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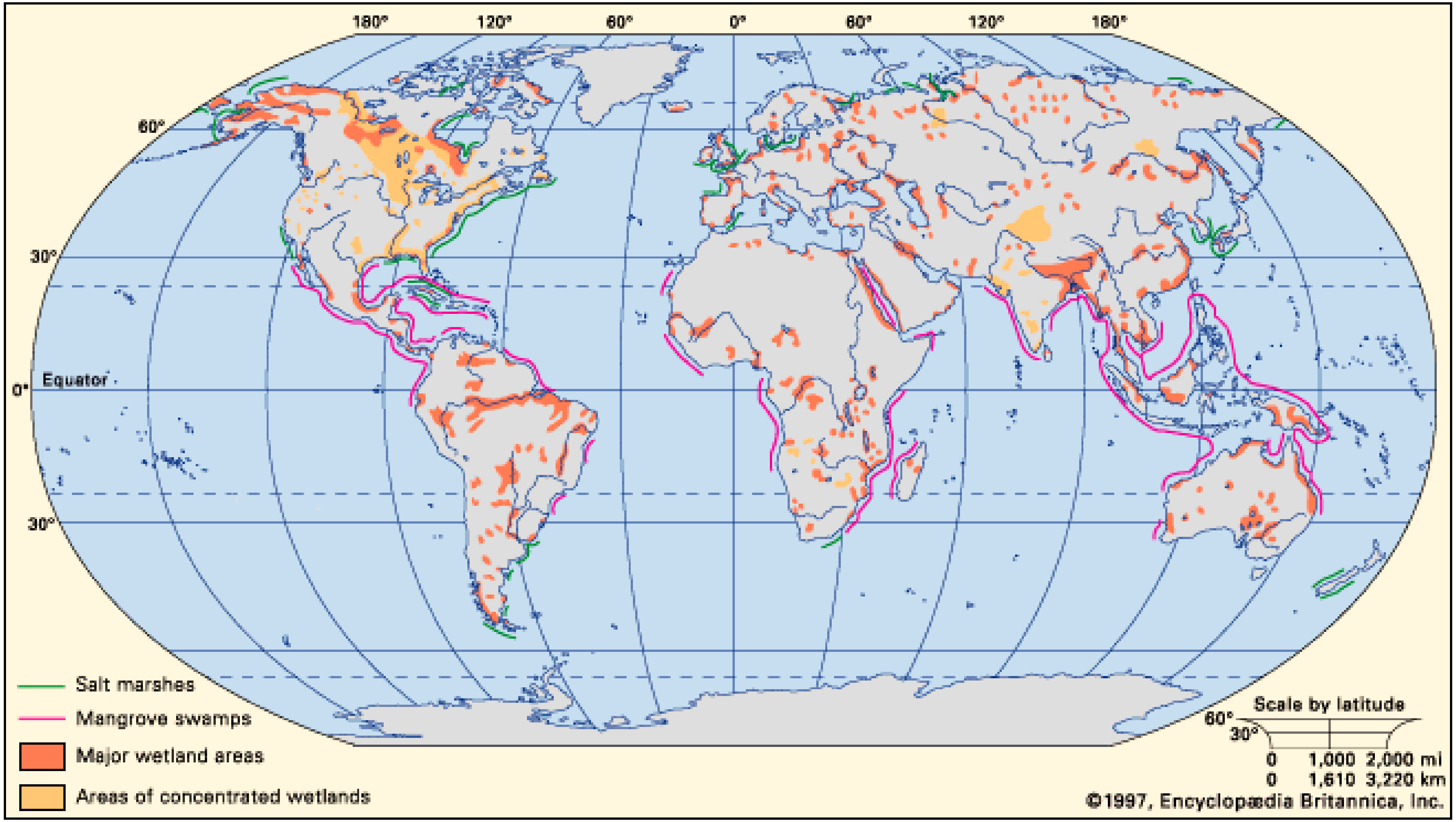
THE UNIVERSITY of EDINBURGH School of GeoSciences

How do you build a model with two scientists when one calls something "*Juncus roemerianus*" and the other calls the same thing "flexible rod-like structures": challenges in cross-disciplinary modelling.

Preliminary thoughts: why would anyone study marshes?

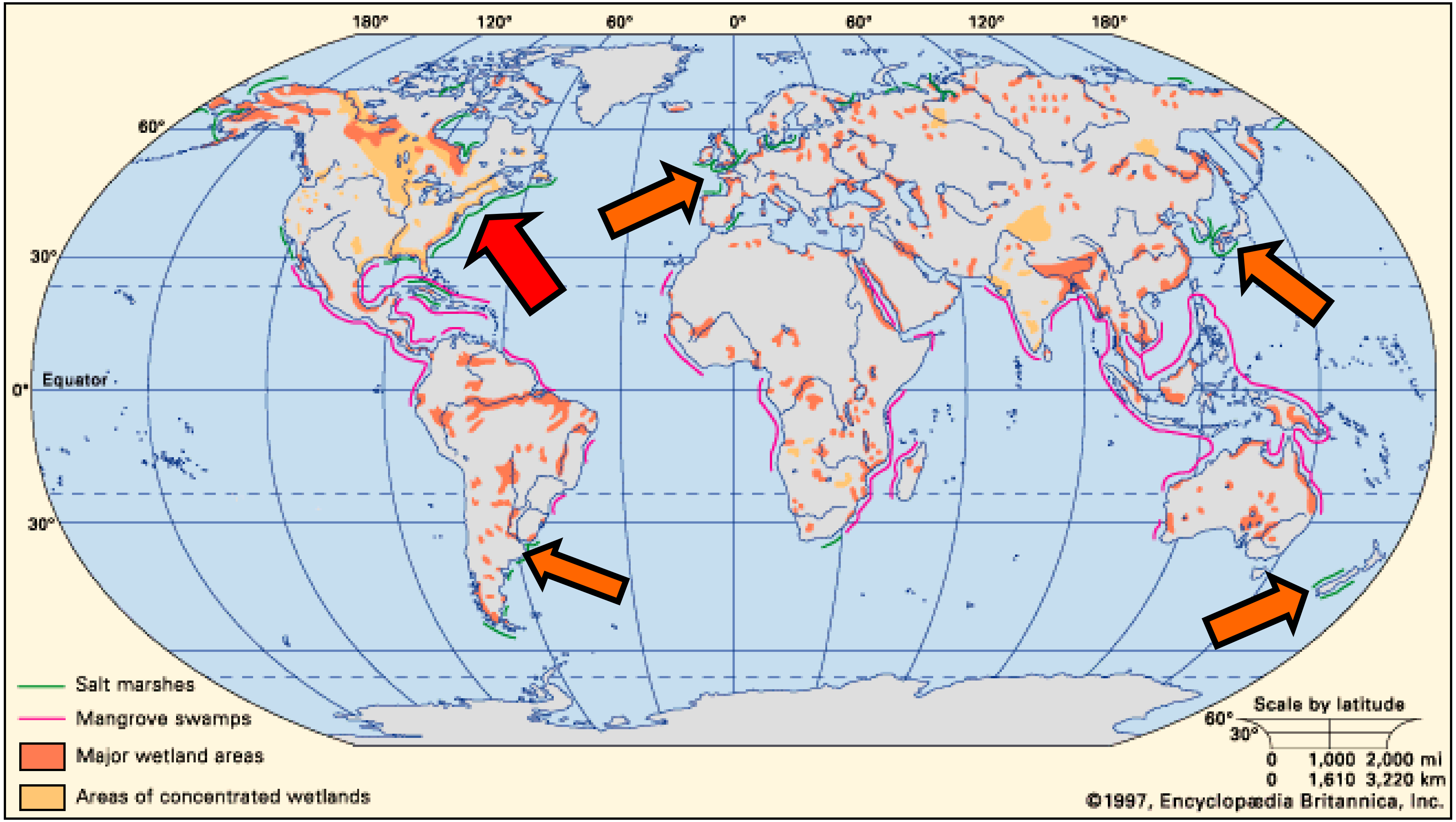
Photo: Guillaume Goodwin

Worldwide distribution of salt marshes



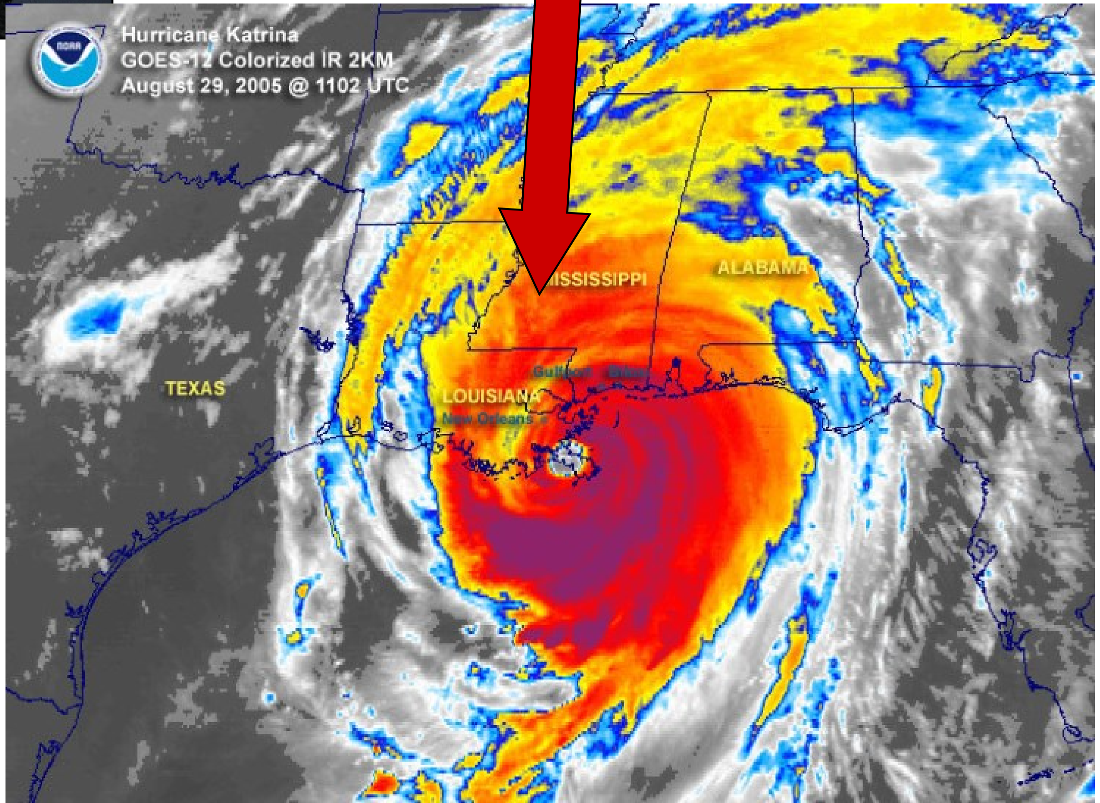
From Encyclopaedia Britannica: http://media-2.web.britannica.com/eb-media/76/6576-004-976E5CF5.gif

Worldwide distribution of salt marshes



From Encyclopaedia Britannica: http://media-2.web.britannica.com/eb-media/76/6576-004-976E5CF5.gif

This damps storm surge from this



And also source of nutrients (e.g., N and P) and sink of organic carbon

How much carbon gets stored?

Table 1. Carbon burial and global area of vegetated coastal ecosystems

Ecosystem	Carbon burial rate ($g\ C\ m^{-2}\ yr^{-1}$) mean ± SE	Global area (km^2)	Global carbon burial* ($Tg\ C\ yr^{-1}$) mean ± SE	Sources: Global area	Sources: Carbon burial
Salt marshes	218 ± 24 (range = 18–1713) n = 96 sites	22 000**– 400 000	4.8 ± 0.5 87.2 ± 9.6	Chmura *et al.* (2003); Duarte *et al.* (2005a)	Chmura *et al.* (2003); Duarte *et al.* (2005a)
Mangroves	226 ± 39 (range = 20–949) n = 34 sites	137 760– 152 361	31.1 ± 5.4 34.4 ± 5.9	Giri *et al.* (2010); Spalding *et al.* (2010)	Chmura *et al.* (2003); Bird *et al.* (2004); Lovelock *et al.* (2010); Sanders *et al.* (2010)
Seagrasses	138 ± 38 (range = 45–190) n = 123 sites	177 000– 600 000	48–112	Charpy-Roubaud and Sournia (1990); Green and Short (2003); Duarte *et al.* (2005b)	Duarte *et al.* (2005a); Duarte *et al.* (2010); Kennedy *et al.* (2010); Duarte (unpublished data)

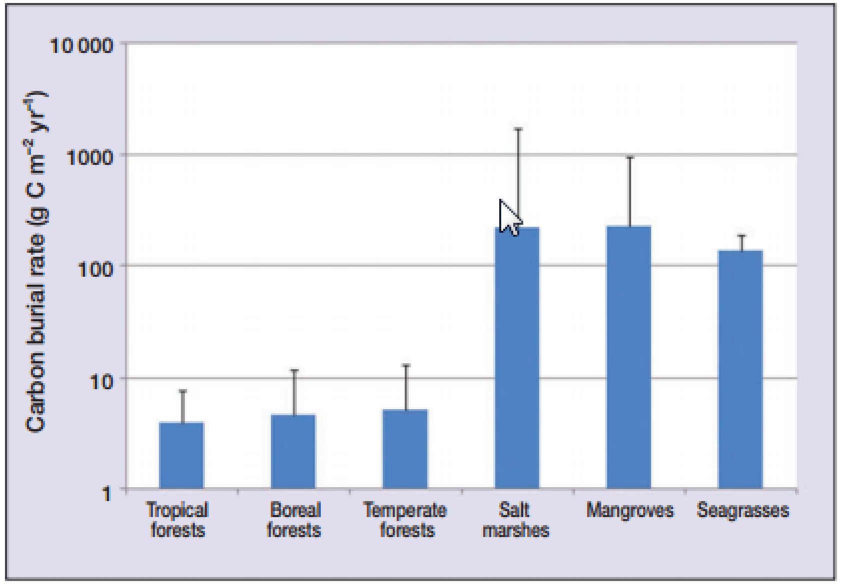
Notes: *We calculated global carbon burial values using the mean carbon burial rate and the minimum and maximum global area values for salt marshes and mangroves. Global carbon burial values for seagrasses are from Kennedy *et al.* (2010). **No global inventory of salt marshes has been published, so Chmura *et al.* (2003) estimated 22 000 km^2 of salt marshes based on inventories for Canada, Europe, the US, and South Africa. SE = standard error.

Temperate forests:
53.0 Tg C yr^{-1}

Tropical forests:
78.5 Tg C yr^{-1}

Boreal forests:
49.3 Tg C yr^{-1}

Elizabeth Mcleod, Gail L Chmura, Steven Bouillon, Rodney Salm, Mats Björk, Carlos M Duarte, Catherine E Lovelock, William H Schlesinger, and Brian R Silliman 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. *Frontiers in Ecology and the Environment* **9**: 552–560.



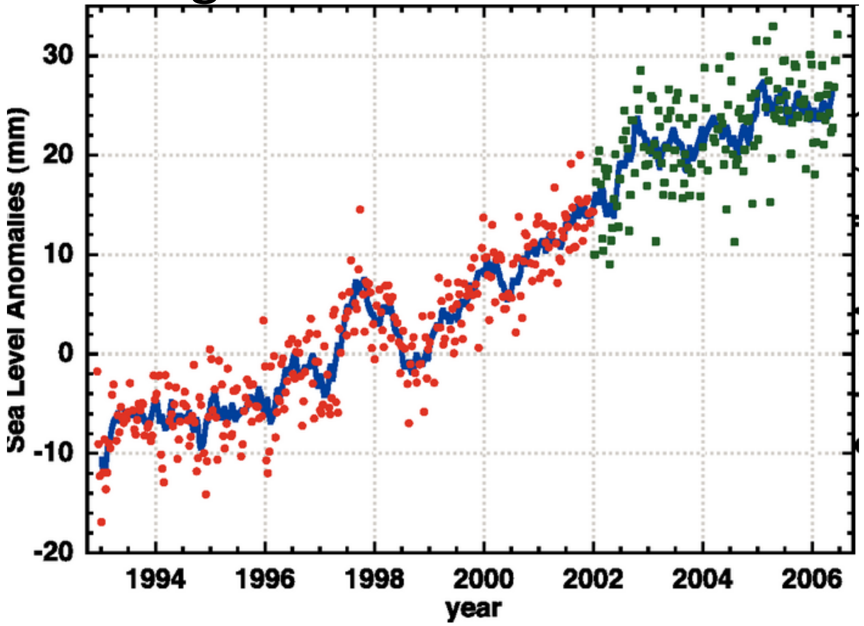
Many reasons to study marshes. But why am I studying marshes?

Interactions result in very interesting patterns

Investigating feedbacks between sedimentation and plant productivity

What controls plant productivity?

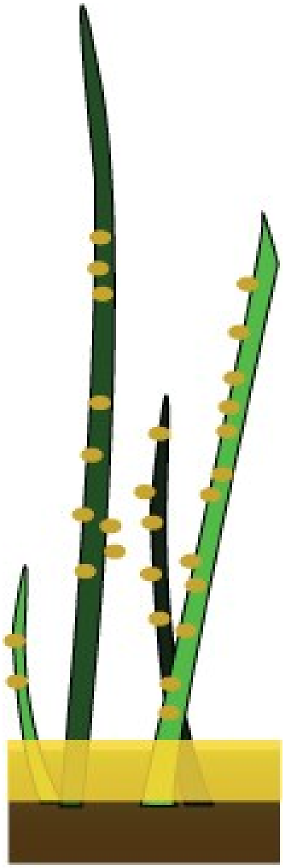
How does sea level rise affect both of these things?

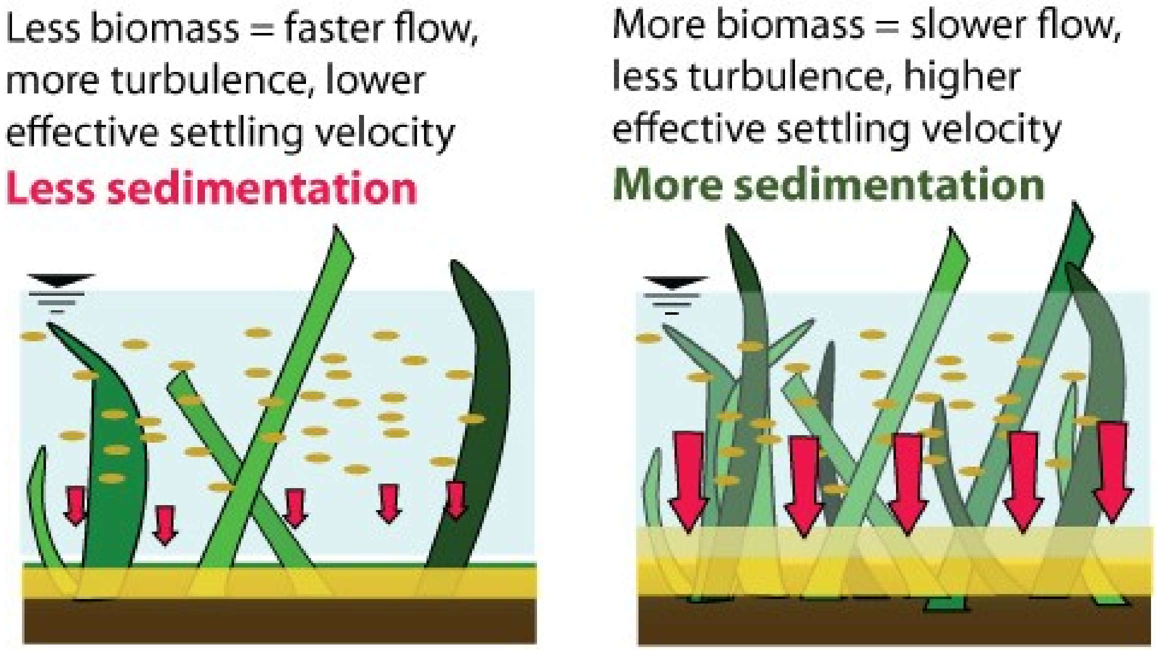


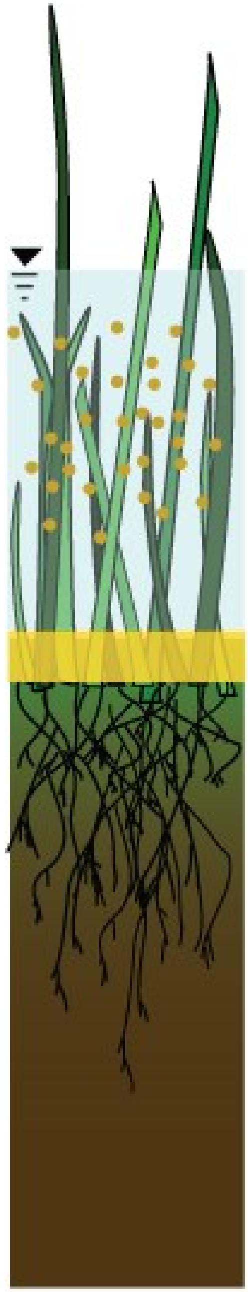
IPCC, global mean sea level from satellite altimeter data

How does plant productivity affect sedimentation?

