Effect of small seagrass *Zostera noltei* on tidal asymmetry in a semi-enclosed shallow lagoon: the Arcachon Bay (SW France)

Sarah Mütterlein[1], Florian Ganthy[1]*, Aldo Sottolichio[2]

[1] Ifremer, LER-AR, F-33120 Arcachon, France
[2] University of Bordeaux, EPOC, CNRS, Allee Geoffroy St Hilaire, CS50023, 33615 PESSAC Cedex, France
*Corresponding author: florian.ganthy@ifremer.fr

Context and Objectives

➢ The Arcachon Bay (Bay of Biscay, French Atlantic Coast)

- Dominated by tides and wind-waves (semi-diurnal tidal range from 1 to 5 m)
- Intertidal flats extensively colonized by seagrass meadows of *Zostera noltei*
- Drastic regression of meadows since 20 years (Fig. 1)

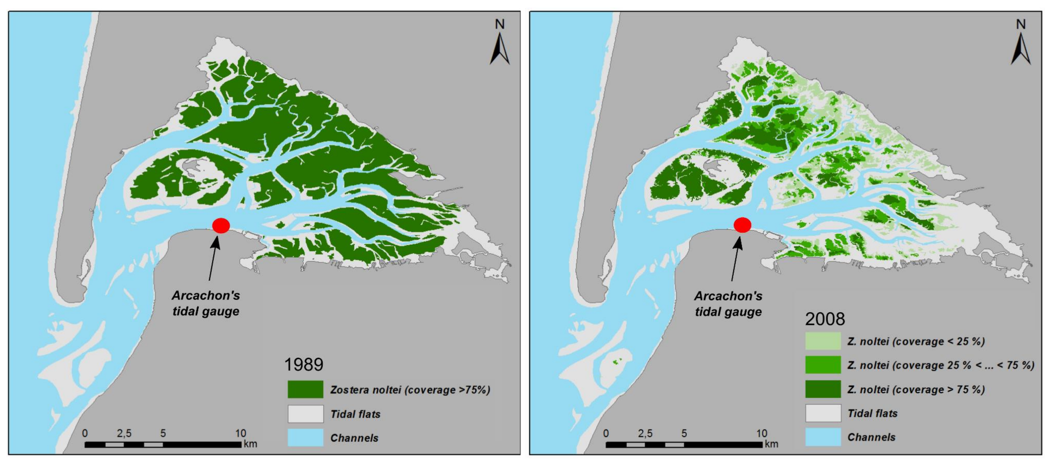

Fig. 1: Cartography of Z. noltei extension in 1989 and 2008 (Plus et al., 2010)

- Infilling of Eastern shallow channels observed simultaneously to seagrass decline

