Transport of plankton in the Benguela upwelling system.

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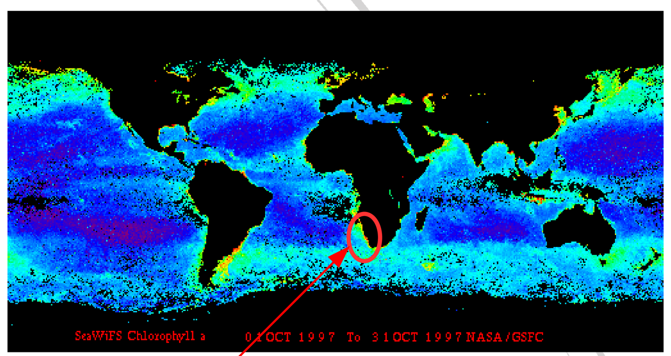
Abstract

We study the interplay of hydrodynamic transport and plankton dynamics in the Benguela upwelling system. We use a coupled system of oceanic flow and a simple biogeochemical model (NPZ type). For the oceanic flow we use two different velocity fields: a) one derived from altimetry data from satellite to study the surface dynamics, and b) from a 3D numerical model, which allows to study the vertical component. We study the effect of the horizontal transport in the formation and dynamics of plankton structures. We compute horizontal Finite Size Lyapunov Exponents (FSLEs) and analyze their correlations with phytoplankton concentrations.

Coupling hydrodynamical and biological model in Benguela

The evolution of the concentrations within a flow is determined by the coupling between the hydrodynamical and biological models, and it is performed by the advection-reaction-diffusion system. We resolve this system using a semi-Lagrangian algorithm. The biological model is derived from Sandulescu et al. [2008] and describes the interaction of a three-level trophic chain in the mixed layer of the ocean, including: phytoplankton P, zoo-plankton Z and dissolved inorganic nutrient N. Horizontal transport is explicitly taken into account in the 2D flow from satellite at $1/4^0$ spatial resolution (Sudre et al. [2008]), and velocity data from the ROMS (Regional Ocean Modeling System) climatological numerical model at $1/12^0$ spatial resolution. The advection is performed in 2D (ocean surface) for both hydrodynamics systems. The nutrient supply due to vertical mixing mimics the upwelling, and it is modeled as a source term in the reaction term of nutrient equation. We add also an eddy diffusion process acting on plankton and nutrients concentrations to incorporate the small-scale turbulence, which is not explicitly taken into account by the velocity fields used. The diffusion coefficient, D, is given by Okubo's formula and the value is the corresponding to the length scale of the velocity data (spatial resolution).



Benguela Area

Advection-Reaction-Diffusion Equations

$$\frac{\partial N}{\partial t} + \mathbf{v}\nabla N = F_N + D\nabla^2 N$$
$$\frac{\partial P}{\partial t} + \mathbf{v}\nabla P = F_P + D\nabla^2 P$$
$$\frac{\partial Z}{\partial t} + \mathbf{v}\nabla Z = F_Z + D\nabla^2 Z$$