“Simple” interactions between vegetation, hydrodynamics and sediment transport.



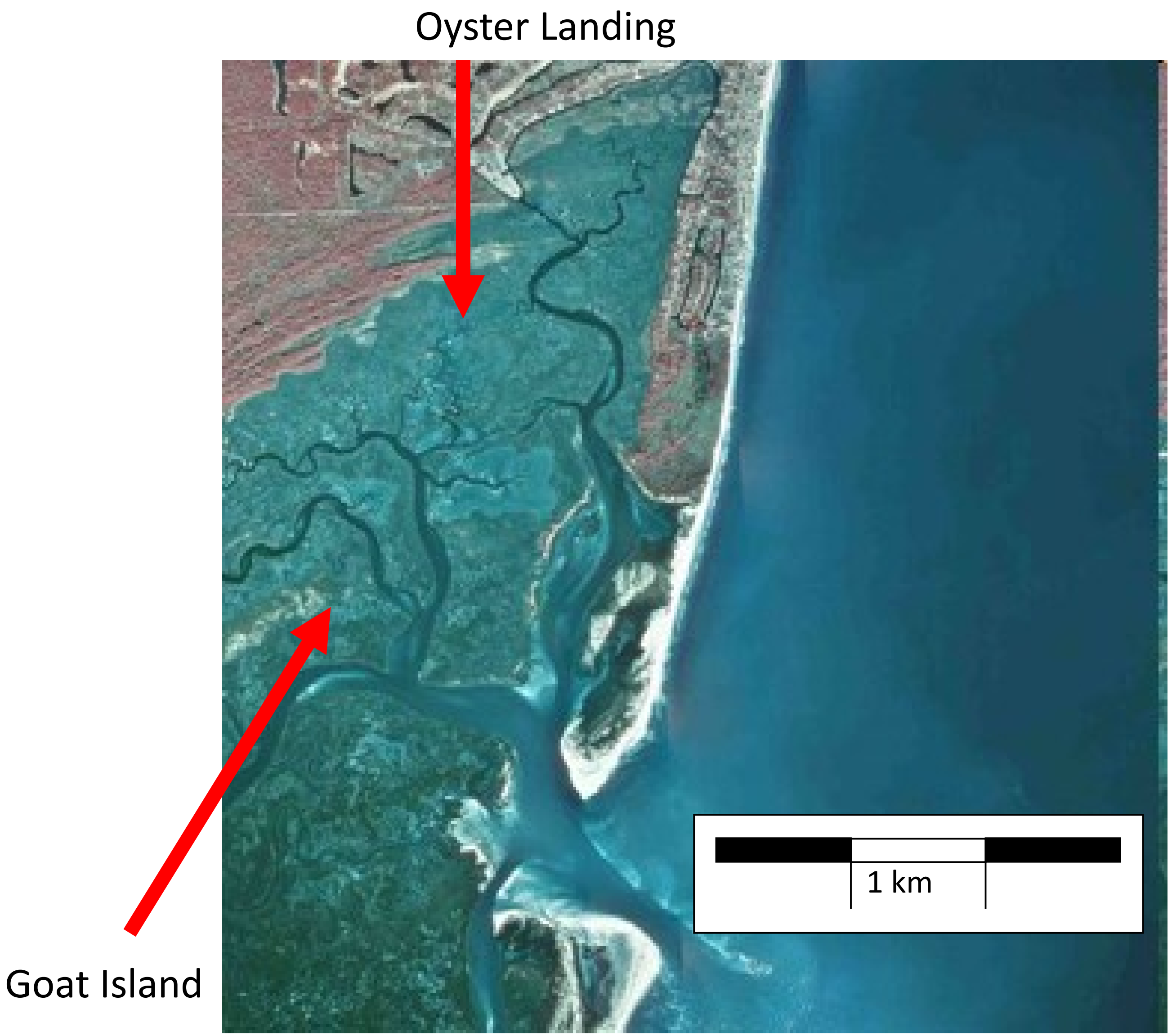




North Inlet, South Carolina

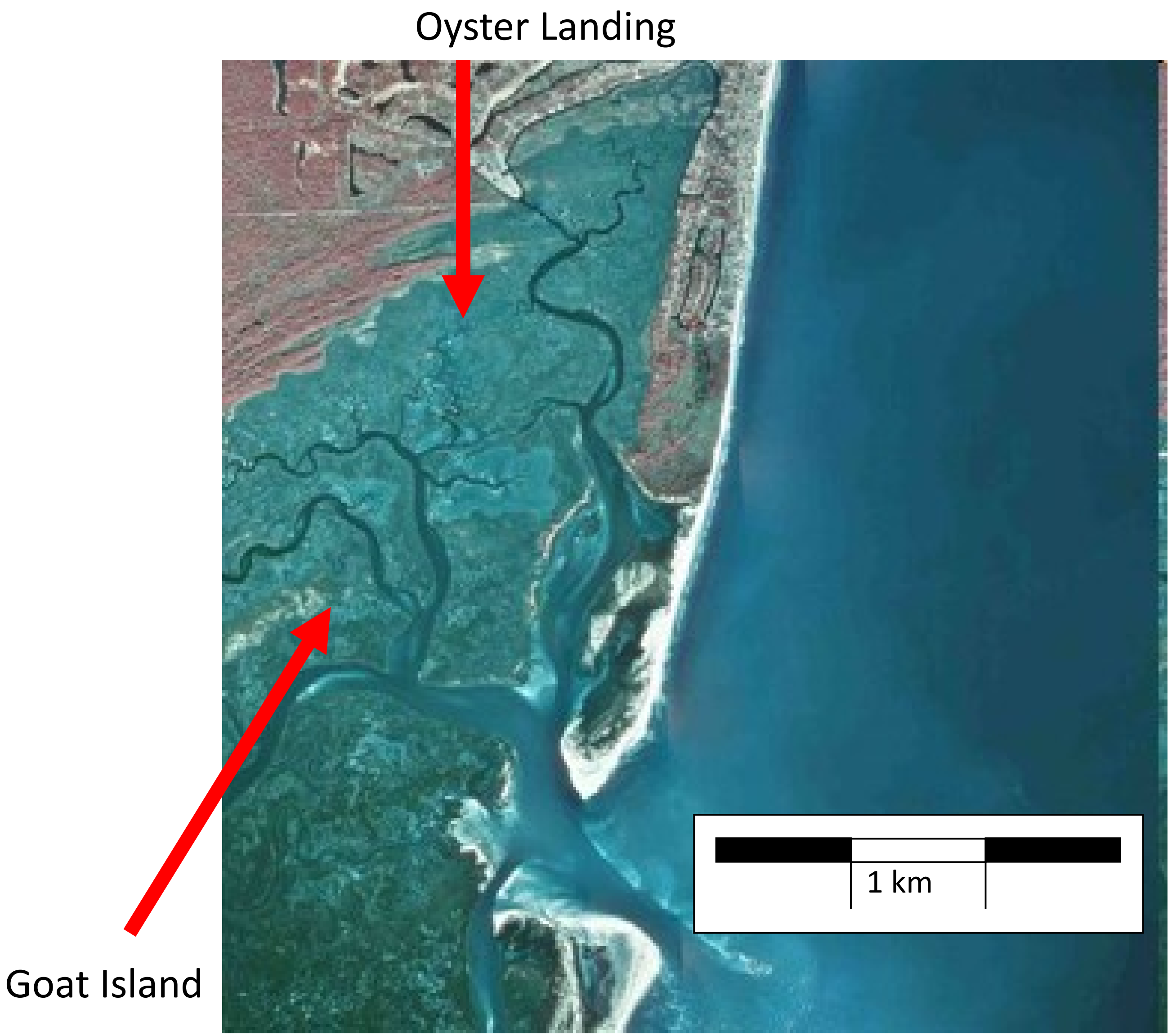
What data do we have at North Inlet?

- 12 sites on 2 distinct marshes (Oyster Landing and Goat Island)
- Each site has two sampling plots
- Marshes are populated by *Spartina alterniflora*



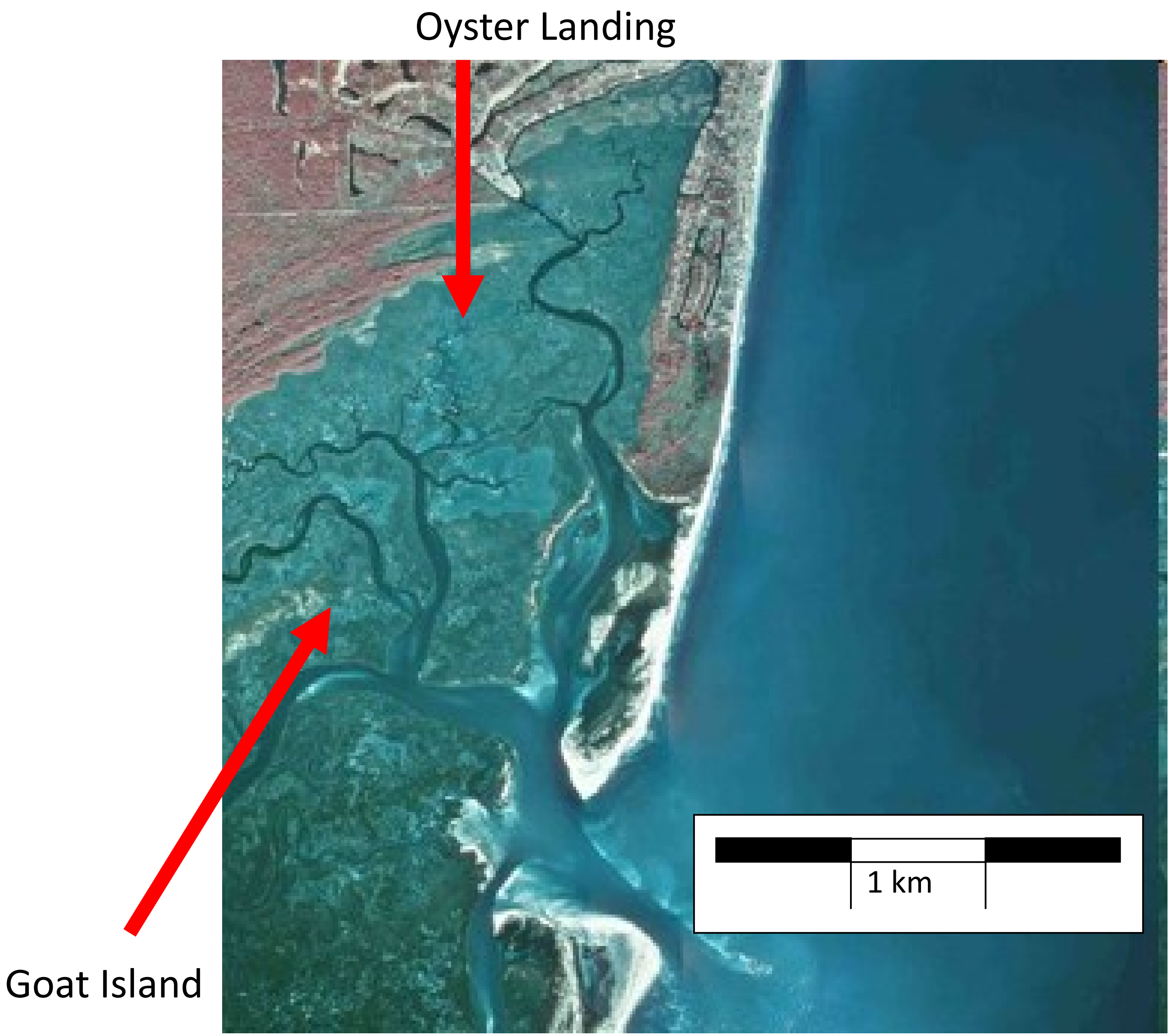
What data do we have at North Inlet?

- At each plot:
  - Monthly measurements of stem density
  - Monthly measurements of standing biomass
- And on a subset of plots
  - Monthly measurements of leaf areas
- Measurements began in 1984 and continue today.

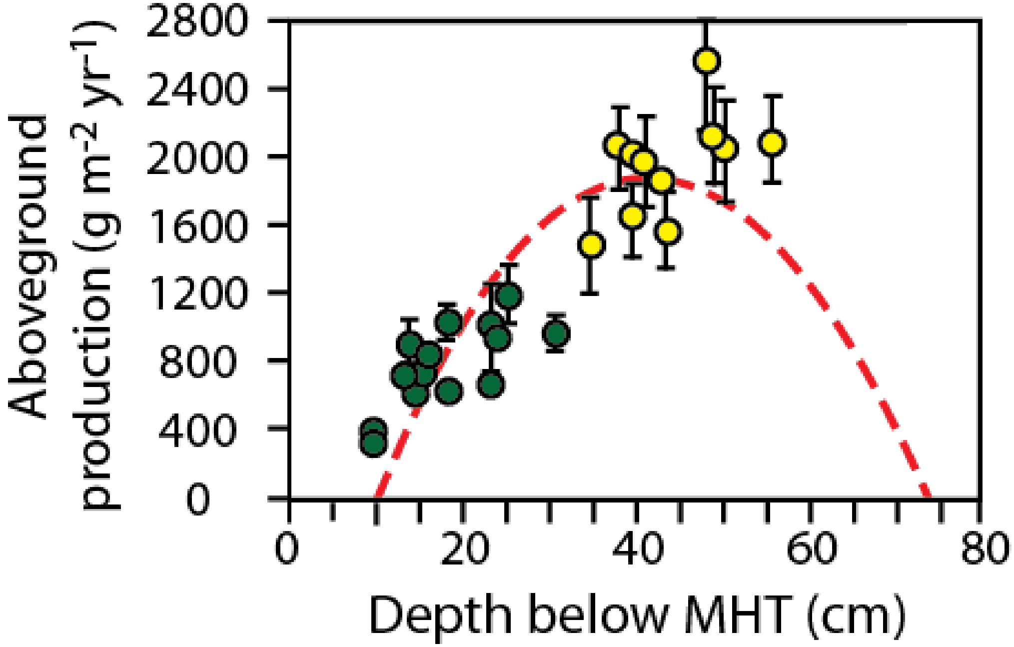


What data do we have at North Inlet?

- In addition
  - Measurements of stem heights
  - Measurements of the density of plant material
  - ^{210}Pb cores
  - Measurements of marsh sediments (density, organic matter, etc)
  - Detailed measurements of sedimentation rates

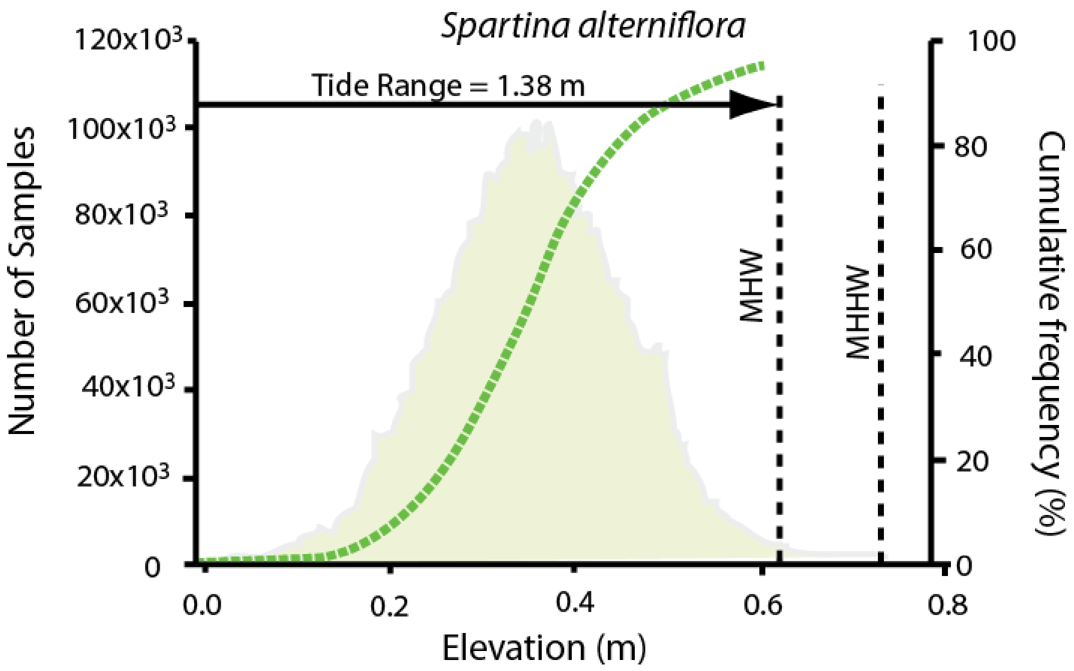


What controls the productivity of marsh vegetation?



Direct sampling of vegetation

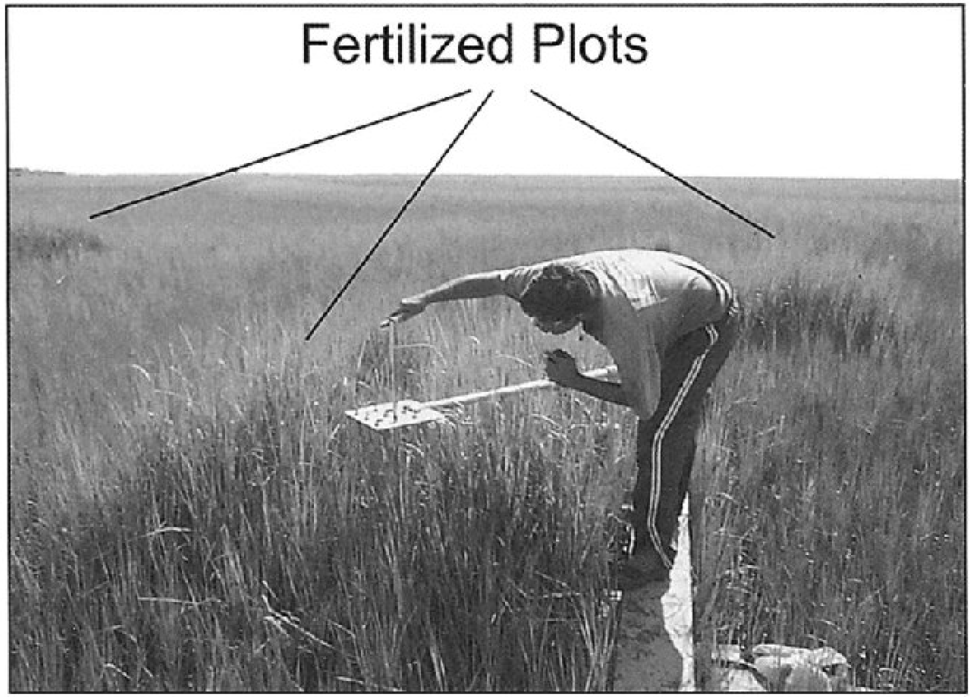
Morris, J.T. et al., 2002. *Ecology*, *83*, 2869-2877.



