BIOGEOCHEMICAL FLUXES ACROSS THE GULF OF LIONS : A COUPLED MODELING APPROACH

Marie-Hélène Tusseau-Vuillemin [1] and Laurent Mortier [2]*

[1] Institut de Biogéochimie Marine - Ecole Normale Supérieure, 1, rue Maurice Arnoux, 92120 Montrouge, France
[2] Ecole Nationale Supérieure des Techniques Avancées, 32, boulevard Victor, 75015 Paris, France

Abstract.
A thirteen compartment biogeochemical model has been coupled with a general circulation model so as to quantify the exchanges between the Gulf of Lions and the open Mediterranean. Quasi-equilibrium is obtained after one year of spin-up simulation, and model computations compare reasonably well with field data. Nitrate inputs from the Rhône river, the sediment and marine advection are compared. Regarding the open sea, the margin acts most of the time as a nitrate sink. During winter, however, it is shown to export nitrate toward the open sea through cascading of dense waters.

Key-words : nitrogen, circulation models, Gulf of Lions

Introduction

The Gulf of Lions is one of the major margins in the western Mediterranean (~20000 km^2) and forms a shallow receptacle for the most important Mediterranean river, the Rhône. The oligotrophic character of the Mediterranean sea is locally counterbalanced by continental inputs of nutrients (1), as shown by CZCS images that reveal a permanent higher productivity in the Gulf of Lions than in the adjacent area (2). Whether this river impact is confined to the coastal area or can extend offshore remains poorly understood and depends both on the biogeochemical functioning of the Gulf of Lions and on its exchanges with the open sea. In order to obtain some insight into the nitrate cycle from the Rhône river toward the open sea, we developed a coupled three-dimensional biological model of the Gulf of Lions.

Methodology

General circulation model. The hydrodynamics of the Gulf of Lions has been numerically simulated with a general circulation model covering the whole northwestern Mediterranean Sea (8.5°W-17°E x 34.8°N-44.8°N), whose results have been truncated to our area of interest (2.5°E-7°E x 41.5°N-43°N). This finite difference, primitive equation model has previously been described in (3, 4, 5). For this simulation, the horizontal grid mesh is 1/8° in longitude and 1/10° in latitude (*i.e.* ~11 km x 11 km). 31 vertical levels (z-coordinates) of increasing thickness are used (6 m at the surface, 140 m at the bottom). The bottom topography is based on the DBD5 atlas. This rather coarse resolution does not allow to describe mesoscale processes, but the northern current and the deep water formation are well simulated (5, 6).

Biological model. The biological model describes C, N and Si cycling through the pelagic food-web as represented by thirteen compartments. The model is described *in extenso* elsewhere (7 and 8). Emphasis has been given to the mechanisms describing photosynthesis and organic matter degradation (9, 10). The nitrate stock can be renewed only by mixing with the deeper layers, whereas ammonia is part of a complex remineralization loop involving bacteria, zooplankton and heterotrophic nanoflagellates. Detritic silica settles down and is progressively dissolved throughout the water column. The calibration of the biogeochemical model was achieved on a one-dimensional basis (7), with a one-year data set (twelve 200 m-profiles of temperature, salinity, NO_3, Si and chlorophyll) available from a fixed FRONTAL station (43°24'N, 07°52'E, Fig. 1) commonly used for 1D models (*e.g.* 11).

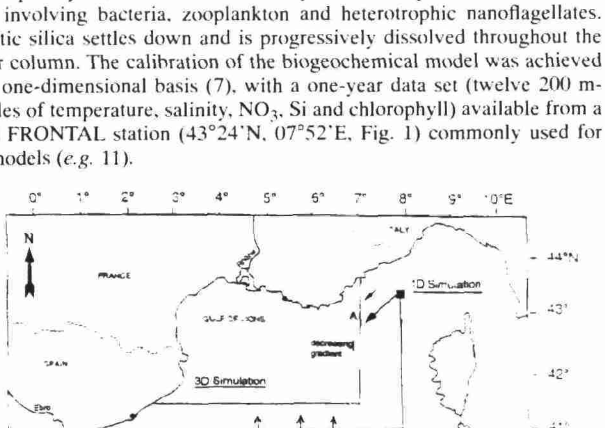

Fig. 1 : The simulation domain and a schematic description of the boundary conditions.

