How sediment, subsidence, and sea level create geohazards on deltaic margins

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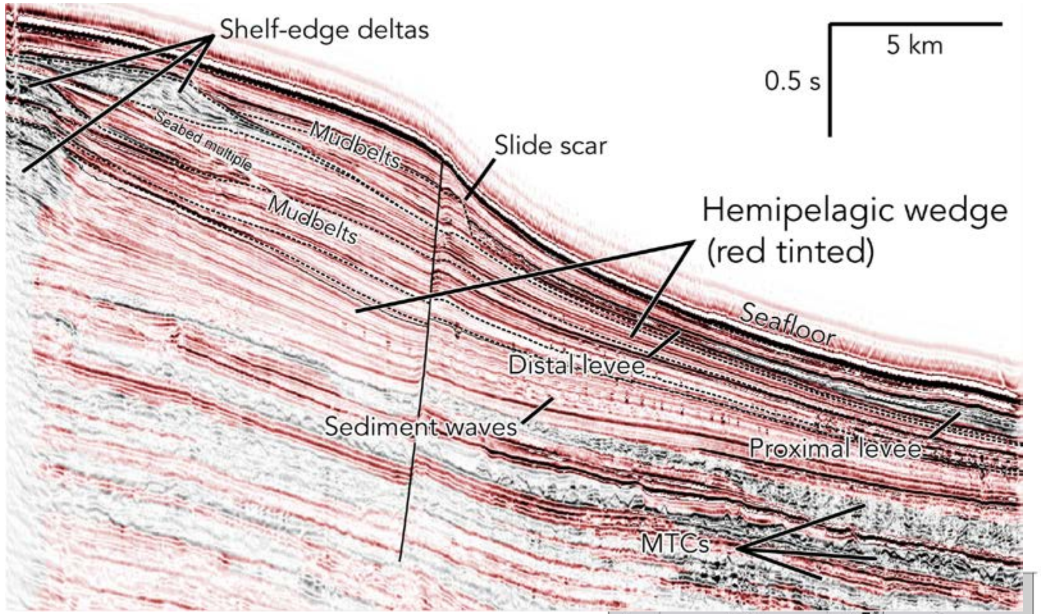
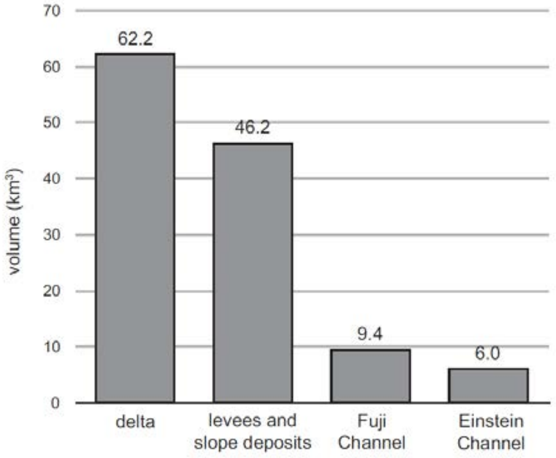
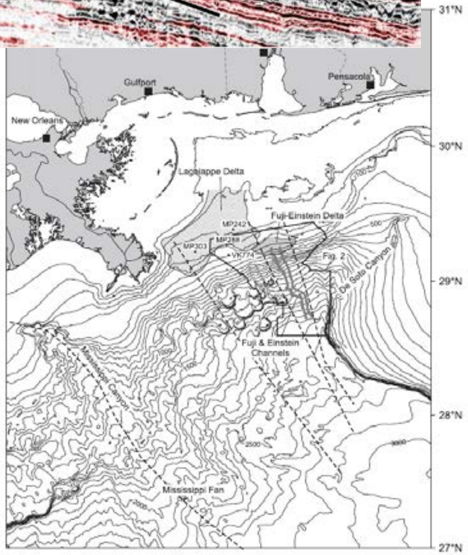
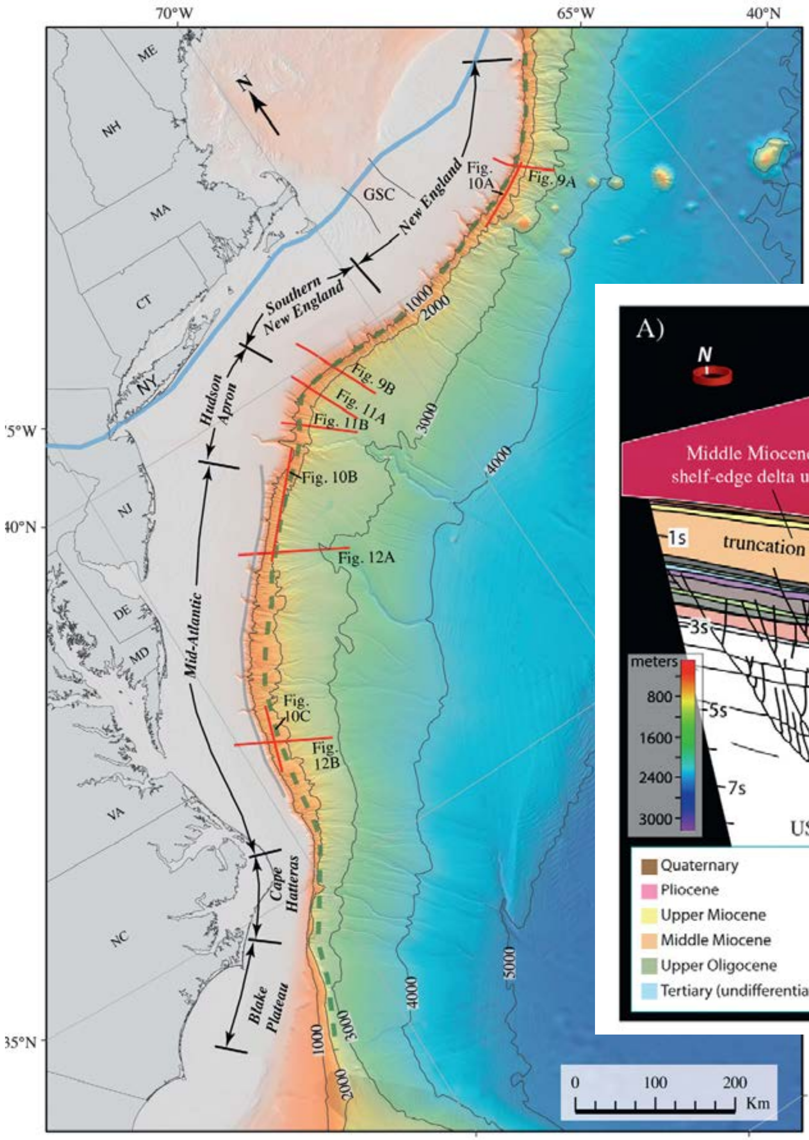
The structure of coastal depositional margins is largely set by the deltaic deposition during highstand and even lowstand

Sylvester et al., 2012, *SEPM Sep. Pub.*

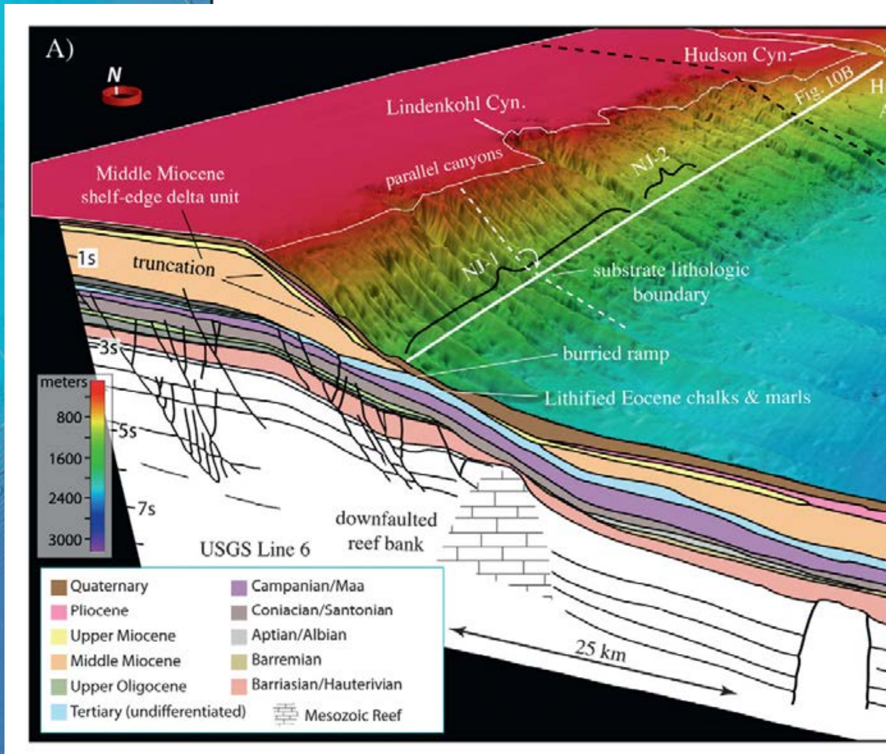








Brothers et al., 2013, *Marine Geology*

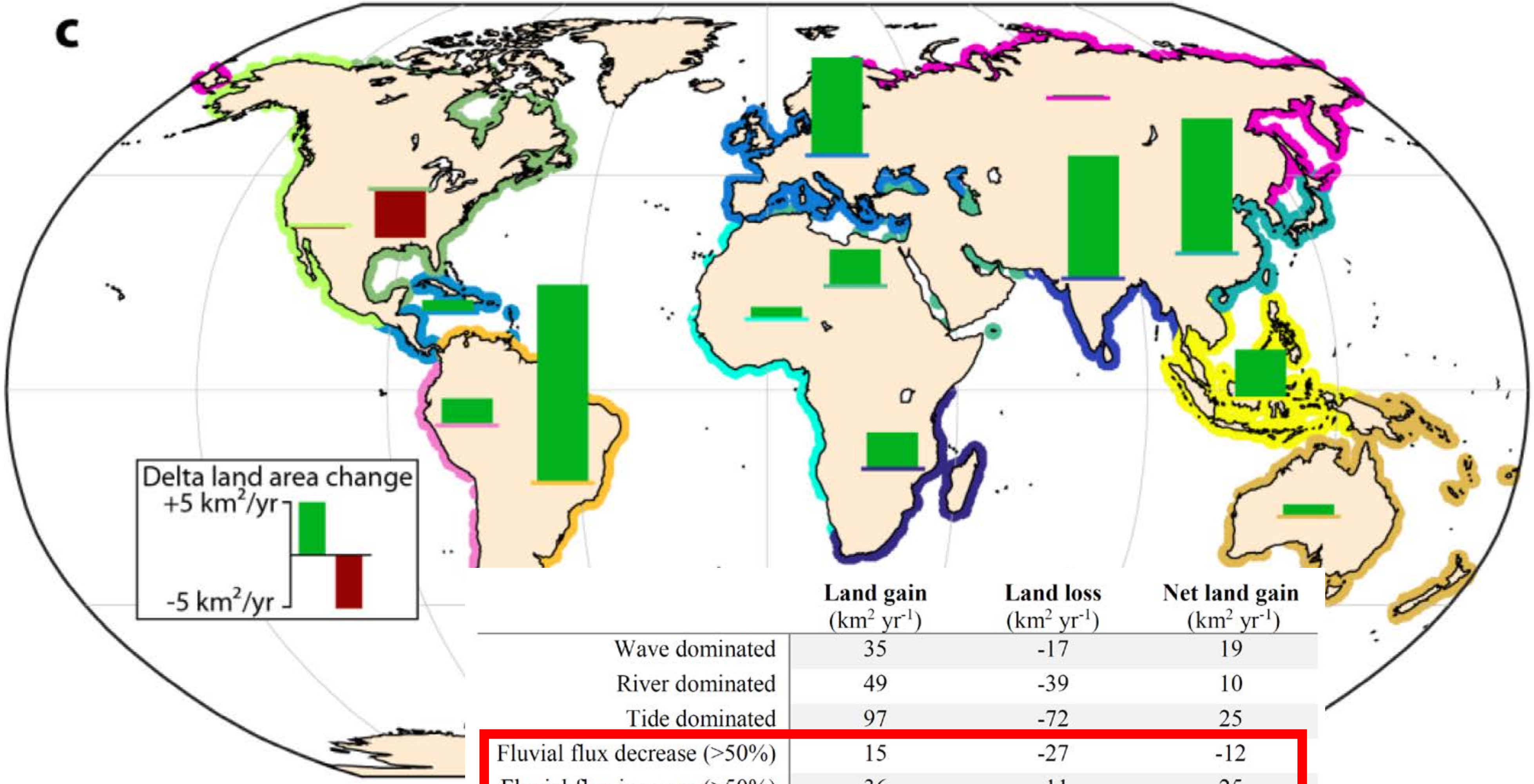


The key geohazard facing deltaic environments is land loss

GREEN = land gain
BLUE = land loss

Donchyts et al., 2016, *Nature Climate Change*
Pekel et al., 2016, *Nature*

Globally, deltas are still depositional, though, human influenced deltas show more signs of erosion

