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Influence of currents on the seagrass meadows revegetation in shallow water systems (near shoreline)

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Abstract

This work concerns the 3D hydrodynamics in a lagunar ecosystem subject to tide, wind effects and freshwater runoffs, in shoreline areas where seagrass meadows is decreasing year after years. The goal is to better understand if the strength of the currents induced by these forcing mechanisms can be the main cause of the seagrass regression.

We suspect that the present density of the meadow is far too small to permit these aquatic plants to resist against the energy of the currents and maybe the mechanisms of wave breaking. In our case, Berre lagoon is situated in a windy area, and its size is large enough to permit wave systems to develop in the deeper part of the lagoon (9m). One part of the numerical study is to determine the 3D currents induced by the main forcing mechanisms (tide, wind, freshwater runoff) separately or concurrently for a pertinent range of the forcing parameters. About 10 of such scenarios (time-dependent for tide effect, or stationary without tide effect) have been considered. The numerical simulation is performed for the whole lagoon, and then, with a finer grid (1m x 1m), in subregions corresponding to the revegetation areas (typically 100m x 100m). For the purpose of revegetation (by transplantation), it is needed to add into the model the interaction between the meadow and the flow. Different phenomenological laws have been considered; such laws take into account the characteristics of the meadow (density, height and size of the leaves, in particular), but also the ratio of the water column depth to the meadow height. This is one of the reason for which a fine grid simulation is needed.

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Governing equations of hydrodynamics (code MARS3D-IFREMER):

Navier-Stokes equations:
+ Boussinesq approximation - $\rho' << \rho 0$
incompressible equation of continuity,
$\rho \sim \rho 0$ *in momentum equation except for the buoyancy term*
+ hydrostatic assumption - H<<L

$$u'_t + uu'_x + vu'_y + wu'_z - fv = -\left(1/\rho_0\right)P'_x + (nz \cdot u'_z)'_z + F_x$$

$$v'_t + uv'_x + vv'_y + wv'_z - fu = -\left(1/\rho_0\right)P'_y + (nz \cdot v'_z)'_z + F_y$$

$$u'_x + v'_y + w'_z = 0$$

$$P'_z = -g\rho$$

Boundary conditions

Boundary conditions on the free surface $z = \eta(x,y): \quad \rho_0 v(u'_z, v'_z) = (\tau_{0x}, \tau_{0y}), \quad w = u\xi'_x + v\xi'_y + \xi'_t.$

On the lower bottom boundary $z = -H(x,y): \quad \rho_0 v(u'_z, v'_z) = (\tau_{bx}, \tau_{by}), \quad w_b = -u_b u'_x - v_b v'_y.$

u, v, w – components of velocity vector, f – Coriolis force, ξ – free surface elevation, P – pressure,

nz – coefficient of vertical turbulent exchange, $F_x = (2Au'_x)'_x + (A(u'_y + v'_x))'_y, F_y = (2Av_y)'_y + (A(u'_y + v'_x))'_x,$

A – coefficient of horizontal diffusion, $(\tau_{0x}, \tau_{0y}), \ (\tau_{bx}, \tau_{by})$ –tension stress on the free surface and on the bottom

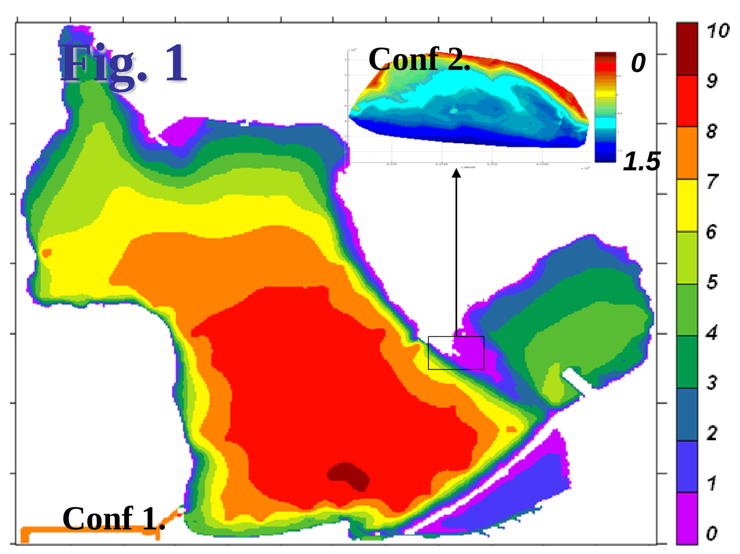
Observing area and simulation's scenarios

