

ZOOPLANKTON TRANSPORT AND DISTRIBUTIONS IN THE GULF OF LIONS: ESTIMATES FROM A LAGRANGIAN MODEL AND OPTICAL REMOTE SENSING DATA

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ABSTRACT

We develop a Lagrangian model to simulate the transport and distributions of zooplankton in the Gulf of Lions (GoL) coupling with the circulation model Symphonie and an individual based model (IBM). We consider zooplankton behaviour using a simple swimming pattern. Chlorophyll *a* concentrations retrieved from SeaWiFS data are used to estimate the food concentrations of the IBM. Individuals are released in the Rhône river plume from May to October 2001 and are tracked for 40 days. Results suggest that passive individuals spread in the GoL but different patterns occur depending on the season and the initial depths of release. About 16% to a half of individuals remain in the GoL and the percentages of particles released at deeper layers are higher than those at upper layers. From June to September simulations with swimming behaviour increase the number of particles remaining on the shelf compared to simulations of passive particles. The zooplankton transport and distributions are strongly related to the hydrodynamic structures and zooplankton swimming behaviour connected with food.

Index Terms— Zooplankton, Lagrangian, Gulf of Lions

1. INTRODUCTION

Investigating the relationships between zooplankton and marine ecosystems is crucial to understand the mechanisms guiding the biological production^[2]. Owing to its natural complexity, zooplankton cannot be fully studied only using in situ observation and laboratory experiments. Lagrangian particle-tracking models are particularly efficient tools for zooplankton dispersal simulation. They are often used to examine the role played by various physical processes, to study transport processes over an entire basin and to simulate complex and interactive processes acting at different scales^[13,16,20].

Zooplankton organisms are critically dependent on their physical environments but they are not necessarily passive

particles^[2,5]. They swim vertically which influences their spatio-temporal distributions.

In order to study zooplankton behaviour, individual based models (IBMs) are often used as they are able to represent important properties for coupling individual behaviour and physical processes^[2,7]. As the swimming behaviour depends on several individual characteristics such as size, weight and development stage, several authors have increased the complexity of their models to simulate growth and development of individuals^[7,16]. IBMs of zooplankton have been coupled to circulation models (or observations), and particle-tracking including behaviour has been used to examine sources, sinks, and retention of plankton in dynamically changing flow fields^[4,22].

Phytoplankton is important for IBMs as food of zooplankton. Phytoplankton can be estimated from ecosystem models^[7]. It can also be derived from remote sensing data. The satellite-mounted optical sensors (e.g. SeaWiFS, MODIS) capture images that are calibrated, analyzed and processed in order to extract information about chlorophyll *a* concentrations and other biogeochemical properties^[11]. Uitz et al.^[21] have examined the potential and derived the functions of using the near-surface chlorophyll *a* concentrations to infer the vertical distributions of phytoplankton.

The Gulf of Lions (GoL) is an interesting area to study the influence of water circulation and estuarine inputs on biological activity and distribution. The GoL is one of the most productive areas in the Mediterranean owing to important river discharges from the Rhône river, strong wind mixing on the shelf, eddy, upwellings and vertical mixing. Furthermore, the GoL is a major anchovy spawning area in the North Western Mediterranean (NWM)^[8,17], owing to its relative high primary production over the year^[6].

In this paper, we use a Lagrangian model coupling with the circulation model Symphonie and an IBM to estimate the zooplankton transport and distributions in the GoL. Our goal is to investigate the influence of hydrodynamic processes and swimming behaviour on zooplankton transport and distributions. In the following text, the term “particles” will be used to describe zooplankton individuals.

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2. MATERIALS AND METHODS

2.1. Circulation model

The time-varying three dimensional (3D) flow fields in the GoL have been constructed by the circulation model Symphonie. A detailed description of the model is given by Marsaleix et al.^[14] and references therein. During last ten years the model has been successfully used for several studies in the NWM^[1,9,18]. The modelling results have been recently validated using the satellite measurements by Bouffard et al.^[3].

2.2. Individual based model

The IBM is based on the model built by Francois and Wolf^[7]. Growth of weight depends on ingested food and simulated as follows:

$$\begin{aligned} \text{Ingestion} &= \text{Mean}(\text{Grazing}) \times dt \\ \text{Grazing} &= 1.72 \times 2.1^{(\text{Temp}/10)} \times (\text{Weight})^{0.8} \times \\ &\min\left(1, \frac{\max(\text{Food}-5, 0)}{100}\right) \\ \text{Egestion} &= 0.3 \times \text{Ingestion} \\ \text{Respiration} &= (0.01 \times (\text{Weight})^{0.8} \times 3.4^{(\text{Temp}/10)}) \times \\ &dt + 0.02 \times \text{Ingestion} \\ \text{Weight}(t+1) &= \text{Weight}(t) + \text{Ingestion} - \text{Egestion} - \\ &\text{Respiration} \end{aligned}$$

Here dt is the time step of the IBM and set as one hour. $Temp$ and $Food$ are temperature and food concentrations at the place where particles located. Temperature is from the output of the Symphonie and food concentrations are estimated from SeaWiFS data. The initial weight of individuals is set as $0.05\mu\text{gC}$ and the maximum is set as $100\mu\text{gC}$.