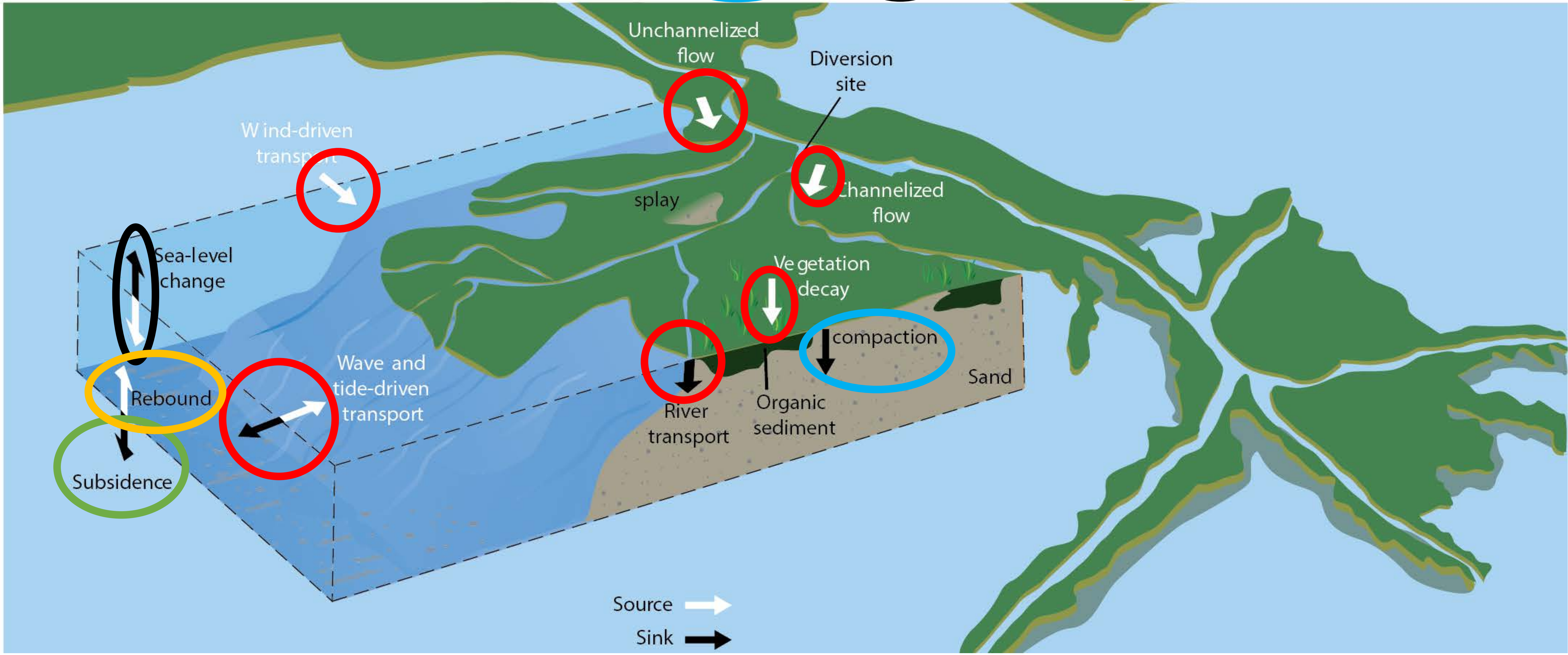


	Land gain ($km^2\ yr^{-1}$)	Land loss ($km^2\ yr^{-1}$)	Net land gain ($km^2\ yr^{-1}$)
Wave dominated	35	-17	19
River dominated	49	-39	10
Tide dominated	97	-72	25
Fluvial flux decrease (>50%)	15	-27	-12
Fluvial flux increase (>50%)	36	-11	25

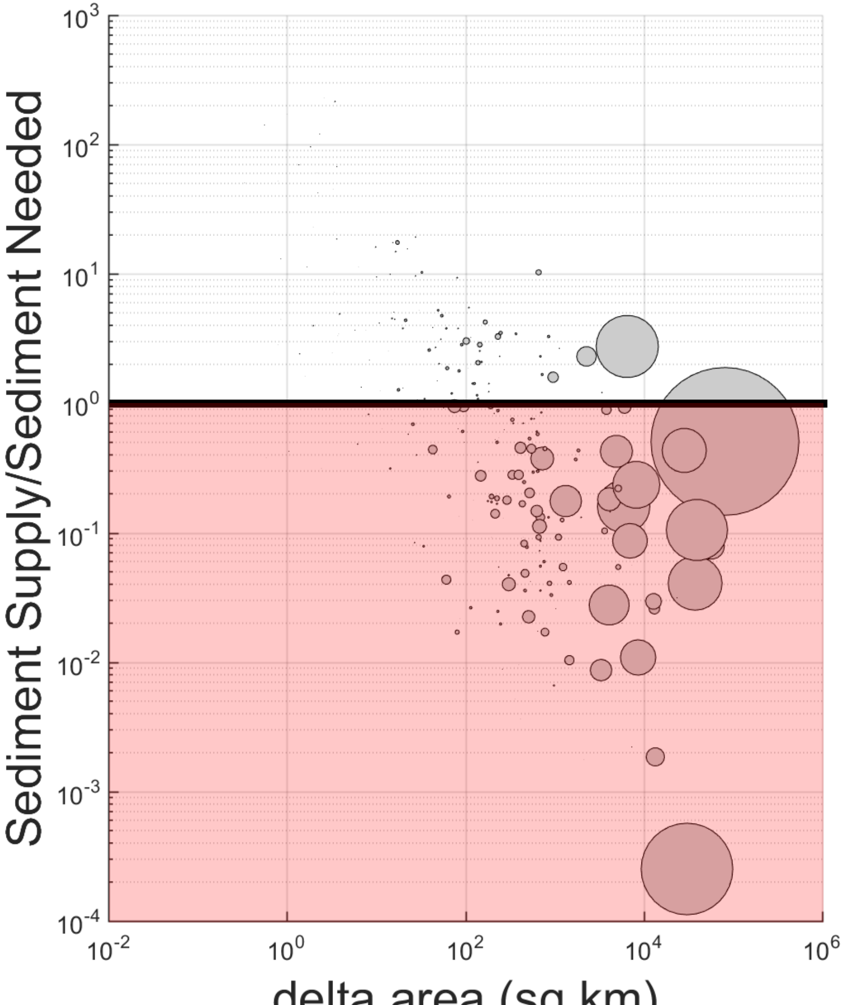
Nienhuis et al., In Review, *Nature*

Landloss is governed by the deltaic sediment mass balance

$$\Delta E = A - S_{A+N} - S_L - T + R \quad [LT^{-1}]$$



From models like this we know that most deltas are on the verge of drowning



Deltas in the red account for 250M people living on deltas

Giosan et al., 2014, *Nature*
Edmonds et al., *in review*

Needed is defined as the amount of sediment it takes to raise the delta plain 1 m in 100 years

There are three key challenges in the deltaic sediment mass balance that the community is poised to answer

1. What governs the mass balance of "blue sediment" along river deltas and coastlines at yearly to millennial time-scales?

$$A = \frac{Q_s * f}{\lambda * a}$$

2. What is the spatial variability of subsidence in river deltas?

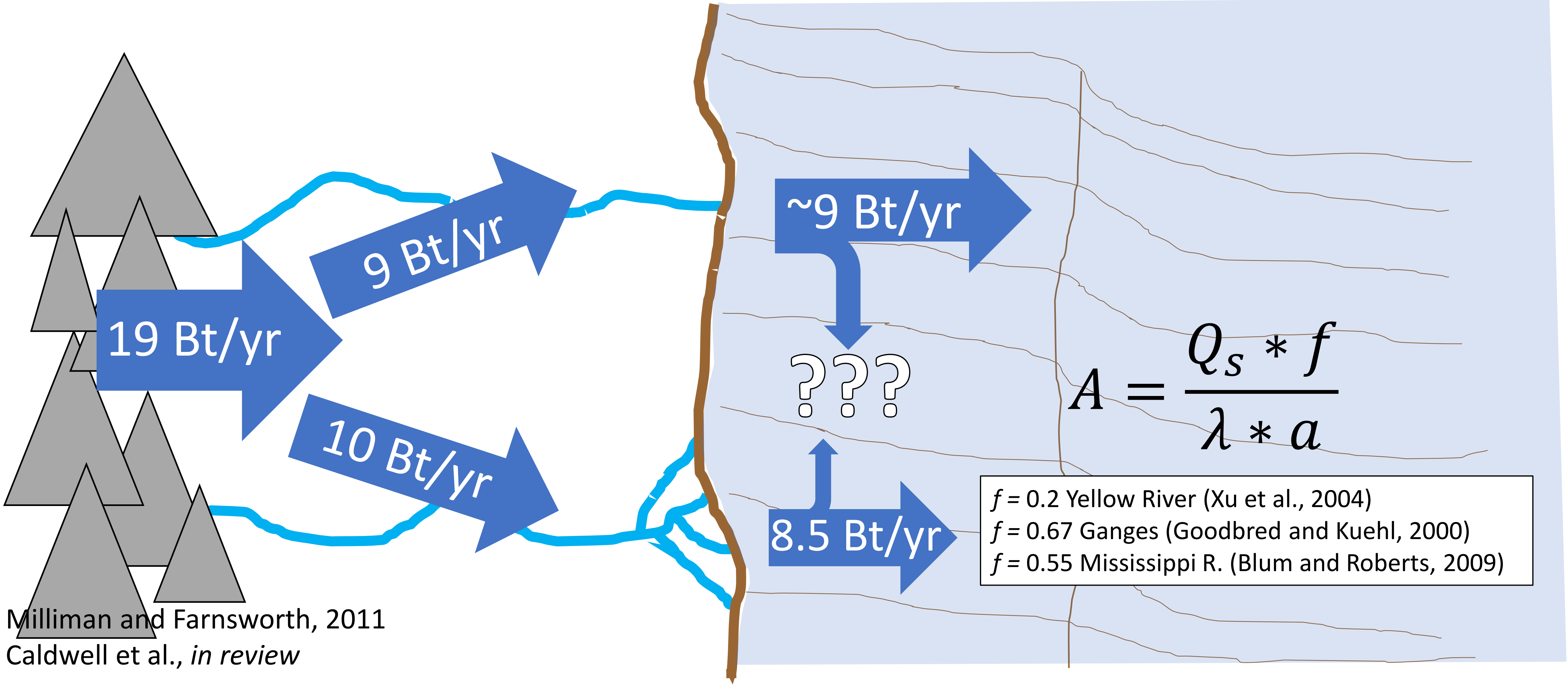
$$S_{A+N} + T - R$$

3. Thinking forward, what are the tipping points in the deltaic sediment mass balance?

$$\Delta E = A - S_{A+N} - S_L - T + R$$

What governs the mass balance of “blue sediment” along river deltas and coastlines at yearly to millennial time-scales?