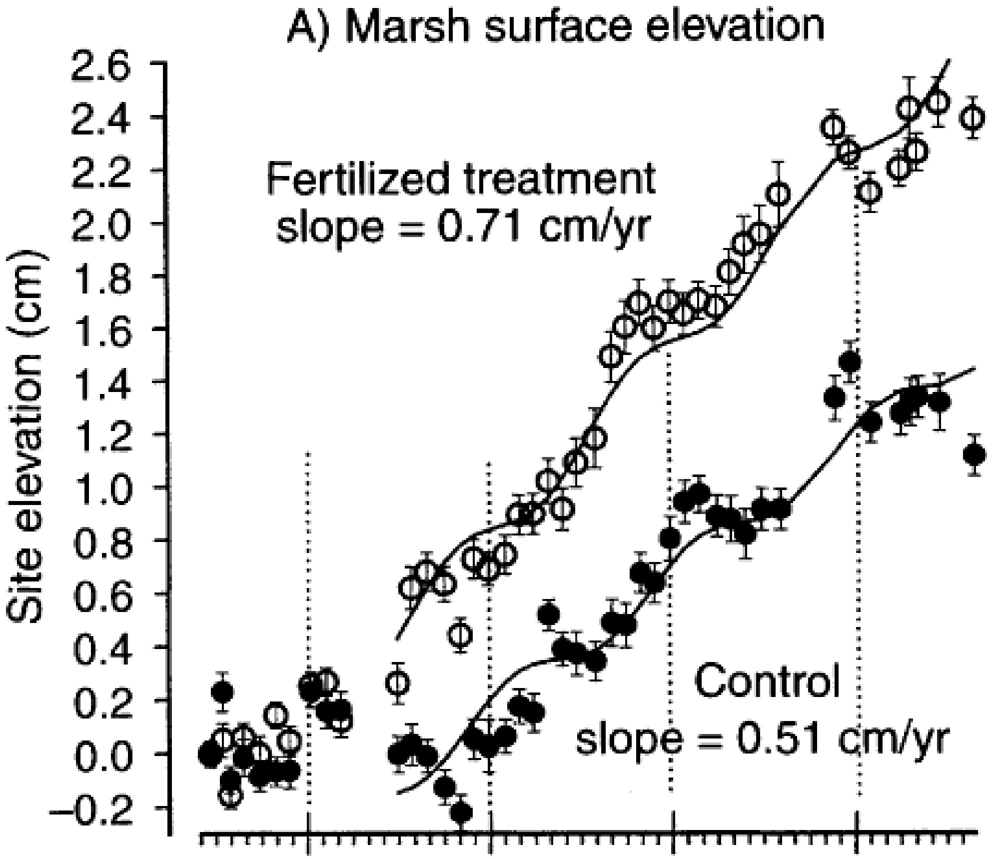
LIDAR surveys

Morris, J.T. et al., 2005. *International Journal of Remote Sensing*, 26(23): 5221-5234.

Do plants affect sedimentation rates?



Morris, J.T., et al. 2002. *Ecology*, *83*, 2869-2877.

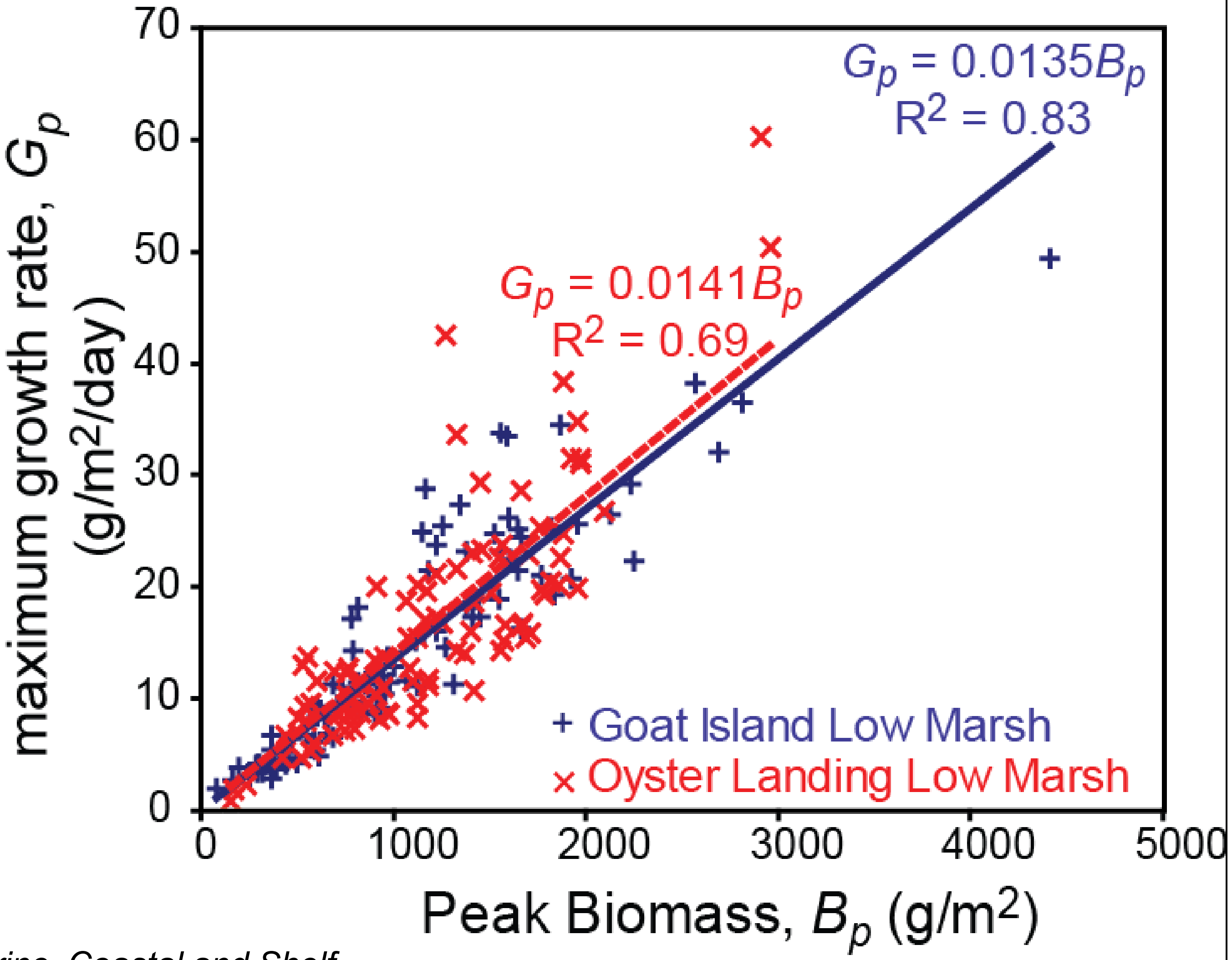


So how do you go about translating these data into a model?

$$M = G - \frac{\partial B_{ag}}{\partial t}$$

Try to know something about the change in biomass

- Mortality: Difference between growth rate and standing aboveground biomass

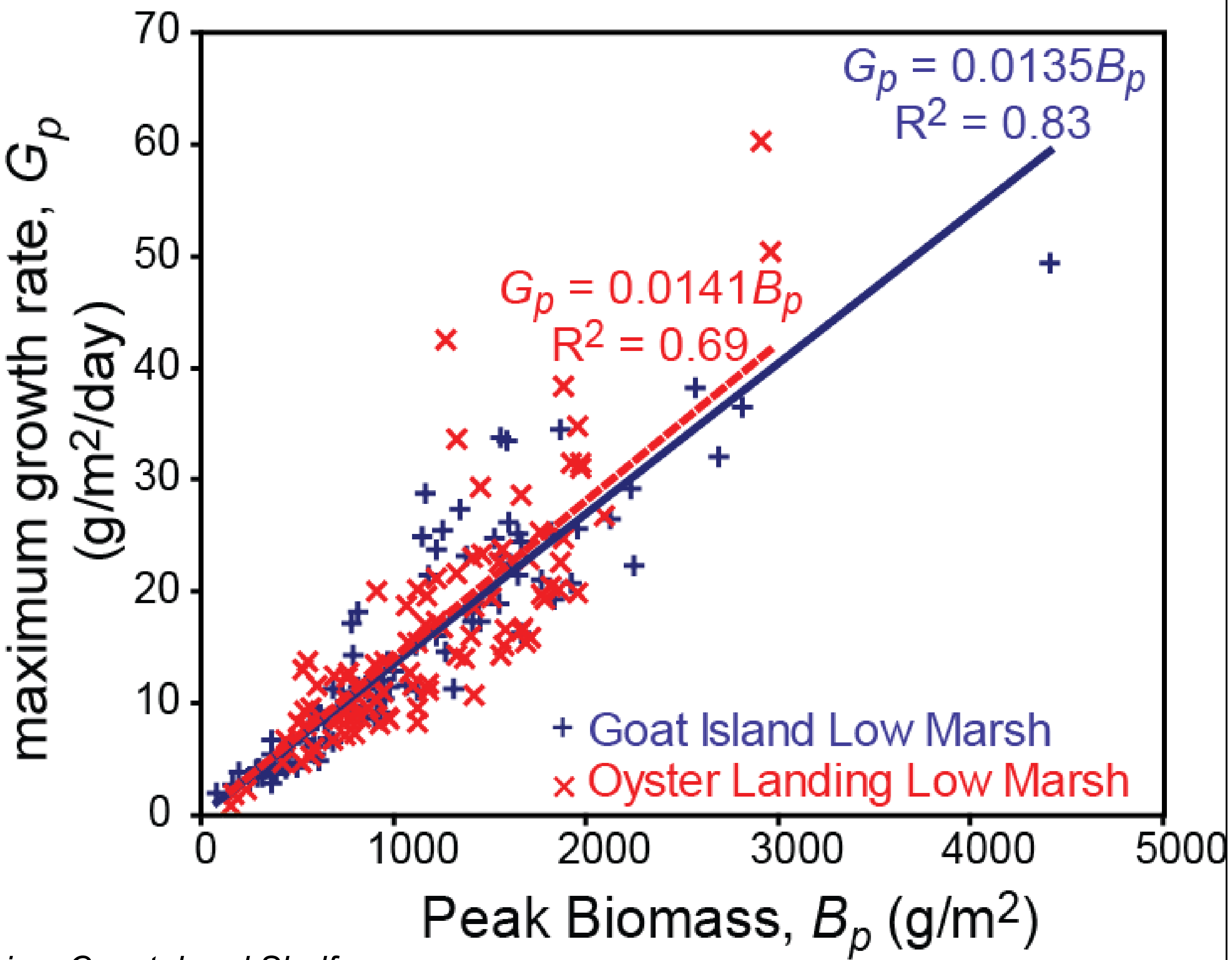


Mudd et al. 2009. *Estuarine, Coastal and Shelf Science*, 82(3), 377-389.

$$M = G - \frac{\partial B_{ag}}{\partial t}$$

You track this through time to get biomass

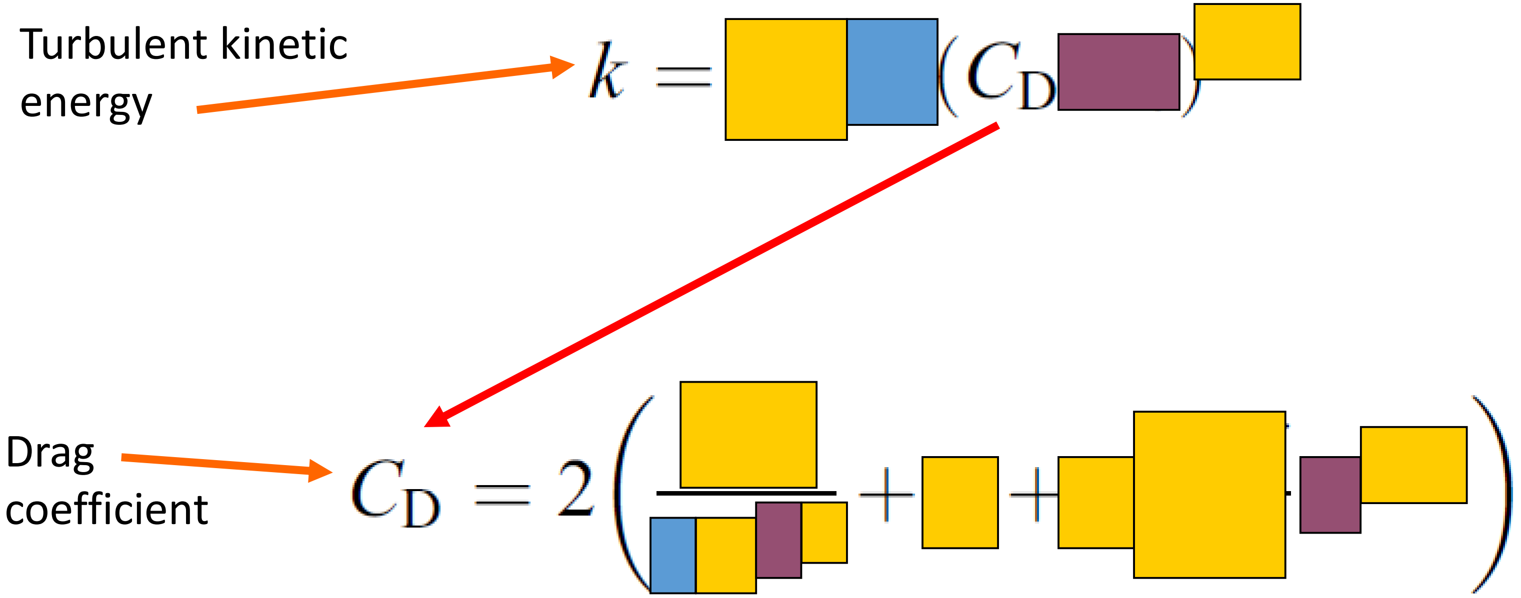
- Mortality: Difference between growth rate and standing aboveground biomass



Mudd et al. 2009. *Estuarine, Coastal and Shelf Science*, 82(3), 377-389.

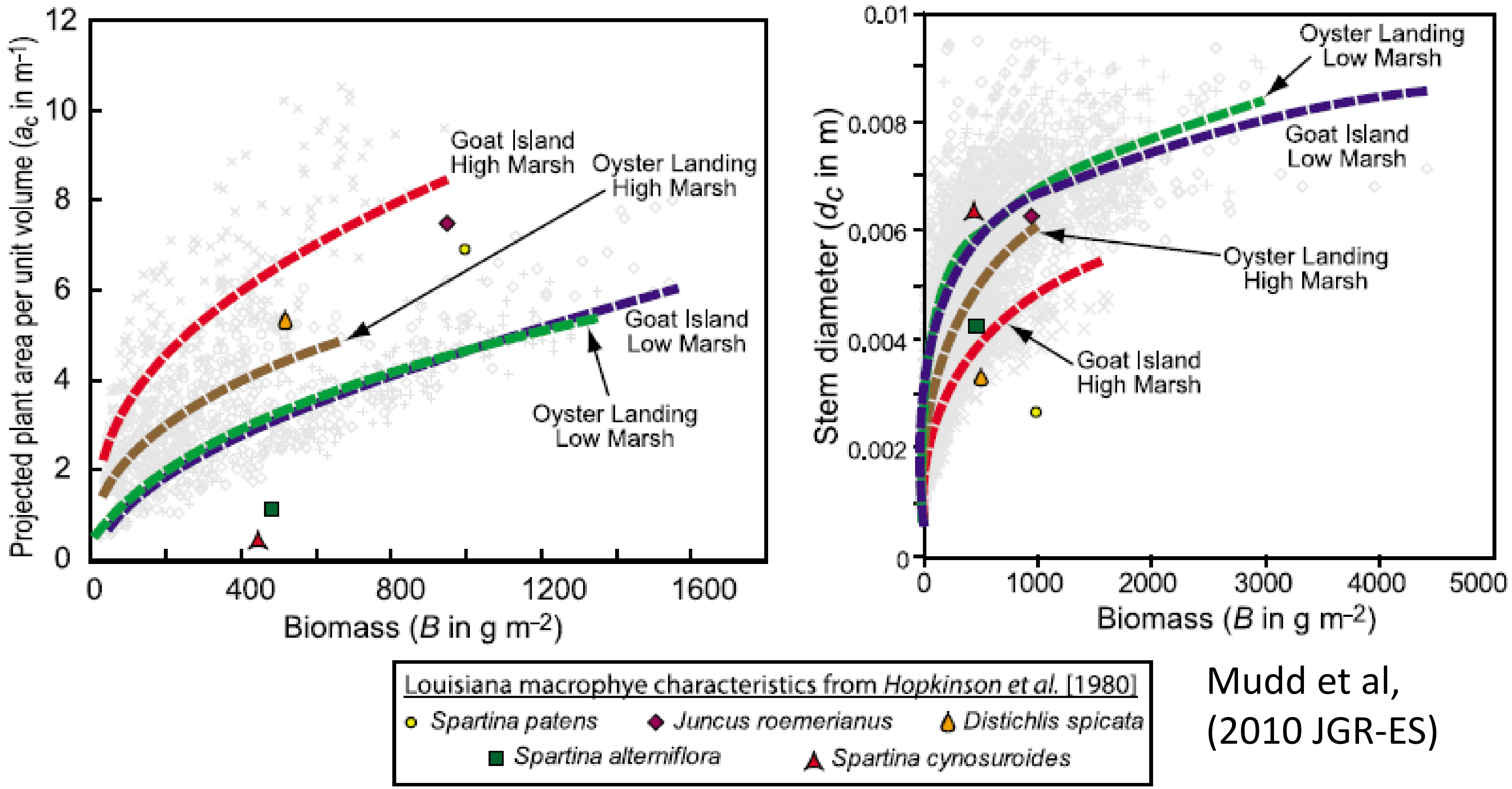
What about settling? It is a function of plant characteristics.