➢ The seagrass *Zostera noltei* : a well known ecosystem engineer

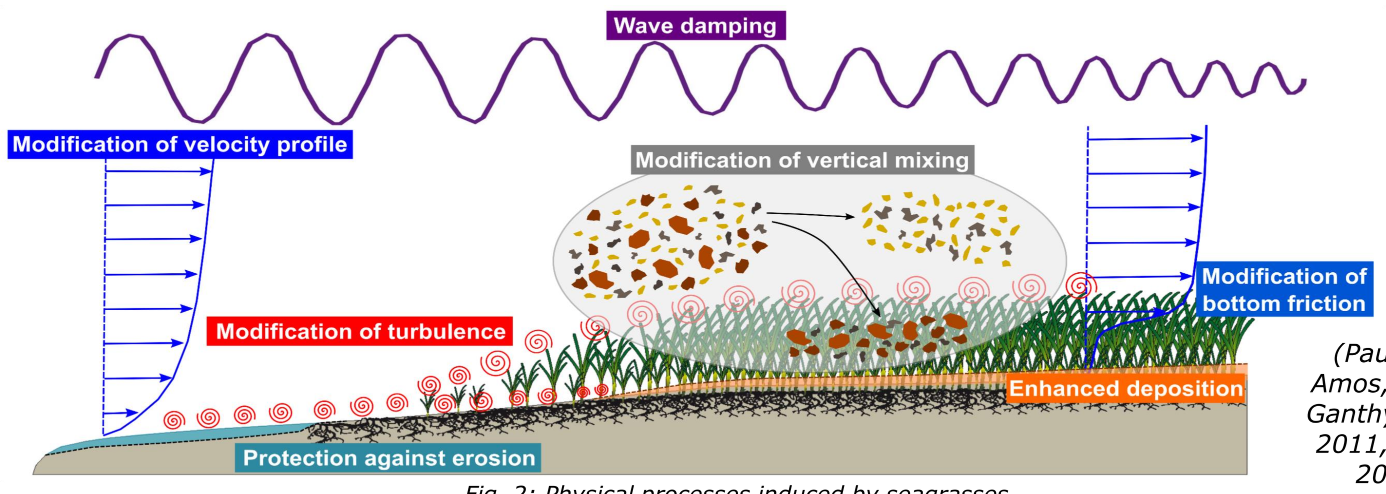

Fig. 2: Physical processes induced by seagrasses

May the spatio-temporal variability of Z. noltei meadows substantially modify tidal propagation and asymmetry within the Arcachon Bay?

Methods

➢ 3D numerical modelling

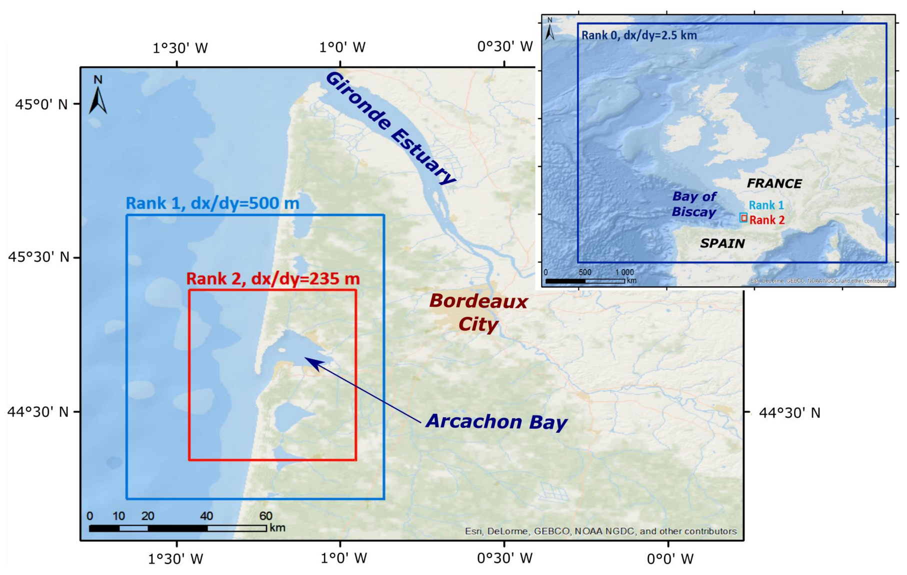

Fig. 3: Spatial limit and resolution of model ranks

- MARS3D model developed by Ifremer *(Lazure and Dumas, 2008)*
- 3 ranks with increasing spatial resolution
- Effects of seagrass on hydrodynamics explicitely calculated by source terms in momentum and turbulence closure equations (*Kombiadou et al., 2014*)
- Tide forced at open boundary using FES2012 tidal solution (*Carrère et al., 2012*)
- Model validated against tidal gauge and pressure sensors data with Root Mean Squared Error (RMSE) <0.1m
- Runs over 35 days (tidal forcing only) for 5 contrasting seagrass situations (***Table 1***), other parameters being kept constant

Table 1: Characteristics of the five seagrass situations used for the simulations

Simulation ID	Coverage*	Leaf length (cm)**	Leaf width (mm)**	Leaf density ($n.m^{-2}$)**
Unvegetated	-	-	-	-
Winter-89	>75%	4.5	0.5	16000
Summer-89	>75%	20.0	1.1	80000
Winter-08	<25% ; 25%<.<75% ; >75%	4.0 ; 4.2 ; 4.5	0.5	4000 ; 8000 ; 16000
Summer-08	<25% ; 25%<.<75% ; >75%	13.0 ; 14.0 ; 20.0	1.1	20000 ; 40000 ; 80000

**Coverage corresponds to different areas presented in Fig.1.density.*
***Seagrass characteristics were choosen representative to seagras seasonality within the Arcachon Bay*

➢ Tidal asymmetry analysis

- Method by Nidzieko and Ralston (2012) over the last 29 days of simulation, for both water levels (γ_h) and depth-averaged velocities (γ_u):

$\gamma = \frac{\mu_3}{\mu_2^{3/2}}$ where the *m*-th moment about zero is defined as: $\mu_m = \frac{1}{N-1}\sum_{i=1}^{N}(n_i)^m$ and *N* is the number of samples n_i.