Blue sediment is a key part of the global sediment cycle but we have no idea how much is stored or exported



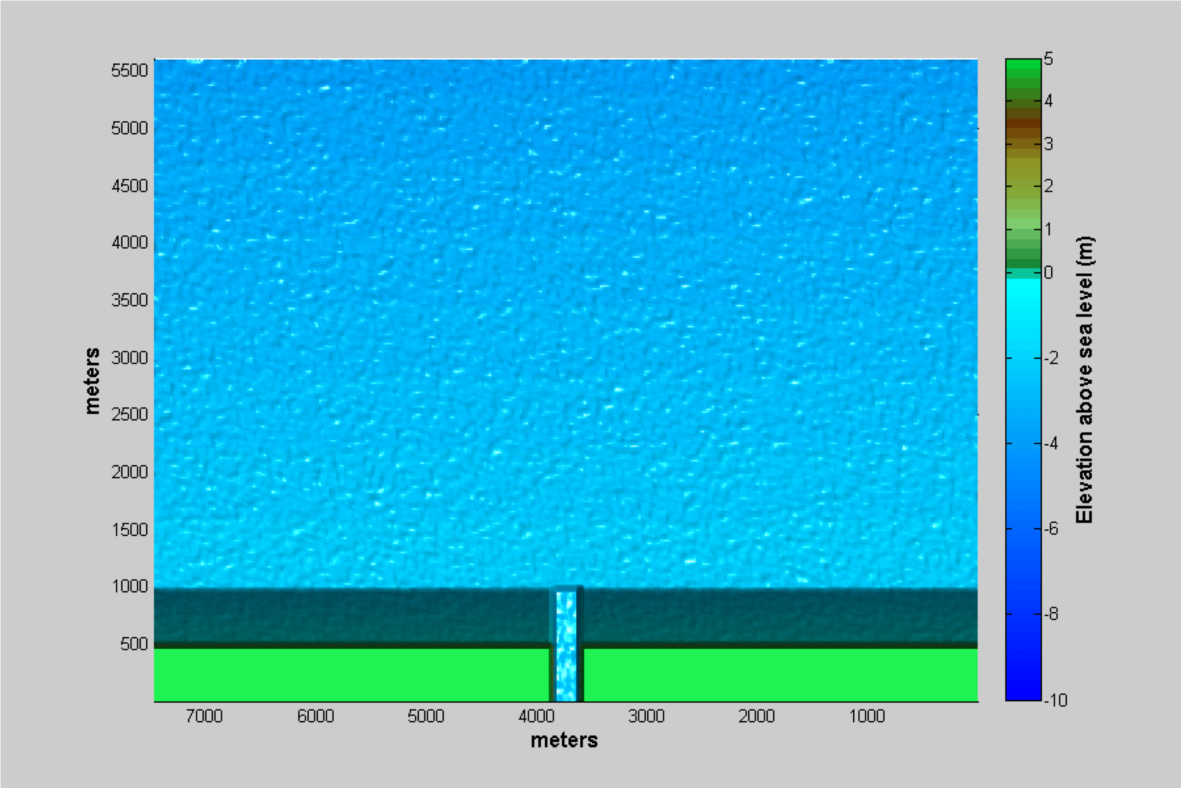
$$A = \frac{Q_s * f}{\lambda * a}$$

f = 0.2 Yellow River (Xu et al., 2004)
f = 0.67 Ganges (Goodbred and Kuehl, 2000)
f = 0.55 Mississippi R. (Blum and Roberts, 2009)

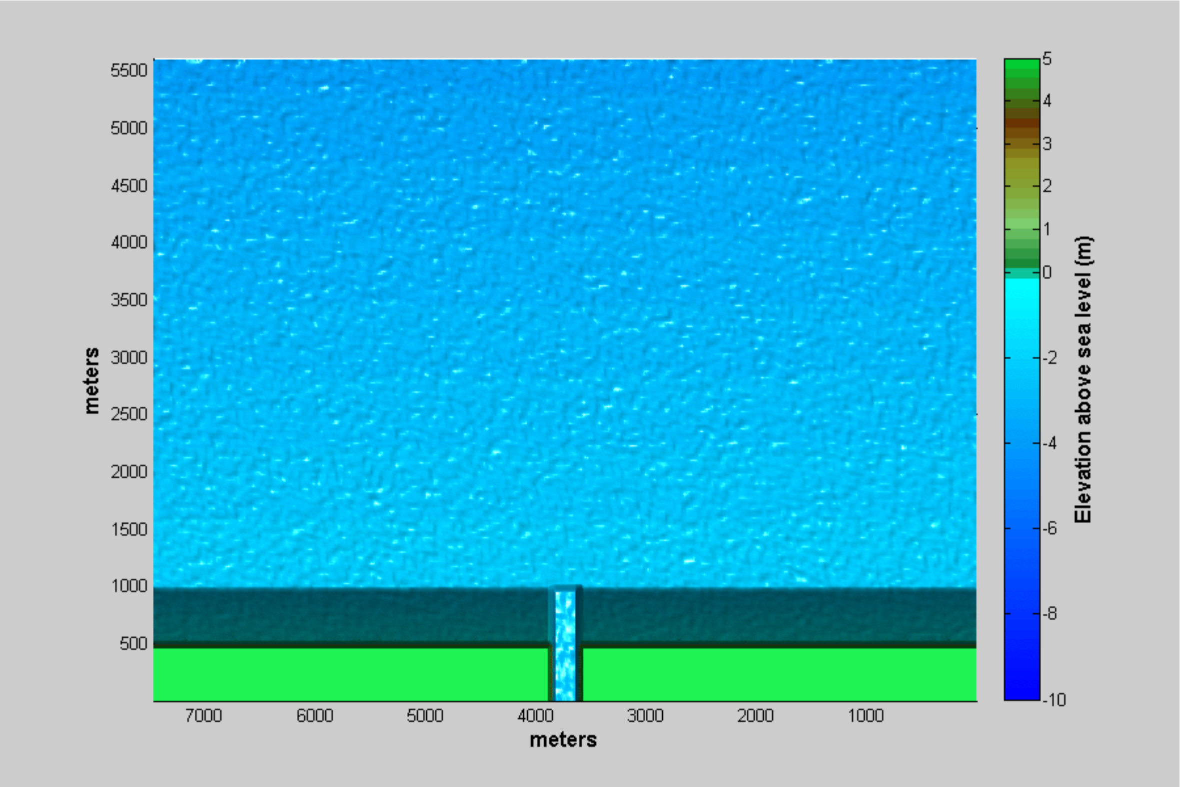
Milliman and Farnsworth, 2011
Caldwell et al., *in review*

f is controlled by delta structure, sediment caliber, and vegetation

Muddy delta, *f* = 0.4

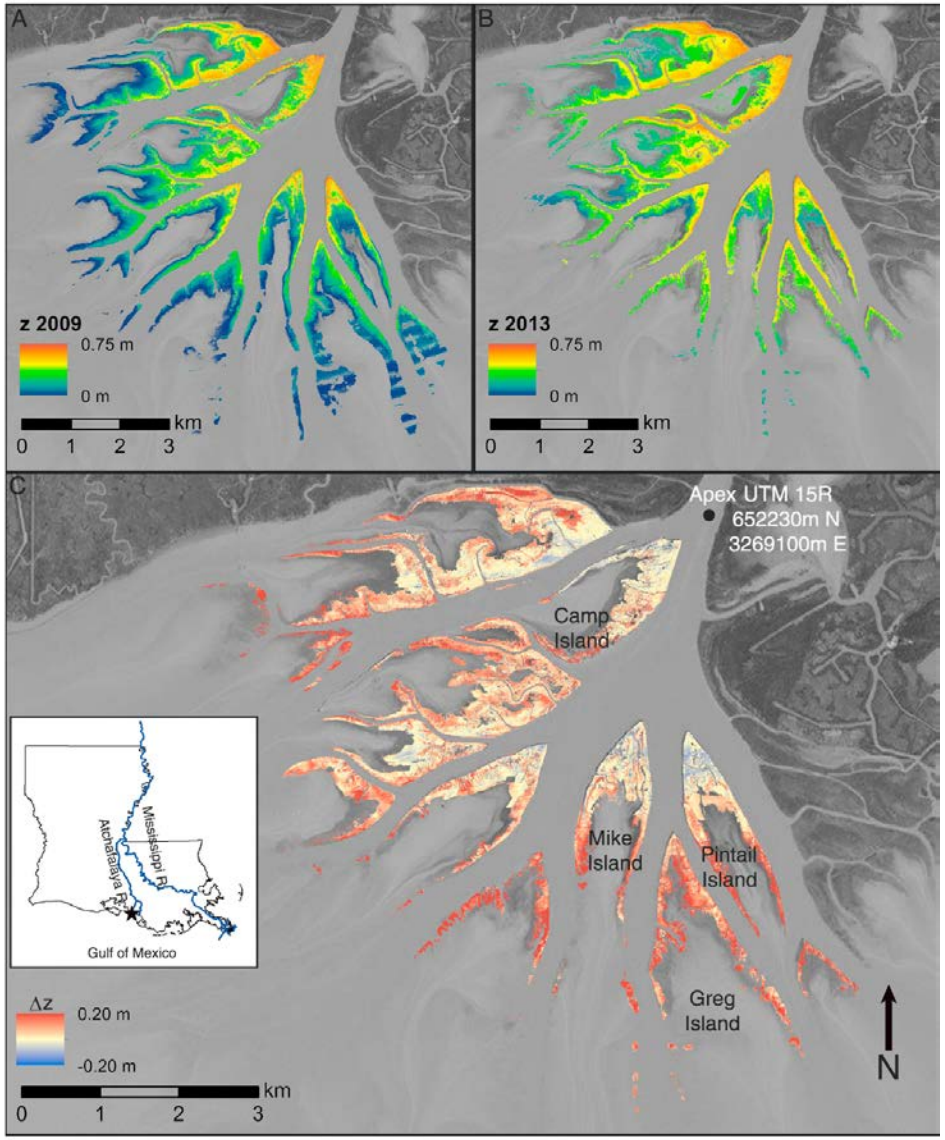


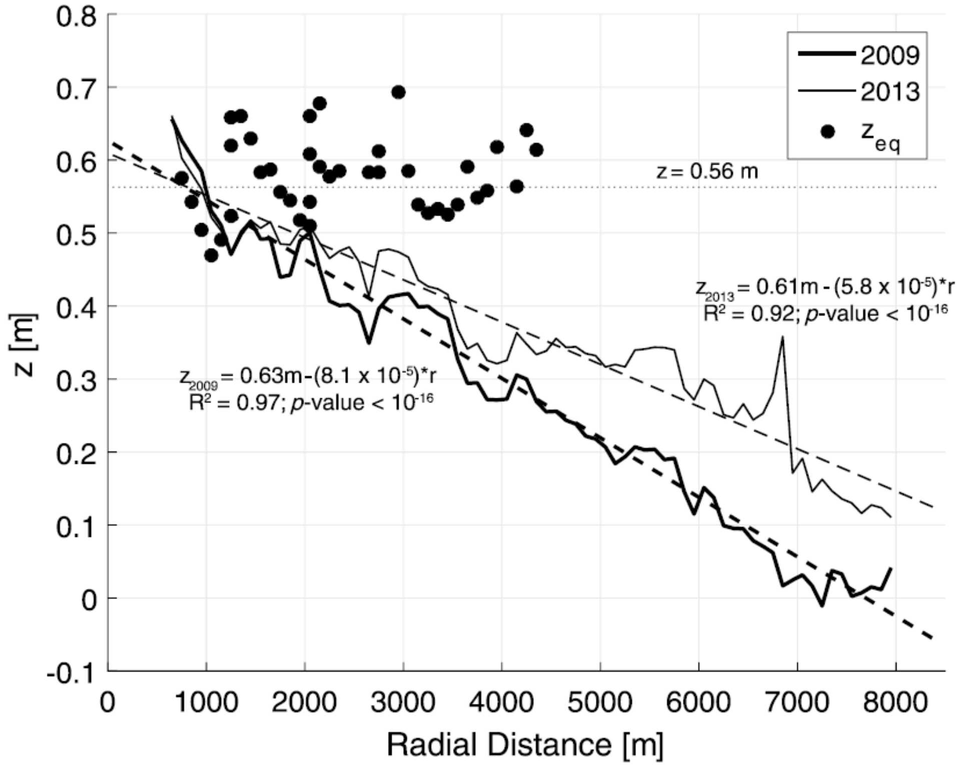
Sandy delta, *f* = 0.9



Caldwell and Edmonds, 2014, *JGR-ES*

We are only beginning to understand how sedimentation works on river delta topsets



