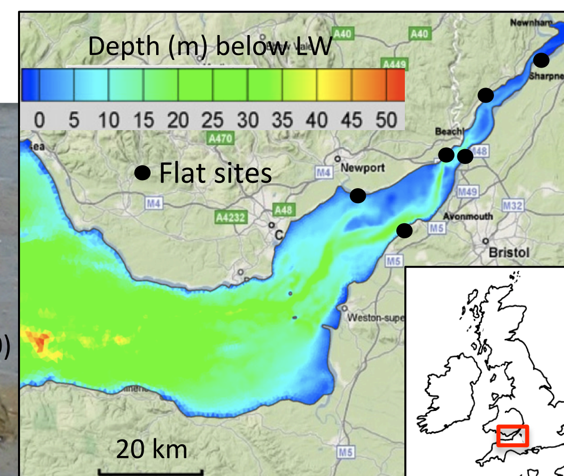
Wadden Sea Flats, Netherlands
(mean range 2.4 m, spring 2.6 m)





Severn Estuary Flats, UK
(mean range 7.8 m, spring 8.5 m)





(Xia et al. 2010)

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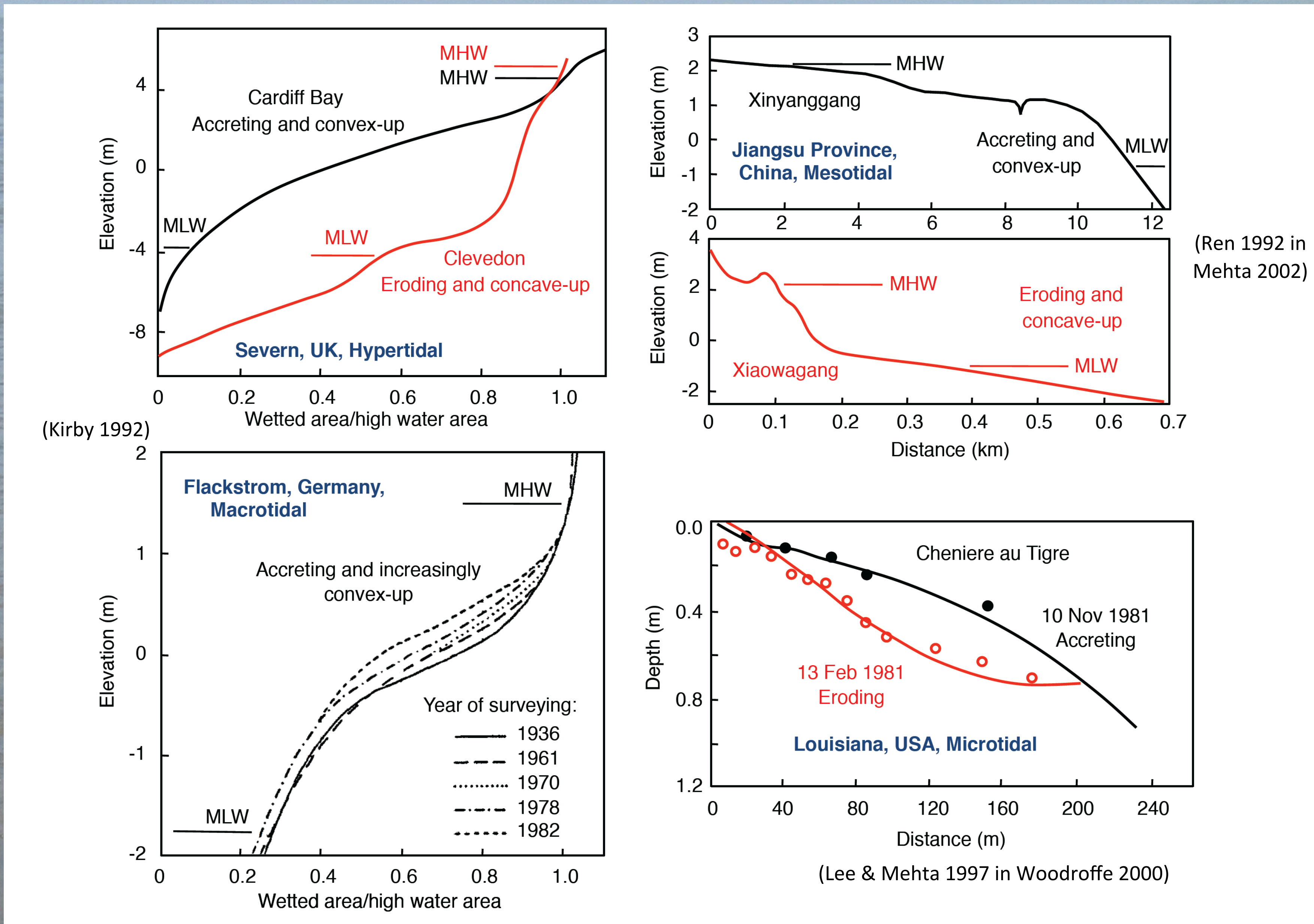
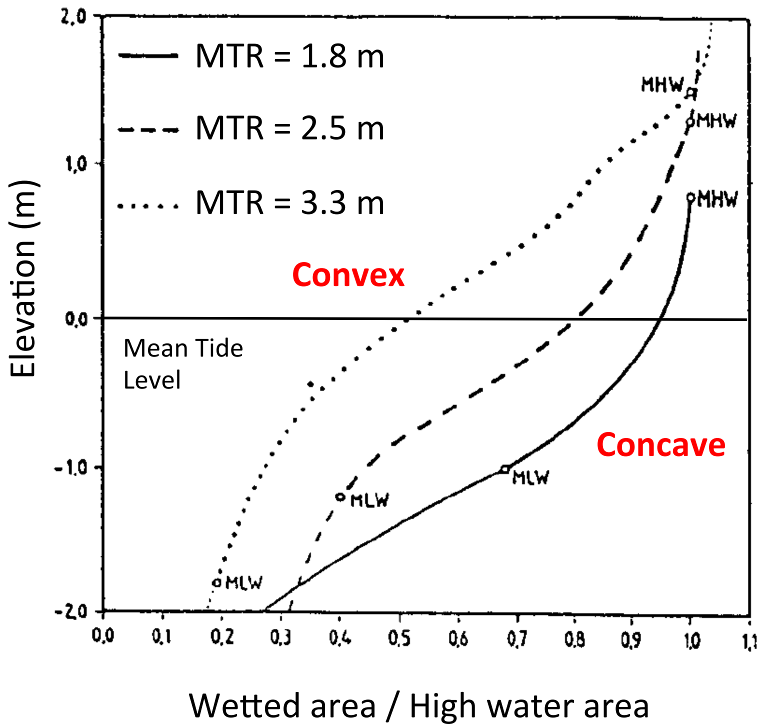
Accreting flats are convex upwards; Eroding flats are concave upwards

