

3D modelling of summer hypoxia in a highly turbid urbanized macrotidal estuary, coupling hydrodynamics, sediment transport and biogeochemical processes

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Motivation

- The Gironde estuary is one of the largest European estuaries, in terms of area, river flow and sediment fluxes.
- The influence of the tide and the residual circulation increases the time of residence of water and particles.
- A highly turbid turbidity maximum zone (TMZ) develops.
- Because of light attenuation, heterotrophy is favored in the TMZ, which is often oxygen depleted.

- In summer:
 - water temperature increases: biogeochemical reaction rates are enhanced.
 - river flow decrease moves the TMZ up estuary, in Garonne around of Bordeaux city and in Dordogne rivers.
 - contribution of urban effluents proportionally increases with river flow decrease.

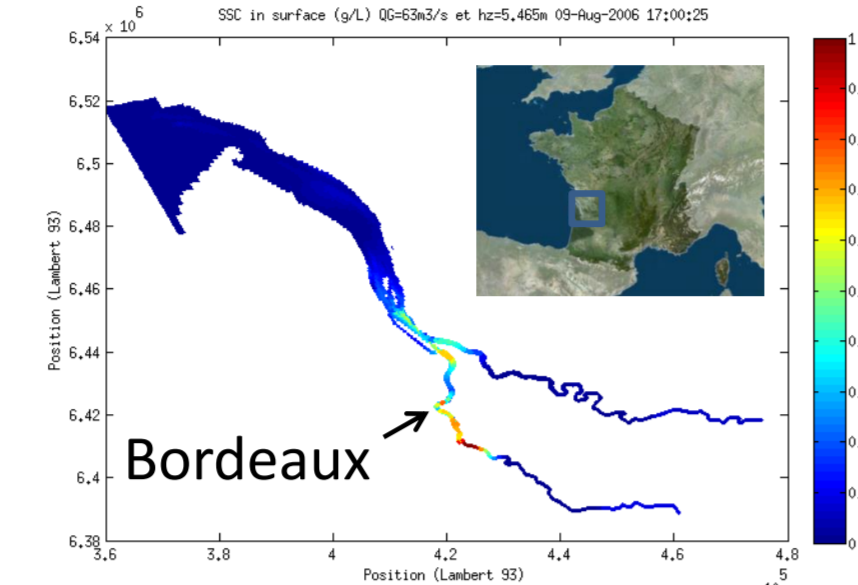


Fig 1: SSC in surface (g/L) in summertime

- Summer hypoxia events appears in the Garonne in the presence of urban effluents.

The aim is to answer these questions:

- What are the relative contribution of the TMZ and urban effluents?
- What are the impact of climate change (low river and temperature increase) ?
- Which biogeochemical processes (organic matter degradation, nitrification) dominate?

Methods

- A three-dimensional dissolved oxygen model was developed by coupling hydrodynamics, sediment transport and biogeochemical processes.
- Our model describes the transport of solutes and suspended material, and the major biogeochemical mechanisms.
- The parameter values are based on original experimental data on the study site.

14 variables:

- Particulate organic carbon from litter and dead phytoplankton: POC_{litter} and $POC_{detrital}$
- Particulate organic carbon from phytoplankton: $POC_{phytoplankton}$
- Dissolved organic carbon from river: $DOC_{fluvial}$
- Particulate and dissolved organic carbon from urban effluents (CSO: Combined Sewer Overflow and WTP: Wastewater Treatment) : POC_{CSO} , POC_{WWTWP} , DOC_{CSO} , DOC_{WWTWP}
- Dissolved oxygen, ammonium and nitrate: O_2 , NH_4 and NO_3
- Suspended sediment concentration (SSC) and salinity

7 biogeochemical reactions :

- photosynthesis is limited by light
- respiration and mortality of phytoplankton
- mineralization of POM and DOM in water
- mineralization of POM in the mud
- nitrification
- aeration