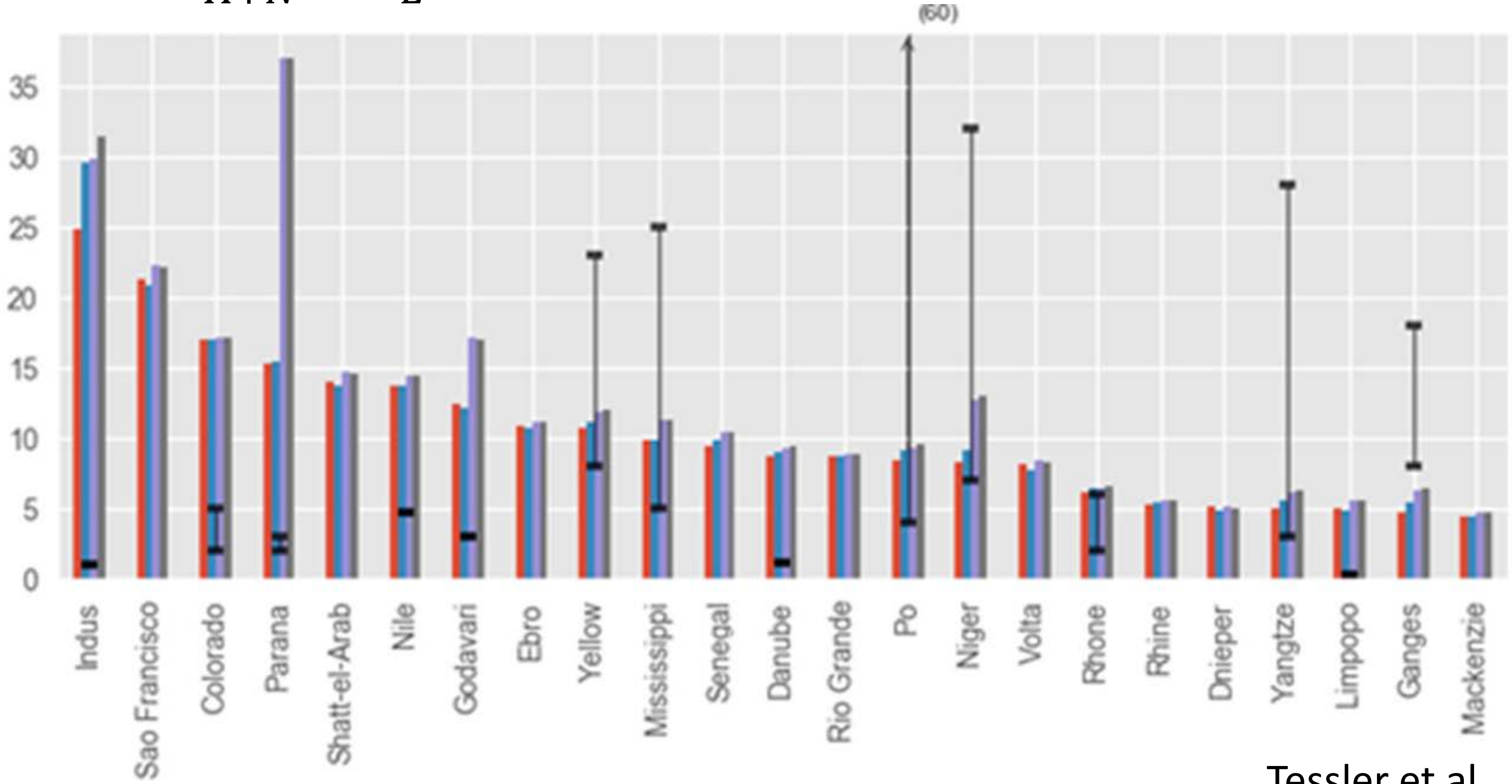


Wagner et al., 2017, *GRL*

What is the spatial variability of subsidence in river deltas?

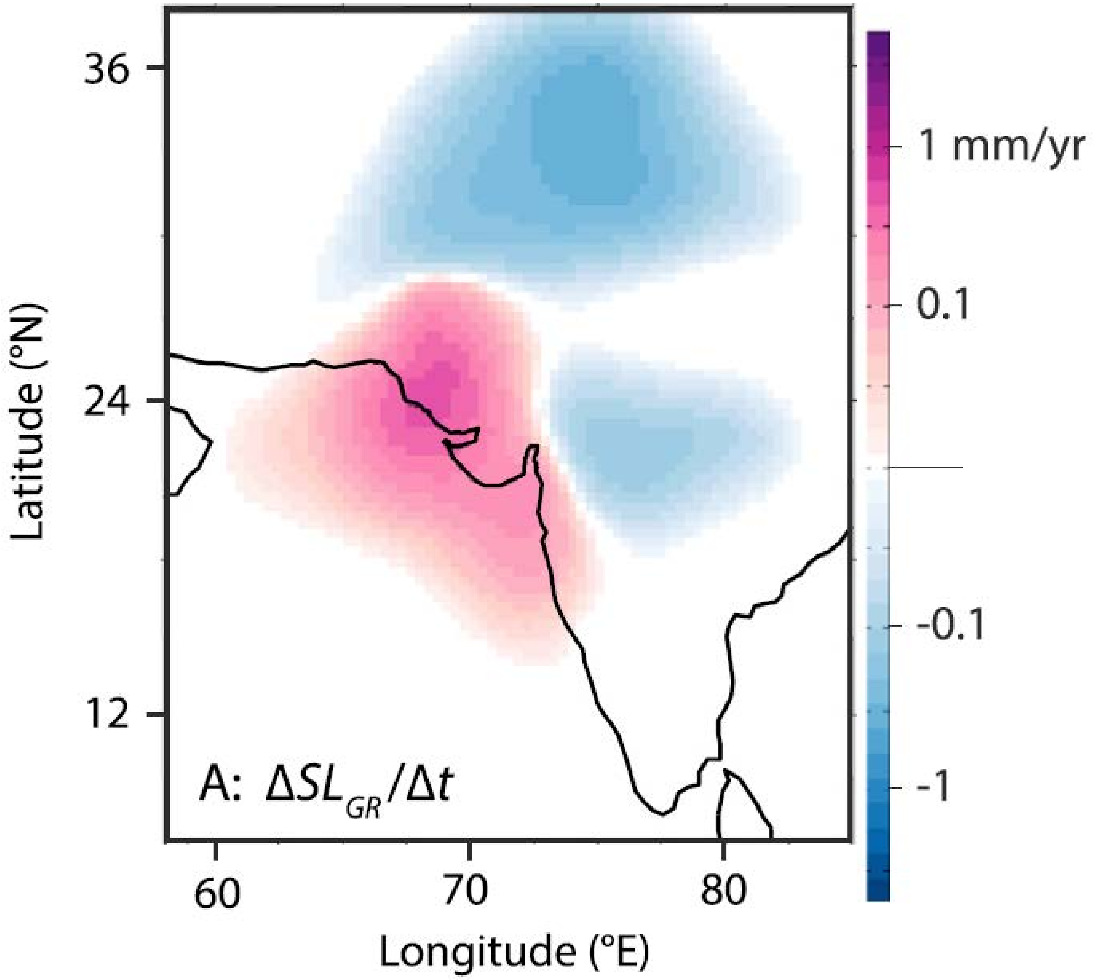
Relative sea level change is estimated via a steady state assumption

- One approach is spatially average over the delta and assume a static topography
  - $RSL = A - S_{A+N} - S_L - T + R$



Tessler et al., 2018, *Geomorphology*

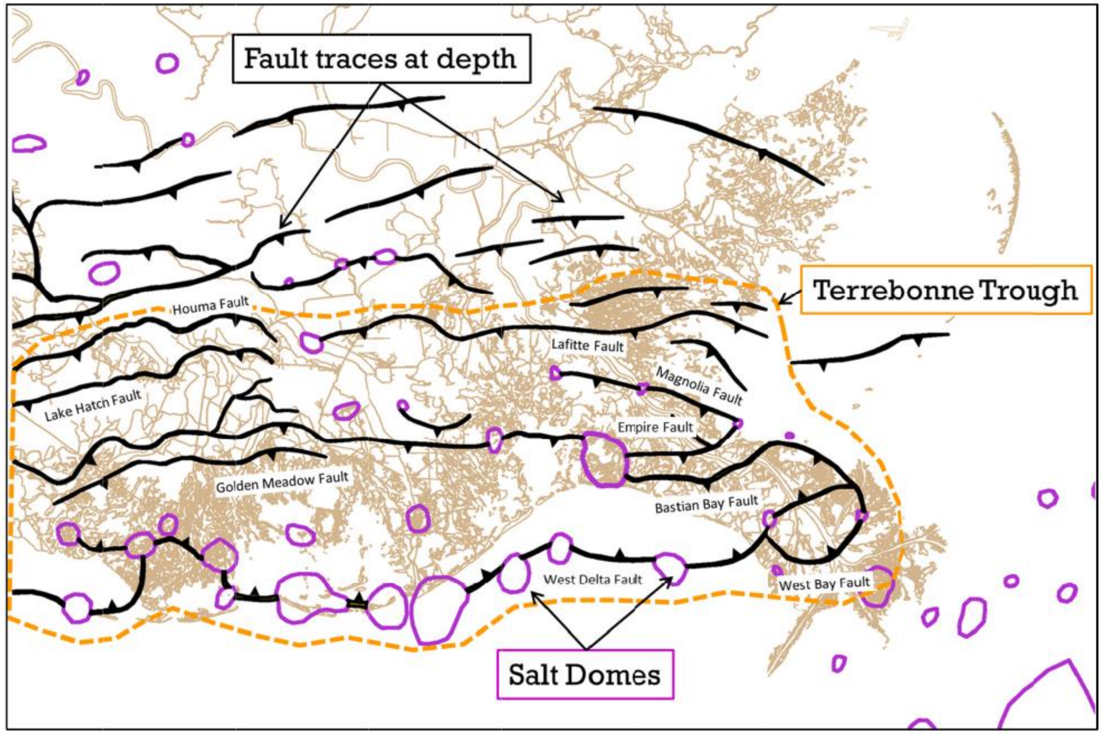
Modeling also shows that deltas can gravitationally create their own sea-level changes