- For water level asymmetry (γ_h), $n = \frac{\partial h}{\partial t}$ - For velocity asymmetry (γ_u), $n = u$, where *u* are across-shore tidal velocities

- γ_h also quantified for decadal data from Arcachon's tidal gauge: running window (29 days length), linear trend tested for significance using Mann-Kendall test (95% confidence level), and seasonality computed and displayed as a box plot

Results and Discussion

➢ Spatio-temporal variability of water level asymmetry (γ_h)

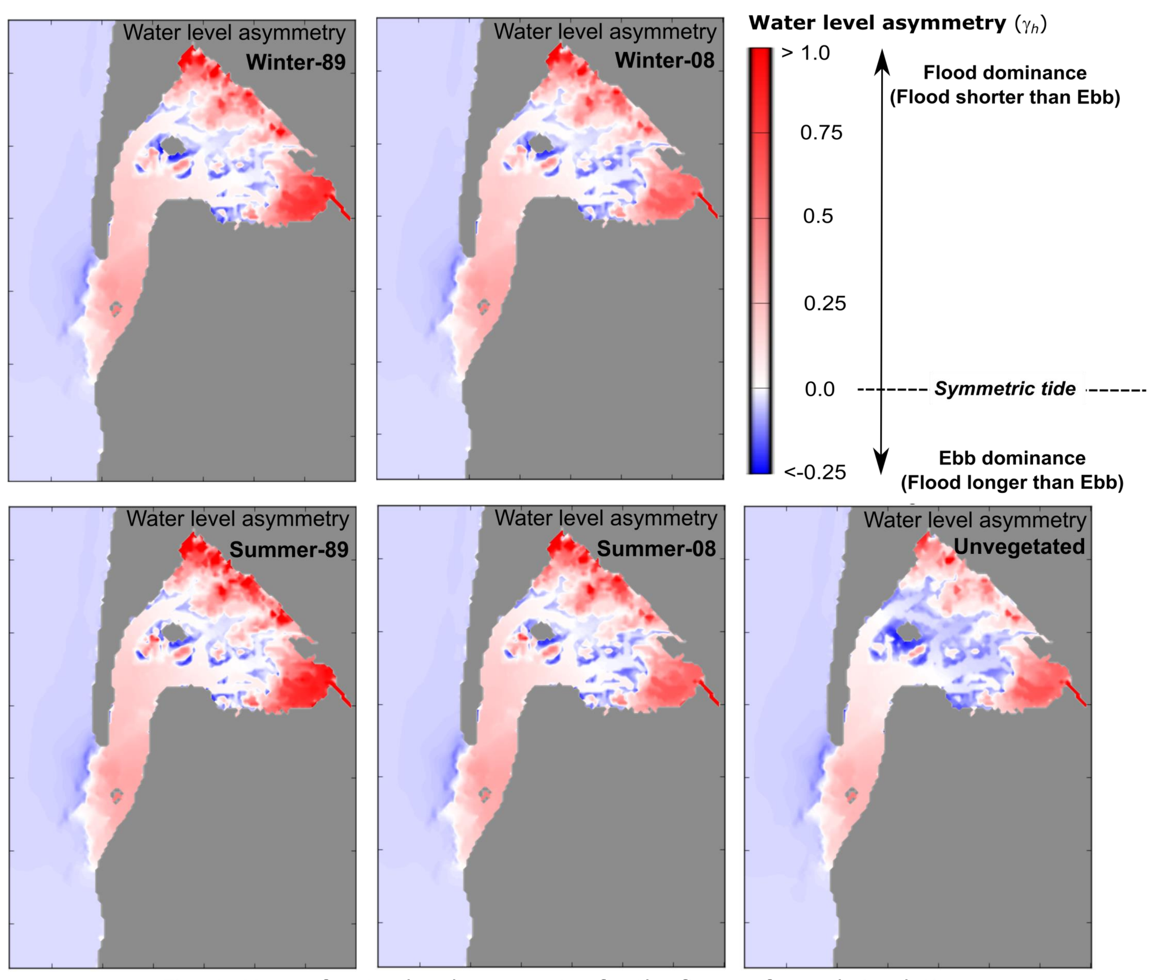

Fig. 4: Maps of water level asymmetry for the five performed simulations

- Similar patterns of γ_h for all runs (Fig. 4):
  - Open ocean: slightly ebb-dominated
  - Inlet: slightly flood-dominated
  - Central part of the Bay: slightly ebb-dominated
  - Inner parts of the Bay: flood-dominated (mostly in the South-East and North-East)