To understand which forcing parameter is more significant for the development of seagrass in the Berre lagoon, it was considered to model separately the currents driven by each parameter, separately and synergicaly:

- ***Tidal effect*** *without wind forcing and inflow from EDF-channel*
- ***Wind forcing*** *without tides and inflow of EDF-channel*
- ***EDF- channel inflow*** *without tide and wind.*
- ***Tidal effect + Wind forcing + EDF-channel inflow***

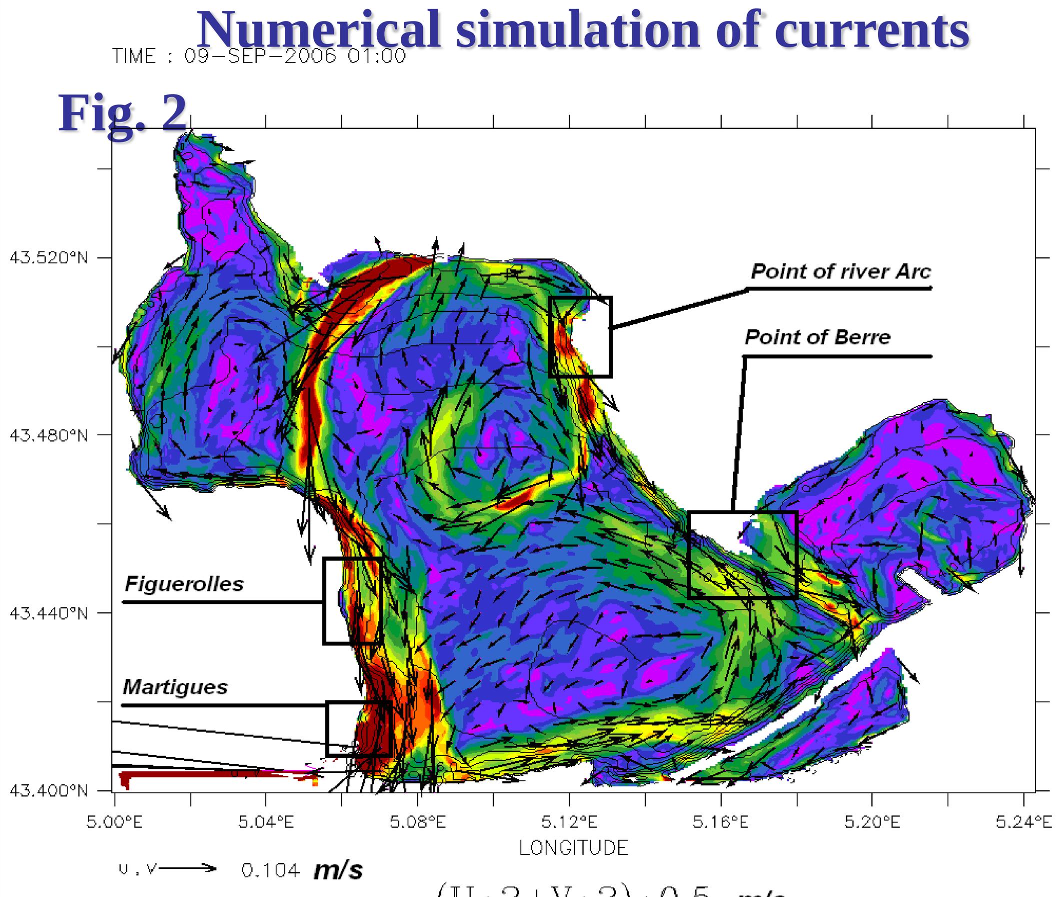
Conf1*: main map of Berre lagoon – grid 377*356 (each 50 m),*
Conf2*: zoomed map for the region of "Point of Berre" – grid 242*87 (each 1 m)*

