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Spatio-temporal analysis of co-evolution between seagrass beds distribution and hydro-morphological changes in Arcachon Bay (France)

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Context and Objectives

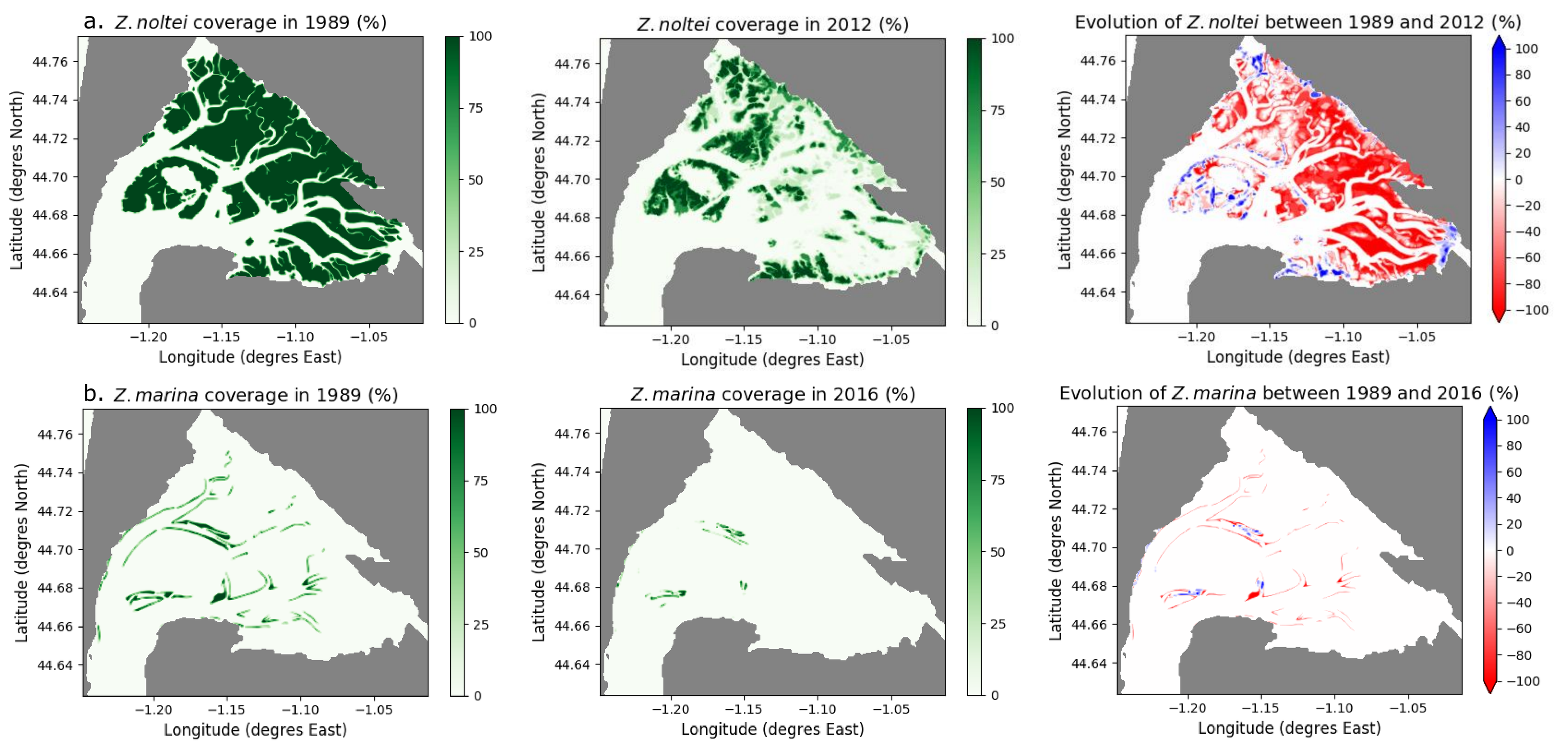


Fig. 1: Spatial evolution of seagrasses: (a.) Z. noltei and (b.) Z. marina

Spatial evolution of seagrass beds in Arcachon Bay

- *Zostera* spp. are well know ecosystem engineers: they damp near-bed hydrodynamics and promote sediment accretion.
- The extent of *Zostera* spp. meadows in Arcachon Bay has drastically decreased in the last 20 years (Fig. 1):
  - -61% for *Z. noltei* between 1989 and 2012
  - -84% for *Z. marina* between 1989 and 2016