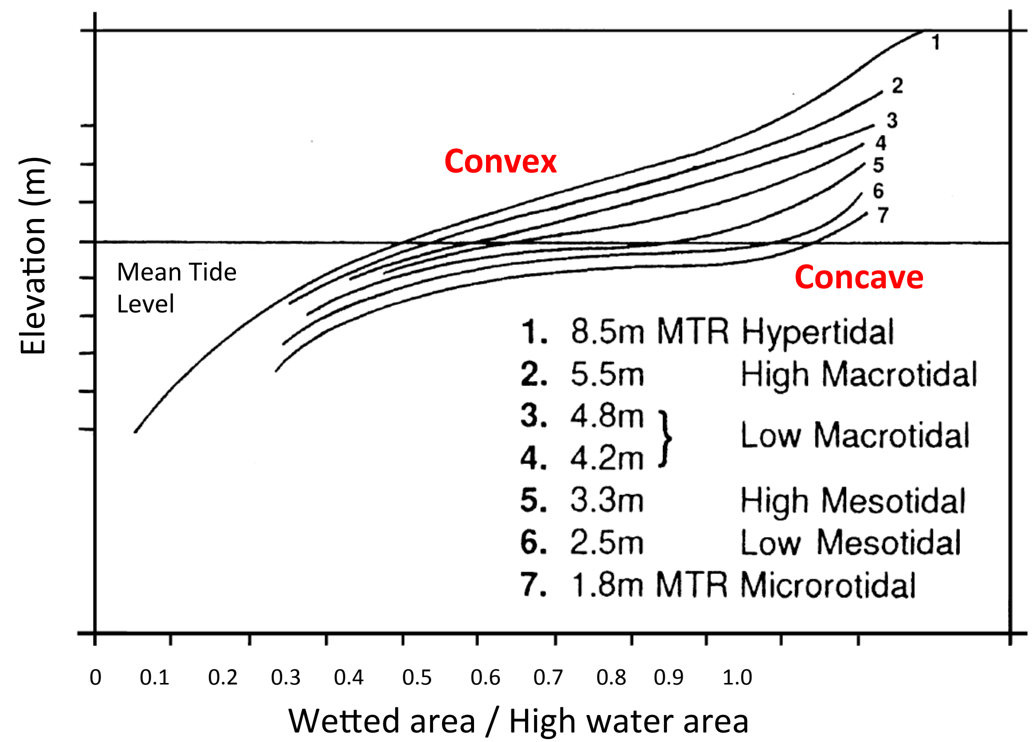


As tidal range increases (or decreases), flats become more convex (or concave) upward.

German Bight tidal flats
(Dieckmann et al. 1987)