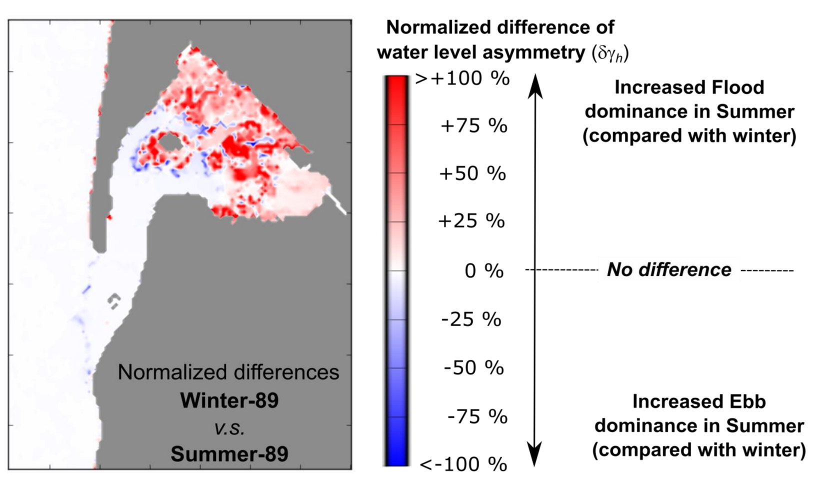

Fig. 5: Normalized difference in water level asymmetry: impact of seagrass seasonality

- γ_h significantly increased (favouring flood dominance) in the presence of seagrass in the central and the eastern part of the Bay (Figs. 5, 6):
  - γ_h is up to 100% higher in Summer-89 than in Winter-89, mostly on tidal flats (Fig. 5), while values are increased by 50-70% between Summer-08 and Winter 08
  - γ_h is decreased by up to 200% in Summer-08 compared with Summer-89, mostly where seagrass meadows have declined (Fig.6a)
  - γ_h is increased by up to 600% in Summer-89 compared with Unvegetated case, both on tidal flats and main channels (Fig.6b)

→ Seasonality and recent decline of *Z. noltei* meadows have a significant impacts on water level tidal asymmetry, mostly on tidal flats.