- Turbulence helps to keep sediment in suspension



Derivation in Mudd et al. 2010, *JGR-Earth Surface*, 115, F03029, doi:10.1029/2009JF001566

Data on vegetation geometry as a function of biomass

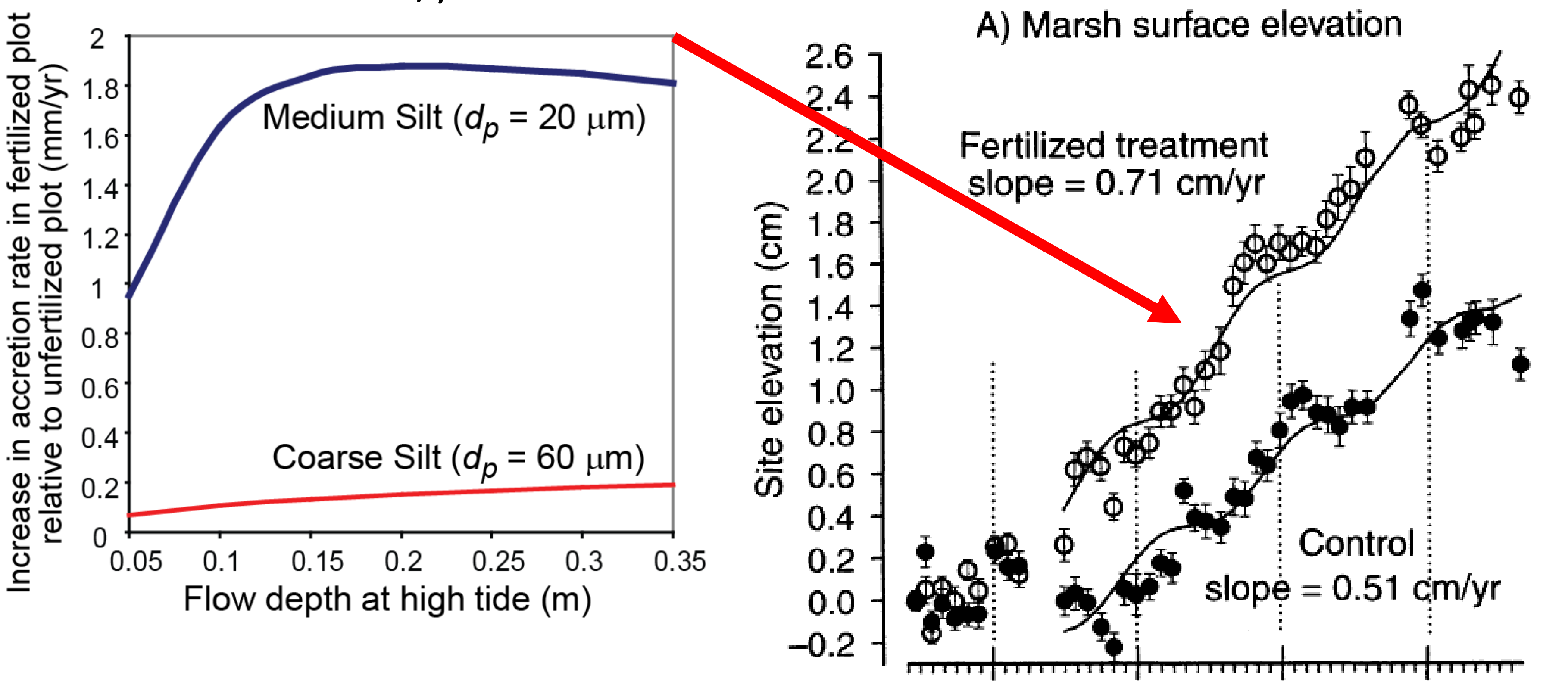


Mudd et al, (2010 JGR-ES)

Allows us to quantify drag and capture efficiency

Predictions constrained by field experiments

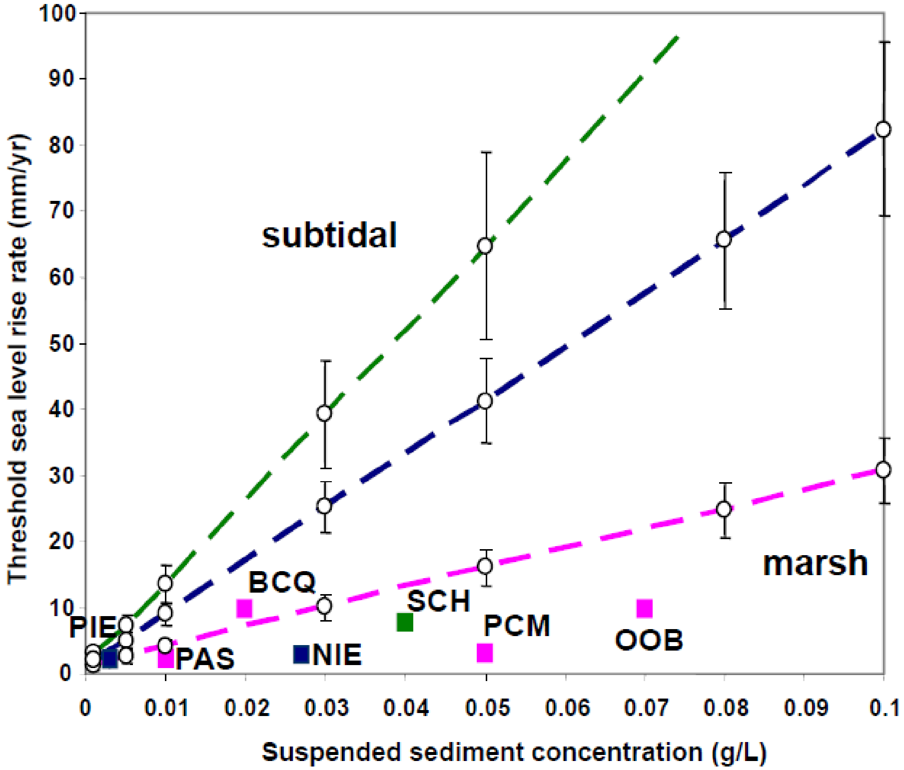
Measured: 2mm/yr



Critical rate of sea level rise for a given tidal amplitude and sediment supply?

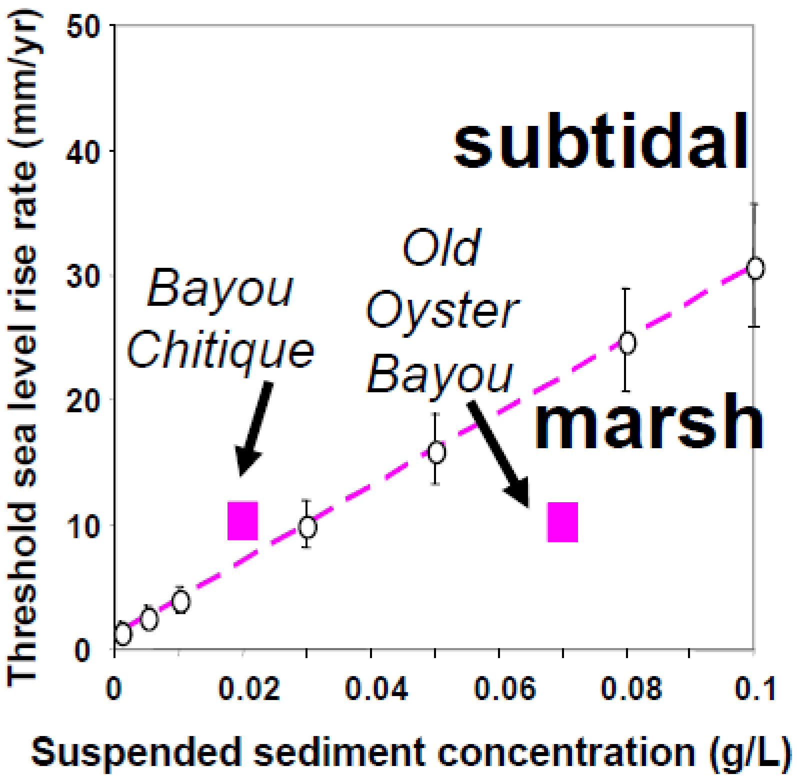
Kirwan et al, GRL 2010)

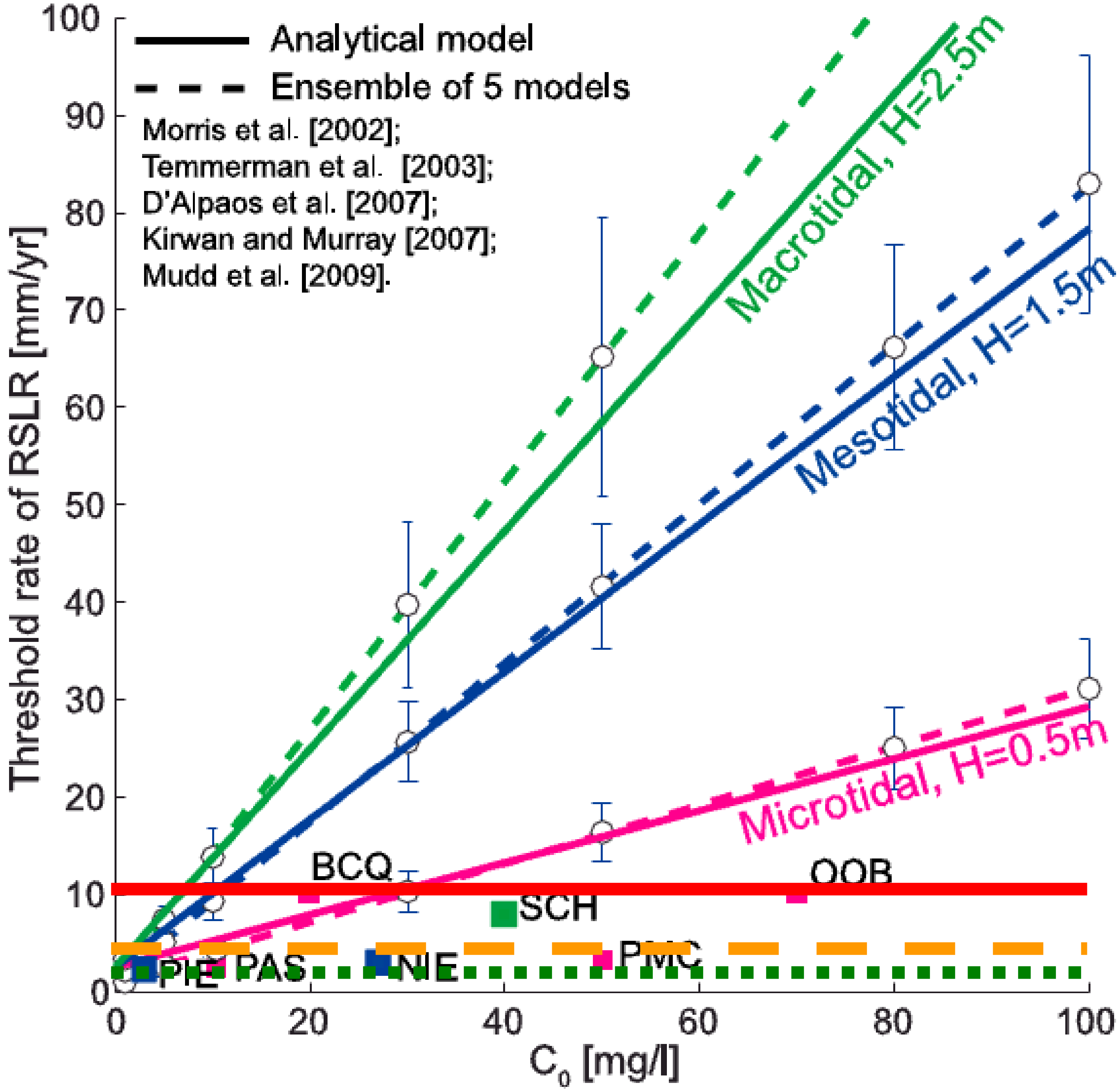
- Pink line and squares: 1metre tidal range
- Blue line and squares: 3 metre tidal range
- Green line: 5 metre tidal range



PIE= Plum Island Estuary, Massachusetts; PAS= Pamlico Sound, North Carolina; BCQ= Bayou Chitique, Louisiana; NIE= North Inlet Estuary, South Carolina; SCH= Scheldte Estuary, Netherlands; PCM= Phillips Creek Marsh, Virginia; OOB= Old Oyster Bayou, Louisiana

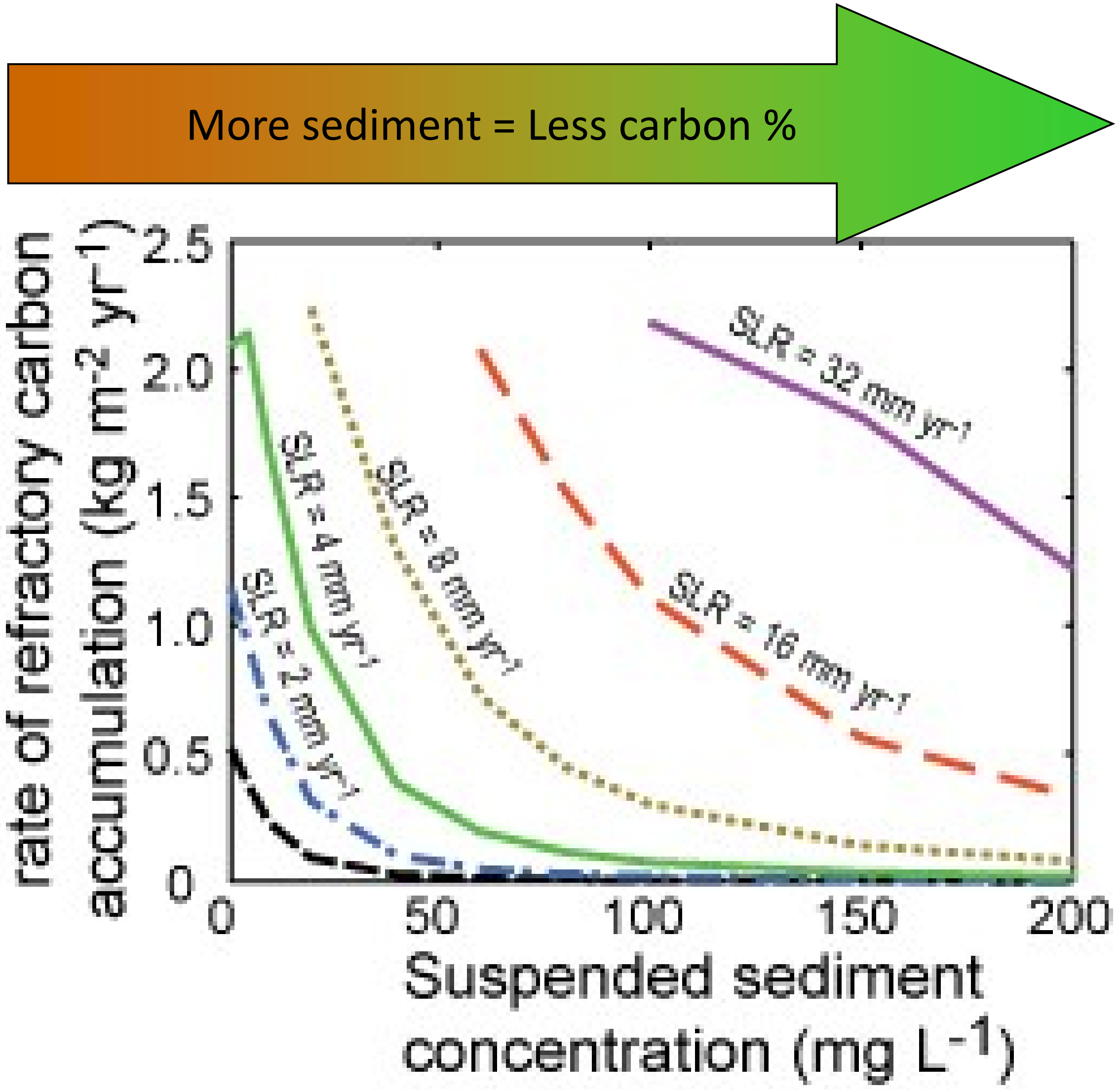
Two example marshes





D'Alpaos et al, 2011 JGR-ES

Feedback between inorganic and organic sedimentation



Carbon accumulation
Mudd et al (2009) ECSS

How to starve a lagoon: the story of Venice

Simon Mudd[1] Andrea D'Alpaos[2]

[1]School of GeoSciences, University of Edinburgh

[2]Dipartimento di Geoscienza, Università di Padova

Photo: Wolfgang Moroder, Wikimedia commons

Chief Vitalstatistix

Area of the Lagoon:
~550 km^2

Area of the marsh:
~37 km^2

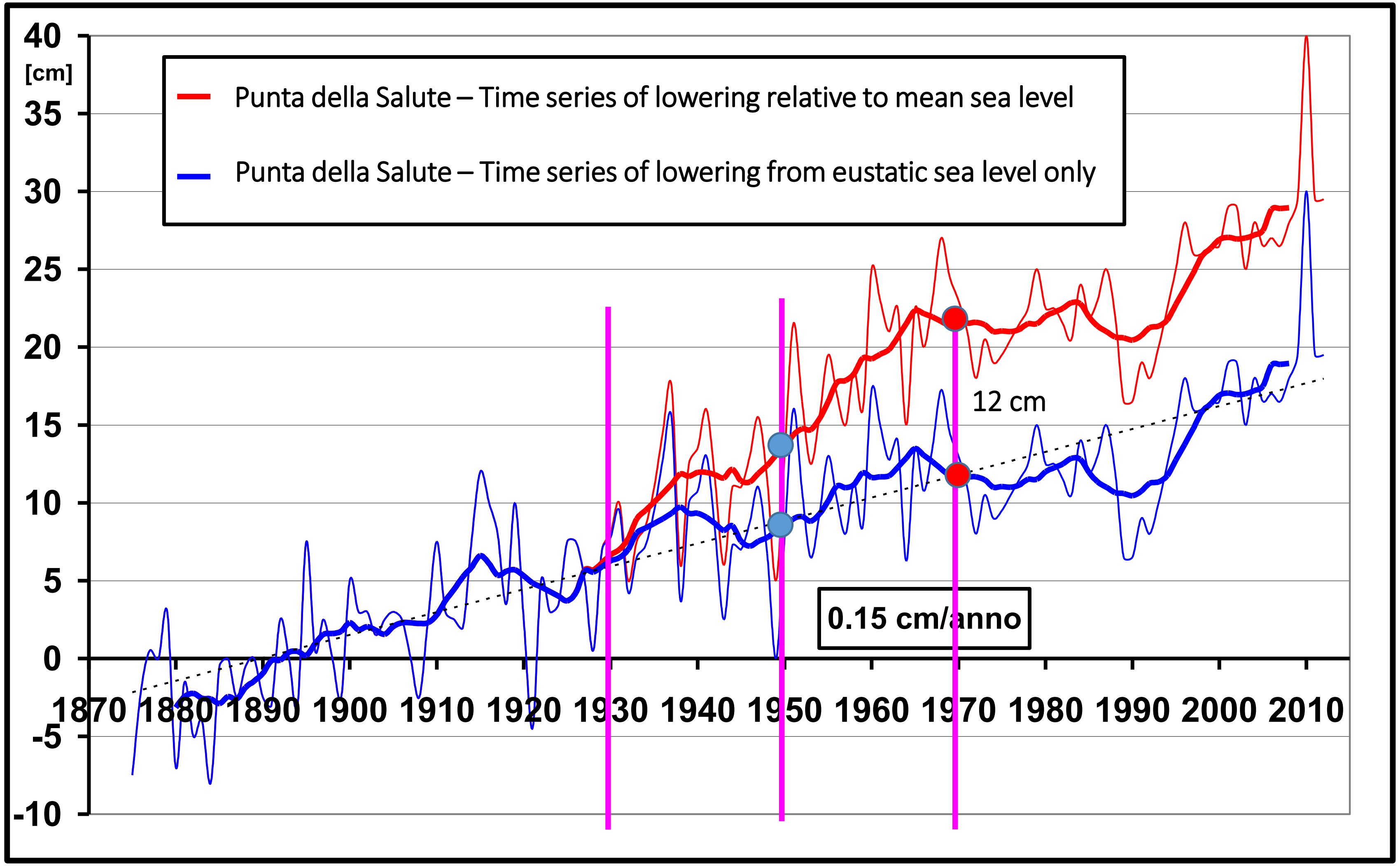
Average depth of the lagoon:
~1.1 m

Tidal range:
± 70 cm

Is Venice sinking?

https://upload.wikimedia.org/wikipedia/commons/9/9b/Acqua_alta_san_giobbe_1DIC.2008.JPG

Is Venice sinking?