Difference arises due to the volume filling, crustal deforming, and the gravitationally attracting affects of sediment

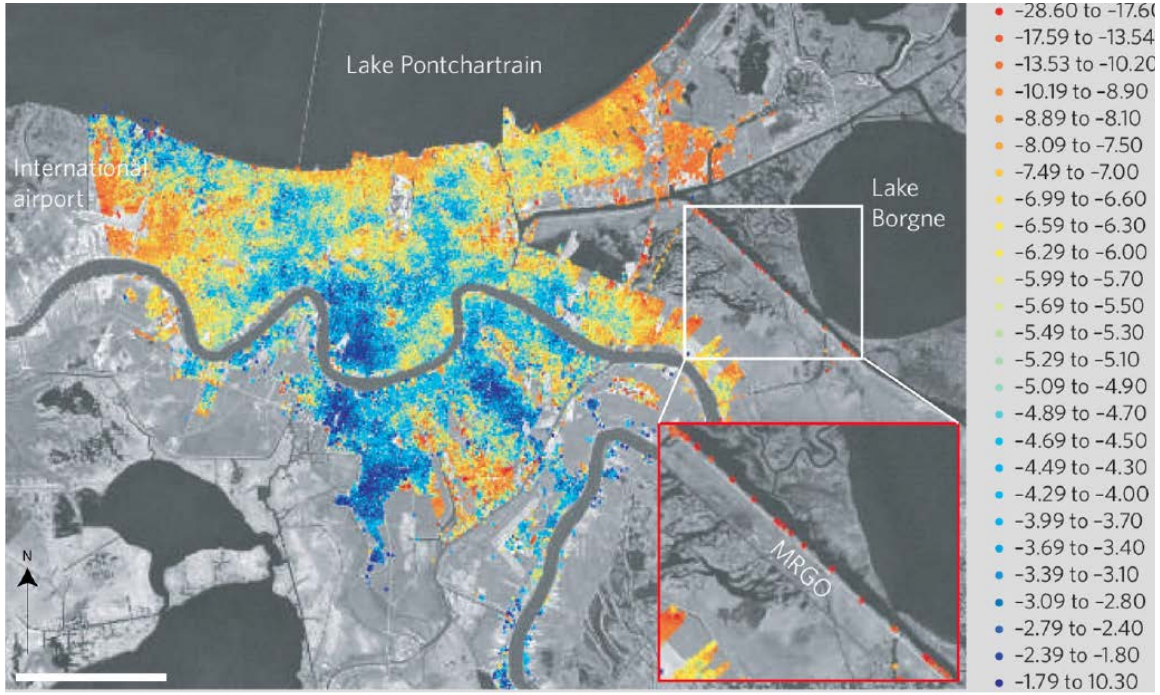
Ferrier et al., 2015, *EPSL*

Over the short term natural subsidence is complicated by faulting in sediments

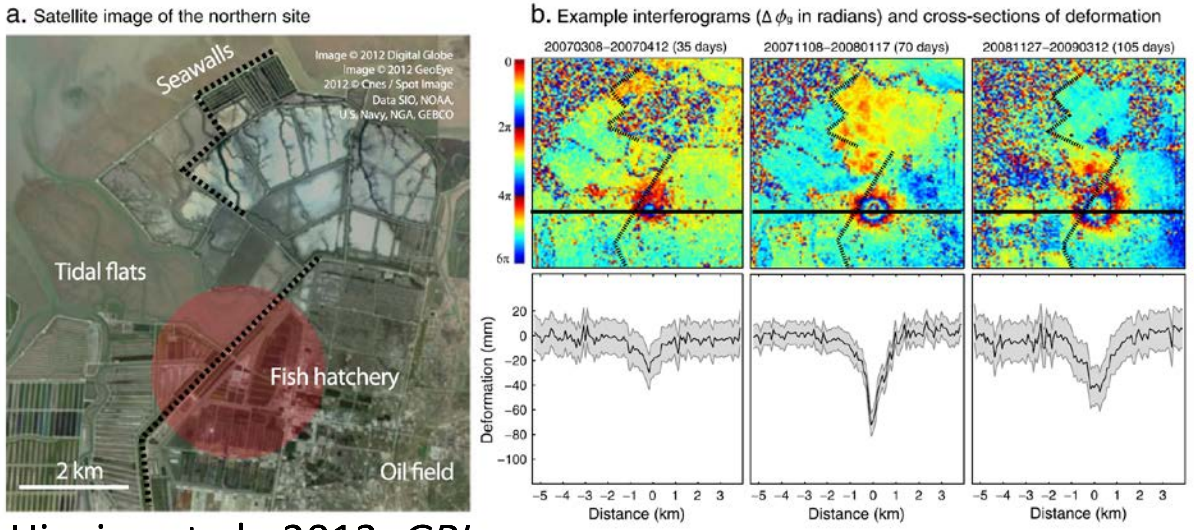


Modified from Gagliano (2003)
See also Armstrong et al., 2014

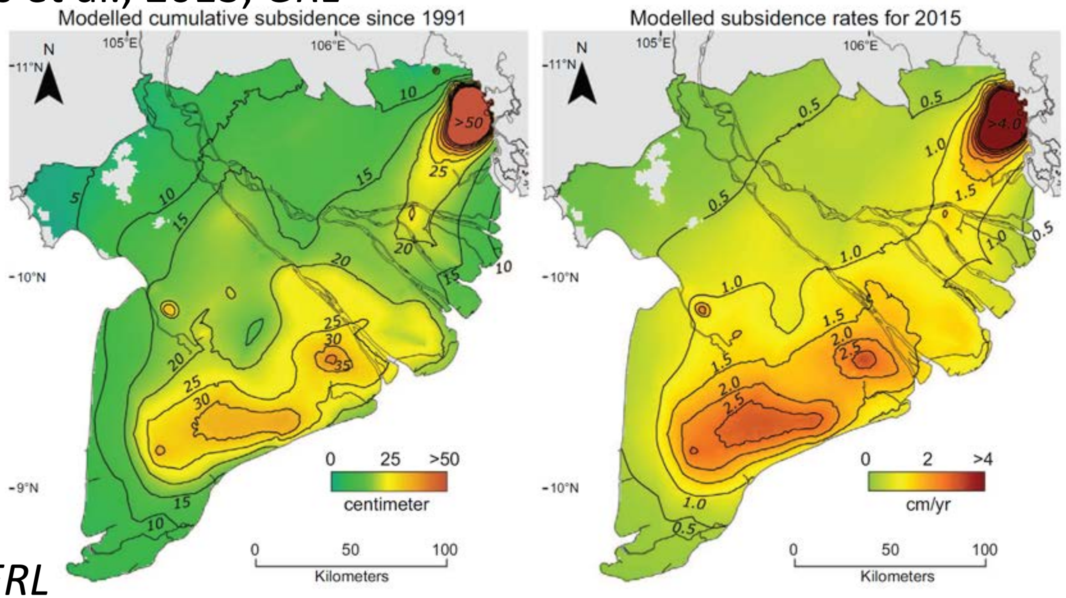
Anthropogenic subsidence can be exceptionally high and variable



Dixon et al., 2006, *Nature*



Higgins et al., 2013, *GRL*

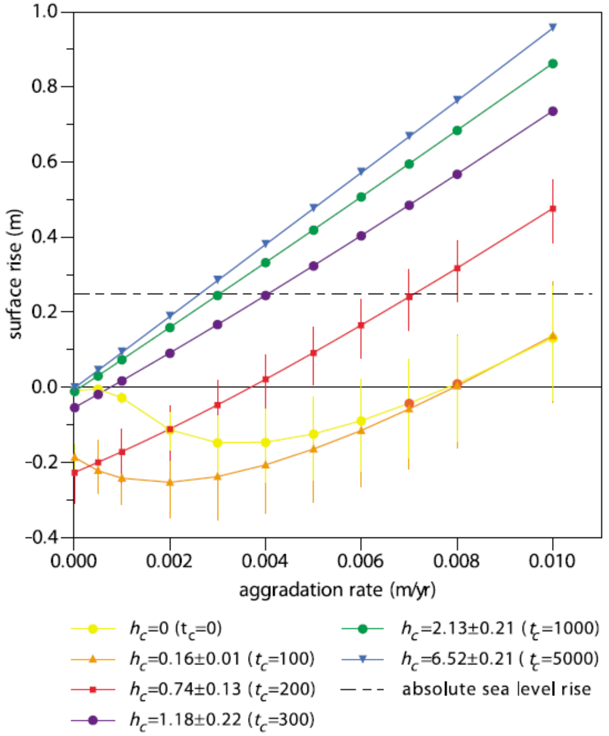


Minderhoud et al., 2017, *ERL*

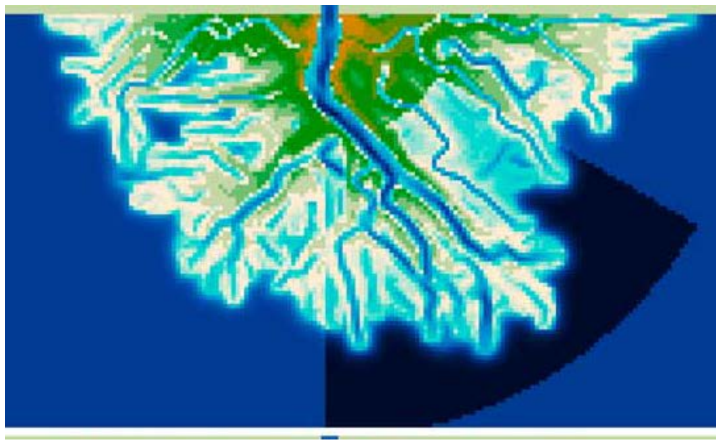
What are the tipping points of delta sustainability?

Tipping points are difficult to define because there are feedbacks among these processes that are unaccounted for