→ Because *Z. marina* was the first showing spatial losses in the bay, the decline of *Z. noltei* may have been a direct consequence of *Z. marina* regression and may have been exacerbated by its own consequences on hydrodynamics and sediment dynamics (i.e. feedbacks).

Objectives:
Investigate relationships between Zostera spp. decline , morphology (water depth, bottom slope) and changes in hydrodynamics (current velocities)

Methods

Spatial analysis of *Zostera spp* decline (1989 to 2012-2016)

- **Comparison of bathymetric data** (year 1992, L'Yavanc, 1995) **and *Zostera* spp. extent** (years 1989, 2005 and 2007, 2012, 2016)**, in terms of bathymetric levels** (*Z(c)*) **and slopes** (*SL(c)*) **classes** (*c*)**:**

→ **Total colonized surface area** (Sz_{tot} *(c)* **or** Ssl_{tot} *(c)*)**,** ex. for 1989 and Z(c)**:**

$$Sz_{tot}^{1989}(c)=\sum Sz_{i}^{1989}(c)$$

where Sz_i is surface area of i^{th} cell with seagrass *(i.e. m² = 0.04 ha)*

→ **Normalized change of total colonized surface area** (dSz_{tot} *(c)* **or** $dSsl_{tot}$ *(c)*)**,** ex. for 2005 and *Z(c)*:

$$dSz_{tot}^{1989}(c)=100\times\left(Sz_{tot}^{1989}(c)-Sz_{tot}^{2005}(c)\right)/Sz_{tot}^{1989}(c)$$

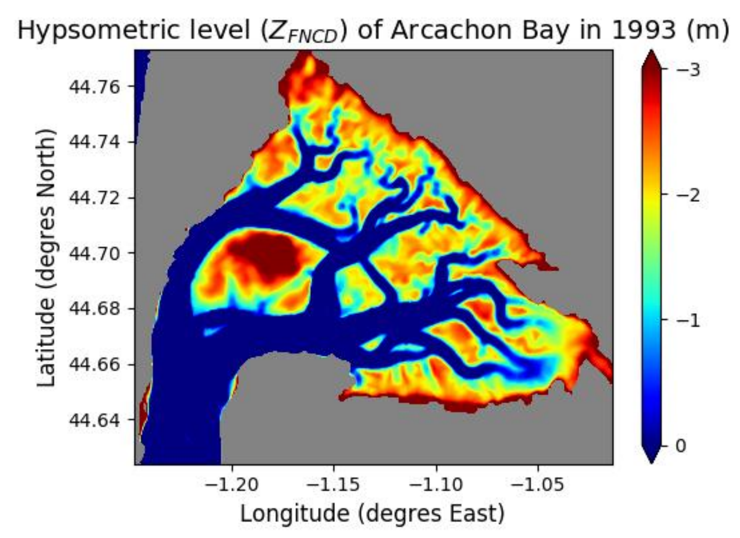


Fig. 3: Bathymetry (1992) of Arcachon Bay.

