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Link between the benthic layer and hypoxia events in a Mediterranean lagoon. Turbulence aspects.

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Introduction

The Etang de Berre, a Mediterranean lagoon located in the south of France (figure 1a), is submitted to an intermittent hypoxia event due to the stratification of the water column generated by discharges of fresh water from an hydroelectric power plant [1] (figure 1b). A specific study, the PREDHYPO project, supported by the University Foundation A*MIDEX, has been developed since one year in order to characterize processes and interactions controlling the oxygen and nutrients transfers within its benthic coastal ecosystem. Several aspects are explored: geochemistry, microbiology and macrobenthic dynamics. One of these is particularly interested in the influence of the benthic boundary layer turbulence on the oxygen consumption. A laboratory experiment has then been developed.



(a) Location



(b) Water fluxes (CNES - SPOT image)

Figure 1: Berre lagoon

Hydrodynamics of the water column above the sediment layer of the lagoon is explored by *in situ* and laboratory experiments. Experiments focus on the benthic boundary layer¹ and, more specifically, on the few centimeters-thick layer above the water/sediment interface. Large-scale hydrodynamics and its influence on hypoxia are relatively well-known. Although the small-scale effect near the sediment interface seems to have a role on the oxygen fluxes, its influence is not so well-documented. The hydrodynamics characterization at such a scale is then a technical challenge.

The role of turbulence on oxygen exchanges at the sediment interface is studied with laboratory experiments. Sediment cores (figure 2a) are sampled from the lagoon bottom in three different locations submitted to different oxic conditions: from oxic to anoxic levels. These cores are then incubated with different oxygenation status of the overlaying water. Flow turbulence is characterized by particle image velocimetry (PIV) for various stirring velocities of the overlaying layer. For each stirring velocity, oxygen consumption rate is also

¹ The benthic layer defines the few centimeters thick layer extending on and near the seabed where organisms (benthos) live.

measured. The analysis presented herein concerns cores collected in the oxic part of the lagoon.

Experimental device

Core chamber

Core chambers are plexiglas-made cylinders (15 cm diameter, 1 cm thick). Cores have been carefully collected without any perturbation of the natural medium at 7.5 m depth. A core is two-third filled with sediment and its highest one-third part is filled with lagoon overlaying water. Organisms live inside the core sediment and contribute to oxygen consumption.

Cores are placed in a transparent parallelipipedic water tank (figure 2b) completely filled with pure water. This trick makes the laser sheet path be insensitive to the core curvature.

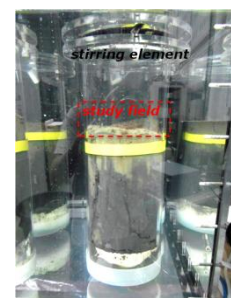
Turbulent flow is generated with a stirring device composed with an external motor magnetically driving a bar placed at the top of the core [2]. Rotation bar velocities vary from 20 rpm to 80 rpm. These have been chosen in agreement with standard oceanographer study for oxygen consumption.

Flow characterization

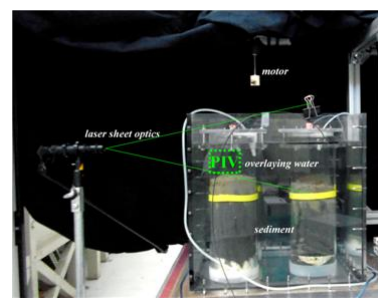
Turbulence in the overlying water column is characterized by PIV. The laser sheet is generated with a pulsed Nd:Yag laser (Spectra Physics Quanta Ray Pro Series, emission wavelength 532 nm, pulse frequency 10 Hz) and illuminates the part of the overlying water just above the sediment (figure 2b). Core water is seeded with glass microspheres (diameter 17 μm , density 1).