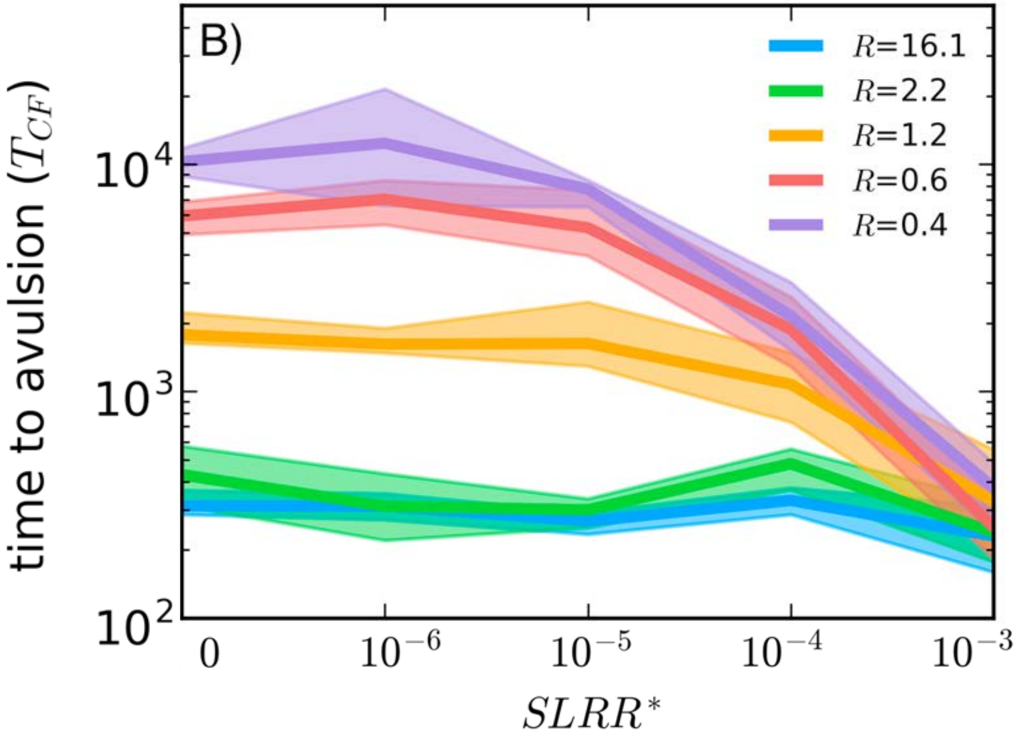
$$\Delta E = A - S_{A+N} - T - S_L$$



van Asselen et al., 2011, *GRL*

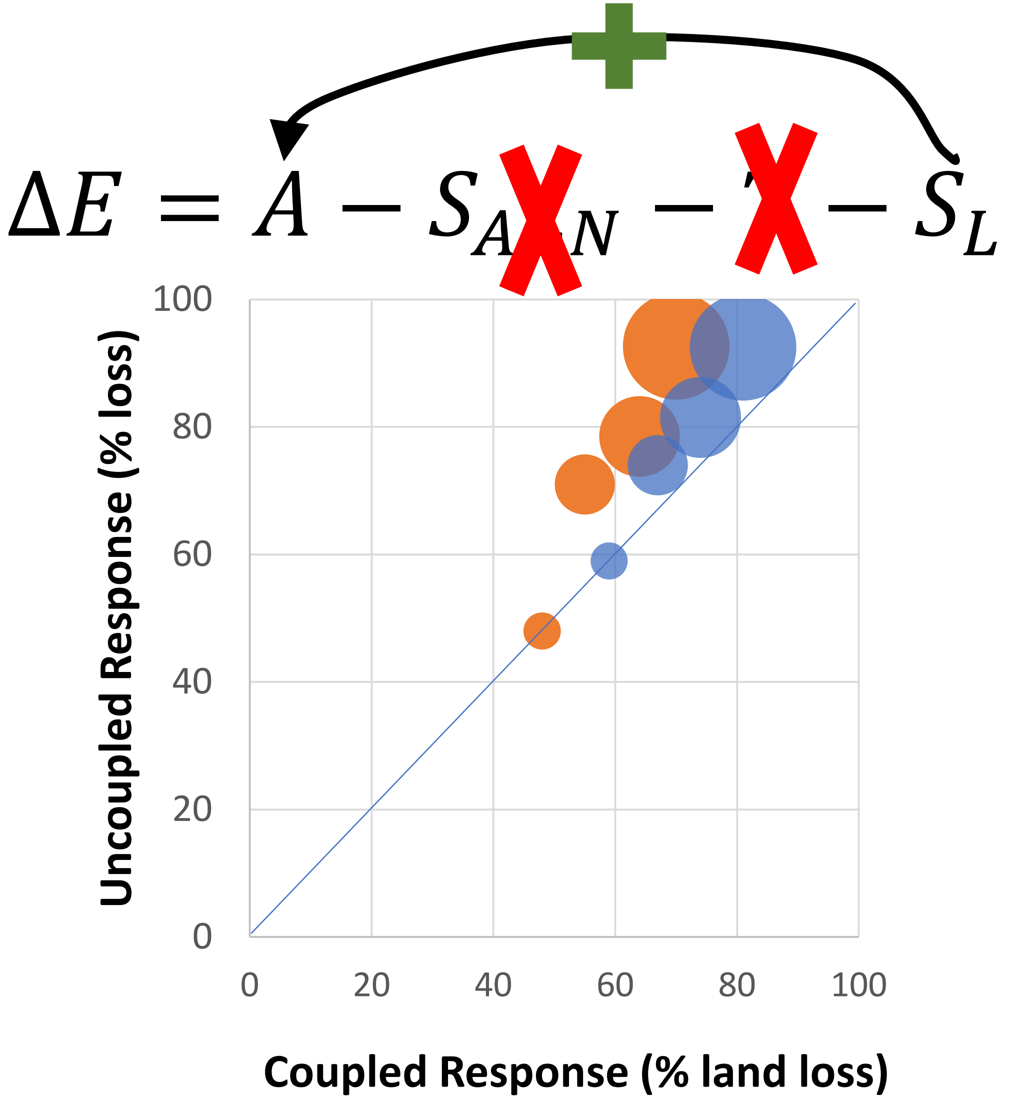


Liang et al., 2016, *GRL*

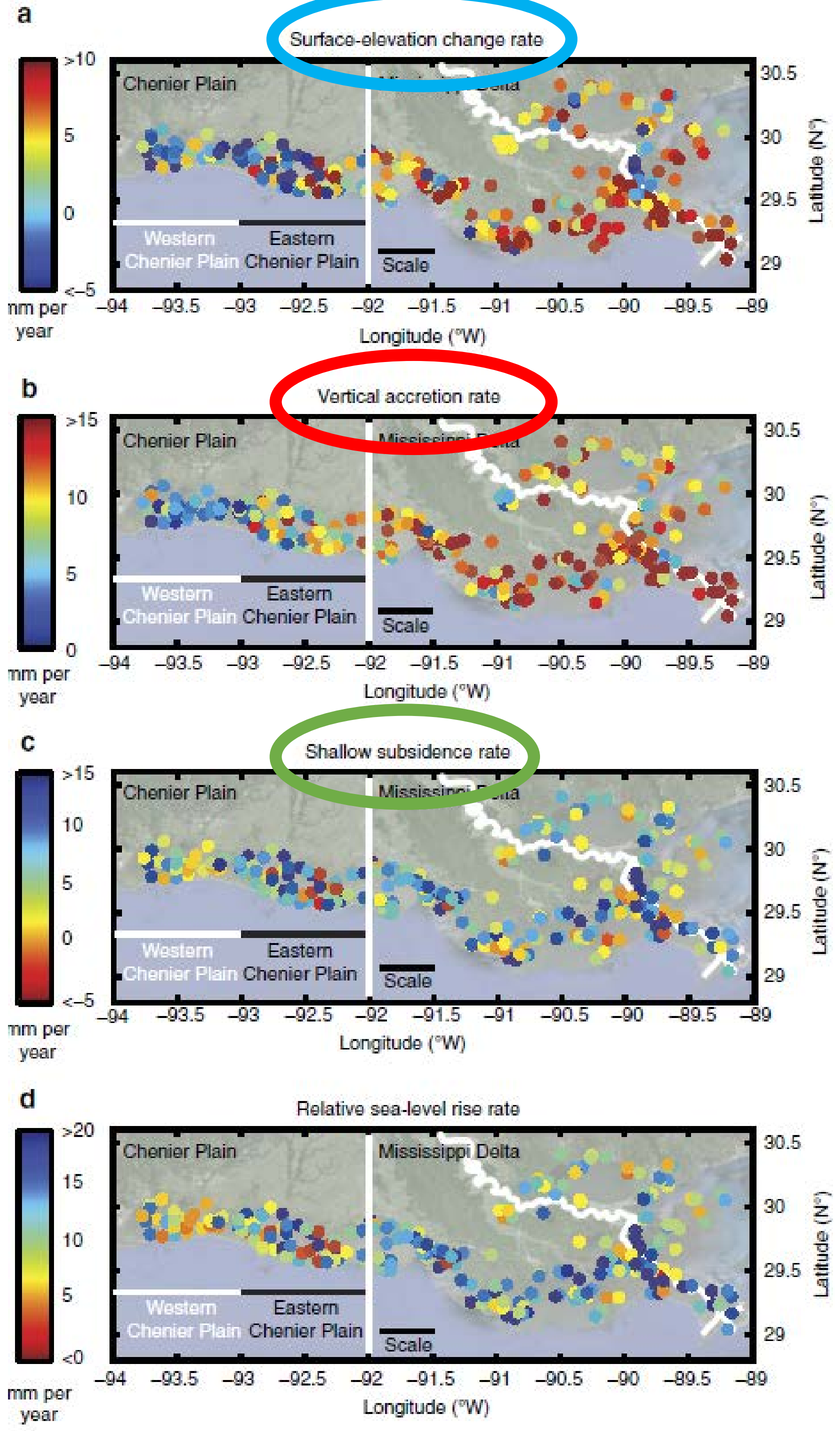


Ratliff et al., 2018, *JGR-ES*

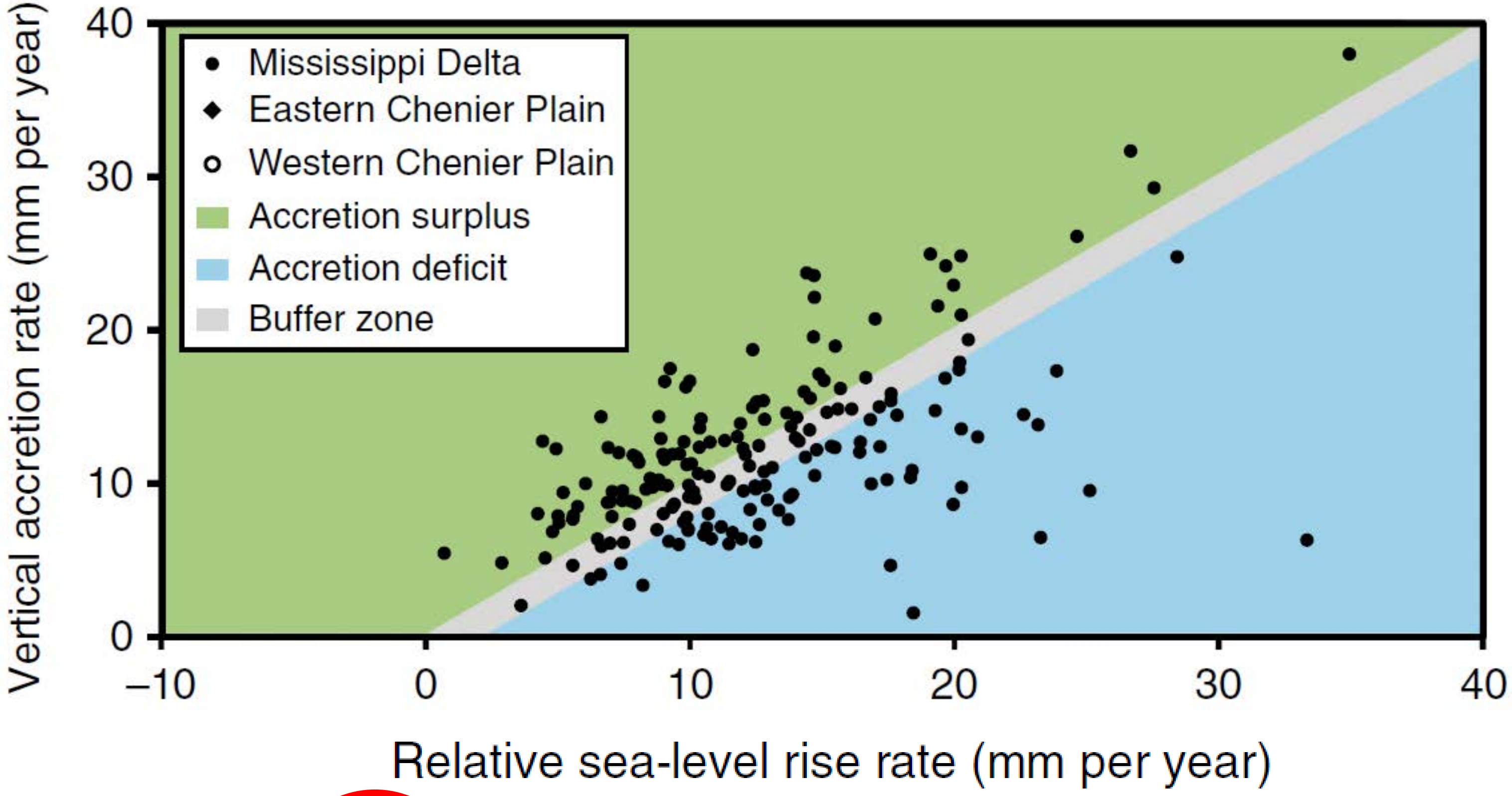
Promising results show that a coupled model loses less land than an uncoupled one