3D numerical model

- **MARS3D model** (Lazure and Dumas, 2008) **is a 3D model which explicitly takes into account the effects of *Zostera* spp. on hydrodynamics** (Kombiadou *et al*., 2014)**.**
- **4 ranks of increasing spatial resolution (Fig. 4)**
- **Tides are forced at the open boundary by the solution FES2012** (Carrère *et al*., 2012)
- **The model was validated against data from Arcachon tide gauge**
- **Three simulations performed over a neap/spring tidal cycle for different seagrass extent :** *Z. noltei* 1989 **and** *Z. marina* 1989**;** *Z. noltei* 1989 and *Z. marina* 2016**;** *Z. noltei* 2012 and *Z.marina* 2016**.**
- **Realistic seagrass characteristics (shoot density, leaf length, leaf width) corresponding to summer development.**
- **Computation of near-bed velocities (*U_{bot}*), and of a theoretical metrics (*F_{loss}*) representative of potential leaf snatching or seagrass scouring:**

$$F_{loss}=\sum_{t=0}^{n}\left(\frac{\tau_F(t)}{\tau_C}-1\right)$$

with $\tau_F(t)=\frac{1}{2}\rho_{wat}\,c_D\,U_{bot}^2(t)$, τ_C the critical stress over which leaves are snatched or scouring may occur (τ_C, computed with $U_{bot,cr}$ = 0,25 m/s; de los Santos *et al*., 2010**)**

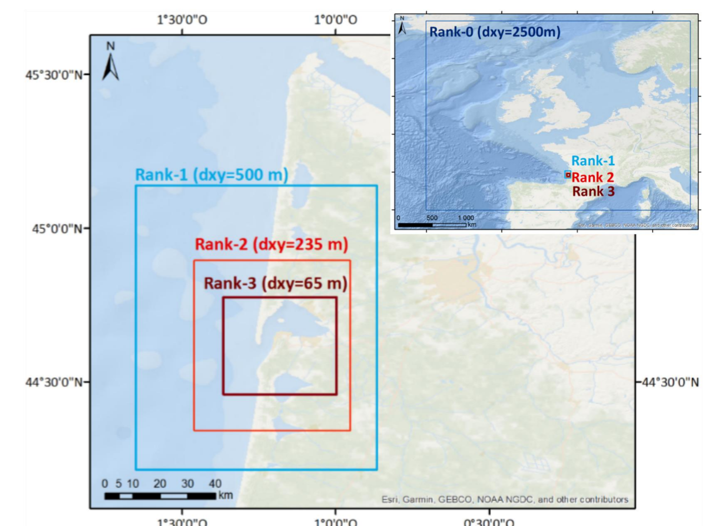


Fig. 4: Extent and resolution of model ranks

Results and discussion

Relationships between seagrass decline and morphology

- **Between 1989 and 2007, *Z. noltei* mainly declined on the deepest areas they colonized. Between 2007 and 2012, *Z. noltei* regressed in areas located below the mean sea level, while they slightly progressed in areas above mean sea level (Fig. 5a and 5b).**
- **Between 1989 and 2007, an important decline of *Z. noltei* was observed on channel edges (steep areas, Fig. 5c).**
- **Between 1989 and 2016 *Z. marina* mainly declined on the deepest and shallowest areas they colonised (Fig. 5e and 5f). Moreover, they also regressed more on channel edges than on flatter areas (Fig. 5g and 5h).**