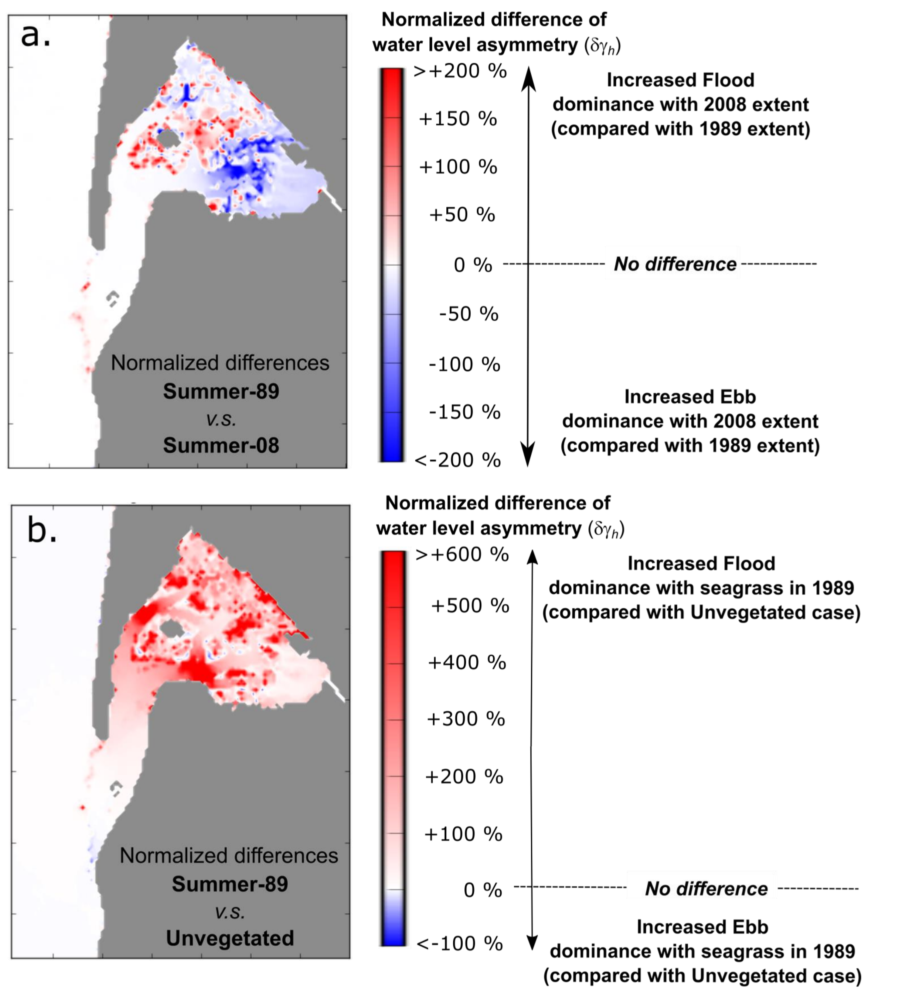

Fig.6: Normalized difference in water level asymmetry: impact of seagrass extent (upper panel) or presence/absence (lower panel)

➢ Spatio-temporal variability of current asymmetry (γ_u)