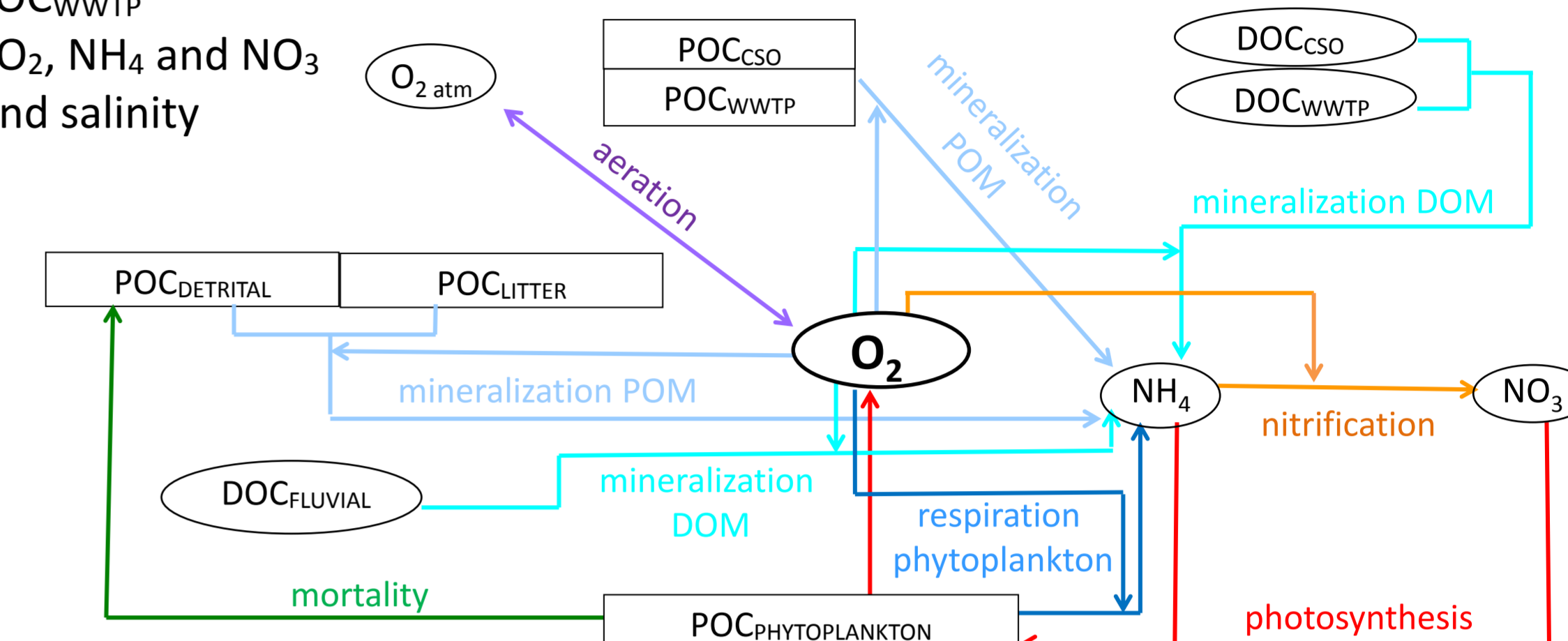


Figure 2: Principle of biogeochemical model developed for the Gironde estuary

Results/Discussion

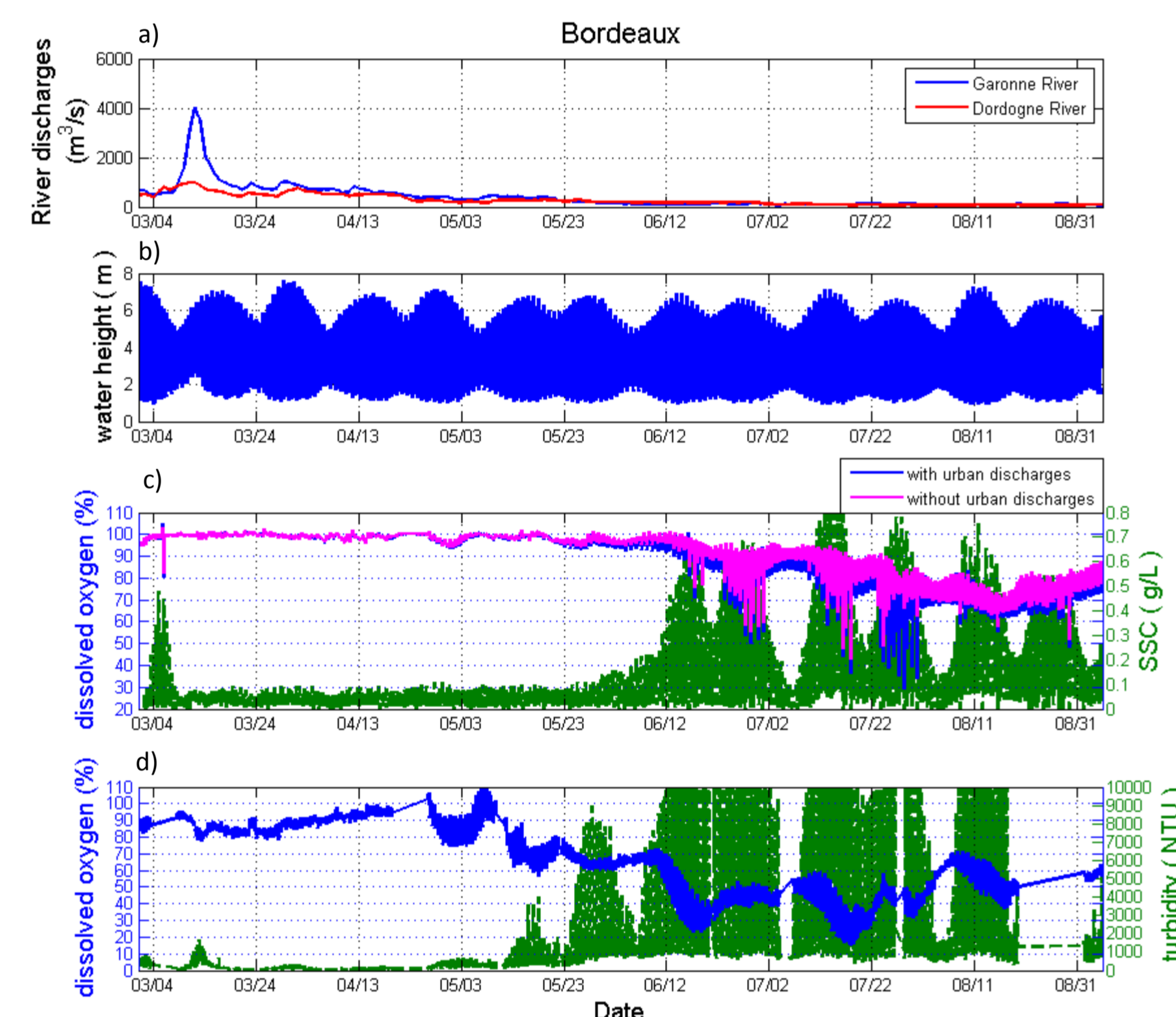


Figure 3: Simulation between 1st March and 5th September 2006.

- Garonne and Dordogne rivers discharges (m^3/s).
- water height (m) at Bordeaux.
- simulated SSC (g/L) and dissolved oxygen (%) at Bordeaux, with discharge of urban effluents (blue) and without (magenta).
- in situ observations: records of turbidity (NTU) and dissolved oxygen (%) at Bordeaux.

The oxygen model results show that:

- There is a correlation between the decrease of dissolved oxygen and the presence of TMZ at low river flow, which occurs in summertime.
- The wastewater discharge into the Garonne river (around the city of Bordeaux), enhances the decrease of dissolved oxygen of about 5 %.
- The model greatly underestimates SSC, below 1 g/L ($10000 \text{ NTU} \approx 6 \text{ g/L}$) and consequently, dissolved oxygen is overestimated.