Three-dimensional model. The biological model has been carried in an off-line mode with a sub-sampling and an averaging every ten days of the velocity, temperature and salinity. The advective scheme is of FCT type, based on the antidiffusive correction algorithm (12). No explicit horizontal diffusion was included.

The thirteen biogeochemical equations ($\partial C/\partial t = -\{\partial(uC)/\partial x + \partial(vC)/\partial y + \partial(wC)/\partial z\} + D_X^H + D_X^V + (\text{Biol.evolution})$)) are simultaneously solved using a fourth-order Runge-Kutta scheme (13) with a 1 hour time-step.

Initial conditions. Initial conditions have been obtained after a one year spin-up run leading to global stationality.

Boundary conditions. As eastern and southern boundary conditions, we used for all biogeochemical compartments the 1D simulation realized during the calibration phase at the eastern entrance of the Gulf of Lions (7, Fig. 1). In order to represent the well-known, dome-shaped structure of the Ligurian Sea divergence, we applied a south-north decreasing gradient to the boundary conditions, as estimated after the Prolig cruise's measurements (14). The exact formulation is given in (8).

As our model does not describe the early diagenesis in the sediments, we had to parametrize the nutrient fluxes at this interface. We take them into account by setting the concentrations of NO_3, NH_4 and Si equal to an observed value, in the bottom layer of the model and at each time-step. These values are spatially and temporally interpolated from a five cruise data set (EROS 2000 project).

The Rhône river has been coarsely described as a pinpoint source of nutrients (NO_3 and Si). The seasonal variations of the nutrient fluxes are described with a statistical model based on a twenty year time-series of data on discharges and nutrient concentrations (1). No non-point source of nutrient is considered. Finally, the atmospheric flux of nutrients was neglected at the scale of the Gulf of Lions, following (15)

Validity of the results. The biological model has been calibrated and thoroughly investigated apart from a three-dimensional simulation (7). The three-dimensional simulation has been compared in detail with available data and shown to provide satisfying results (8).

Discussion : Nitrate fluxes

The quasi equilibrium obtained for all the biogeochemical compartments (8) allows us to analyze the simulated fluxes on an annual scale. We consider here a "margin box", defined as the upper 200 m of the portion of the water column where depth is less than 500 m (Fig. 2, in white). We integrate the daily nitrate fluxes due to biological uptake by phytoplankton (Bio), sediment release (sed), Rhône river discharge (Rhône), vertical turbulent mixing (Mx), zonal (Z), meridional (M) and vertical advection (V) in the margin box. The annual budget of these fluxes is given in Table 1.

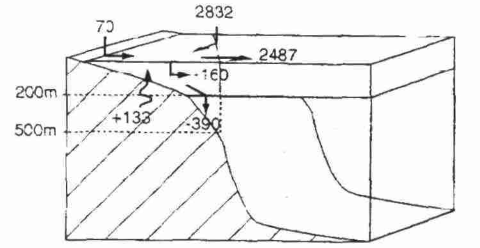

Fig. 2: Schematic description of the margin box (200 upper m where depth is less than 500m) and of the nitrate fluxes analyzed in the discussion.

Table 1 : Predicted integrated annual fluxes of nitrate (thousands of tons of N-NO_3) through the margin box (Fig. 1, in white). The last column (Total) displays the global annual budget for the margin box, which would be equal to zero if the model would be fully stationnary.

Bio	Sed	Rhône	Mx	Z	M	Z+M	V	Z+M+V	**Total**
-159	+133	+71	(+0.3)	+2832	-2487	+345	-390	-45	**(-0.1)**

Z and M are by far greater than the other fluxes, which underscores the predominance of horizontal transport in terms of mass balance. Z and M roughly compensate each other, Z being a positive flux entering the margin box at the eastern boundary, M being the negative flux going out at the southern boundary. Due to the non-divergence of the flow, the water trans