A Kodak camera (1008×1018 pixels, 10 Hz) is triggered with the laser and records one thousand flow image pairs. Home-made *DPIVSoft* software [3] processes image pairs and generates one thousand instantaneous velocity fields which are then postprocessed and statistically analyzed. Typical observed area is 6 cm × 6 cm. Interrogation windows size is 32 × 32 pixels, approximately corresponding to 2 mm × 2 mm.

The observation field is localized near the seabed and includes the symmetry axis of the core. Velocity mapping is performed along the diameter core. Radial (U) and vertical (V) components of the velocity are simultaneously measured.



(a) Sediment core



(b) Water tank side view

Figure 2: Experimental device

Oxygen concentration measurements

An oxygen probe is placed inside the core water and measures oxygen concentration expressed in percent of saturated air. Before the acquisition start, the oxygen level is set to its maximum value, here fixed to 100%. The core is then hermetically closed and oxygen concentration is sampled regularly. When the oxygen level has been reduced to 90% of saturated air, acquisition is stopped. Linear regression of oxygen decrease is then performed to obtain oxygen consumption rate.

Hydrodynamics characterization

Mean velocity maps (figure 3) exhibit a flow radial movement towards the center very near the sediment interface. An ascending flow is generated along the core axis. Large-scale flow in the water column is then conformable to the expected one [2]. The rotating bar drives water towards the core periphery. Water moves downwards along the wall and is then transported towards the center along the bottom. Then an ascending flow is created in the central zone of the overlaying water. For 36 rpm stirring velocity, the water core is complex with a high velocity peripheral region surrounding a more quiescent fluid.