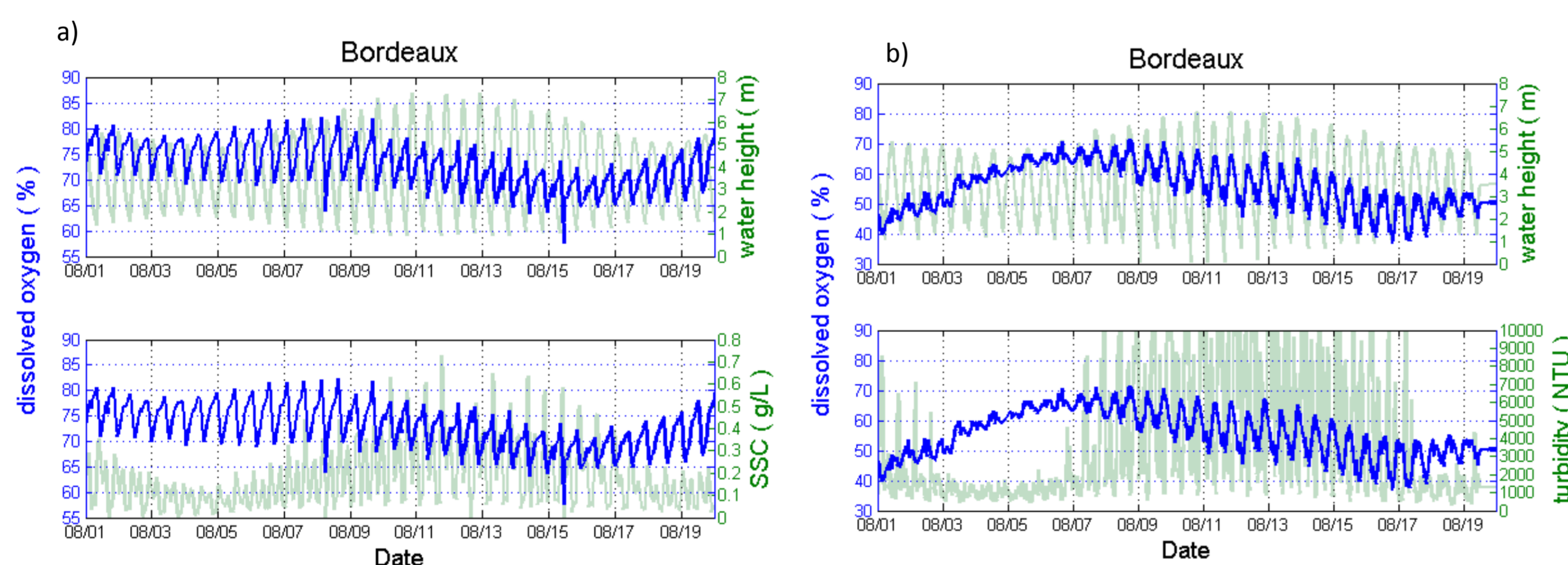


Figure 4: Simulation between 1st and 20th August 2006, with presence of urban effluents. At left (a) the simulated values and at the right (b) observations at the Bordeaux station. At the top, dissolved oxygen in % (in blue) and the water height in m (in green). At the bottom, dissolved oxygen in % (in blue) and the SSC in g/L (in green).

The observations and model results are in agreement qualitatively:

- dissolved oxygen decreases during the spring to neap tide transition, this is associated to the organic matter in the TMZ.
- amplitude of dissolved oxygen is high during the spring tide compared to neap tide, which reveals that oxygen consumption processes are enhanced.
- dissolved oxygen increases again during the neap tide.
- At the scale of the tidal cycle, and contrary with observations, the model simulates the oxygen minimum at high tide instead of low tide.