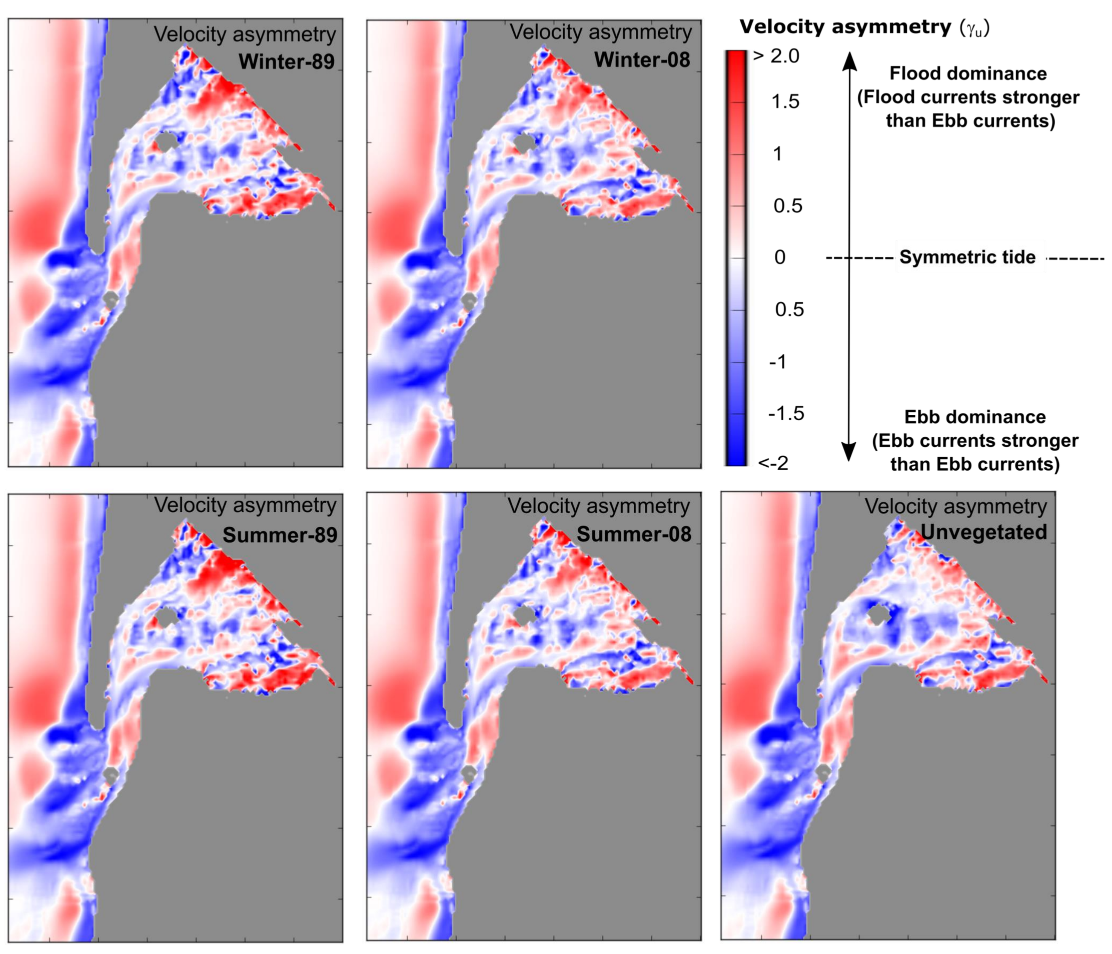

Fig. 7: Maps of current asymmetry for the five situations simulated

- Similarly to γ_h, γ_u shows similar general patterns for all simulations (Fig. 7):
  - Main channels: generally ebb-dominated
  - Inlet sand-banks and inner tidal flats: generally flood-dominated
- Seagrass seasonality causes changes in γ_u by up to 100 %
- Variation of seagrass extent (1989, 2008 or without seagrass) causes changes in γ_u by up to 300%
- γ_u patterns more complex compared with γ_h, excepted in the South-East and North-East of the Bay, where flood dominance is significantly increased by seagrass meadows

→ Seasonality and recent decline of *Z. noltei* meadows have significant but complex impacts on current asymmetry, due to the modifications of the general tidal circulation in the inner parts of the Bay.