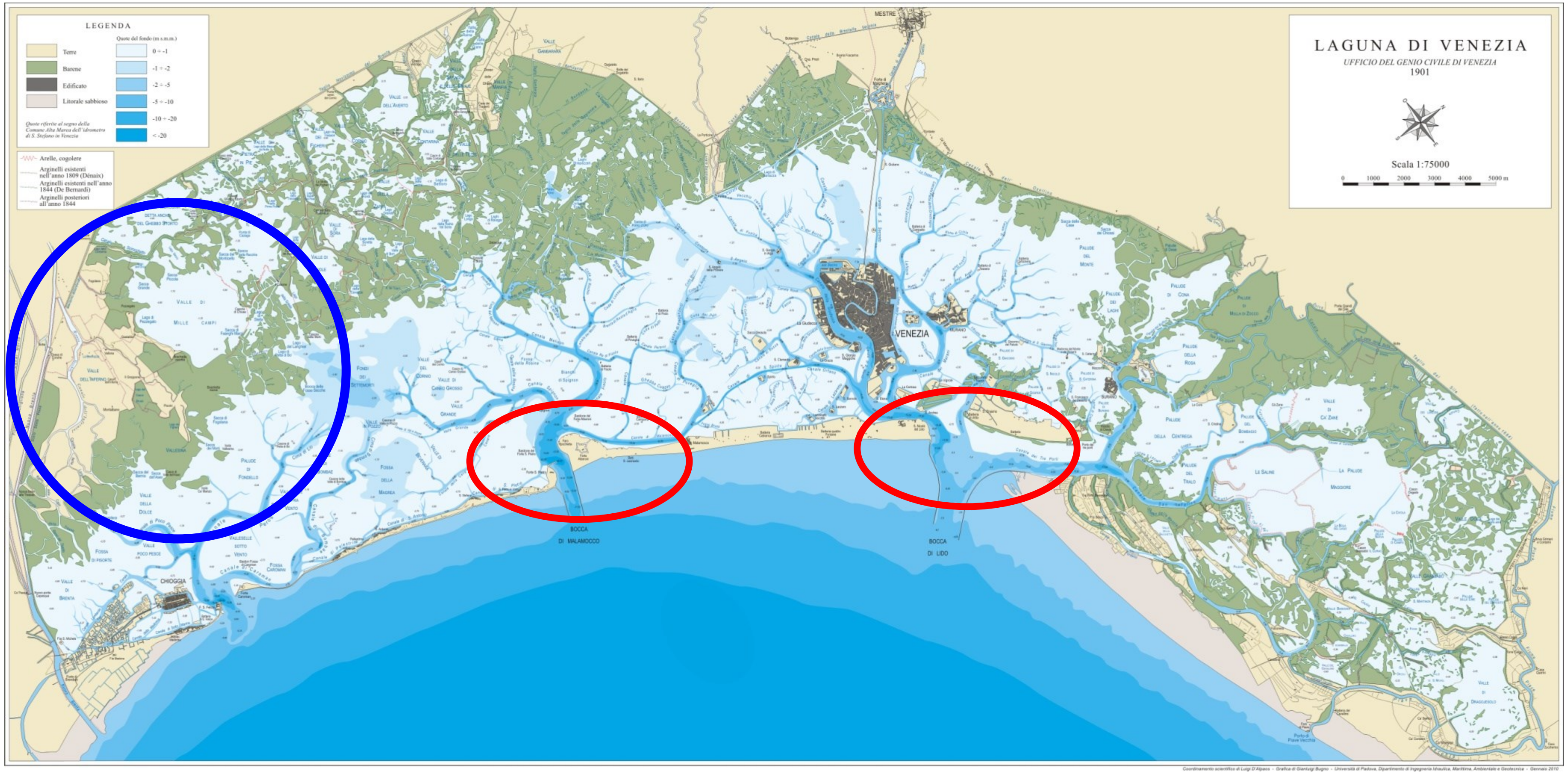
Sediment compaction plus eustatic sea level rise has resulted in ~ 30cm of subsidence relative to mean sea level since 1900.

https://upload.wikimedia.org/wikipedia/commons/9/9b/Acqua_alta_san_giobbe_1DIC.2008.JPG

Reconstructions of marsh bathymetry by Prof. Luigi D'Alpaos
One of the most complete records on Earth
1810

D'Alpaos, L. (2010), Fatti e misfatti di Idraulica Lagunare

Reconstructions of marsh bathymetry by Prof. Luigi D’Alpaos
One of the most complete records on Earth
1901

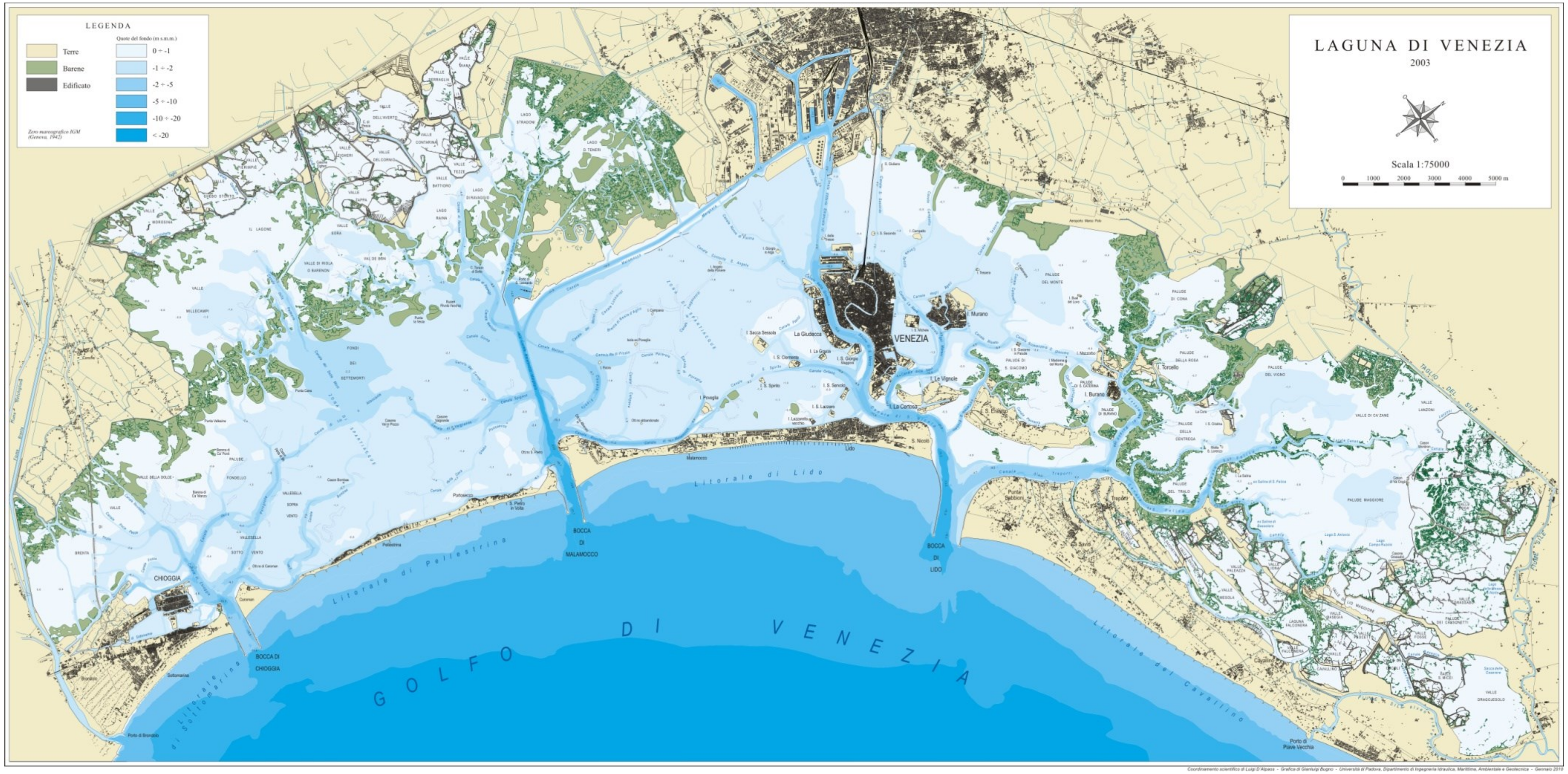


D’Alpaos, L. (2010), Fatti e misfatti di Idraulica Lagunare

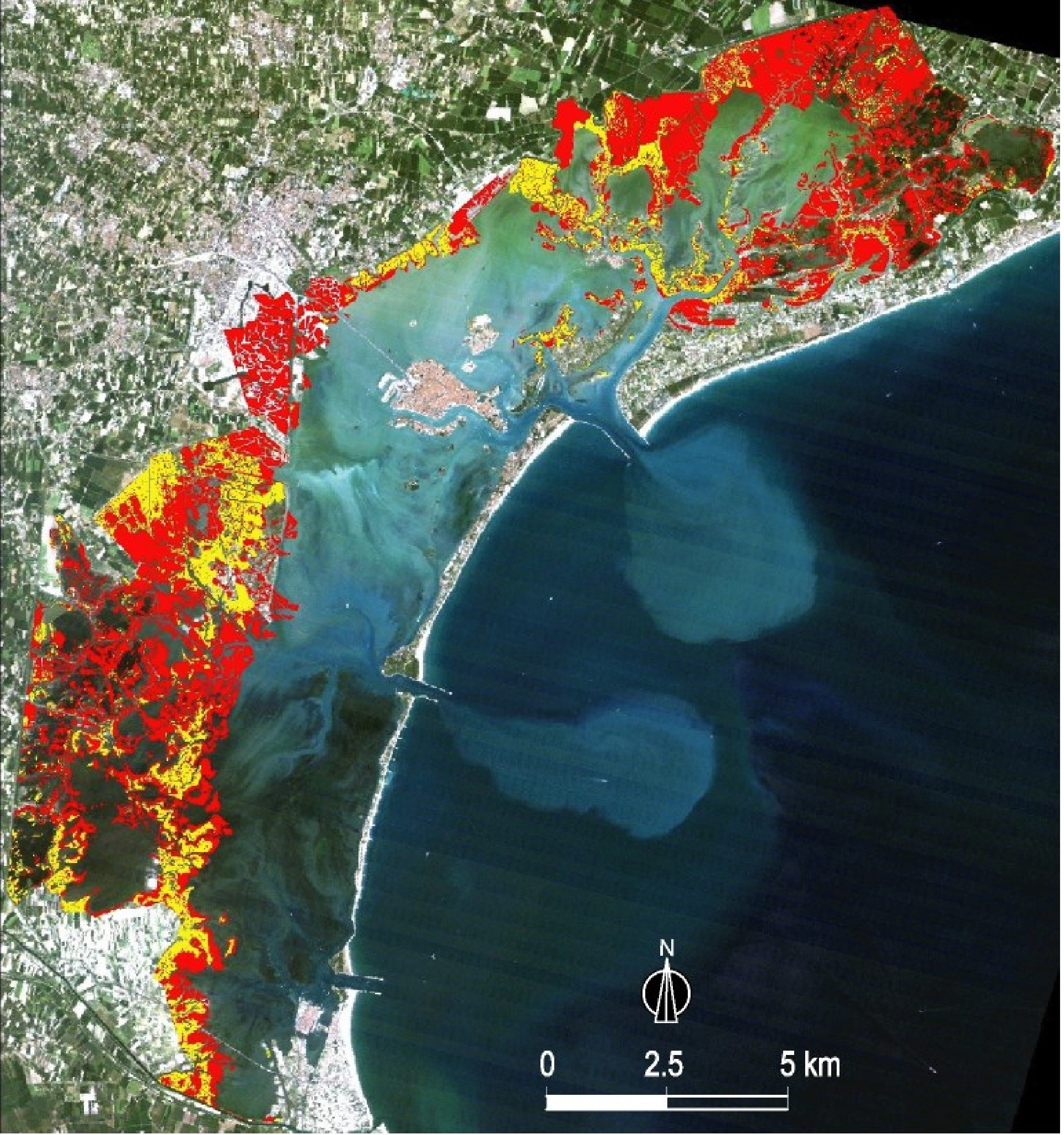
Reconstructions of marsh bathymetry by Prof. Luigi D'Alpaos
One of the most complete records on Earth
1970

D'Alpaos, L. (2010), Fatti e misfatti di Idraulica Lagunare

Reconstructions of marsh bathymetry by Prof. Luigi D'Alpaos
One of the most complete records on Earth
2003



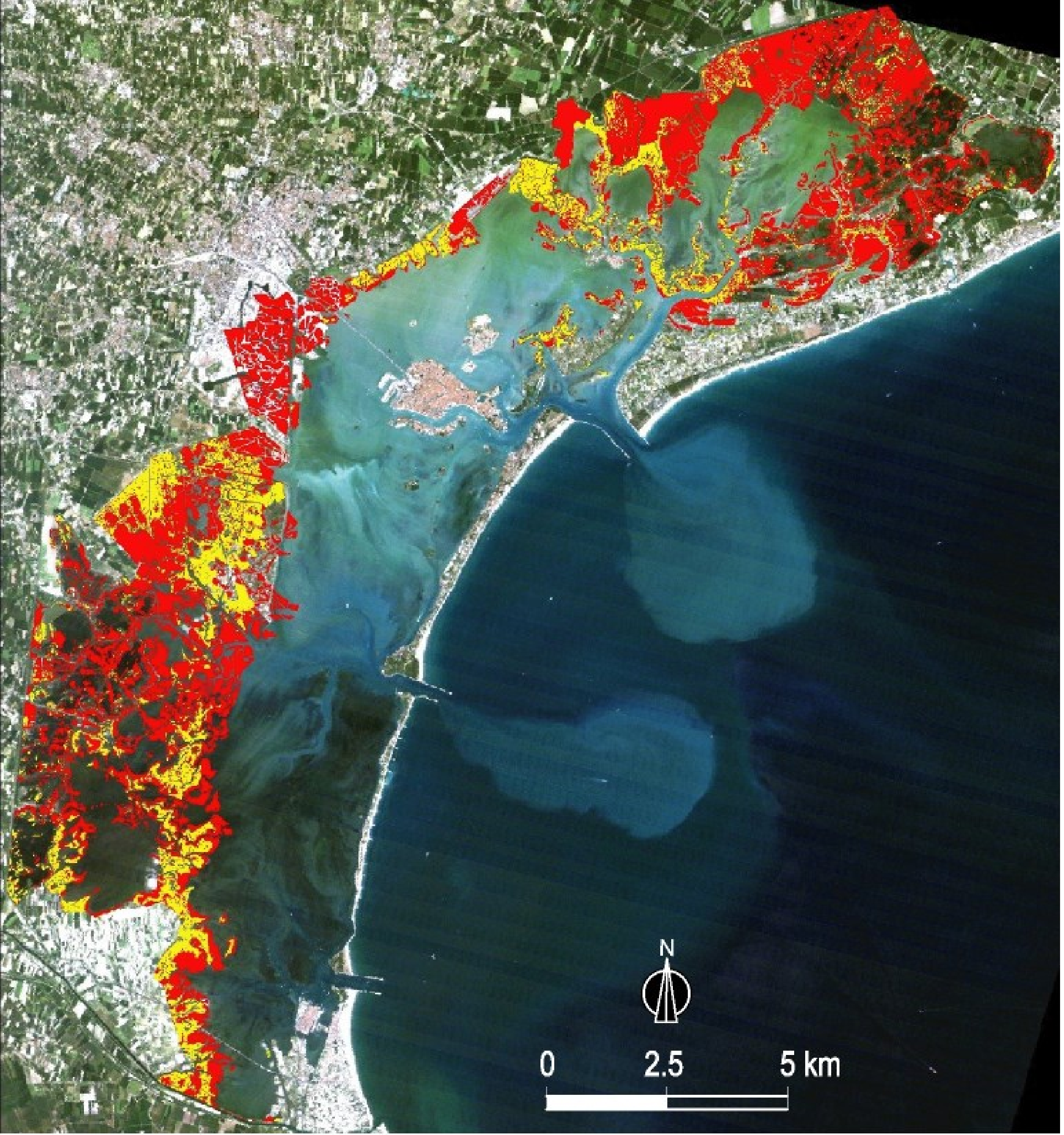
D'Alpaos, L. (2010), Fatti e misfatti di Idraulica Lagunare



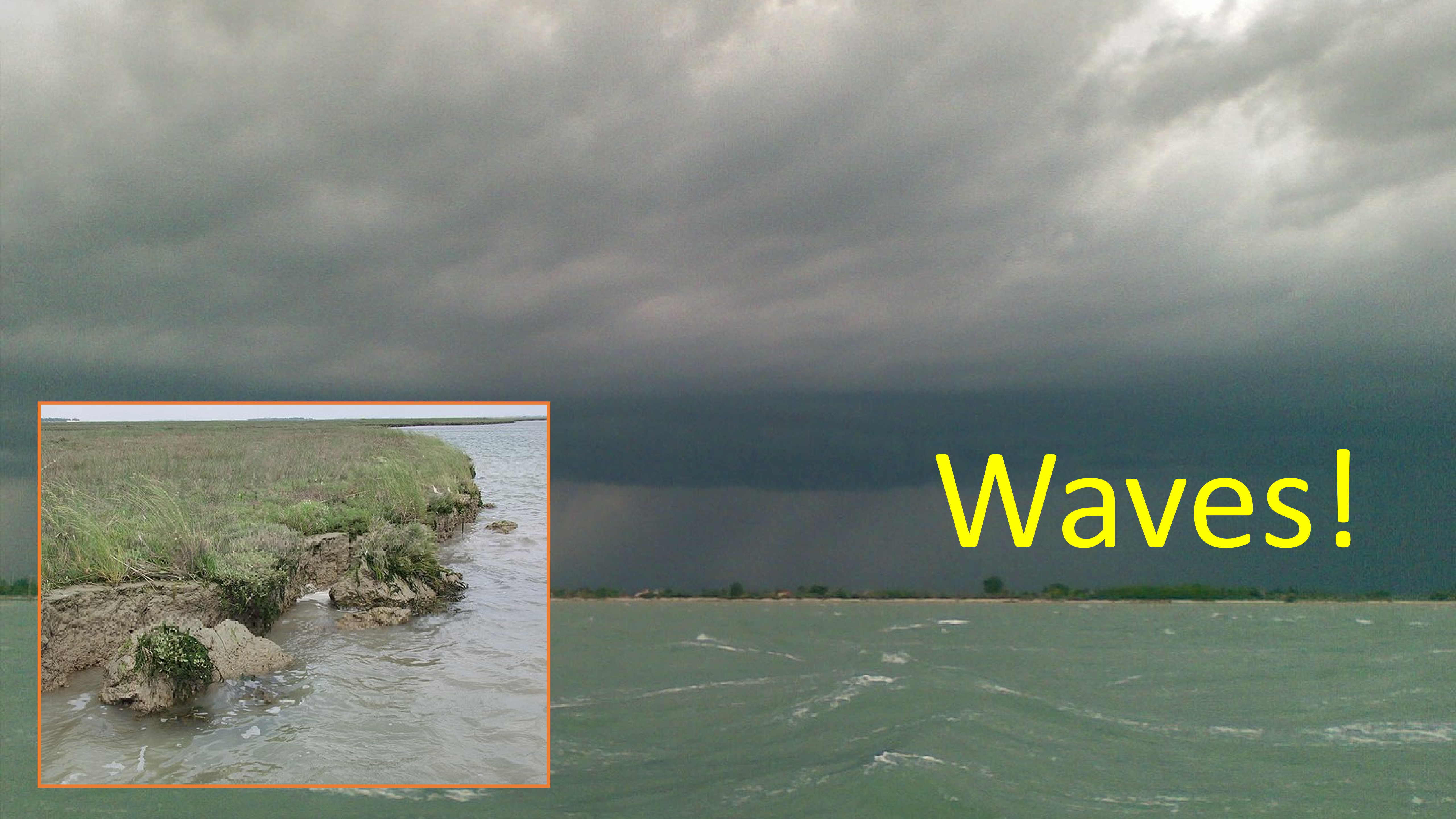
Erosion of the marshes:

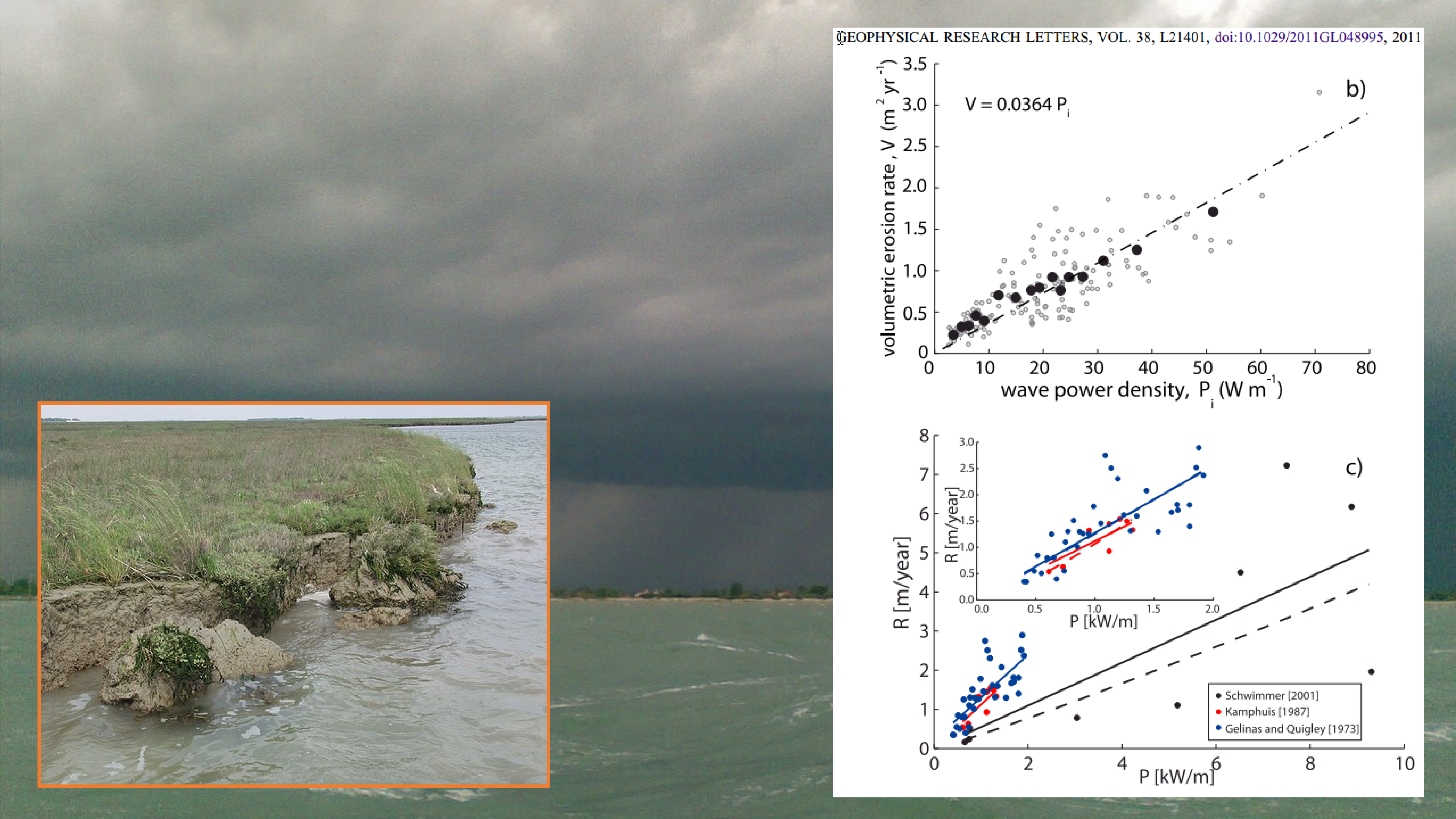
Red is the marsh in 1811

Yellow is the marsh today

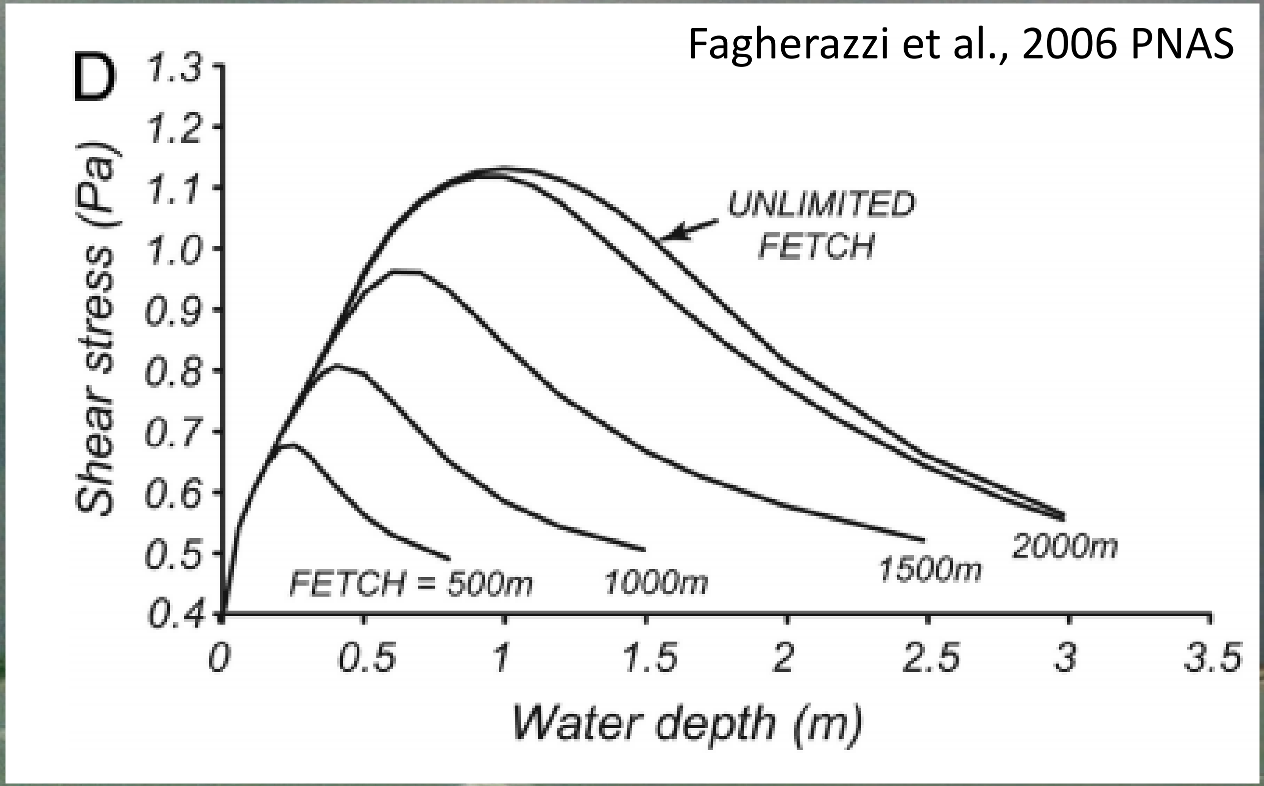


What is going on?


Waves!

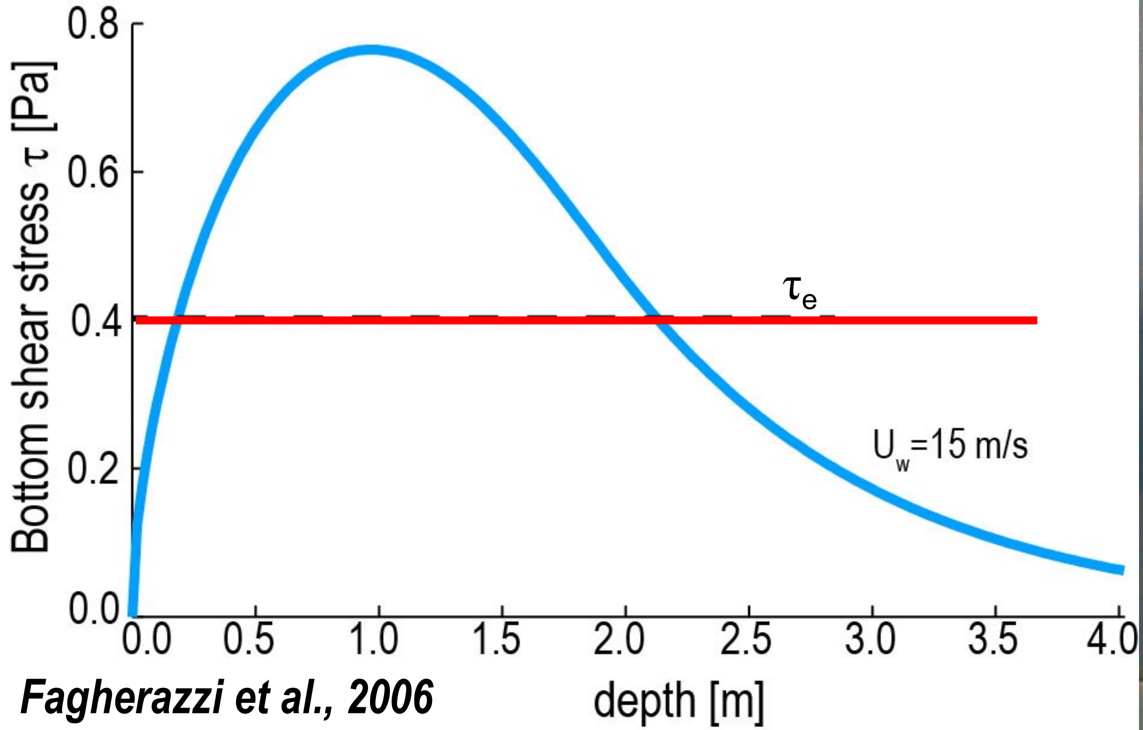


GEOPHYSICAL RESEARCH LETTERS, VOL. 38, L21401, doi:10.1029/2011GL048995, 2011
b)
V = 0.0364 P_i
volumetric erosion rate, V (m^2 yr^-1)
wave power density, P_i (W m^-1)
c)
R [m/year]
P [kW/m]
Schwimmer [2001]
Kamphuis [1987]
Gelinas and Quigley [1973]

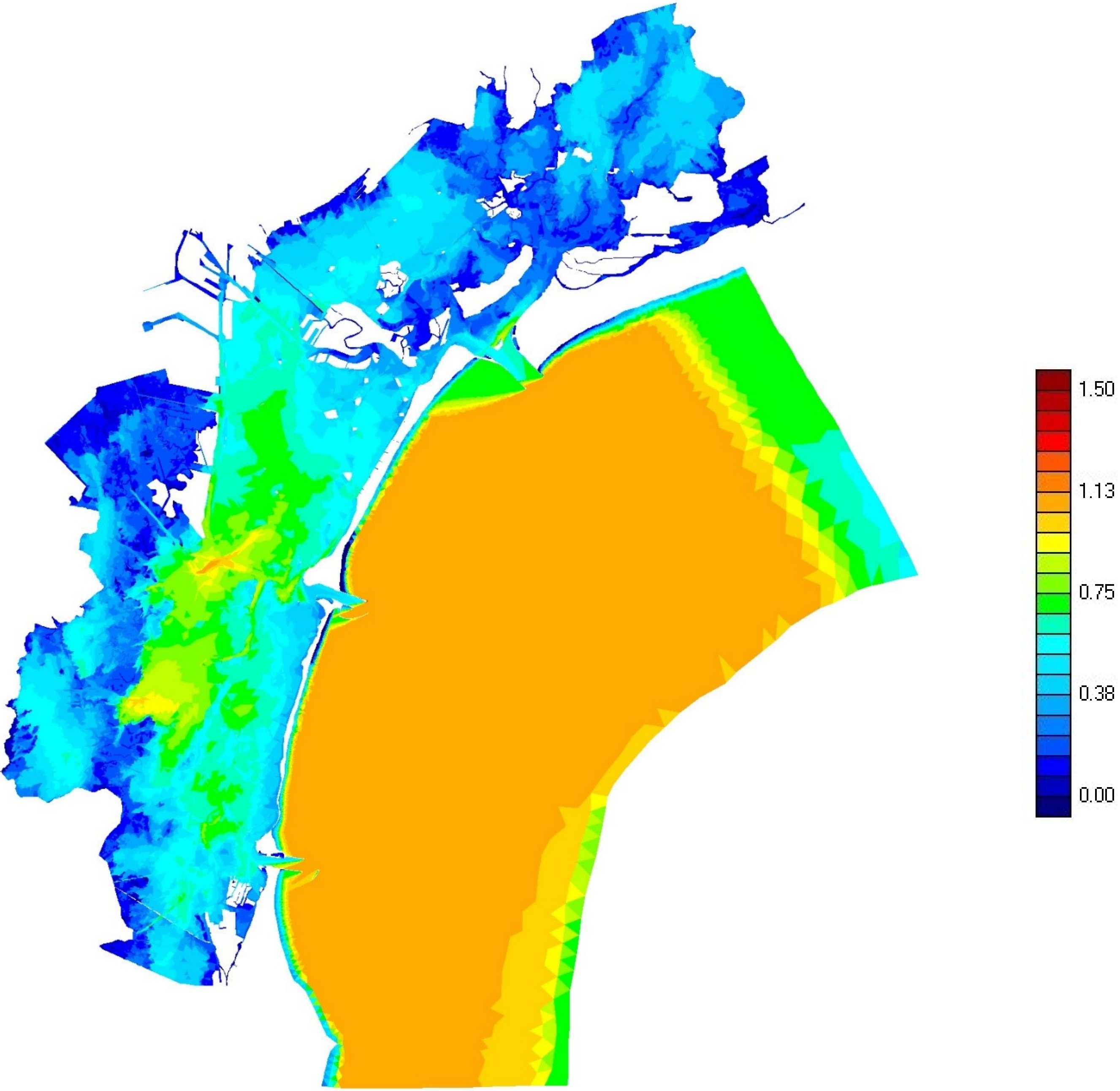

Fagherazzi et al., 2006 PNAS
D
Shear stress (Pa)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
UNLIMITED
FETCH
FETCH = 500m
1000m
1500m
2000m
0
0.5
1
1.5
2
2.5
3
3.5
Water depth (m)

Waves!

$$\tau = \frac{1}{2}\,\rho\, c_f\, u_m^2$$

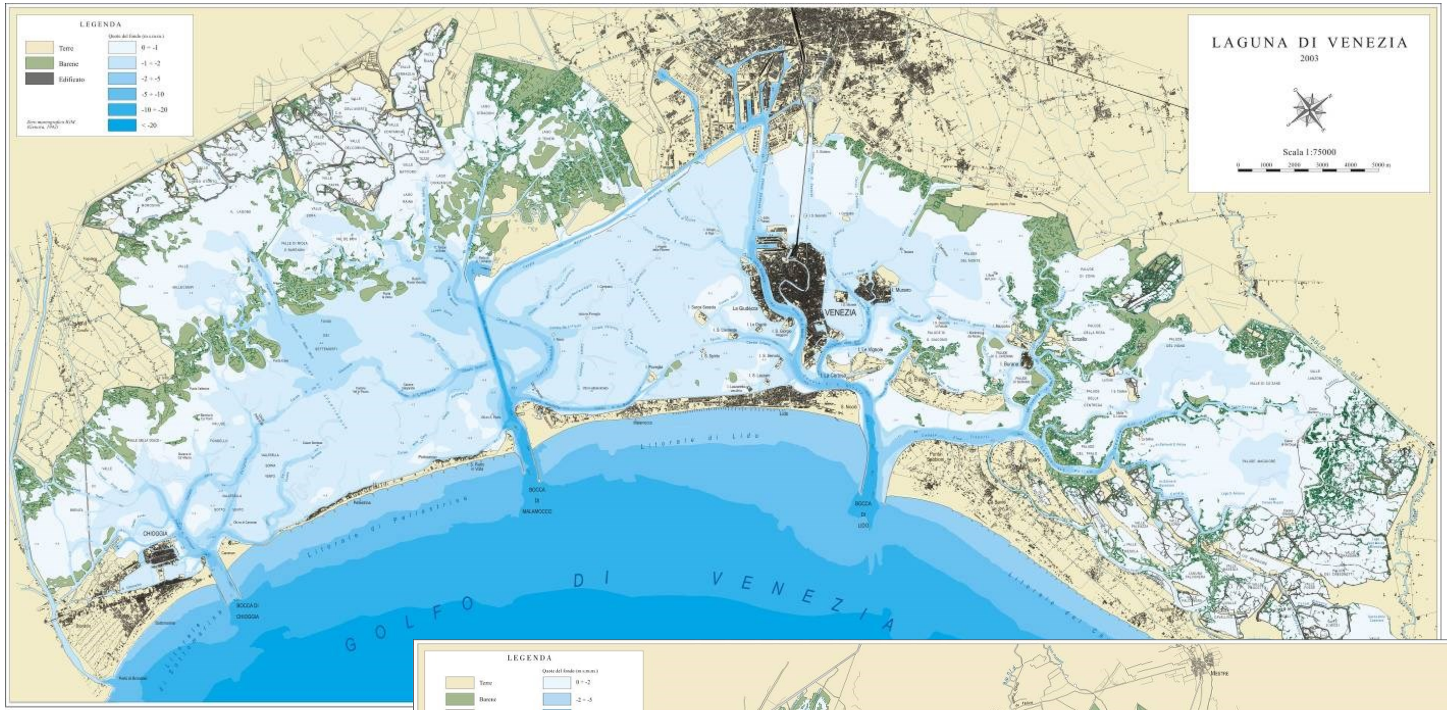


$$Q_e = Q_{e0}\left(\frac{\tau}{\tau_e} - 1\right)\mathcal{H}(\tau - \tau_e)$$



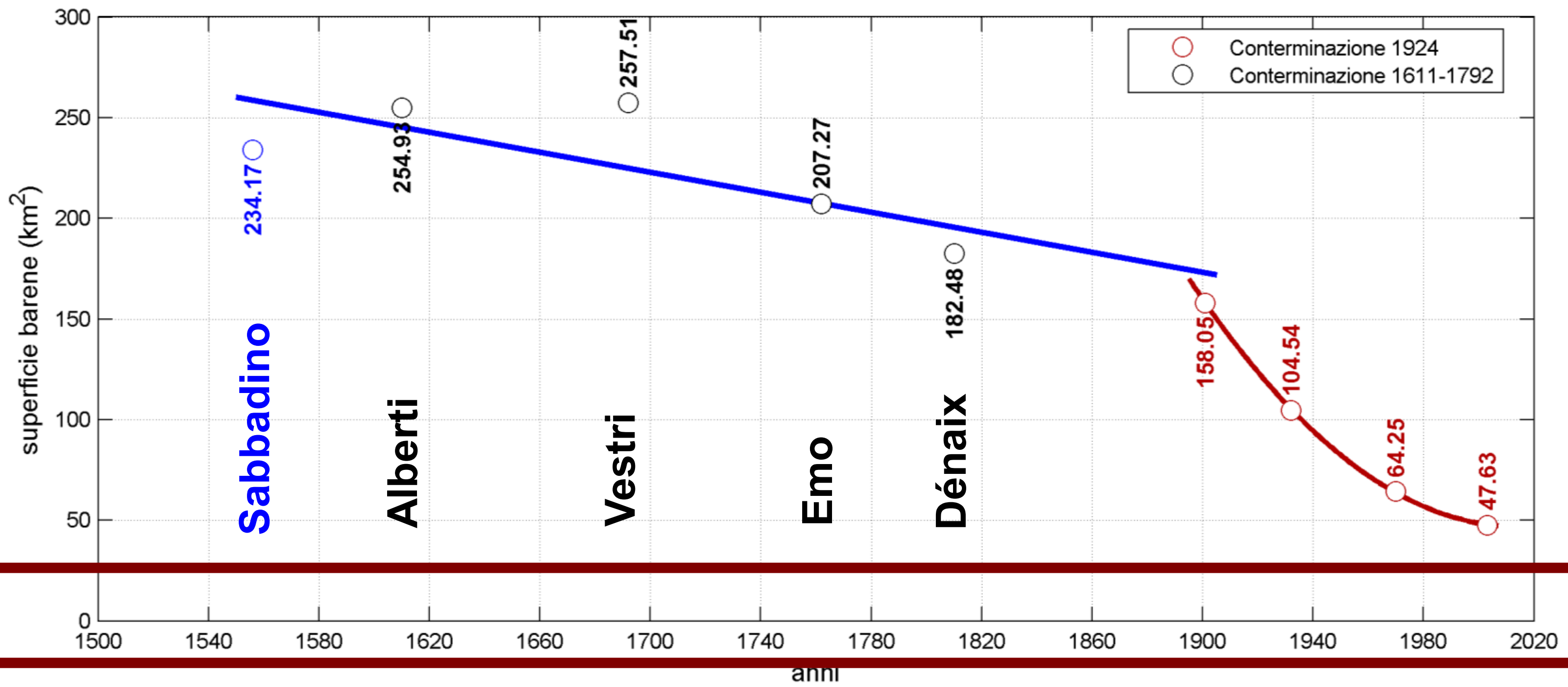
Wave heights

Venice lagoon in 2003

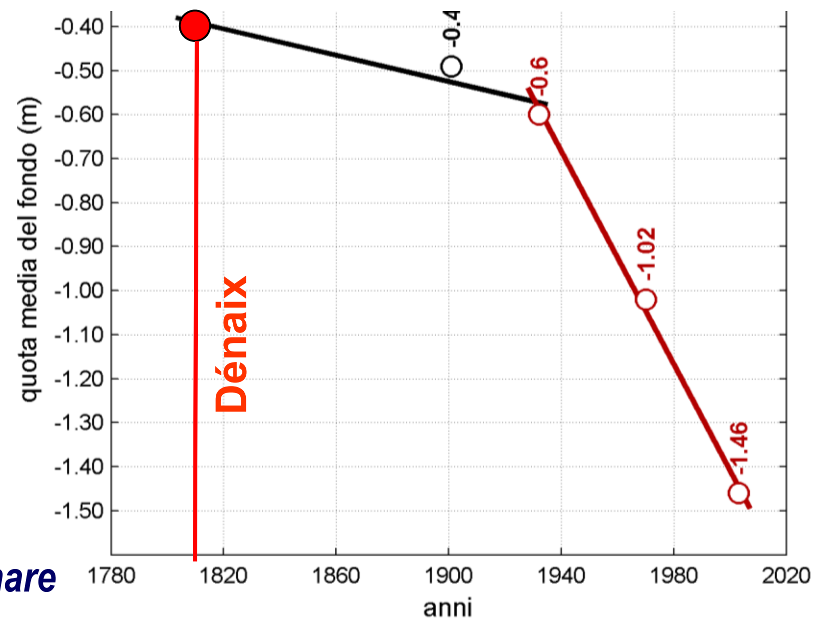


Venice lagoon in 1810 (Denaix)