Lageweg & Slanegan, 2018



The Mississippi River Delta is the only place the mass balance has been calculated



$$RSL = A - S_{A+N} - S_L - T$$

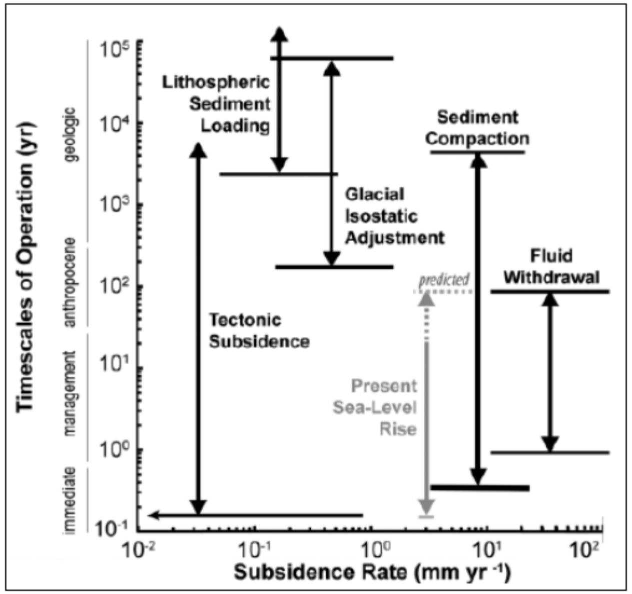
Jankowski et al., 2017, *Nature Communications*

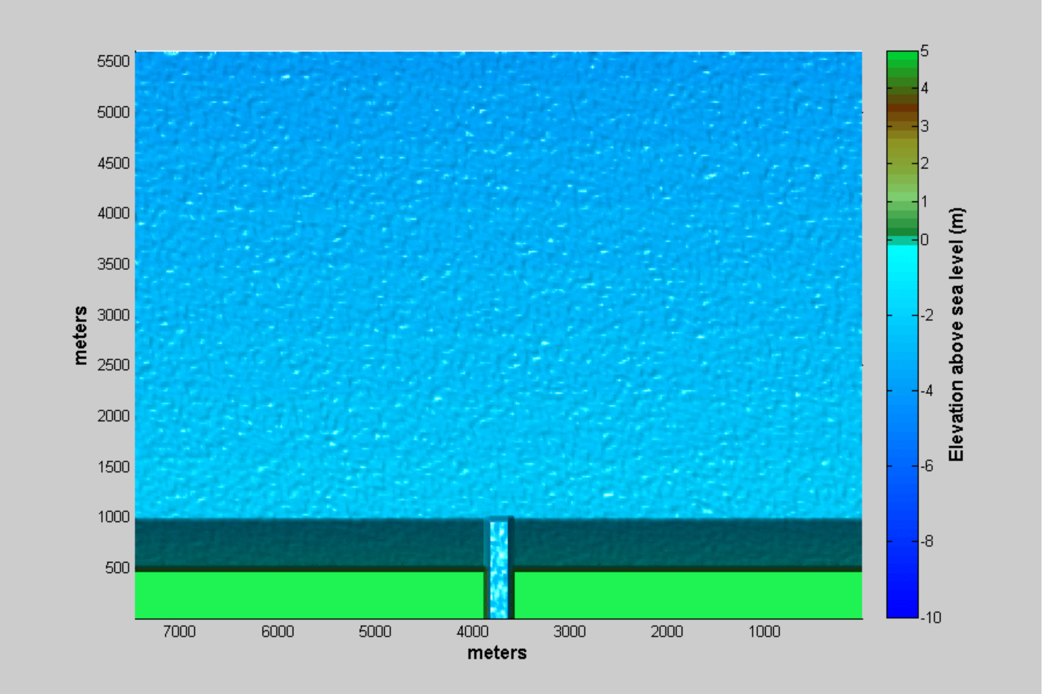
There are three key challenges in the deltaic sediment mass balance that the community is poised to answer

1. *What governs the mass balance of "blue sediment" along river deltas and coastlines at yearly to millennial time-scales?*
   - **Needs**: coastal high-res topography & bathymetry, integrated climate & sed flux models
   - **Ways forward:** Possible approach could use deep learning combined with global datasets of coastal land change, sediment flux, oceanographic conditions to determines controls on *f*
2. *What is the spatial variability of subsidence in river deltas?*
   - **Needs:** Better subsidence measurements that separate causes, more subsidence data
   - **Ways Forward:** UAVSAR (Jones et al., 2016, *JGR-SE),* subsidence supersites (Allison et al., 2016, *EOS*)

Ways forward. The community needs

3. Thinking forward, what are the tipping points in the deltaic sediment mass balance?
    - **<u>Needs</u>**: 2D dynamic subsidence models with faulting and compaction
    - **<u>Ways Forward:</u>** Coupled Morpho-tectonodynamic model of deltaic growth over a deforming substrate to predict *land area* changes in time and space





References

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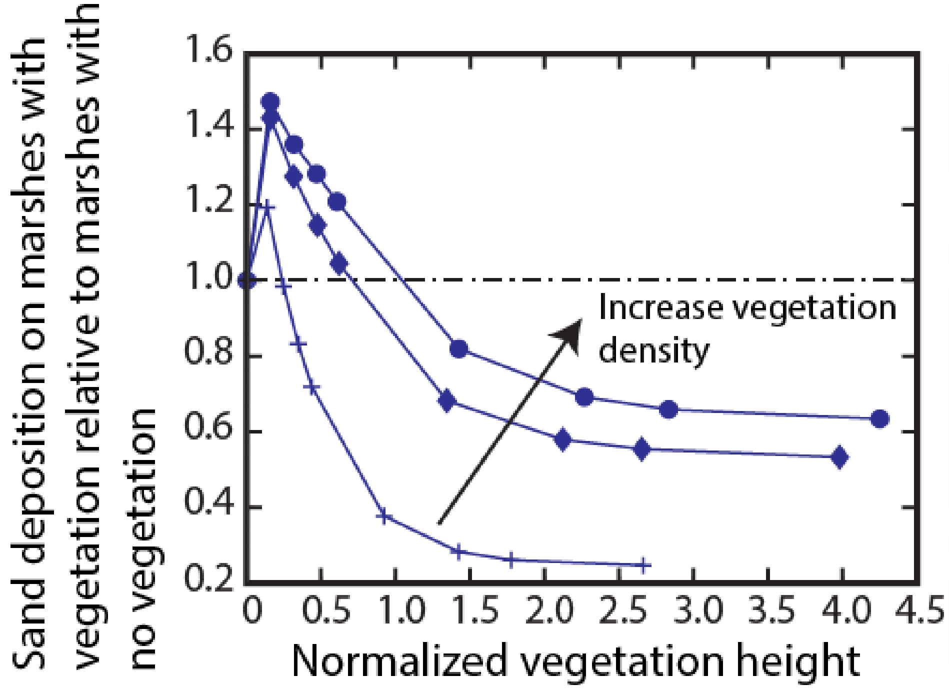
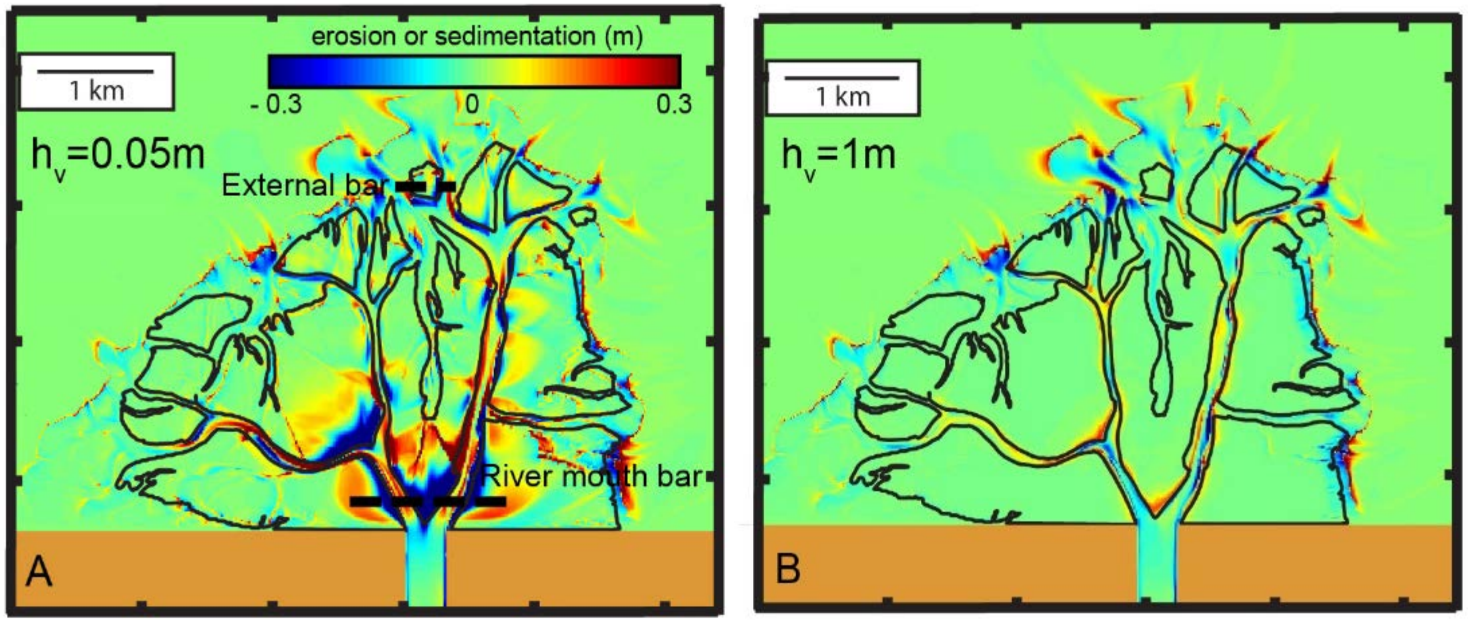
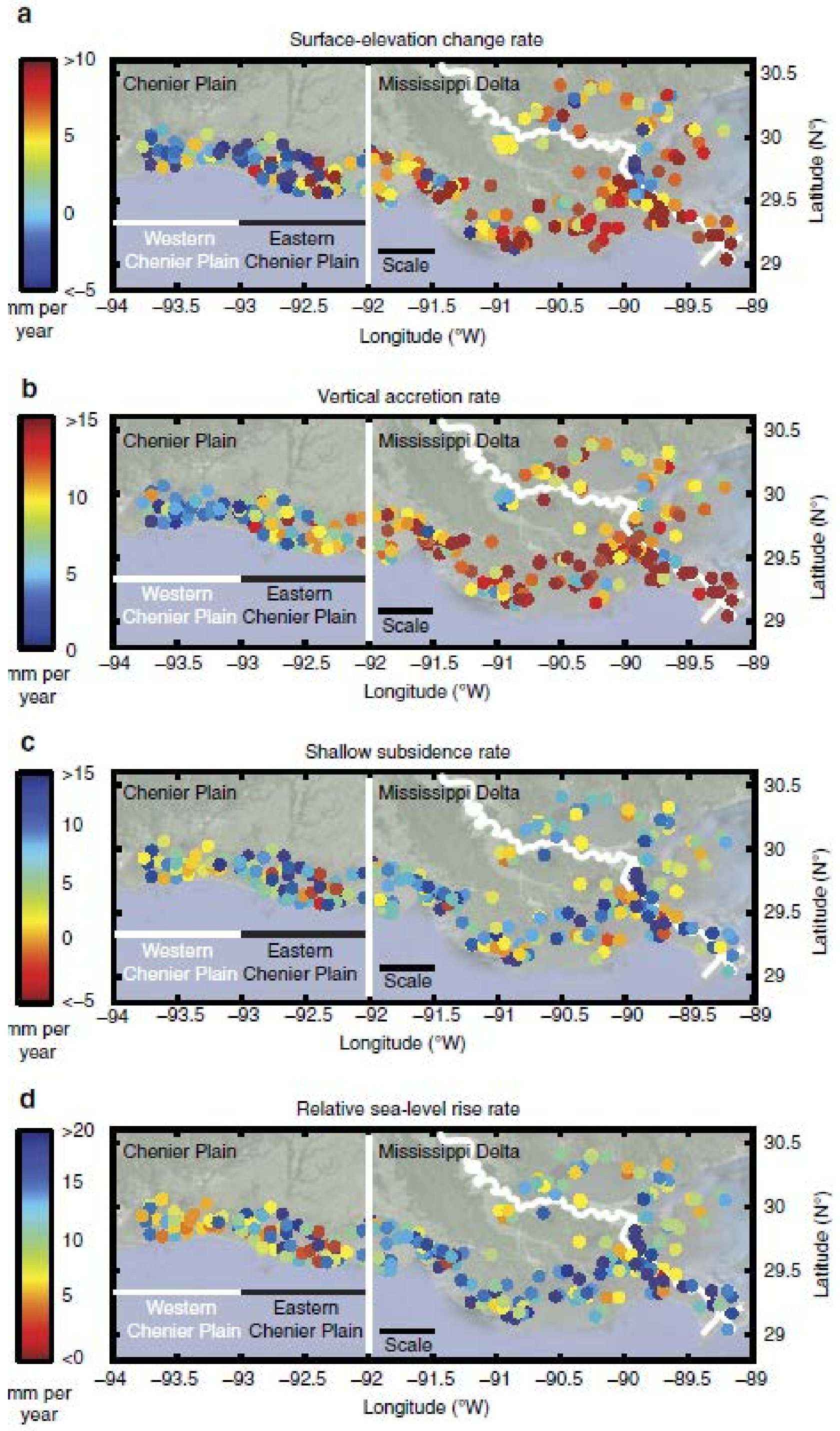