➢ Comparison with decadal tidal gauge data

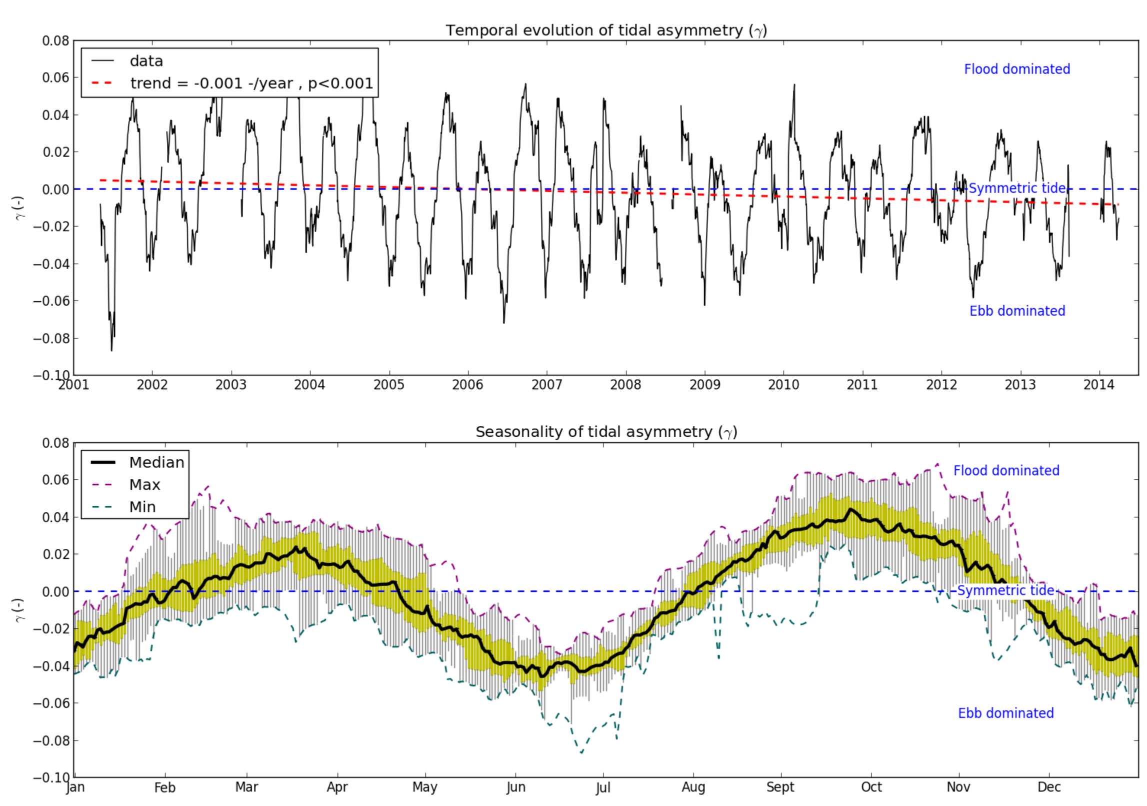

Fig.8: Decadal and seasonal variability in water level asymmetry obtained from Arcahon's tidal gauge data

- Significant decrease of γ_h from 2001 to 2014 (p<0.001) in agreement with model results
- Double-cycle of γ_h within a year:
  - October's peak (flood-dominated): maximum seasonal development of *Z. noltei*
  - The rest of the double-cycle cannot be easily related to seagrass stage of development

→ Seagrass variability may contribute to long-term and seasonal changes of tidal asymmetry, among other factors (sea-level, wave setup, inlet migration…).

Conclusions and Perspectives

Our model shows that the modification of bottom friction induced by the presence of *Zostera noltei* meadows, the seasonality of their development as well as their change in extent have significant impact on tidal propagation and asymmetry within the Arcachon Bay, both on water level and current asymmetry. Regarding the water levels, the presence seagrass meadows tends to damp ebb-dominance and enhance flood dominance, mainly in central/inner parts of the Bay where tidal flat are colonized. Regarding the current asymmetry, seagrass meadows also tend to enhance flood dominance, and to modify tidal circulation in the inner part of the Bay with possible substantial effects on sediment transport. Decadal tidal gauge data analysis show a significant decrease of flood-dominance with time, as well as an important seasonality of water level asymmetry which may be partly attributed to variation of seagrass development and extent. Various external factors such as sea level rise, wave-induced setup and morphological changes of the inlet may also significantly contribute to observed long-term changes. The relative impact among all these environmental factors remains to be quantified.

References:

Carrère L., Lyard F., Cancet M., Guillot A. and Roblou, L. (2012) FES2012: A new global tidal model taking advantage of nearly 20 years of altimetry. *Proceedings of meeting « 20 Years of Altimetry »,, Venice 2012*.

Friedrichs C. T. and Aubrey D. G., 1988 Non-linear tidal distortion in shallow well-mixed estuaries: A synthesis. *Estuar. Coast. Shelf Sci., 27, 521-545.*

Ganthy F., Sottolichio A. and Verney R. (2011) The stability of vegetated tidal flats in a coastal lagoon through quasi in-situ measurements of sediment erodibility. *J. Coastal Res., SI 64, 1500-1504.*

Ganthy F., Sottolichio A. and Verney R. (2013) Seasonal modification of tidal flat sediment dynamics by seagrass meadows of *Zostera noltii* (Bassin d'Arcachon, France). *J. Mar. Sys., 109-110, S233-S240.*

Ganthy F., Soissons L., Sauriau P.-G., Verney R. and Sottolichio A. (2015) Effects of short flexible seagrass *Zostera noltei* on flow, erosion and deposition processes determined using flume experiments. Sedimentology 62, 997-1023.

Kombiadou K., Ganthy F., Verney R., Plus M. and Sottolichio A (2014) Modelling the effects of *Zostera noltei* meadows on sediment dynamics: application to the Arcachon lagoon. O. Dyn., 64,199-1516.

Lazure P. and Dumas F. (2008) An external-internal mode coupling for a 3D hydrodynamical model for application at regional scale (MARS). Adv. Water Resour., 31, 233-250,

Plus M., Dalloyau S., Trut G., Auby I., de Montaudouin X., Emery E., Noël C. and Viala C. (2010) Long-term evolution (1988-2008) of Zostera spp. Meadows in Arcachon Bay (Bay of Biscay). *Estuar. Coast. Shelf Sci., 87, 357-366.*

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