D’Alpaos, L. (2010), Fatti e misfatti di Idraulica Lagunare

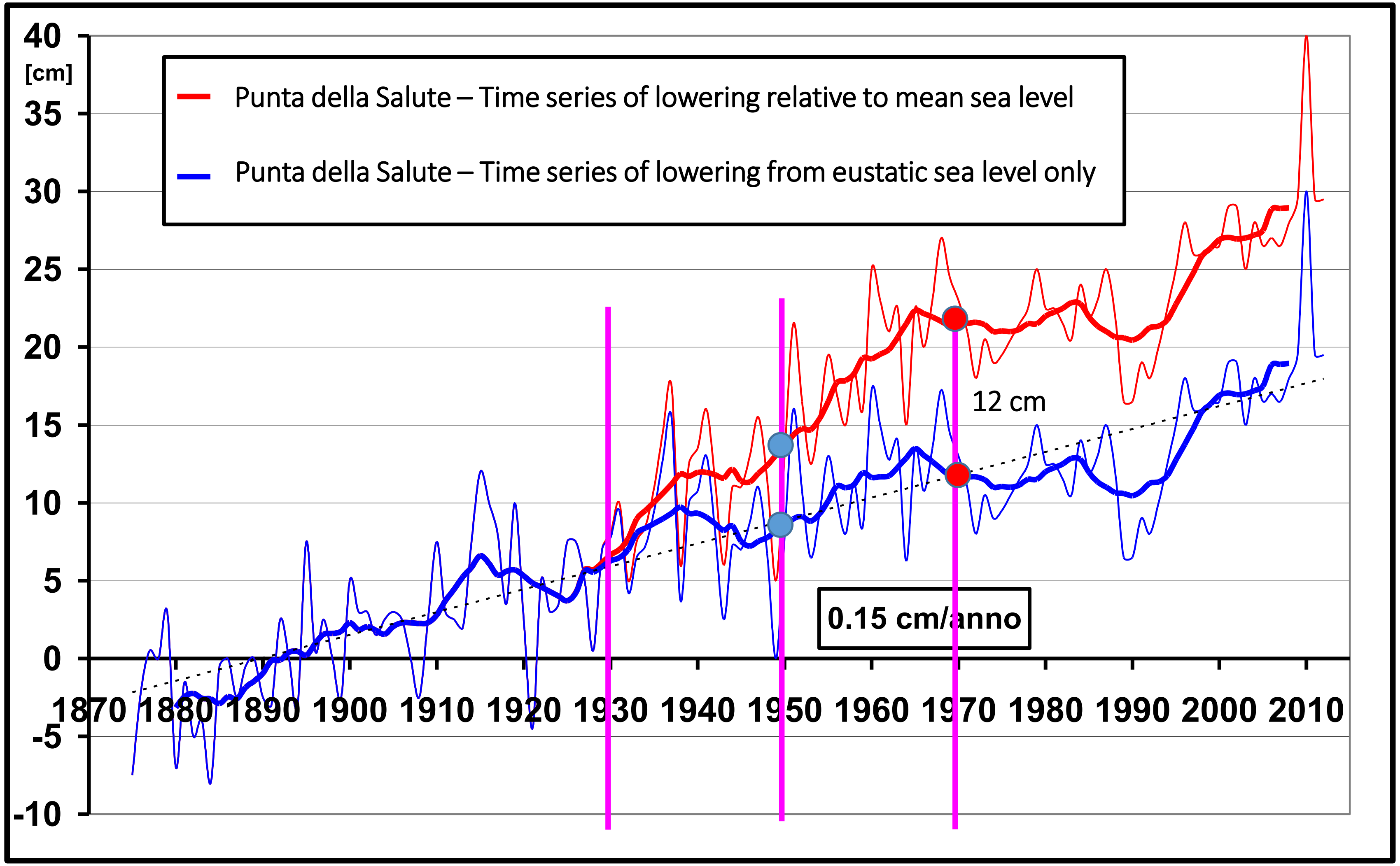


Rapid loss of mean elevation in last century: over 1 metre!!

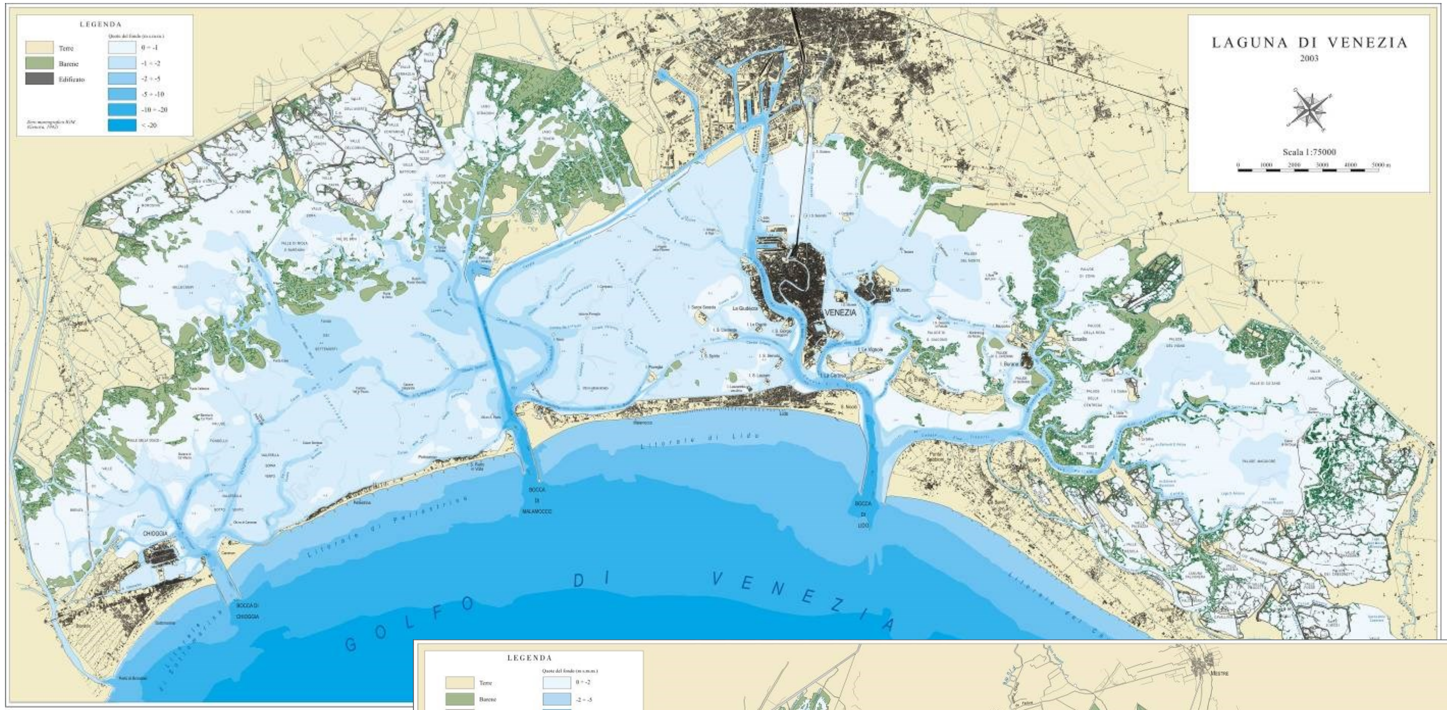


D'Alpaos, L. (2010), Fatti e misfatti di Idraulica Lagunare

Is Venice sinking?



Sediment compaction plus eustatic sea level rise has resulted in ~ 30cm of subsidence relative to mean sea level since 1900.

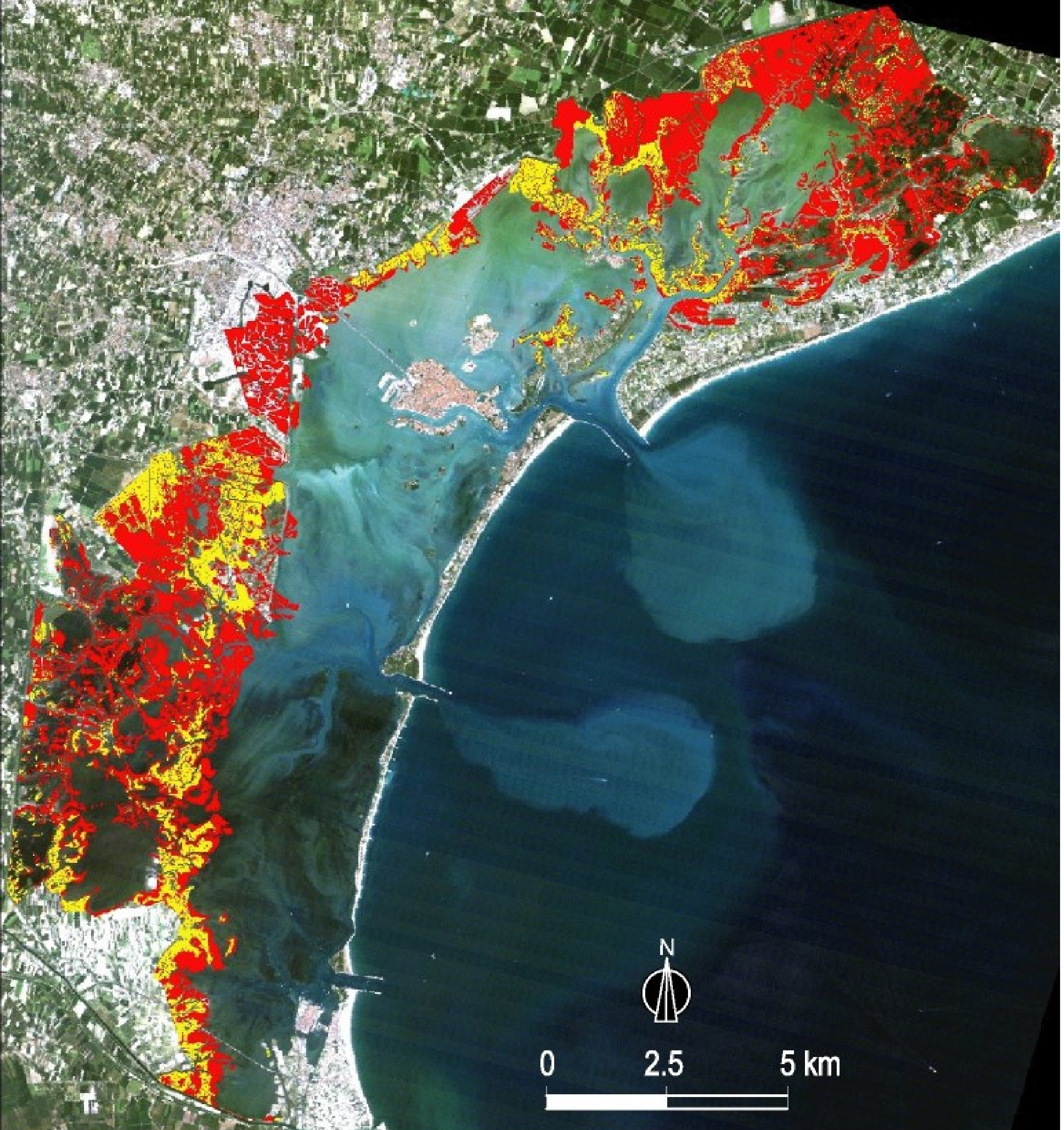


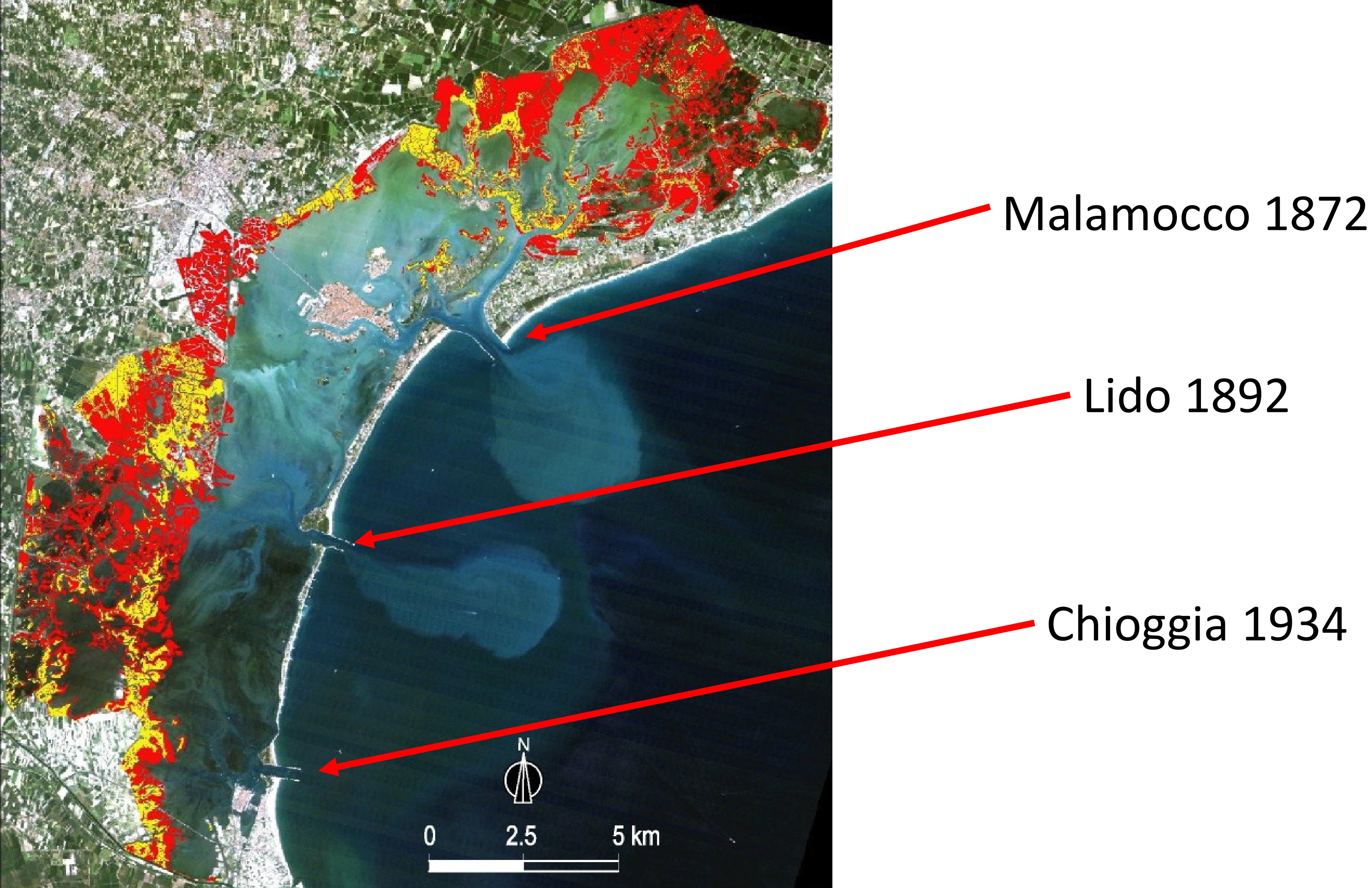
Venice lagoon in 2003

Venice lagoon in 1810 (Denaix)