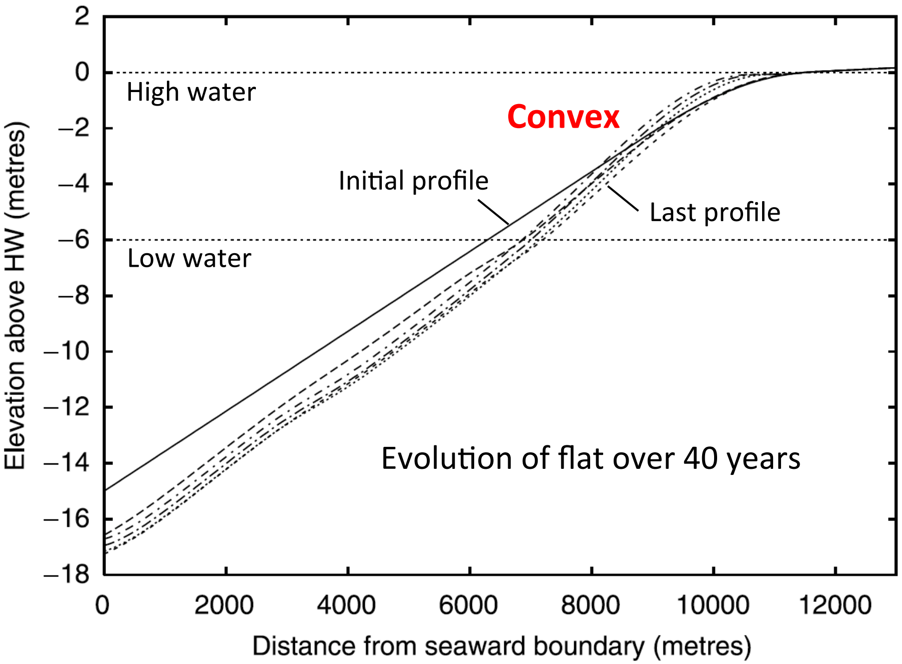


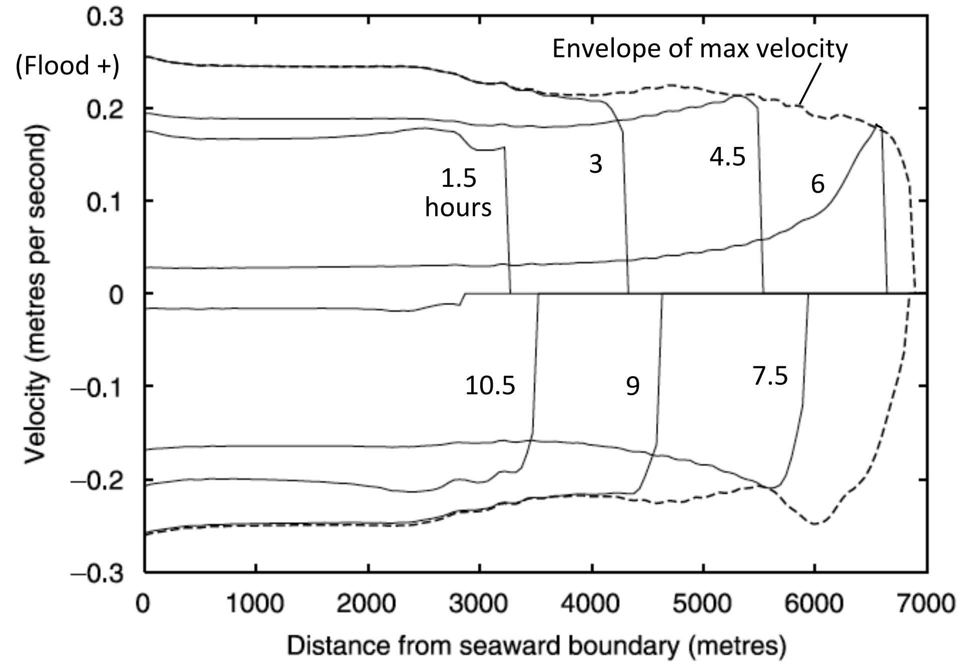
U.K. tidal flats
(Kirby 2000)



Models incorporating erosion, deposition & advection by tides produce convex upwards profiles

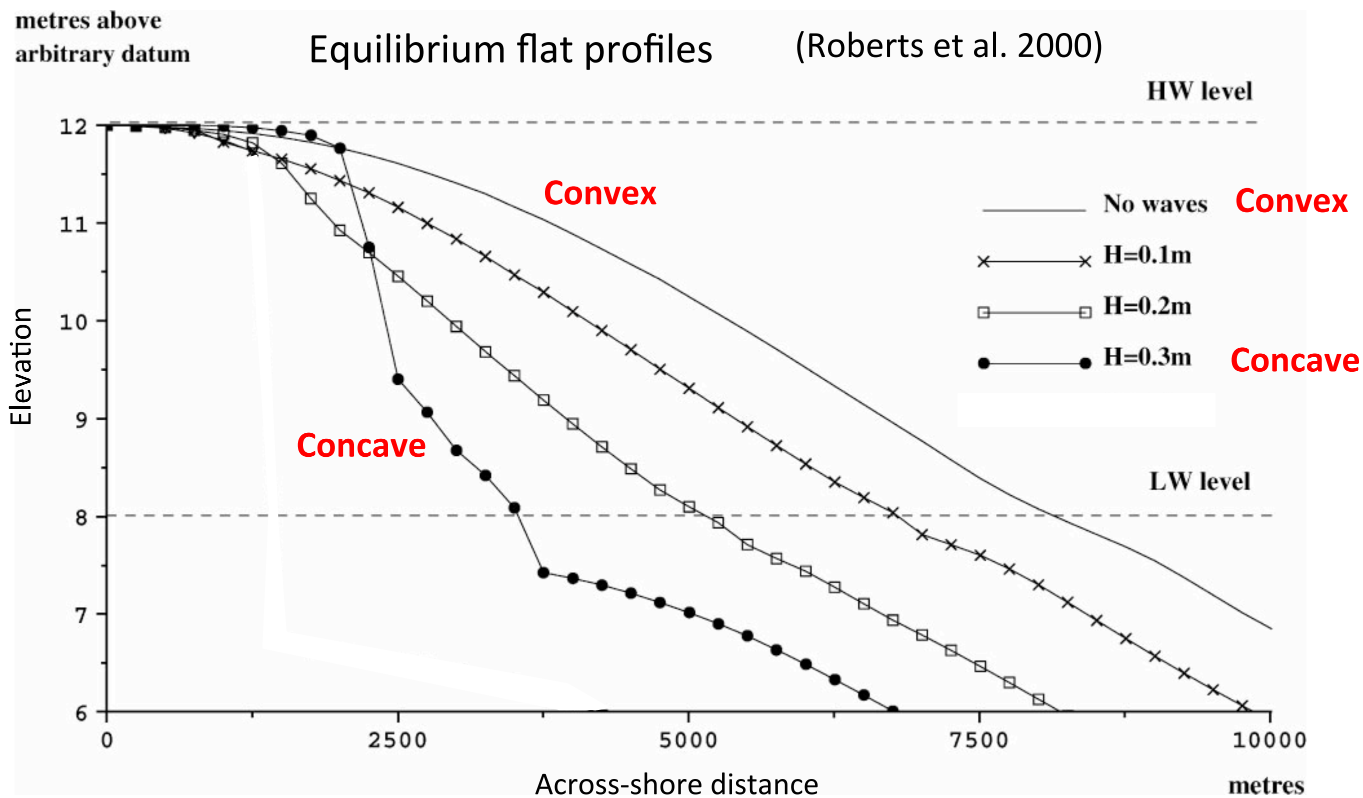
Ex. Pritchard (2002): 6-m range, no waves, 100 mg/liter offshore, w_s = 1 mm/s, τ_e = 0.2 Pa, τ_d = 0.1 Pa





At accretionary equilibrium without waves, maximum tidal velocity is nearly uniform across tidal flat.

Model incorporating erosion, deposition & advection by tides plus waves favors concave upwards profile



4-m range, 100 mg/liter offshore, w_s = 1 mm/s, τ_e = 0.2 Pa, τ_d = 0.1 Pa, H_b = h/2

Tidal tendency to move sediment landward is balanced by wave tendency to move sediment seaward.