References

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Monthly minimum of dissolved oxygen ($\mu\text{mol/L}$)

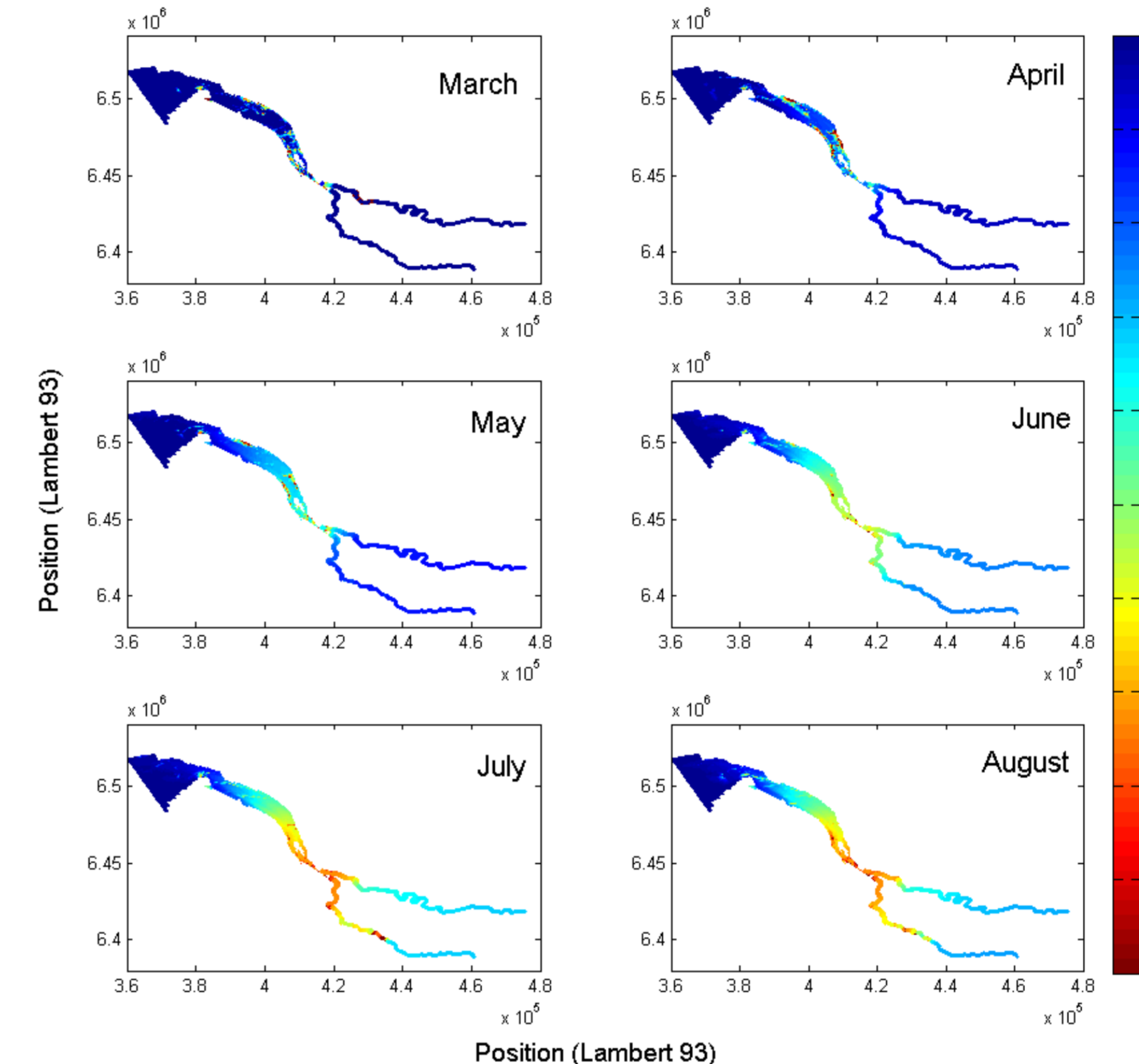


Figure 5: monthly minimum of dissolved oxygen ($\mu\text{mol/L}$) at the surface, with the presence of urban effluents discharges.

- The zone of minimum oxygen extends at the beginning of the summertime.
- The minimum dissolved oxygen is in a lower position compared with observations (not shown).