2.3. Food concentrations estimated from SeaWiFS data

In this paper, we consider only phytoplankton as food. The 8-day composited surface chlorophyll a concentration data from the SeaWiFS sensor are used for the model region (Fig. 1). The vertical distributions of phytoplankton concentrations are assessed based on the surface chlorophyll a concentrations by using the functions derived by Uitz et al.^[21]. Chlorophyll a values are converted to carbon concentrations (the units for food uptake in the IBM) using a C:Chl ratio of 50^[10].

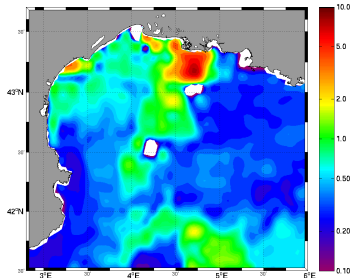


Fig. 1. Interpolated 8-day composited surface phytoplankton density map for the model region from May 1 to May 9, 2001. Values are in mgm^{-3} .

2.4. Lagrangian particle-tracking model

The Lagrangian particle-tracking model has been introduced by Qiu et al.^[19], using an advanced fourth-order accurate Adams-Bashford-Moulton predictor-corrector scheme to integrate $d\vec{x}/dt = \vec{u}(\vec{x}, t)$ over time given the initial condition $\vec{x}(t_0) = \vec{x}_0$. The right-hand side is comprised by a series of stored 3D velocity fields and zooplankton swimming velocity:

$$\vec{u}(\vec{x}, t) = \vec{u}_{sym} + \vec{u}_{swim}$$

The item \vec{u}_{sym} is interpolated in time and space of the daily average velocity fields from the Symphonie, i.e. the velocity values are linearly interpolated from the eight nearest grid cells.

The item \vec{u}_{swim} is treated in two ways: (i) zooplankton are considered as passive drifters for which the transport processes are determined uniquely by the velocity fields; (ii) swimming behaviour has been considered as follows: if a particle is above 50m at 06:00, it will swim down from 06:00 to 08:00; from 18:00 to 20:00 all particles will swim to the layer where the maximum food concentrations located. Otherwise the zooplankton transport processes are only determined by the velocity fields. The maximum depth of particles is fixed to 2m upper than the bottom. The swimming speeds vary as a function of zooplankton weight:

$$\vec{u}_{swim} = \alpha \sqrt[3]{\text{Weight} - 0.05}$$

Here α is a constant and equal to 43.089. $Weight$ is zooplankton weight in a range $0.05\text{-}100\mu\text{gC}$, which is calculated in the IBM.

2.5. Model settings and simulation analysis

After accurate sensitivity tests and considering computing time constraints we decided to run the particle-tracking model with a time step of 300s . We release 1340 particles in the Rhône river plume. These particles are released in a rectangle area of $50 \times 18\text{km}$ (the center 4.8°E , 43.2°N) and at four different depths (5m , 20m , 50m and 80m).

Particles are released at the first days of each month from May to October, 2001 and tracked for 40 days. Although the life spans of different species vary considerably, we use 40 days because they would represent one life duration of many species^[15].

3. RESULTS AND DISCUSSIONS

For the sake of simplicity we show final distribution patterns of particles in June (Fig. 2) representative of the whole set of simulations (from May to October).

3.1. Fate of passive particles

Particles spread in the GoL but with notable differences depending on the month and the initial depths of release. In Fig. 2A we can see that particles scatter almost anywhere on the shelf. After being tracked for 40 days some particles remain in the GoL and others spread on the shelf slope.

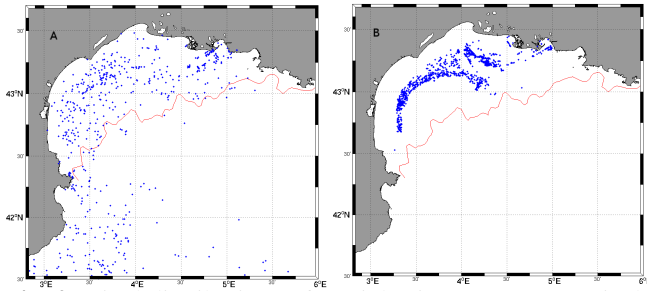


Fig. 2. Final distributions of particles in June: (A) passively (B) with swimming behaviour. Red line remarks the 200m isobath.

The percentages of particles remaining in the GoL are shown in Fig. 3 for different months and different initial depths. Following the season between 16% to an half of particles remain in the GoL, with the maximum in July and the minimum in September. About 35% to 85% of particles released at deeper layers remain on the shelf. These percentages are higher than those of particles released at upper layers (8% to 45%).