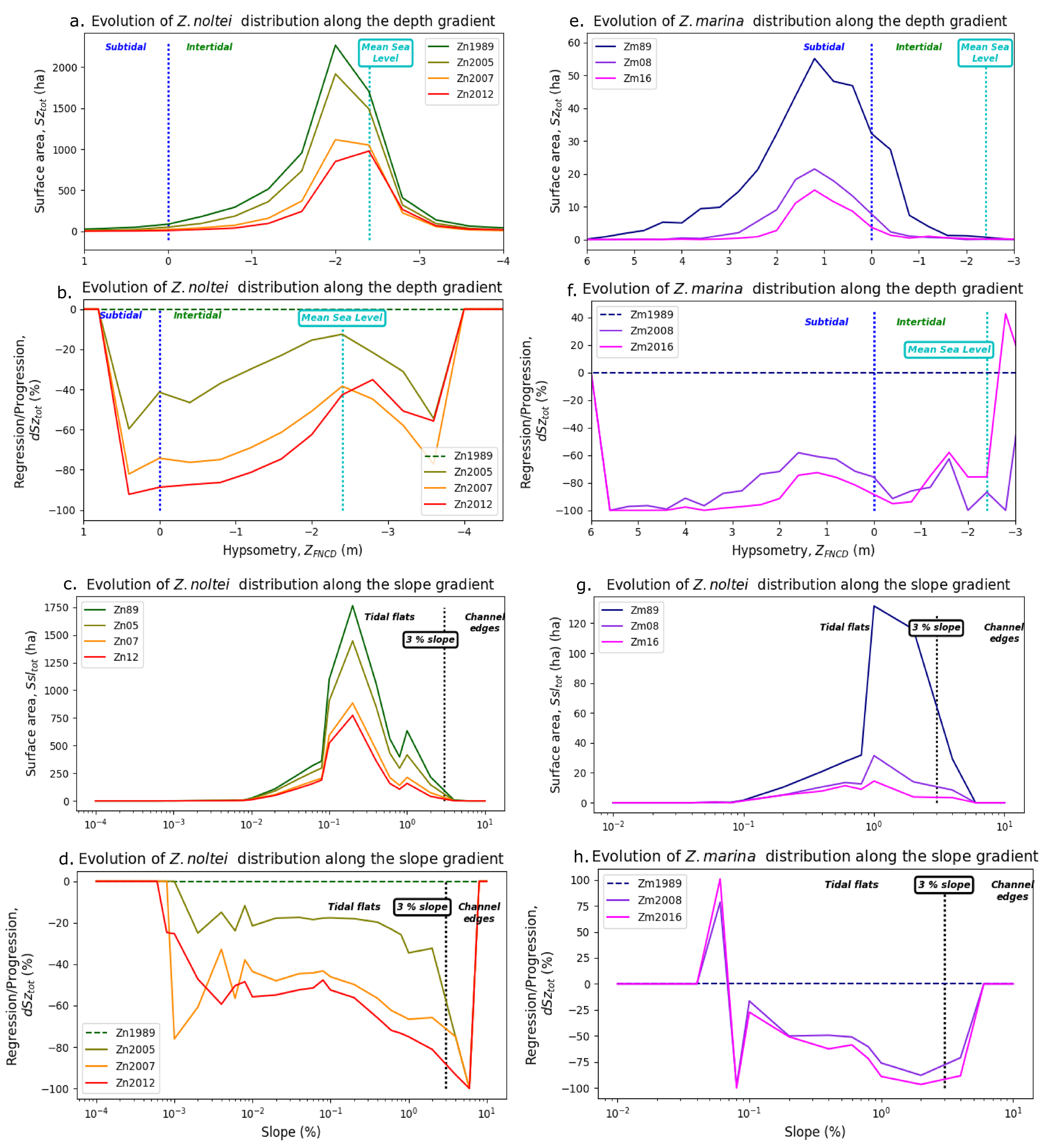


Fig. 5: Relationships between evolution of seagrass area and hypsometry or slope

Impact of *Zostera* spp. decline on hydrodynamics

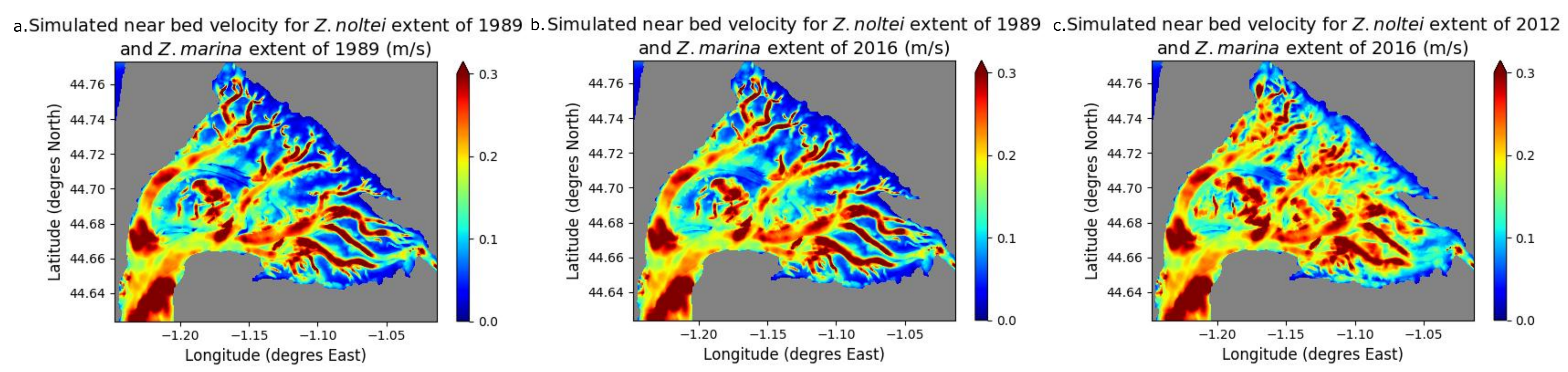
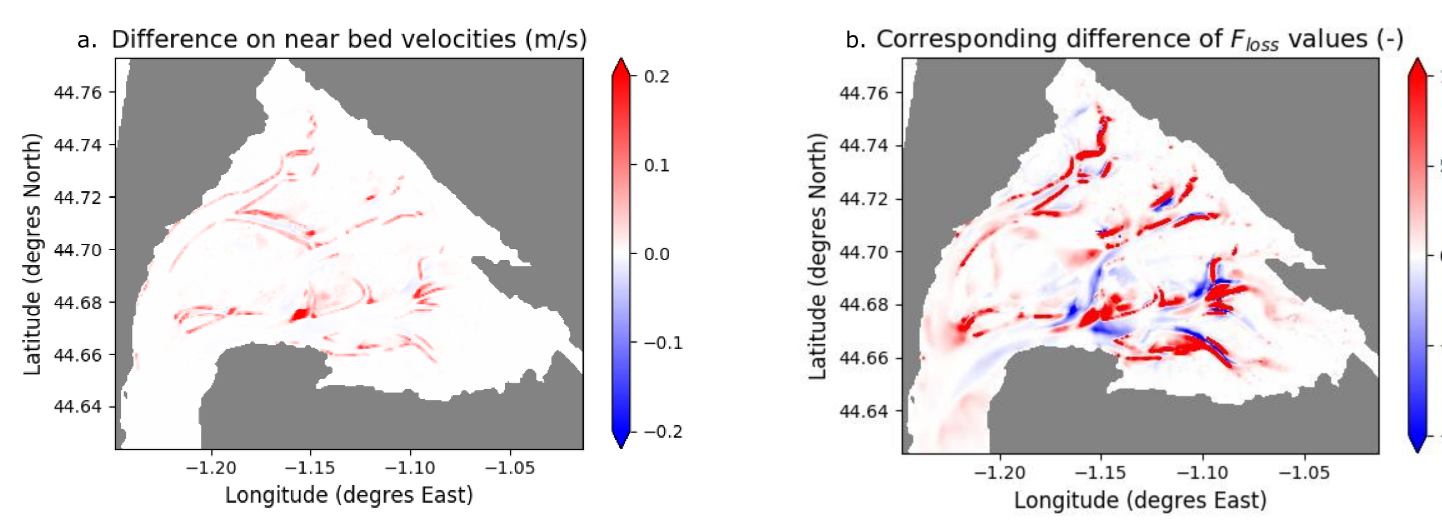


Fig. 6: Near bed velocities: (a) Z. noltei 1989 and Z. marina 1989, (b) Z. noltei 1989 and Z. marina 2016, (c) Z. noltei 2012 and Z. marina 2016

Impact of Zostera marina decline alone



- **In areas where *Z. marina* declined, near-bed current velocities increased by more than 0,2 m/s and velocities on nearby tidal flats also slightly increased (Fig. 6a, 6b, 7a.).**
- **This increase of velocities seems strong enough to significantly disturb *Z. noltei* through leaves removal or scouring on channel edges (Fig. 7b).**

Fig. 7: Impact of Z. marina decline: (a) on near bed velocities and (b) on F_{loss}