Nardin and Edmonds, 2014, *Nature Geoscience*



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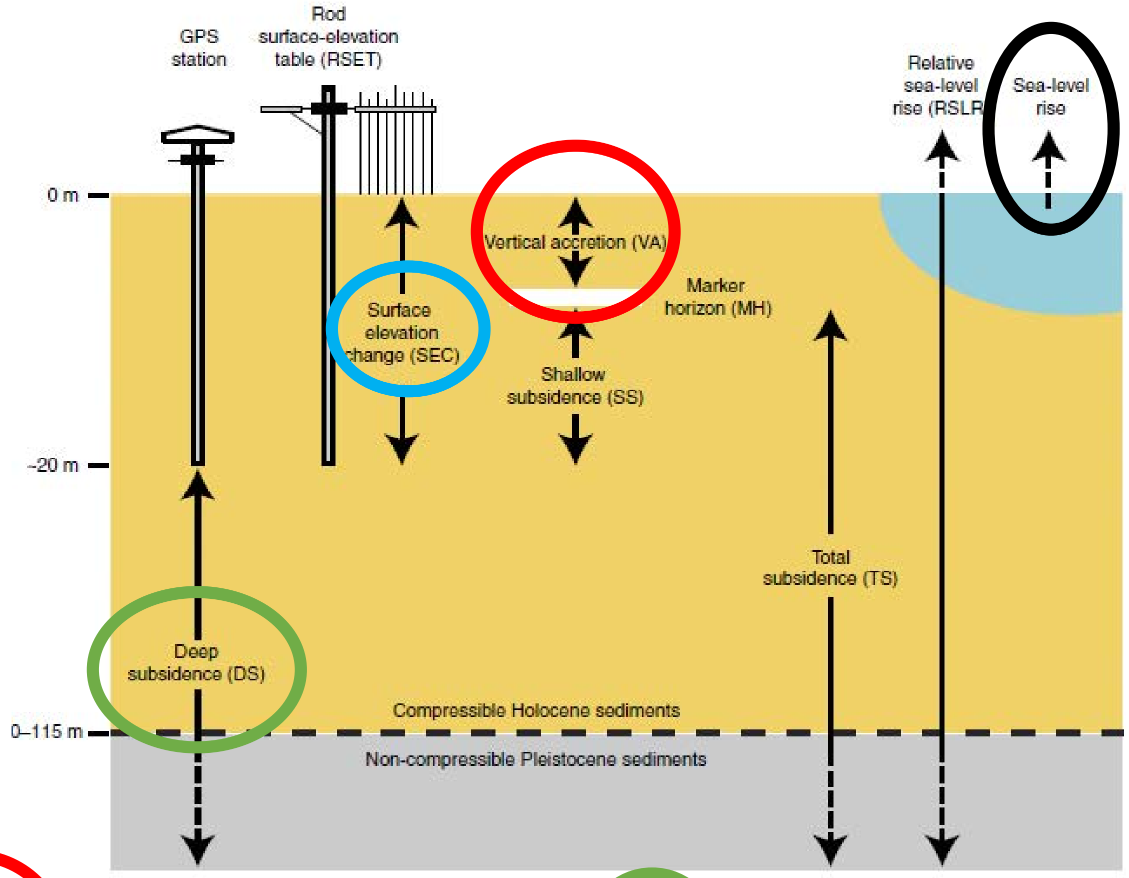
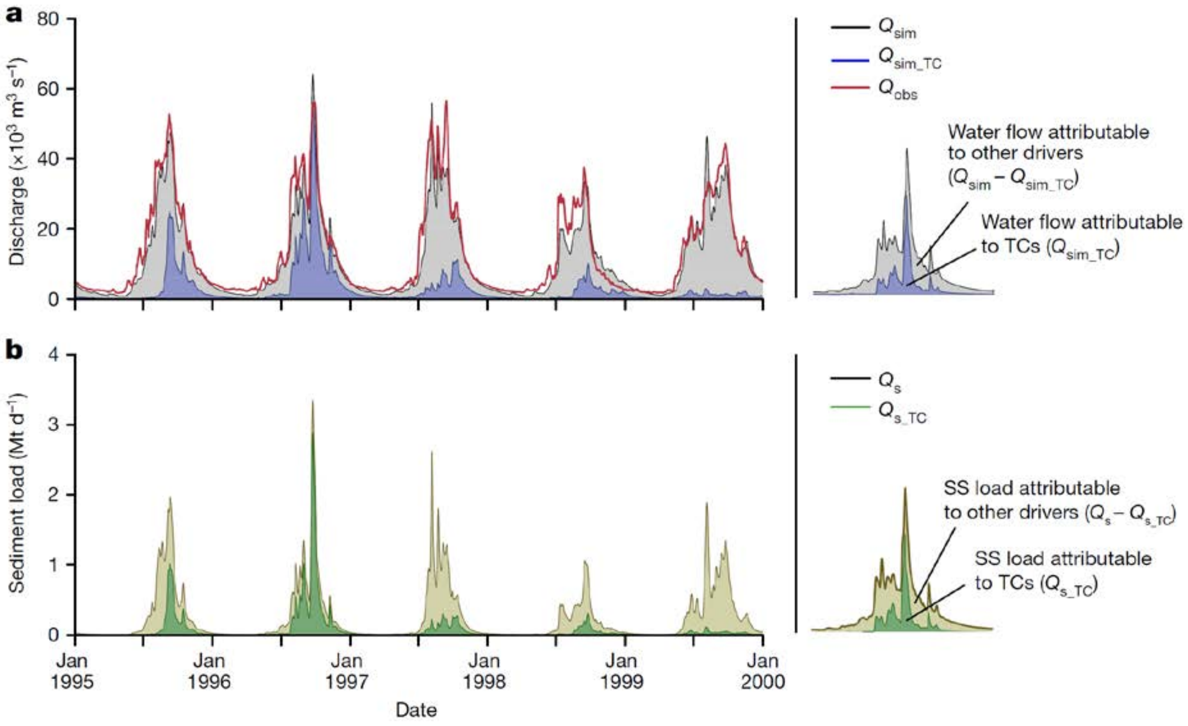


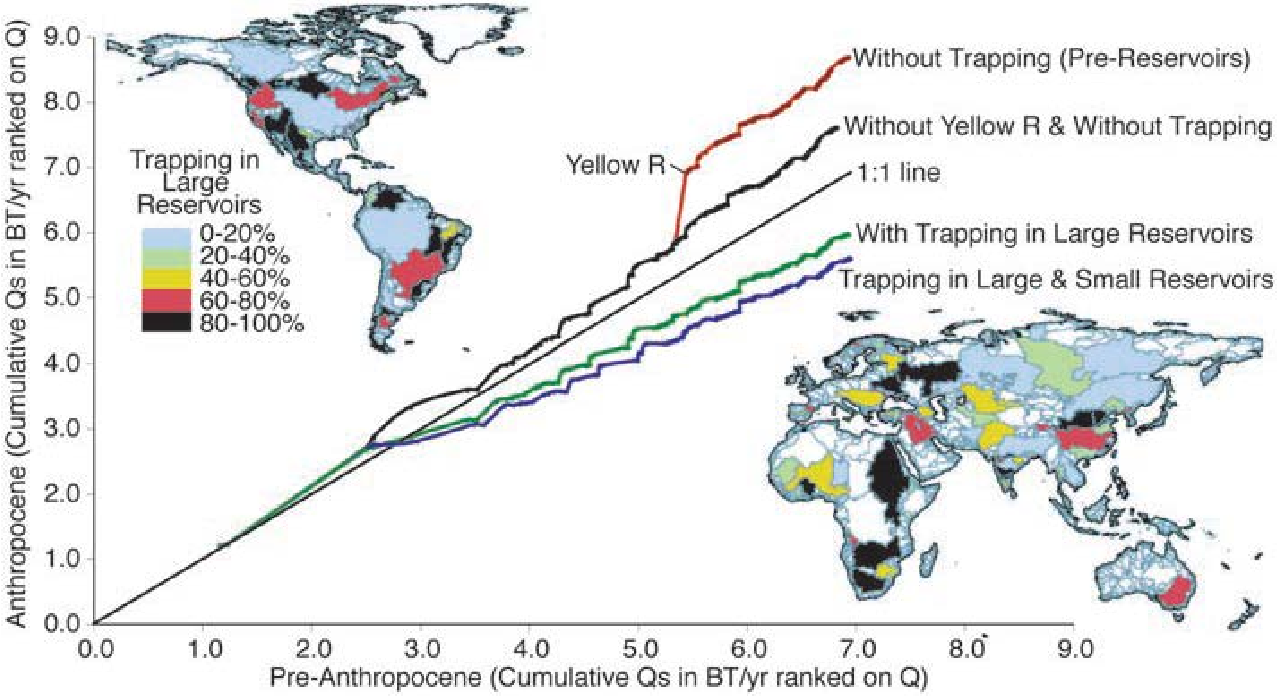
$$\Delta E = A - S_{A+N} - S_L - T$$

Jankowski et al., 2017, *Nature Communications*

Sediment delivery to coastal margins is an old problem but it still deserves attention



Darby et al., 2016, *Nature*



Syvitski et al., 2005, *Science*

Deltas are commonly found on every type of continental margin

Caldwell et al., In Review, *JGR-ES*