Fig. 1



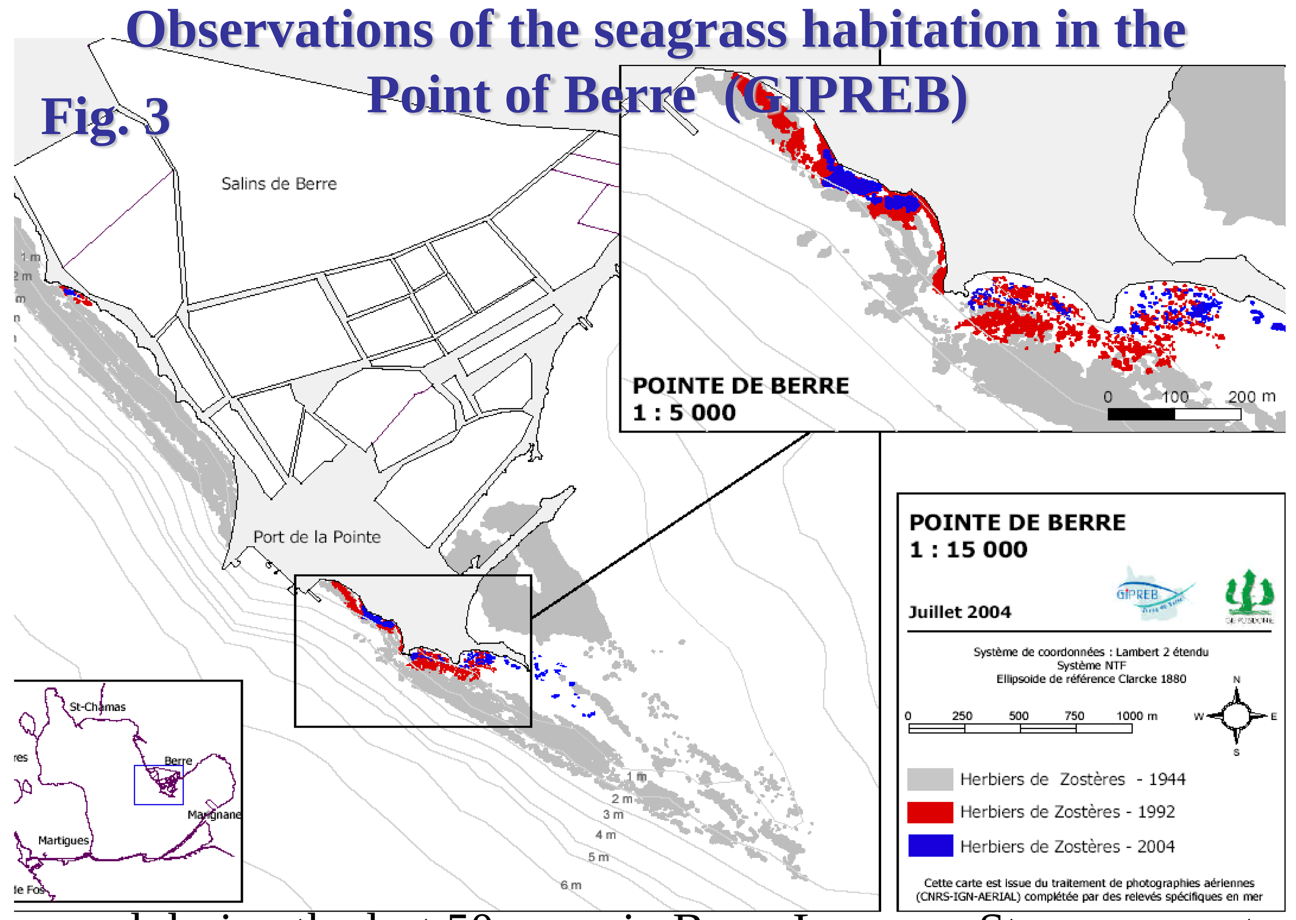
Numerical simulation of currents

Fig. 2



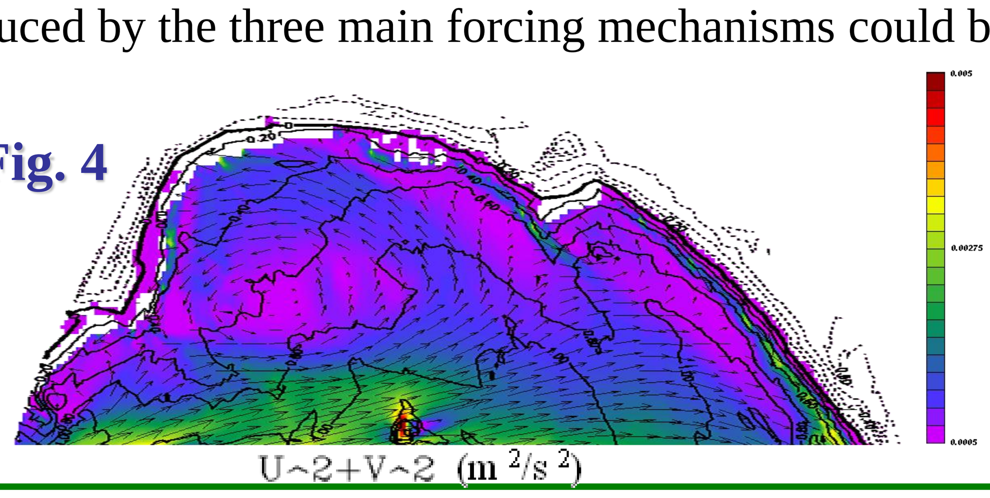
Observations of the seagrass habitation in the Point of Berre (GIPREB)

Fig. 3



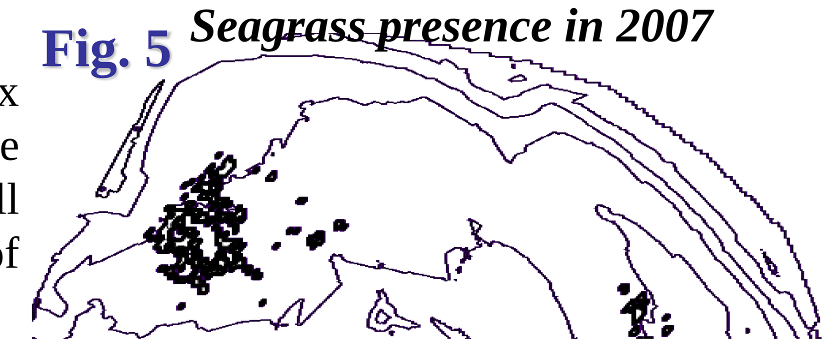
In rectangles are areas where seagrass regression is observed during the last 50 years in Berre Lagoon. Strong currents induced by the three main forcing mechanisms could be one of the reasons of the difficulty to recolonize seagrass.

Fig. 4



For N-NW wind, a vortex exists. In the vortex center the currents are less; that well corresponds to the place of remaining seagrass (2007)

Fig. 5 *Seagrass presence in 2007*



Results of numerical simulation

We consider a typical situation in which the three mechanisms occur concurrently: tidal cycle with amplitude of 30 cm and a half-period of 6 hours, N-NW wind and hydroelectric plant runoff of 200 m^3/s. In Fig. 2, rectangles correspond to the areas where seagrass regression is observed for 50 years. In two areas: Figuerolles and Martigues, the aquatic plants have completely disappeared. When considering the flow velocities in these areas, we see that near shoreline, it reaches high values (about 15-20 cm/s); so, it can be a cause of the seagrass disappearance in these regions. The two other areas, where sparse seagrass remains, were selected for revegetation after 2006 when the reduction of the hydroelectric plant runoff has been decided. As seen in Fig. 2, the velocity of the flow for typical meteorological conditions has the lowest values (about 8 cm/s for the Point of Berre, 12-15 cm/s for the Point of river Arc) in these regions compared with the two other control areas.

Numerical simulations have been performed for large values of the dominant N-NW wind - Mistral, and for large values of the hydroelectric plant runoff (200-250 m^3/s). Fig. 2,4 which represent barotropic flow (square of the velocity modulus), in terms of tidal cycle, N-NW wind 5 m/s, hydroelectric plant runoff of 200 m^3/s, in the Berre lagoon and the Point of Berre resp.).