NPZ model

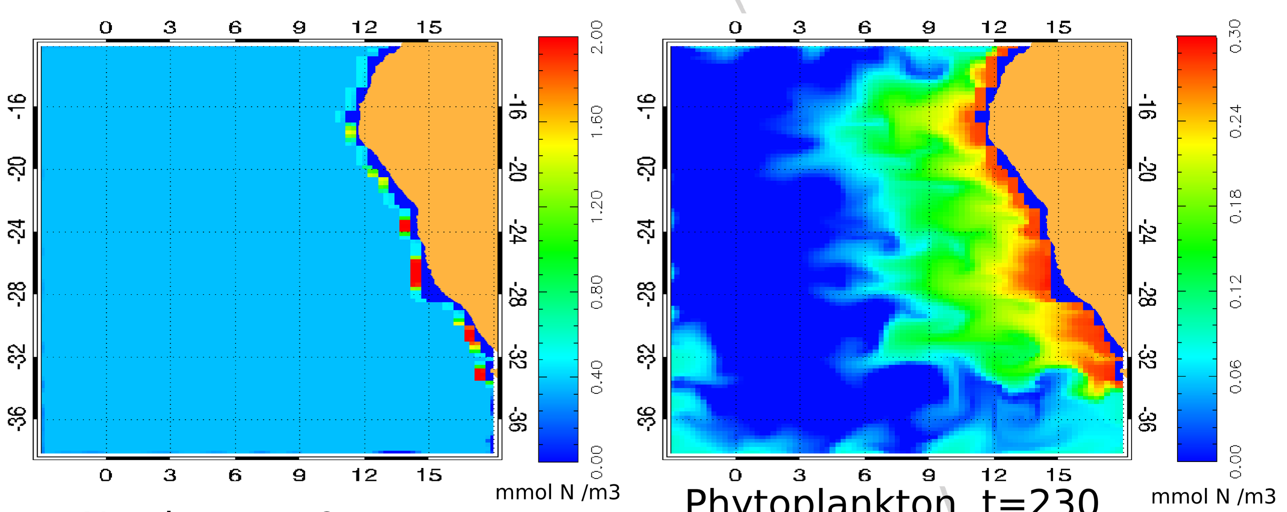
$$\frac{dN}{dt} = F_N = \Phi_N - \beta\frac{N}{\kappa_N + N}P + \mu_N\left((1-\gamma)\frac{\alpha\eta P^2}{\alpha+\eta P^2}Z + \mu_P P + \mu_z Z^2\right)$$
$$\frac{dP}{dt} = F_P = \beta\frac{N}{\kappa_N + N}P - \frac{\alpha\eta P^2}{\alpha+\eta P^2}Z - \mu_P P$$
$$\frac{dZ}{dt} = F_Z = -\gamma\frac{\alpha\eta P^2}{\alpha+\eta P^2}Z - \mu_z Z^2$$

Mixing term, where S is the strength of the upwelling. We use seasonal values.

$$\Phi_N = S(x-y)(N_0 - N)$$

Evolution of phytoplankton concentrations. Spatial structures of phytoplankton

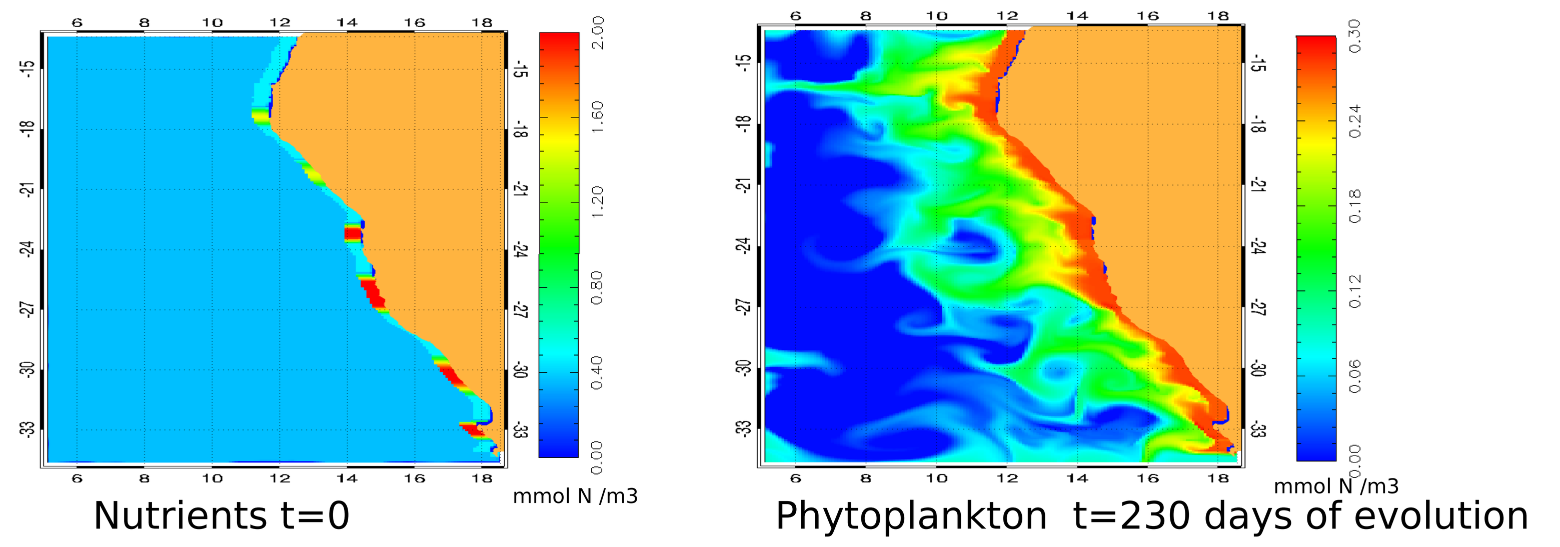
Using velocity data from Satellite (spatial resolution $1/4^0$)