Impact of both Zostera spp. decline on hydrodynamics

- **The decline of both species leads to a generalized increase of near bed current velocities on the intertidal flats, and to a significant decrease in inner channels (Fig. 6a, 6c, 8a).**
- **This increase of velocities is strong enough to significantly disturb *Z. noltei* thought leaves removal or scouring on all tidal flats (Fig. 8b).**

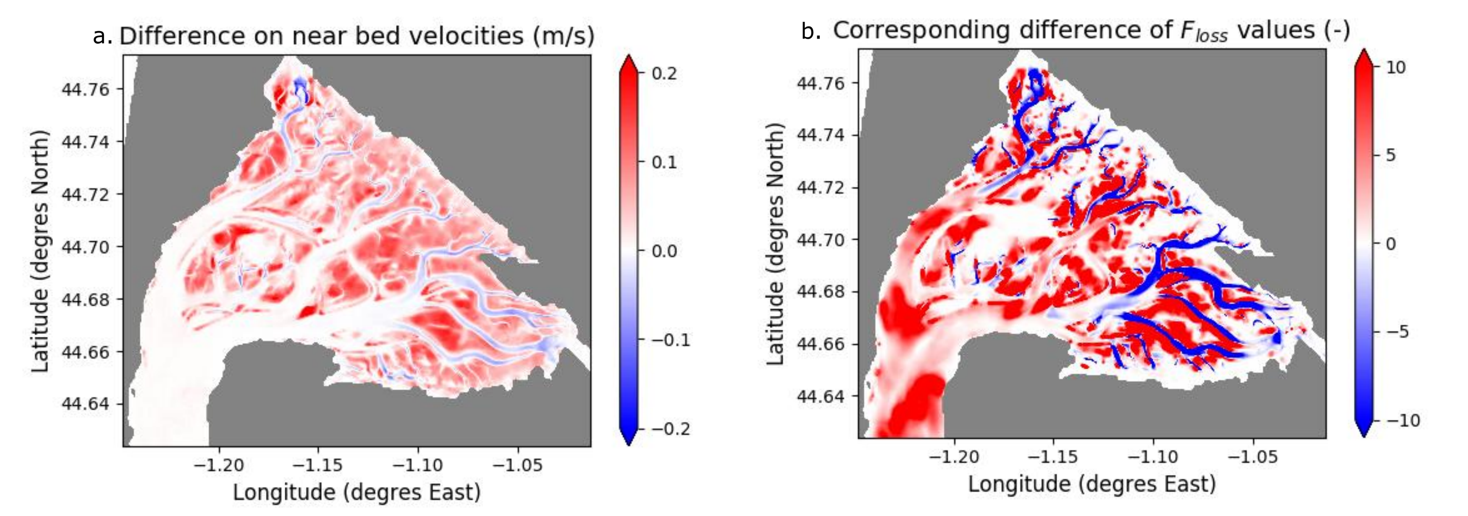


Fig. 8: Impact of both Zostera spp. decline: (a) on near bed velocities and (b) on F_{loss}

Conclusions et perspectives

Spatial evolution results reveal that the decline of the two species mainly occurred on the deepest areas and on channel edges (steepest slopes). Otherwise, model results show that the decline of *Z. marina* significantly increases near bed current velocities on the channel edges and on nearby intertidal flats. This higher velocities seem sufficient to cause leaf removal and scouring on *Z. noltei*. Thus, *Z. marina* decline may have locally initiated *Z. noltei* loss through increase of hydrodynamics and subsequently erosion. As *Z. noltei* decline also strongly increased current velocities, this suggests that a positive feedback (self-amplification mechanism) between hydro-sediment dynamics and *Zostera* spp. contributed significantly to the total seagrass regression in the bay. Furthermore, model results showing decreased velocity in inner channels due to *Zostera* decline tend to confirm that the observed infill would be a direct cause of this evolution. To complete this study, changes on sediment dynamics induced by *Zostera* spp. decline will be quantified through hydro-sedimentary modelling.

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