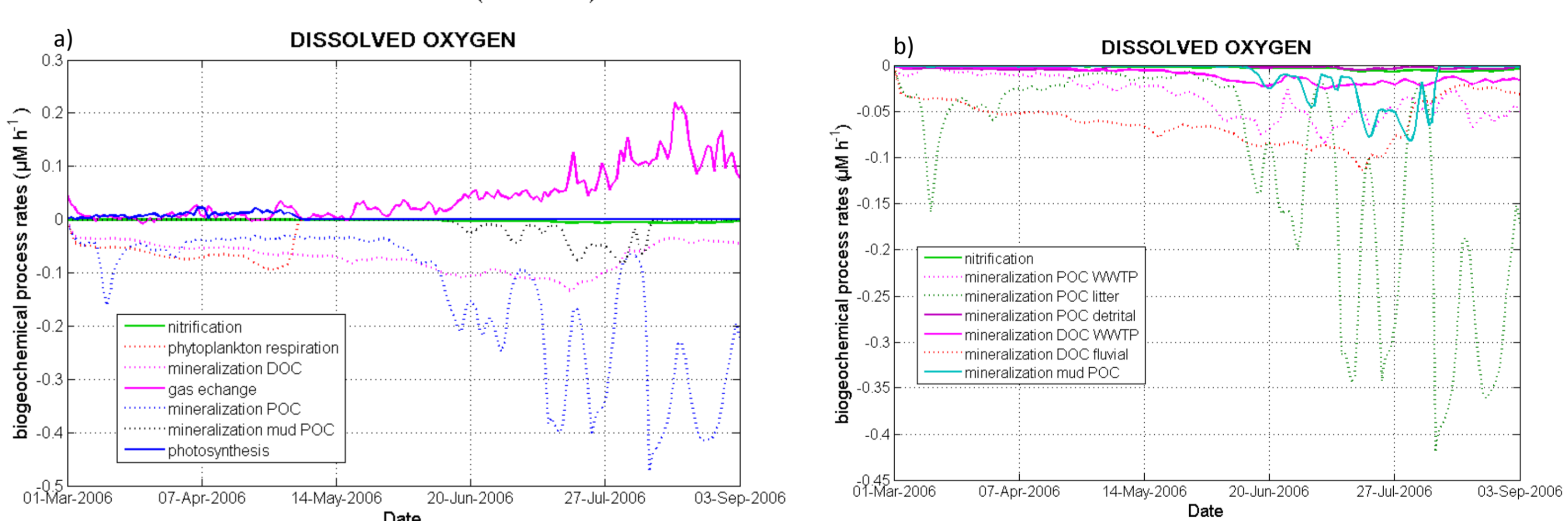


Figure 6: Simulation between 1st March and 5th September 2006 in the Bordeaux area, with presence of urban effluents.

- Evolution of daily averaged values of individual biogeochemical processes rates that affects dissolved oxygen.
- Same variables, but distinguishing different POM and DOM origins.

The influence of biogeochemical processes affecting dissolved oxygen shows:

- The consumption of oxygen by mineralization of litter POM dominate .
- The gas exchange of dissolved oxygen with atmosphere is very important.
- The intensity of nitrification processes is very low in the model.

Conclusions

- A 3D dissolved oxygen model has been implemented in the Gironde estuary. First results, with minimum calibration, reproduce satisfactory a decrease of dissolved oxygen saturation in summertime. This decrease is more important under impact of urban discharges.
- At the scale of the spring neap tide, dissolved oxygen decreases when the transition to spring at neap tide. This corresponds with the maximum SSC.
- At the present state, modelled dissolved oxygen concentrations are too high and the suspended sediment concentrations are too low compared to observations.
- The dissolved oxygen concentration is inversely correlated with tidal cycle.

Ongoing and perspectives

- Improve hydrodynamics and hydro-sedimentology, in order to better simulate the TMZ in the upstream region of the estuary in summer.
- Improve kinetics parameters of nitrification.

Once the dissolved oxygen model is calibrated, different scenarios will be tested:

- The increase of water temperature due to global warming.
- Wastewater discharge from Combined Sewer Overflow during summer storm event.
- The management of urban effluent discharge as a function of tidal patterns.