Nutrients t=0 — Phytoplankton t=230 days of evolution

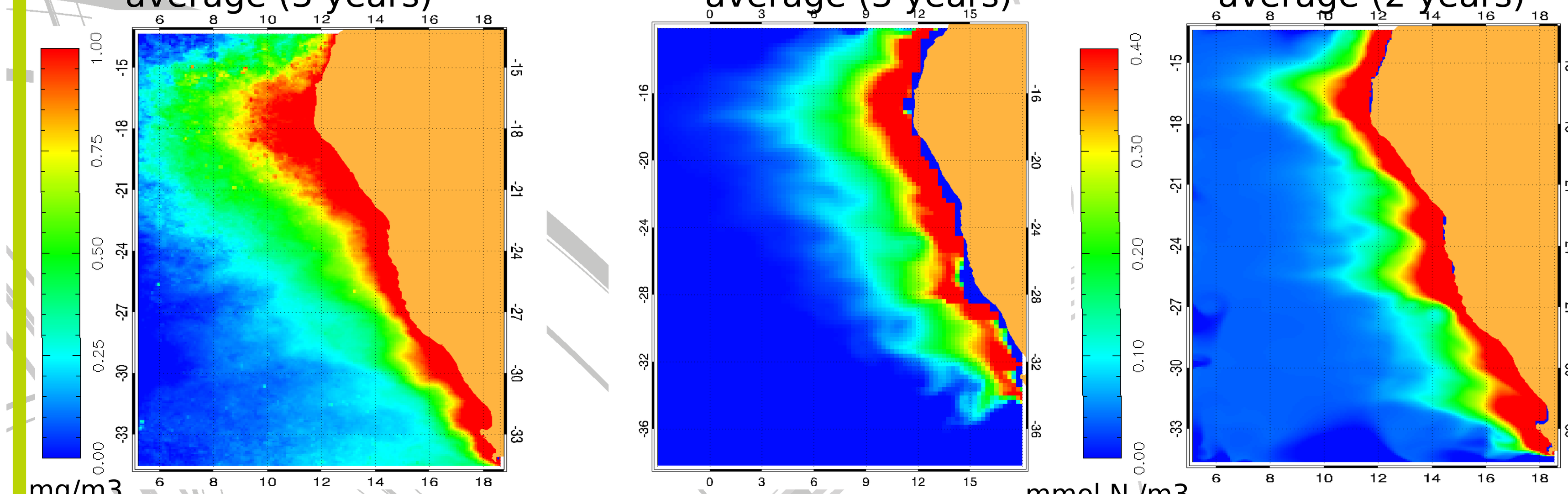
Spatial structures in plankton distributions from both dynamics of the turbulent medium and of the marine ecosystem are more clear in the south than in the north of Benguela. From ROMS velocity data the structures are clearer because this flow is more turbulent and the spatial resolution is finer than the satellite velocity data.

Using velocity data from ROMS (spatial resolution $1/12^0$)