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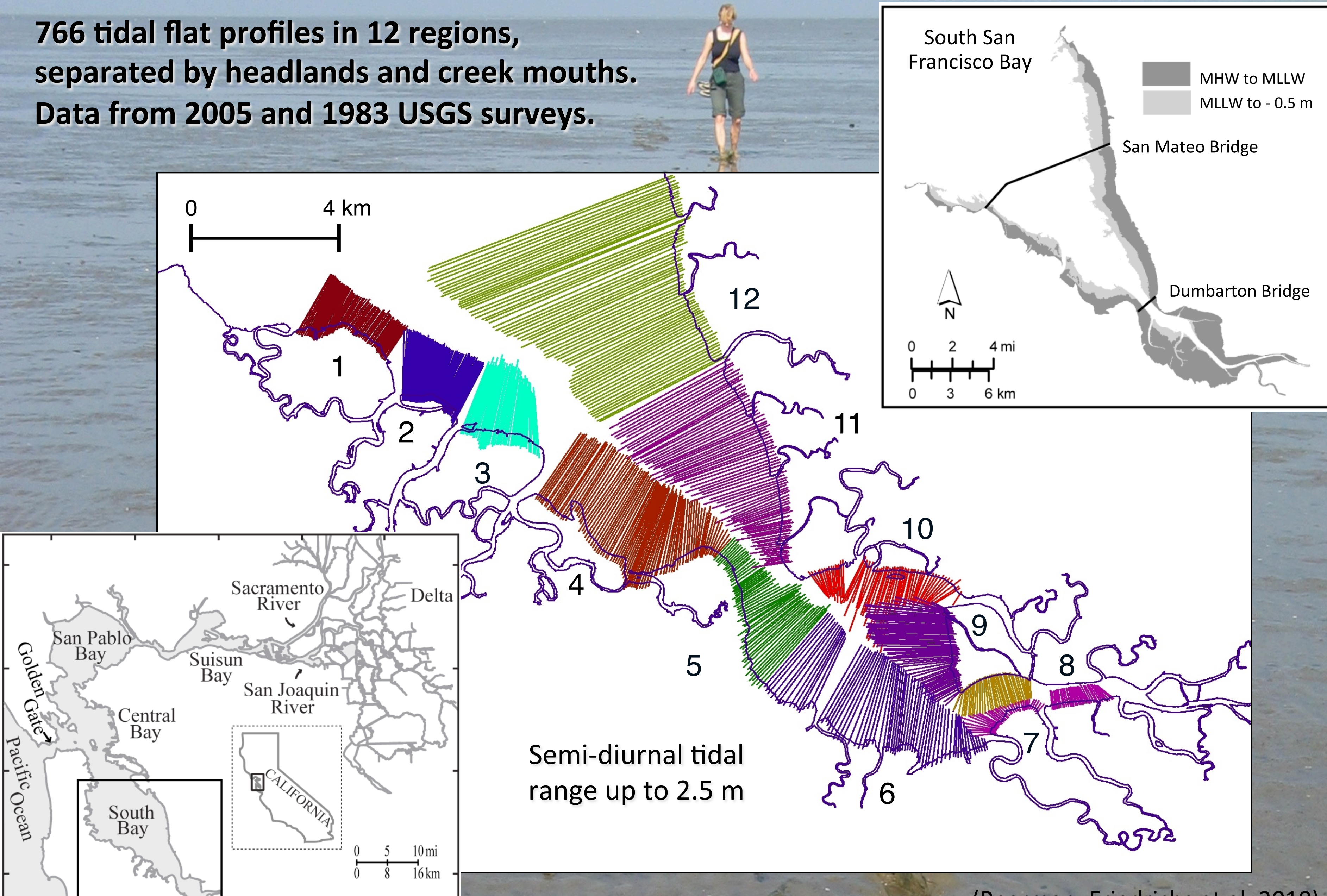
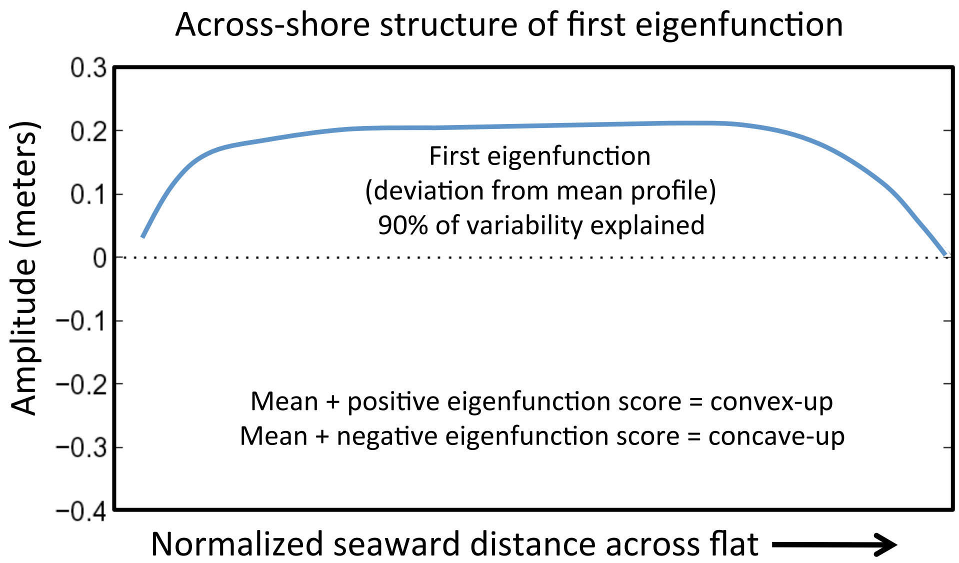
South San Francisco Bay case study:

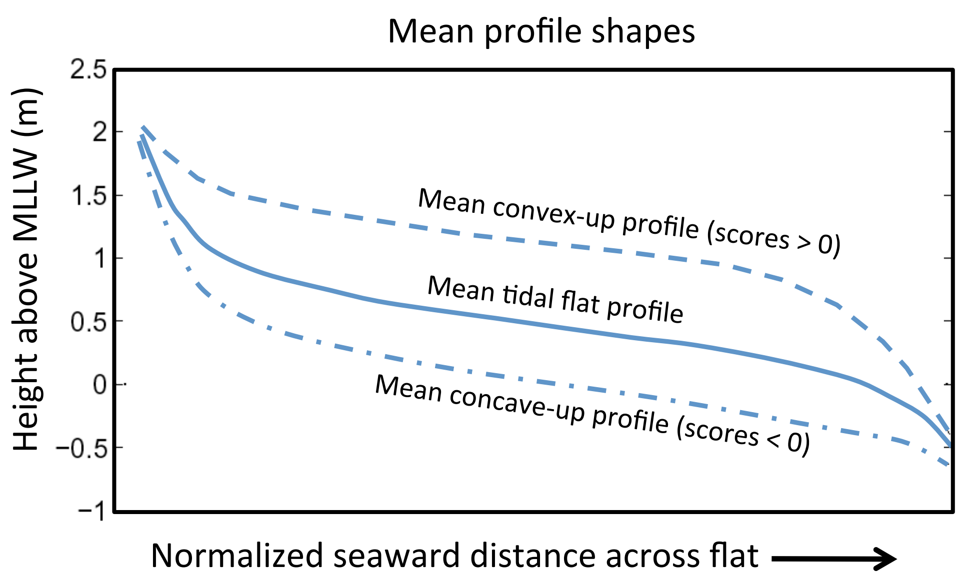
766 tidal flat profiles in 12 regions, separated by headlands and creek mouths. Data from 2005 and 1983 USGS surveys.

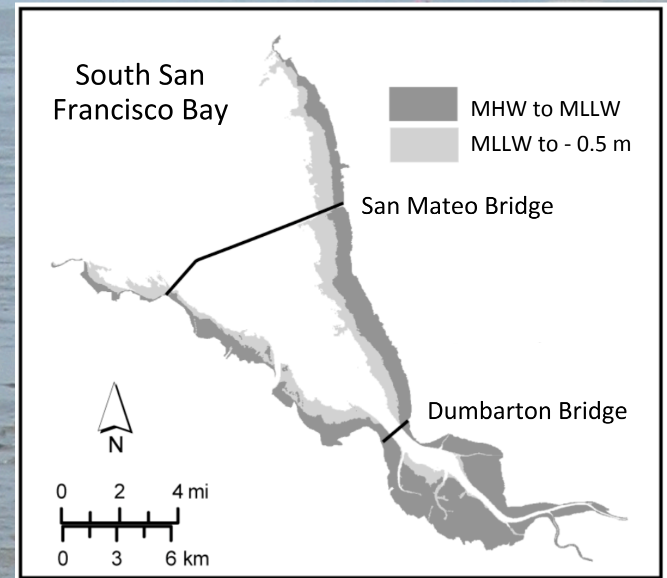


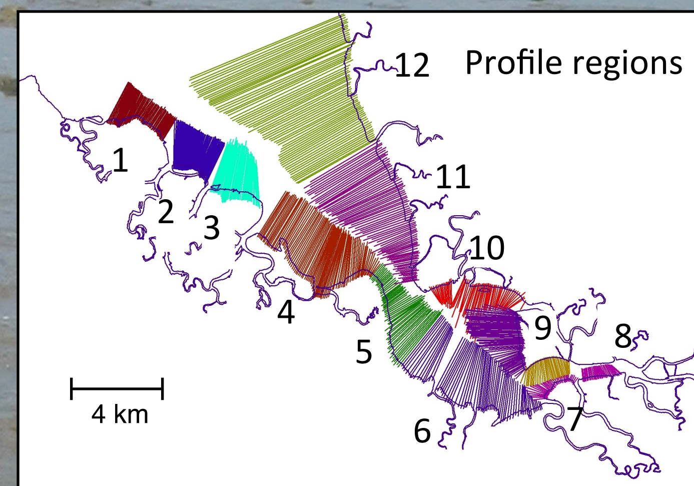
(Bearman, Friedrichs et al. 2010)

Dominant mode of profile shape variability determined through eigenfunction analysis:



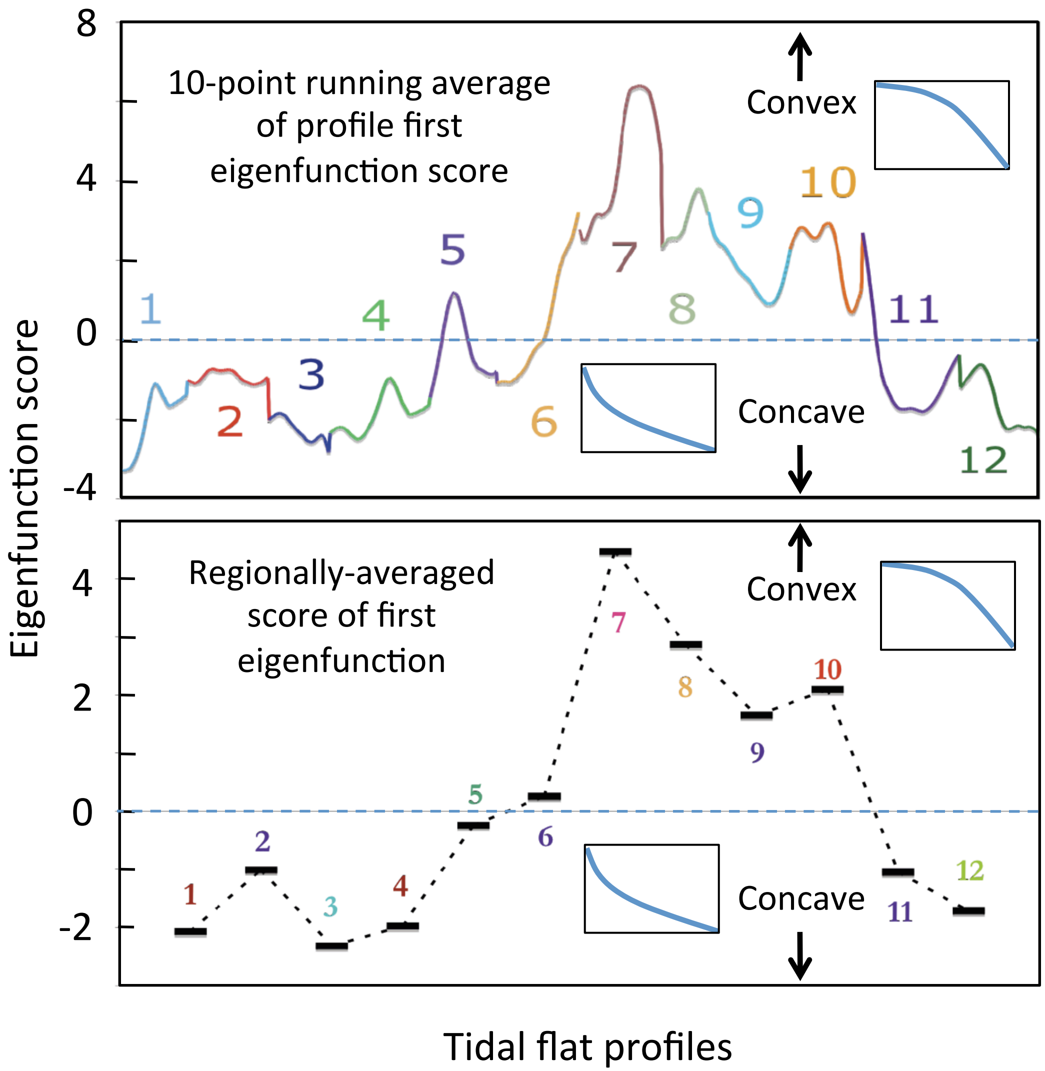


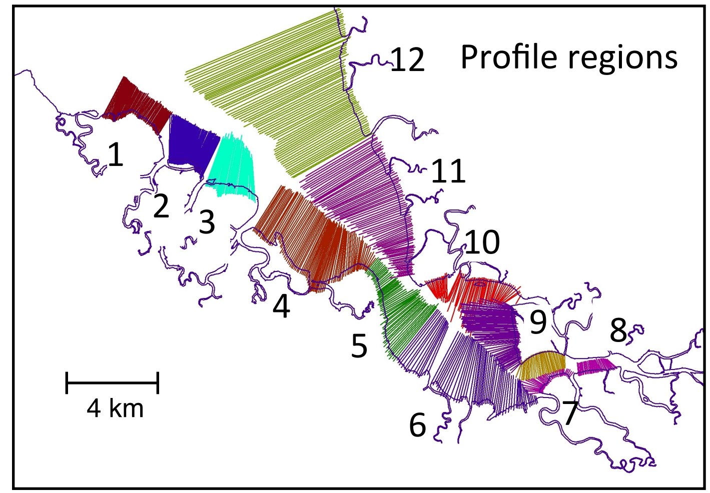




(Bearman, Friedrichs et al. 2010)

Significant spatial variation is seen in convex (+) vs. concave (-) eigenfunction scores:

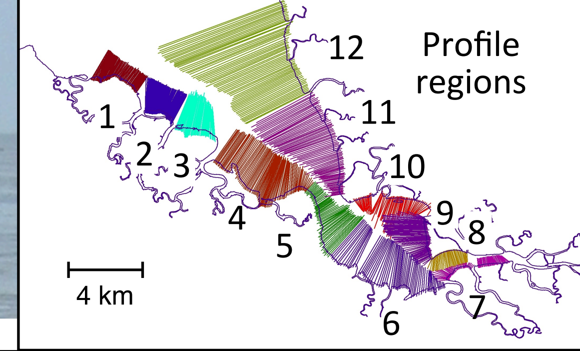


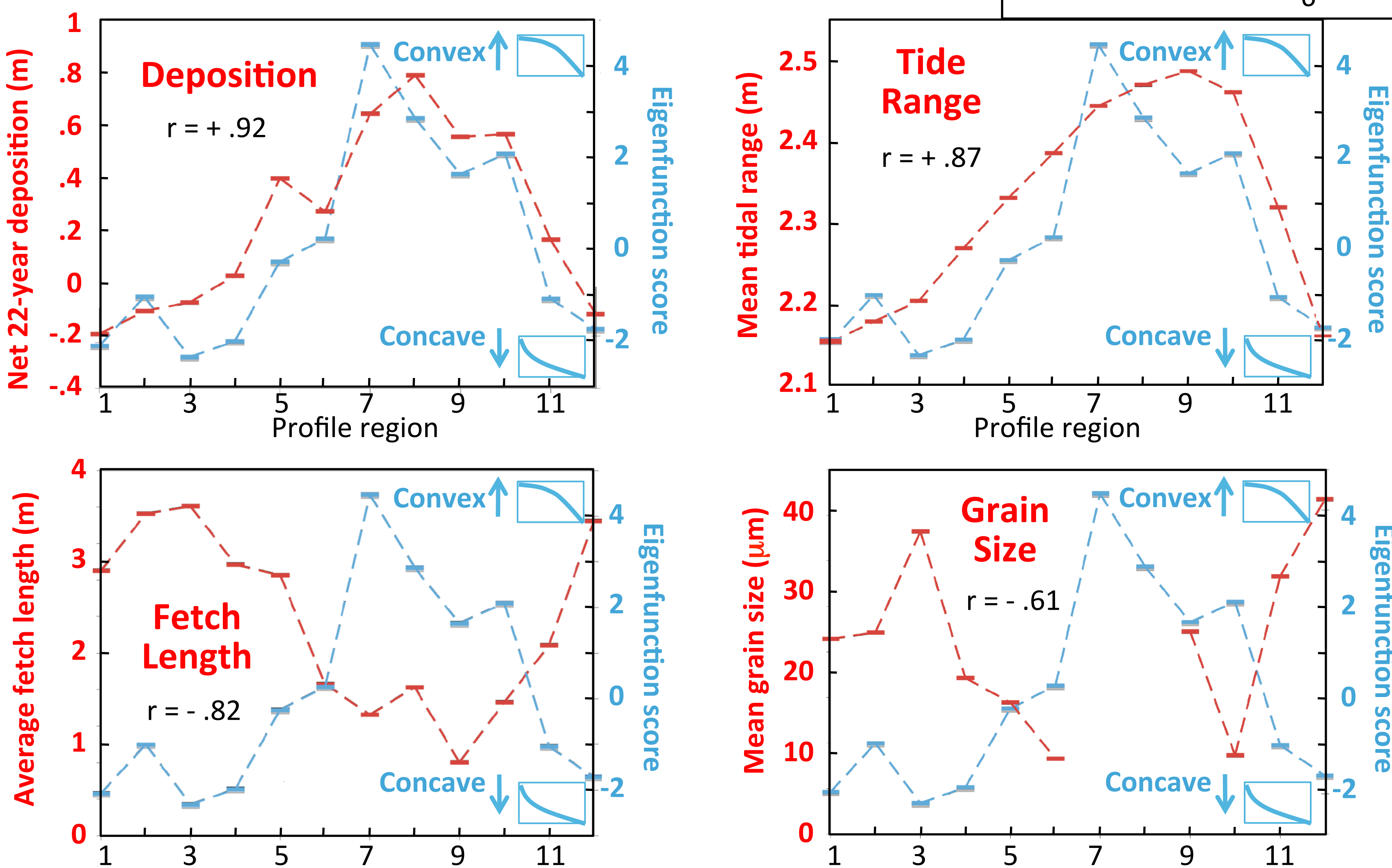


(Bearman, Friedrichs et al. 2010)

-- Deposition & tide range are positively correlated to eigenvalue score (favoring convexity).

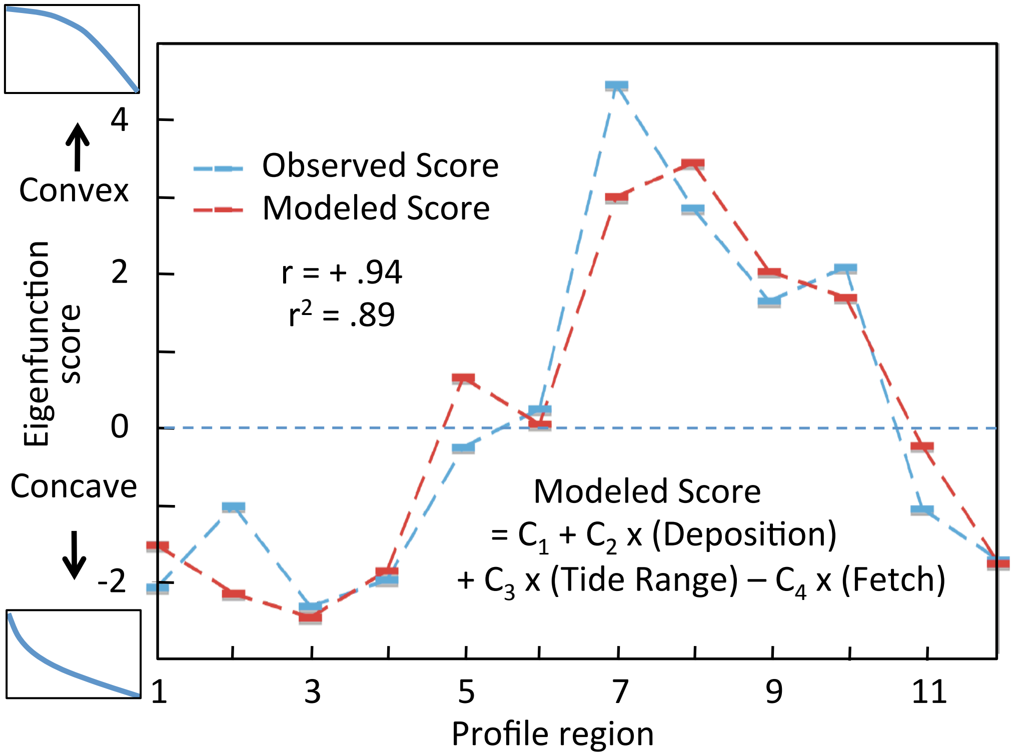
-- Fetch & grain size are negatively correlated to eigenvalue score (favoring convexity).

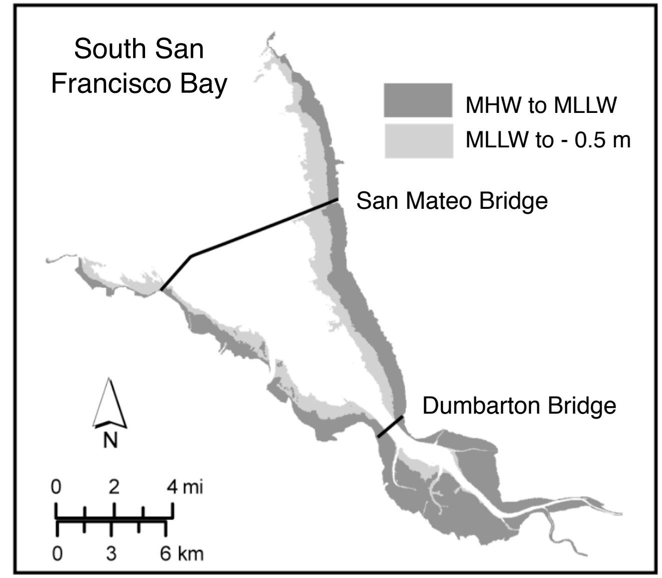


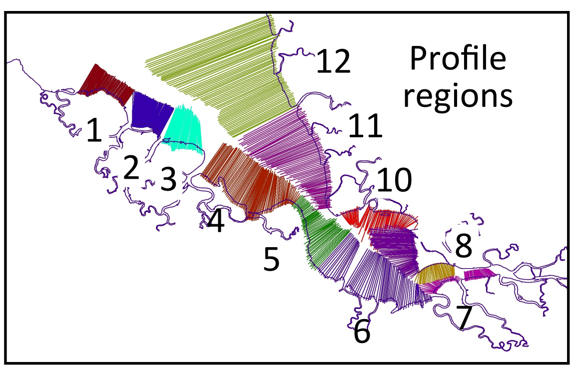


(Bearman, Friedrichs et al. 2010)