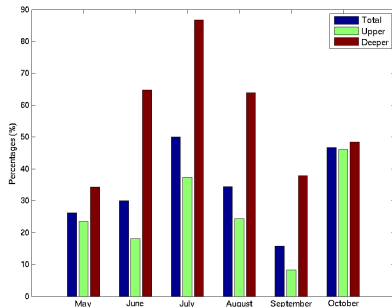


Fig. 3. Percentages of particles remaining in the GoL. “Upper” means percentages of particles released upper than 45m, “Deeper” represents percentages of particles released deeper than 45m and “Total” remarks all particles.

Particle distributions are strongly related to the hydrodynamic structures on the shelf. A large number of particles remain in the GoL especially particles released at deeper layers. One reason is that the shelf circulation is weak in the main areas of the GoL (data not shown). Thus the transport speed of particles is small. Another reason is due to gyres and eddies on the shelf^[12]. When particles enter in, they are prevented escaping from the GoL.

3.2. Fate of particles with swimming behaviour

Simulations with swimming behaviour present that a large number of particles finally remain in the GoL and the distribution patterns vary depends on months. The initial depths of release do not seem to affect the final distribution patterns. The percentages of particles remaining on the shelf are almost the same for different initial depths of release (data not shown).

Compared to simulations of passive particles, simulations with swimming behaviour show less spreading in particle dis-

tribution patterns (Fig. 2B). Most of the particles concentrate in the central part of the GoL.

We calculate differences between percentages of particles remaining in the GoL in simulations of passive particles and those with swimming behaviour (Table 1). Compared to simulations of passive particles, an obvious increase in the number of particles on the shelf is observed in the simulations with swimming behaviour from June to September. However, a decrease is observed in October.

Table 1. Differences in particles remaining in the GoL of simulations with swimming behaviour and those of passive particles (%)

May	June	July	August	September	October
0	+70	+45	+65	+65	-28

The trajectories of one particle released at 20m simulated in May with and without swimming behaviour are presented in Fig. 4. Only affected by the 3D flow fields, the particle stays in the layers upper than 10m at most of the time. The diel vertical migrations are obviously observed for the particle with swimming behaviour. The particle is obliged to swim deeper to avoid visual predators in the day and swims to feed in relatively productive surface waters at night. The swimming speed increases with weight. The growth of weight calculated in the IBM is also presented in Fig. 4. When the particle is in deeper waters, the growth of weight pauses. That is because phytoplankton concentrations are low in deeper waters and therefore ingestion of particles is low.

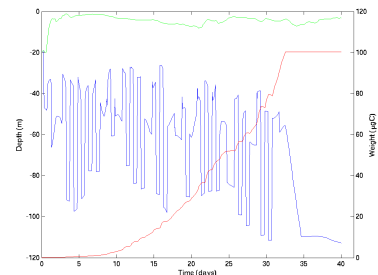


Fig. 4. Vertical migrations of one individual released at 20m tracked passively (Green Line) and with swimming behaviour (Blue Line). Growth of weight (Red Line) of the individual is also plotted.

The maximum food concentrations are in the layers of about 30-50m (data not shown). Therefore most of particles in simulations with swimming behaviour stay in the layers deeper than 30m. The diel vertical migration is one reason why more particles remaining in the GoL from June to September in simulations with swimming behaviour compared to those of passive particles. It can also explain the decrease in October combined with the flow fields. The monthly average circulation patterns at 50m in October are shown in Fig. 5. A strong current is observed in the Rhône river plume as the intensity about $0.1\text{m}\cdot\text{s}^{-1}$. The current flows westwards and then southwards, which will carry particles quickly out of the GoL.

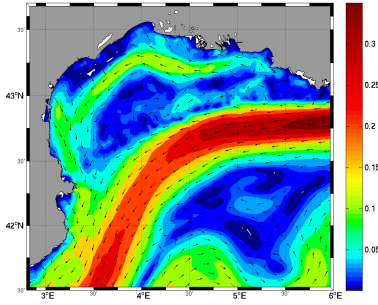


Fig. 5. The intensity of the monthly average currents ($m.s^{-1}$) at 50m in October. Black arrows represent directions of currents.

4. CONCLUSIONS

We develop a Lagrangian model to simulate the transport and distributions of zooplankton in the GoL coupling with the 3D circulation model Symphonie and an IBM.

Our results suggest that the particle transport and distributions are strongly related to the hydrodynamic structures and zooplankton swimming behaviour connected with food. Particles spread almost anywhere in the GoL after being transported passively for 40 days, when released in the Rhône river plume. The distribution patterns and the number of particles remaining in the GoL depends on the season, the initial depths of release and the swimming behaviour.

In this paper we only consider the influence of advection and the swimming scheme is overly simple. As a next step, we will include diffusion and more biological processes during the life time of particles and associated changes in swimming velocity.

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