Nutrients t=0 — Phytoplankton t=230 days of evolution

Comparison Phytoplankton with Chlorophyll from Seawifs data

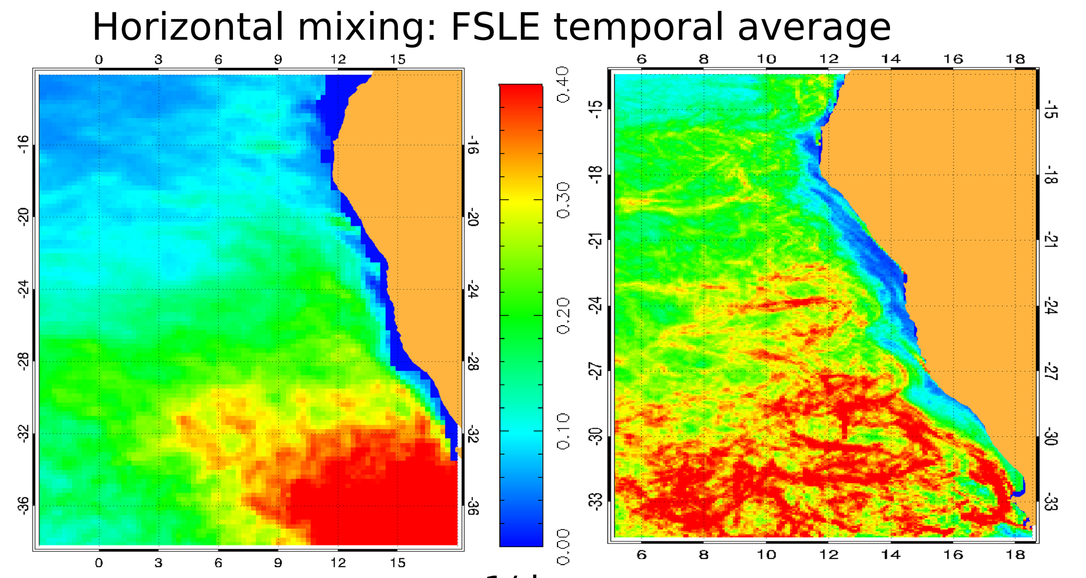


Seawifs data average (3 years) — Phytoplankton average (3 years), Satellite — Phytoplankton average (2 years), ROMS

- Spatial distribution of phytoplankton concentration is high close to the coast and decrease offshore.
- Chlorophyll concentration higher in the north than in the south.
- Horizontal mixing is larger in the south than in the north.
- This suggests a negative correlation between phytoplankton (Chlorophyll) and horizontal mixing (*Rossi et all [2008]*).

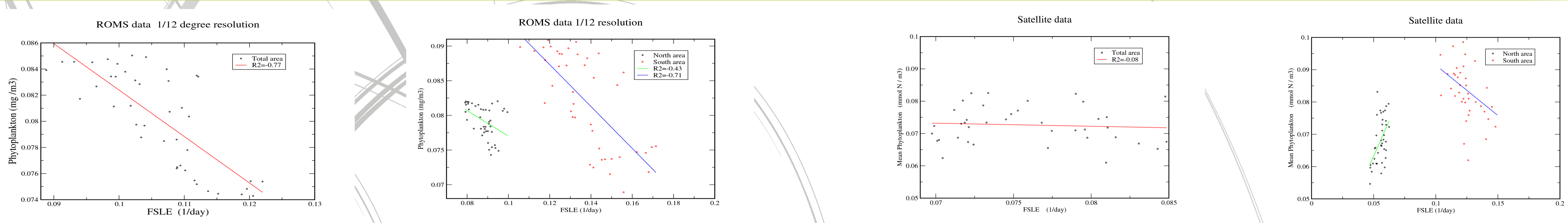
Horizontal mixing from Finite Size Lyapunov Exponents (FSLE)

Horizontal mixing: FSLE temporal average



Satellite (3 years) — 1/day — ROMS (one year)

Correlation FSLE-phytoplankton concentrations: Effect of transport and mixing in the biological evolution of phytoplankton



Using velocity data from ROMS at 1/12 degree of spatial resolution we find a negative correlation between Horizontal mixing and phytoplankton concentration. However, if we use velocity data from satellite, this negative correlation is only in the south of Benguela. Is there a scale effect?

Conclusions

- We find spatial structures of phytoplankton concentrations from both dynamics of the flow and of the marine ecosystem. In the south of Benguela, the structures are more clear since the flow is more turbulent.
- The model yields a spatial distribution of phytoplankton concentration similar to the chlorophyll given by SeaWifs data from satellite.
- Horizontal mixing is higher in the south than in the north, and chlorophyll concentration is larger in the north than in the south.
- A negative correlation between horizontal mixing and phytoplankton concentrations computed in this model is clear for the velocity data from ROMS and not for velocity data from satellite. A possible explanation is because the difference of spatial resolution between velocity data.

References:
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