Current attenuation in the seagrass meadow

The current attenuation by the seagrass has been considered by using the bottom roughness suggested by Nepf (1999) for Point of Berre area (red rectangle in Fig. 6). The following characteristics have been used: seagrass height l , shoot diameter d, number of shoots per m^2 n, ratio of seagrass depth to water depth of 70% and bottom roughness $z0$ given by:

$$z0 = \left(\sigma(1)(\xi + H) - H\right) / exp\left(k / \left(\left(1 - 0.003 / H\right) C_B + 0.5 \cdot 1.17 \cdot 0.3\right)^{0.5}\right)$$

Fig. 6

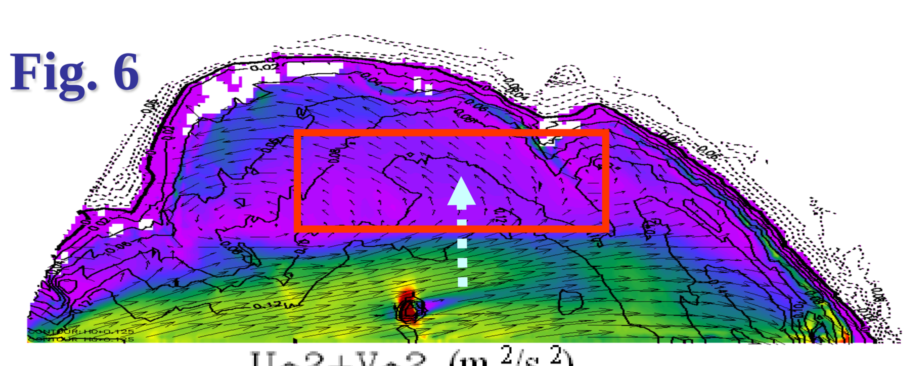


Fig. 7

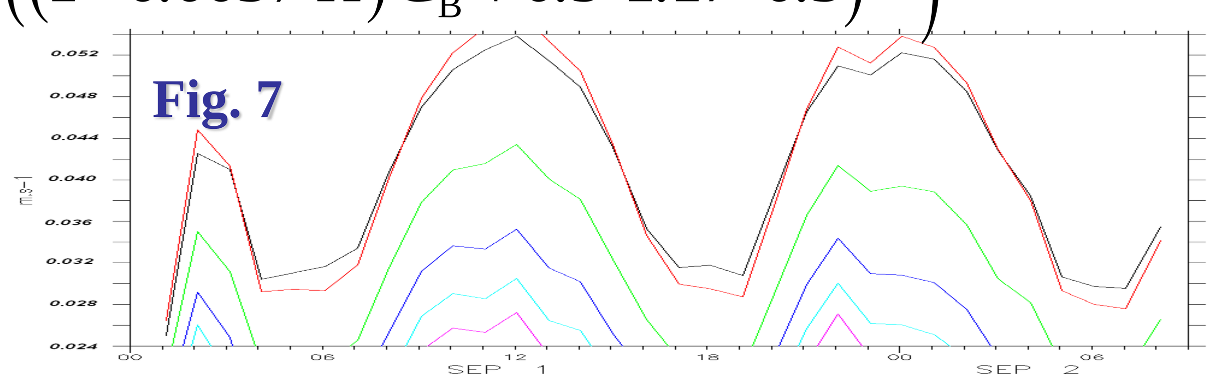


Fig. 7 - time evolution of frontal velocity component (black line – 1 m before entrance in rectangle with seagrass, red line – at the seagrass entrance, green line – 1 m after seagrass entrance, blue line – 2 m after seagrass entrance, light blue line – 3 m after seagrass entrance, rose line – 4 m after seagrass)

Perspectives

For the purpose of revegetation strategy, we plan to improve the model in two directions, to better understand the interaction between the seagrass meadow and the currents:

- Better evaluate the free surface elevation, to take into account correctly the ratio of seagrass depth to water depth.
- Consider the wave propagation up to the breaking: indeed, breaking has to be prevented, as it can play important role on the sediment resuspension (and so, turbidity).