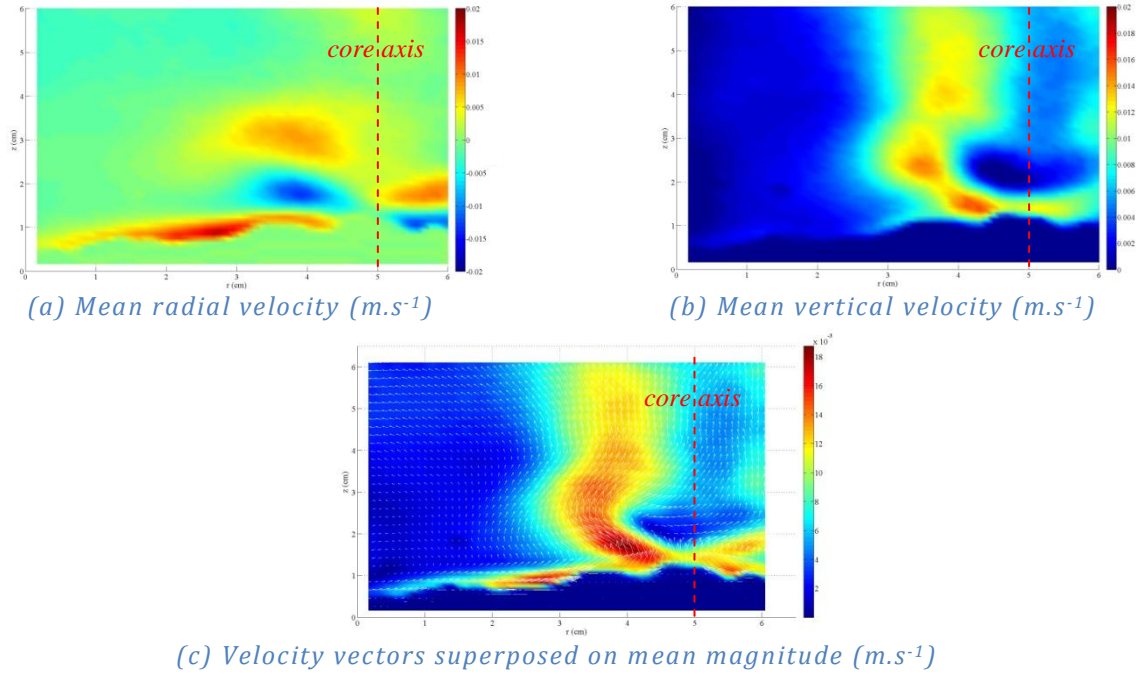


Figure 3: Velocity mapping for a stirring velocity 36 rpm

Shear is important in the central region near the interface where the peripheral high velocity region exists (figure 4a): Reynolds stresses $uv(=\overline{u'v'})$ changes its sign. The turbulent kinetic energy $k_t \approx \frac{1}{2}(\overline{u'^2} + \overline{v'^2})$ is rather strong in the same region (figure 4b). Turbulence is consequently more active near the core axis and at the sediment interface. On the contrary, it is quasi null in the vicinity of the cylinder edge.

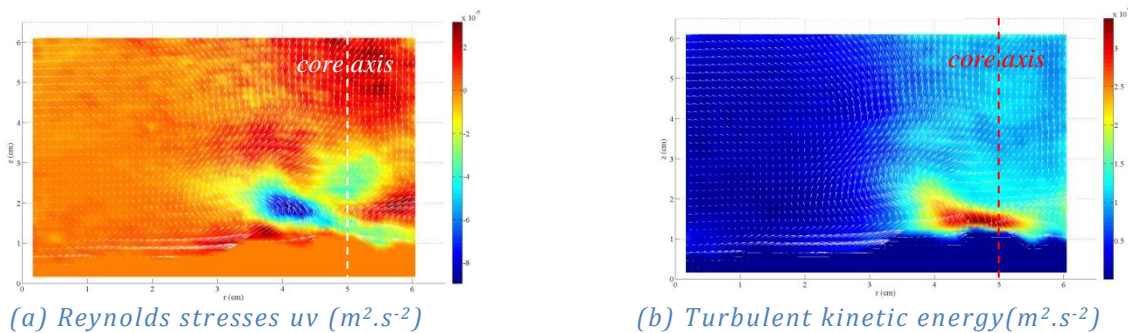


Figure 4: Velocity mapping for a stirring velocity 36 rpm

As expected, turbulent kinetic energy is enhanced by increasing stirring velocity particularly in the region near the centerline and in the neighbouring of the interface (figure 5).

Turbulence is mainly active in the 2 cm above the water/sediment interface near the core centerline. It is an interesting conclusion because of the questionable link between the few centimeters thick benthic layer and the oxygen consumption.