Tide + Deposition – Fetch Explains 89% of Variance in Convexity/Concavity







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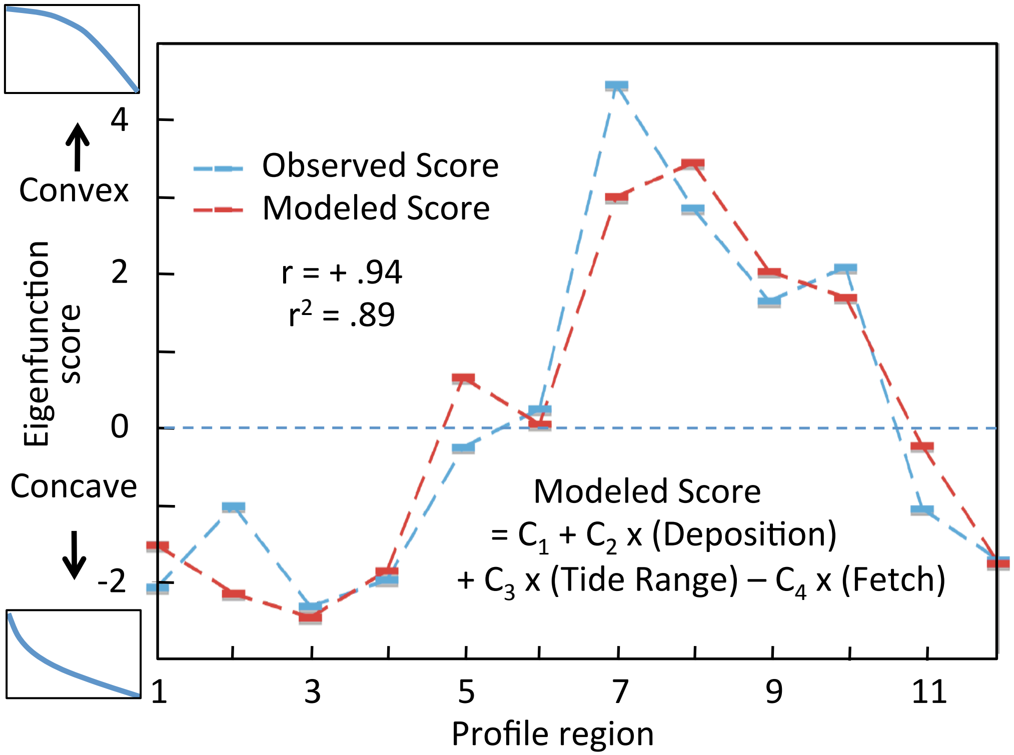

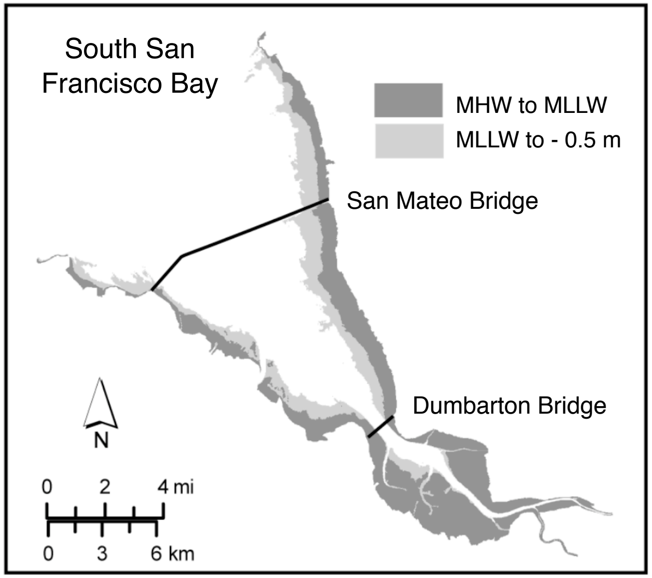

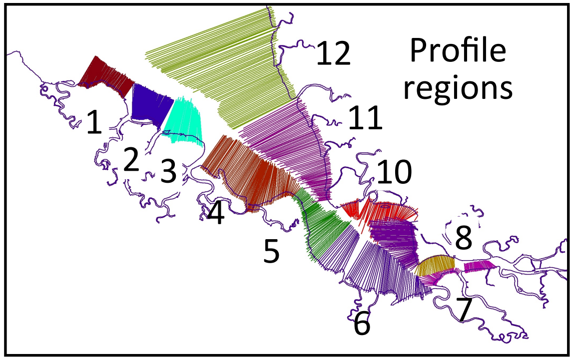

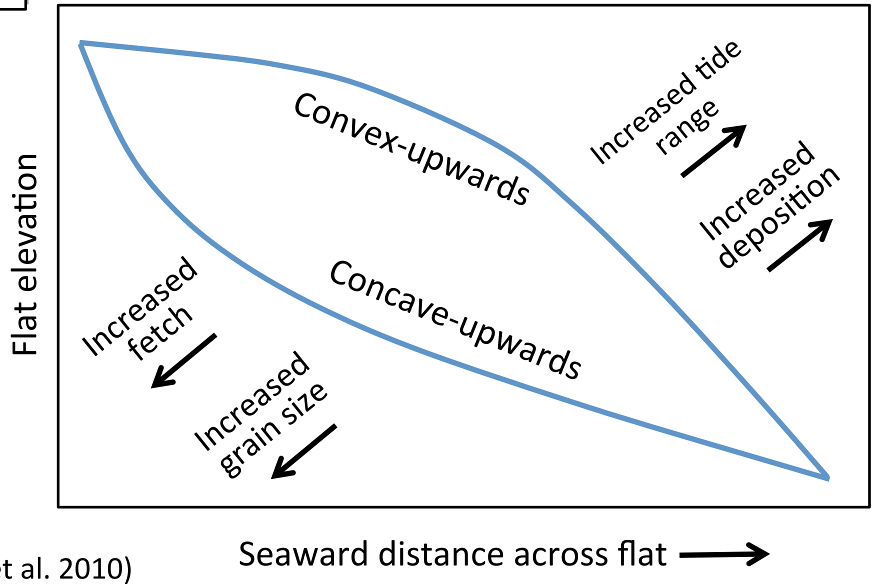

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