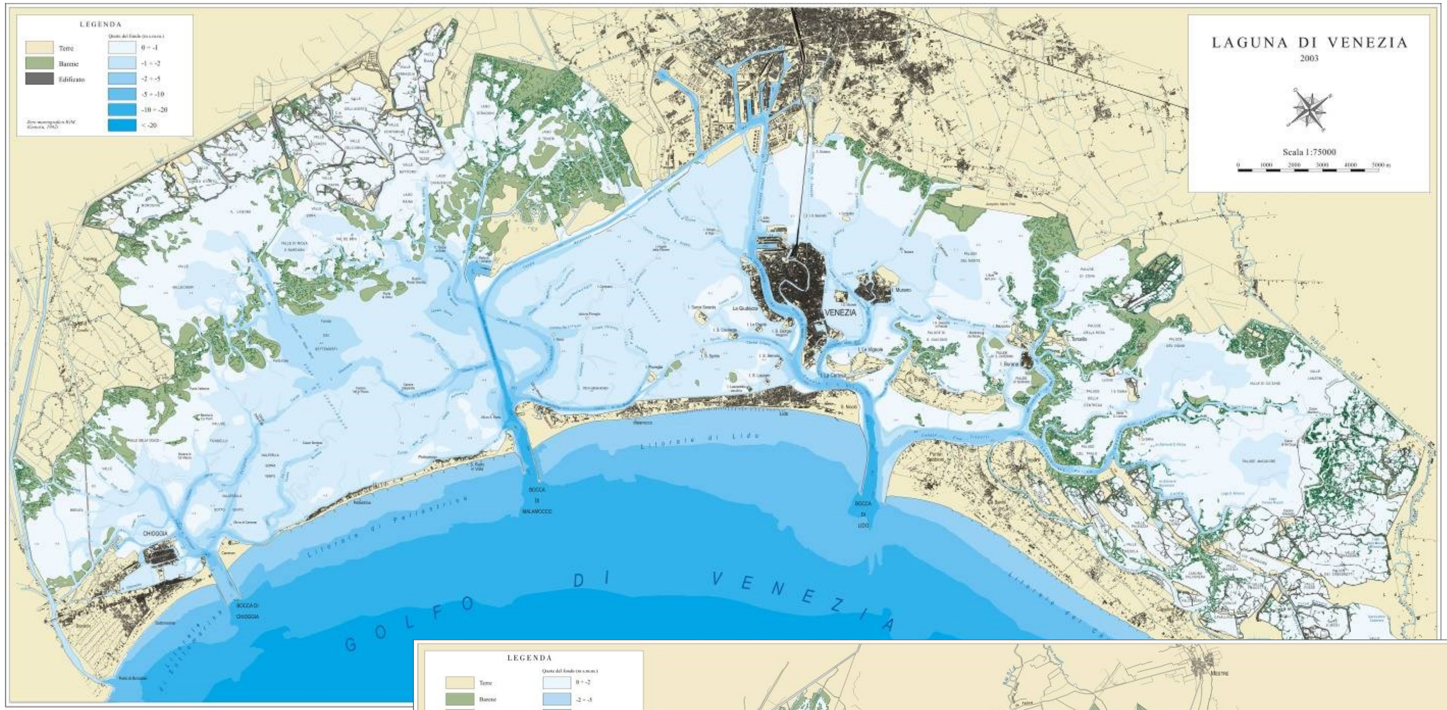
LOSS NOT FROM EUSTATIC SEA LEVEL RISE OR SEDIMENT SUBSIDENCE

D'Alpaos, L. (2010), Fatti e misfatti di Idraulica Lagunare


N
0
2.5
5 km


Malamocco 1872
Lido 1892
Chioggia 1934
N
0
2.5
5 km

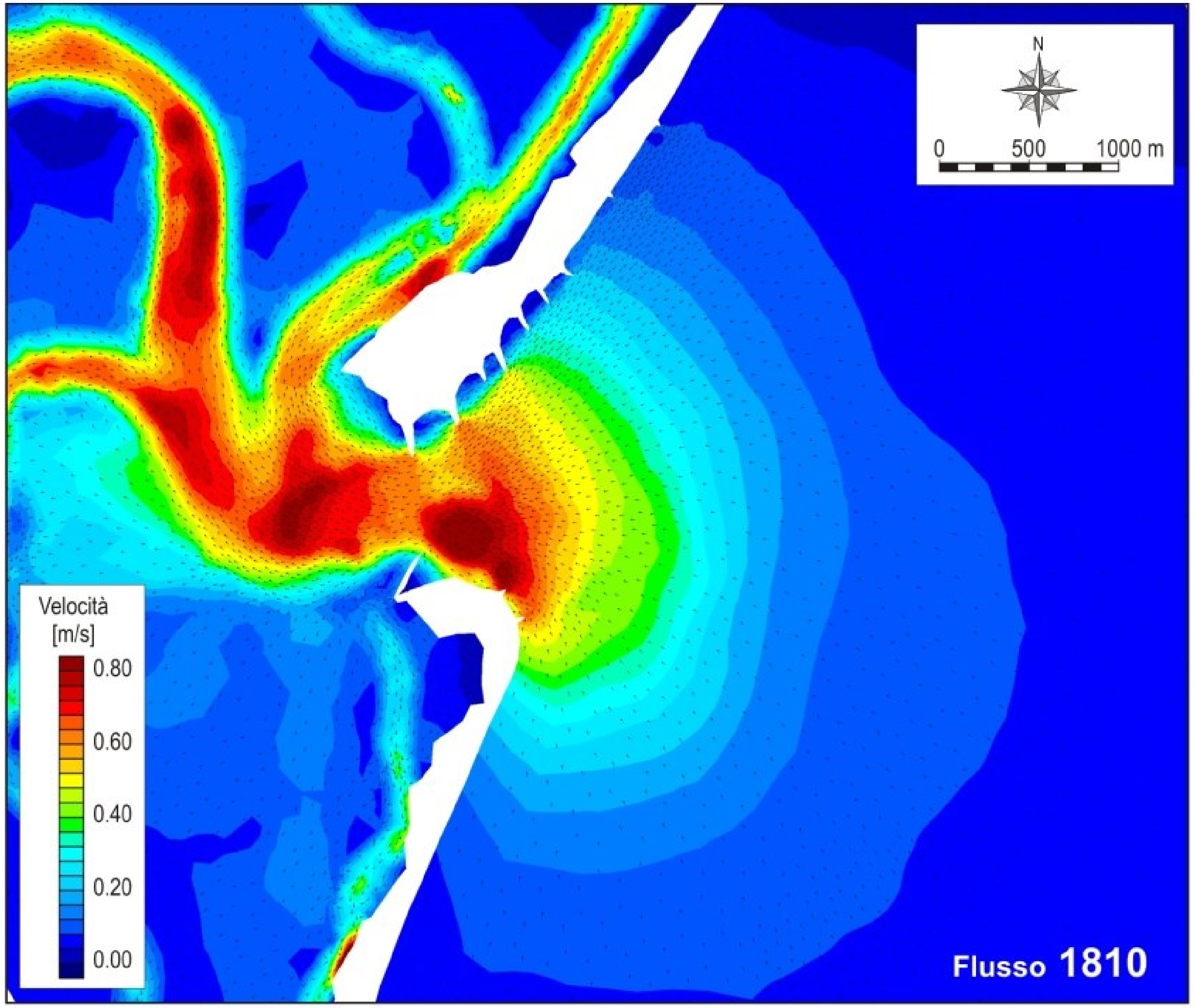
Venice lagoon in 2003

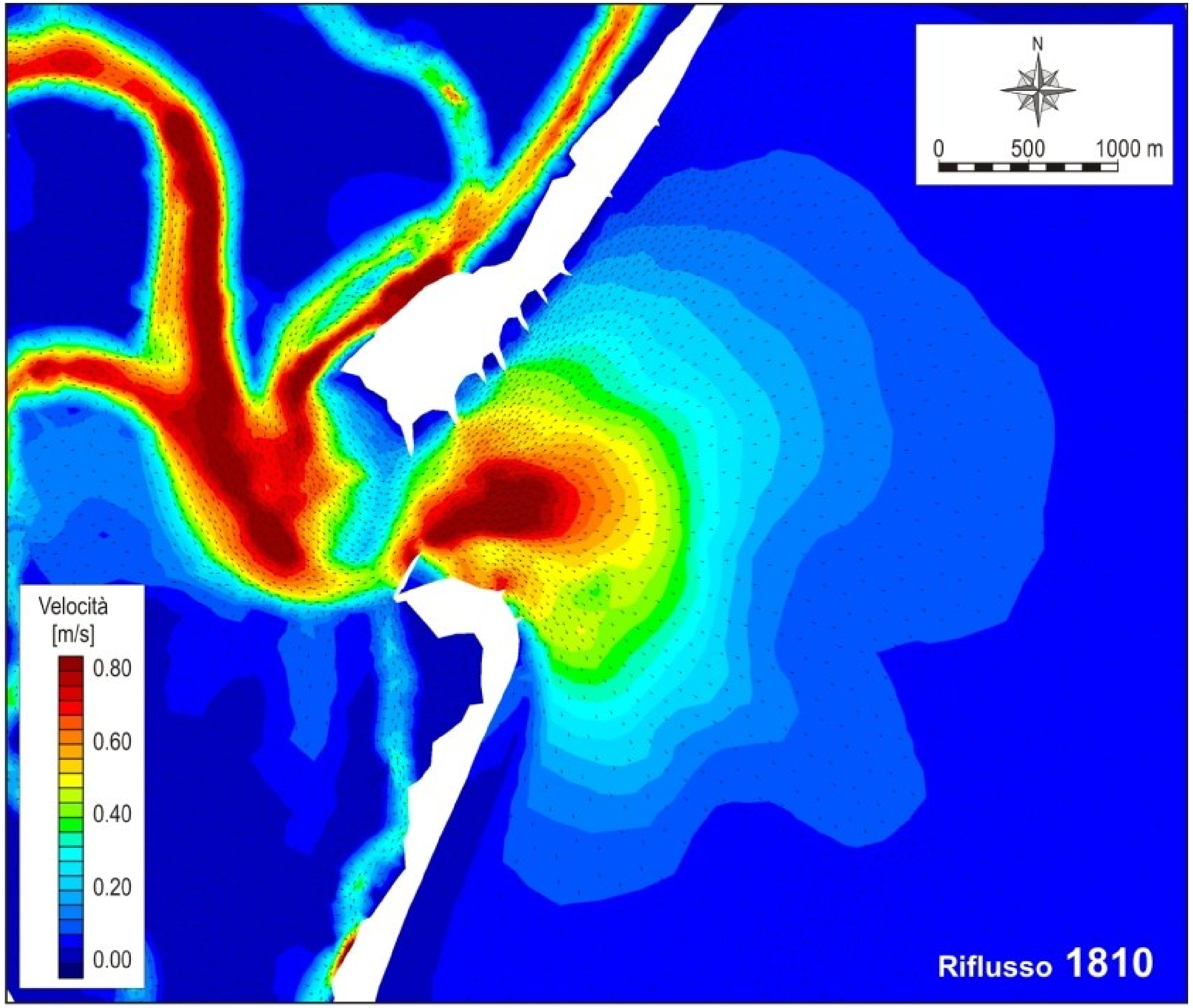


Venice lagoon in 1810 (Denaix)

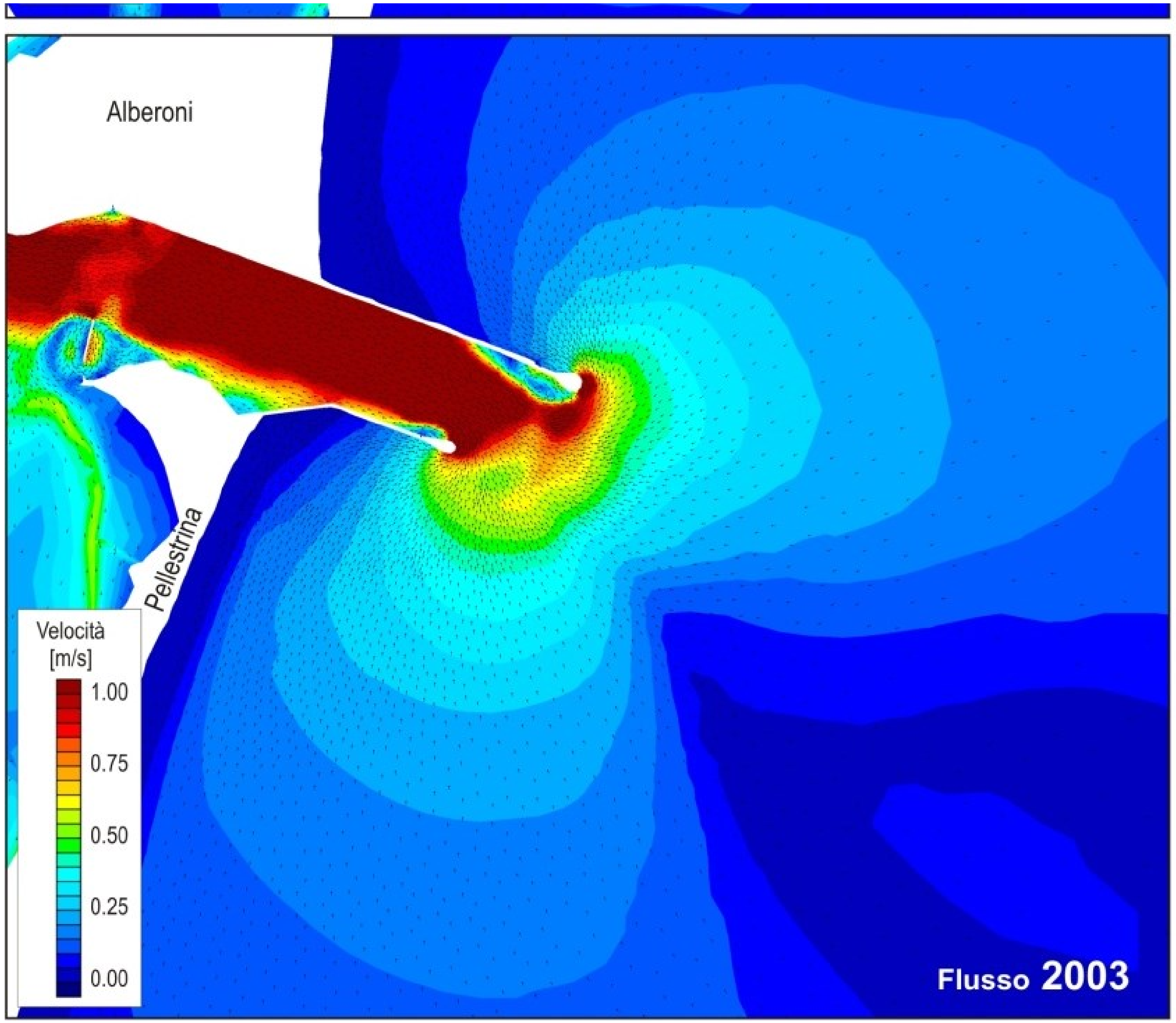
Anthropogenic modifications

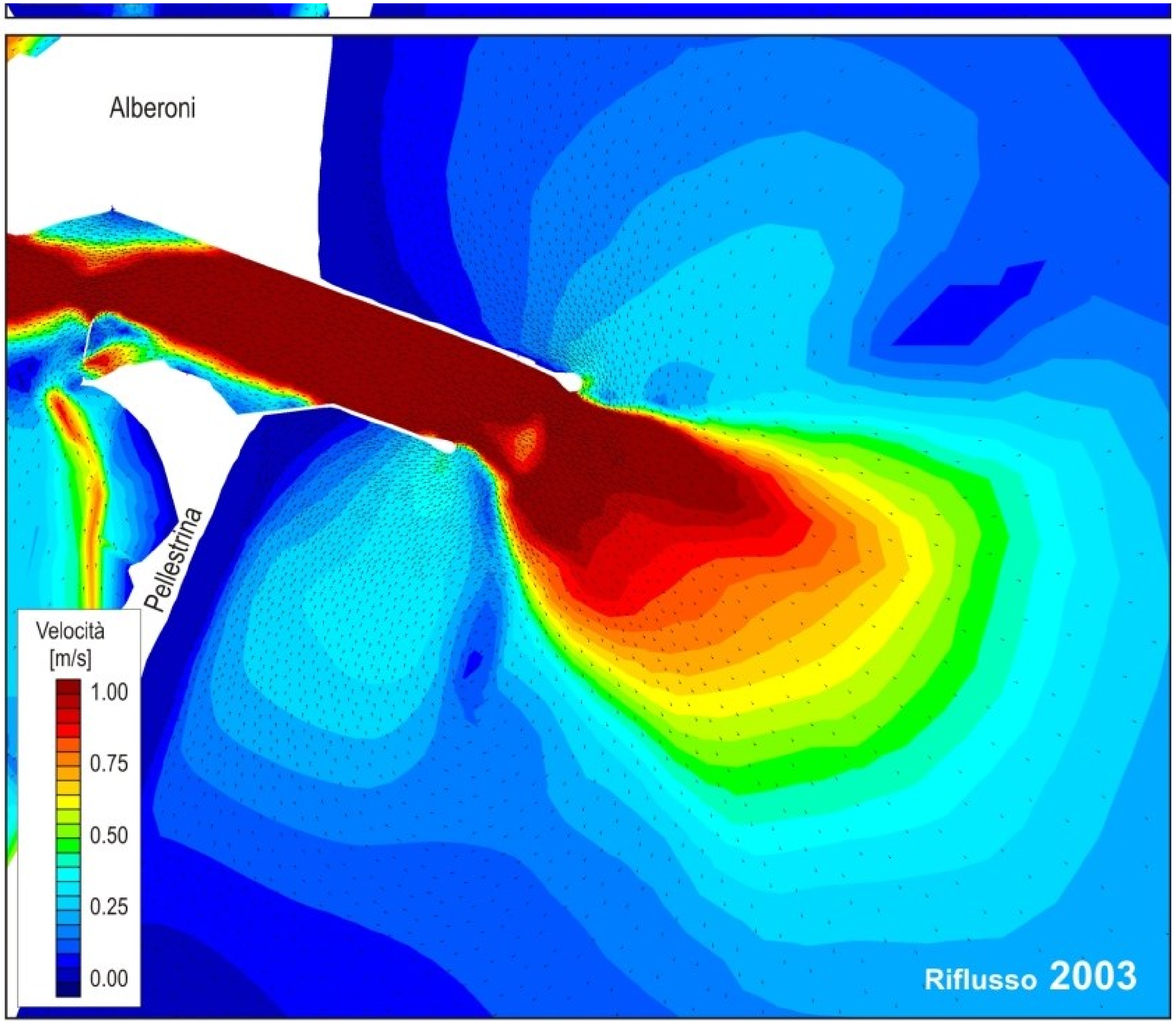
D'Alpaos, L. (2010), Fatti e misfatti di Idraulica Lagunare





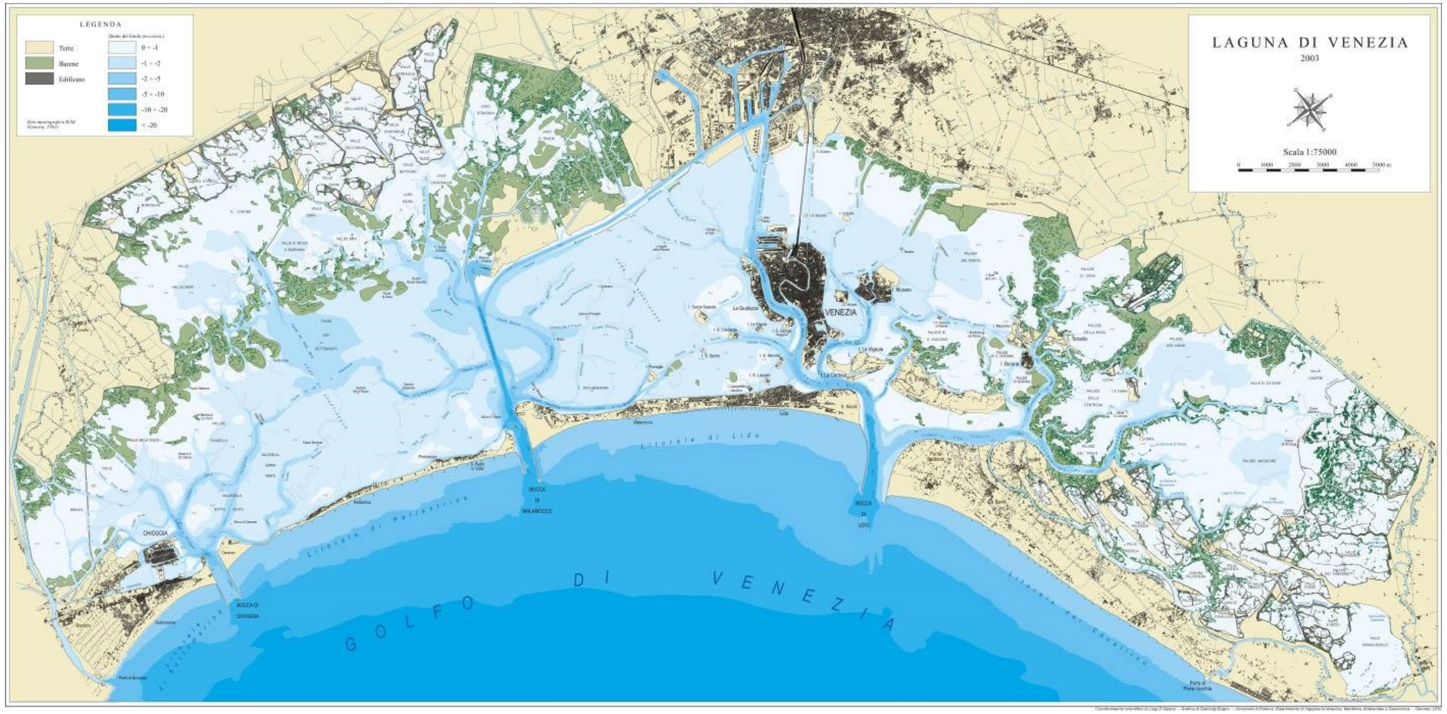
Before inlets

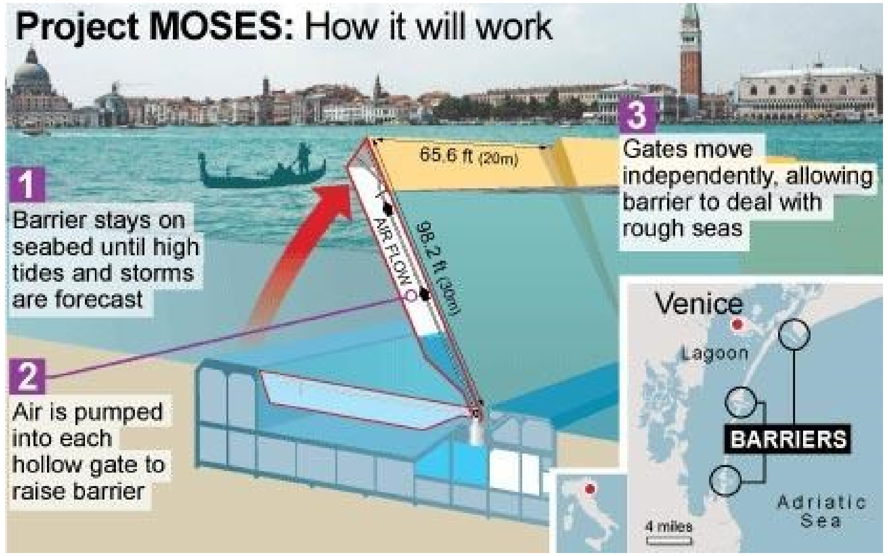




After inlets

The future:





Telegraph