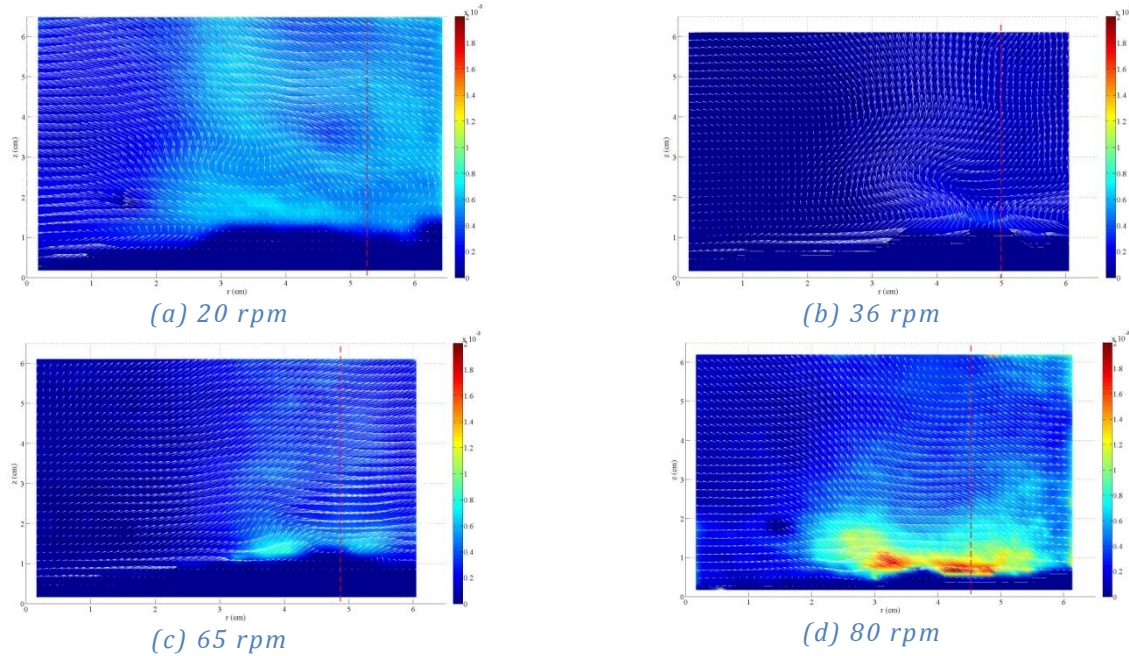


Figure 5: Turbulent kinetic energy ($\text{m}^2.\text{s}^{-2}$) for increasing stirring velocity (the red line indicates the approximated core centerline)

Oxygen consumption rates

Besides velocity measurements in the water column, the oxygen consumption has been measured for the same stirring velocities as previously. Figure 6 presents time decrease of oxygen in percent of saturated air in a core for various stirring velocities and for an initial 100% percent of saturated air oxygen level. For a better understanding, oxygen concentration has been non-dimensionlized by its initial value. The exhibited linear time decrease is an expected result.

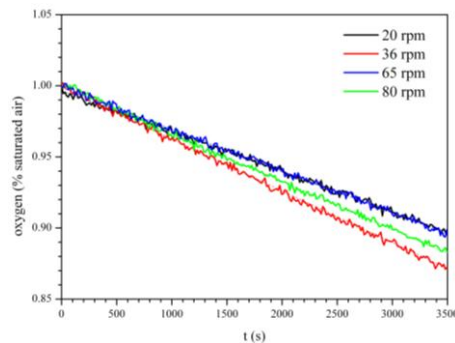


Figure 6: Oxygen consumption for different stirring velocities

The main problem to study oxygen consumption is that a core is a living medium. Indeed, two days separates oxygen concentration measurements. 20 rpm and 36 rpm cases have been performed the same day while 65 rpm and 80 rpm ones have been performed two days later.

In two days, water and sediment living organisms could be dying despite an existing water oxygenation. It means that we can directly compare, on one hand, 20 and 36 rpm cases and, on the other hand, 65 and 80 rpm ones.

Slope is 25% less for the 36 rpm velocity than for the 20 rpm one. Stirring and then turbulence tend to act highly on the consumption rate. Two days later, the 65 rpm slope is quasi equal to the 20 rpm slope, implying that less organisms are now living in the core. The slope fall is then only 15% from 65 rpm to 80 rpm velocities.

However, a global behavior can be exhibited with a stronglier oxygen concentration decrease for higher stirring velocities. Future experiments would have to be performed again to consolidate these results.

Conclusion

The aim of this study is to characterize the effect of turbulence on the oxygen consumption rate in the benthic layer. A laboratory experiment has then been developed. Sediment cores with various oxygen levels are submitted to different turbulence intensities. PIV measurements are performed to characterize flow turbulence and oxygen consumption has been measured in a parallel way. First results have been presented.

Turbulence has been shown to be mainly active in the 2 cm above the water/sediment interface near the core centerline. A high stirring velocity implying high turbulence obviously improves oxygen consumption rate within the core. Turbulence would clearly affect oxygen fluxes within this specific region.

Experiments have to be repeated to confirm this trend for different core samples to take into account the effect of the microtopography of the sediment interface and for different initial oxygen concentrations in the water column. Future core sampling in the Berre lagoon are already programmed.

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