The Effects of Vertical Mixing Parameterization on 3-D Models of a Pelagic Ecosystem

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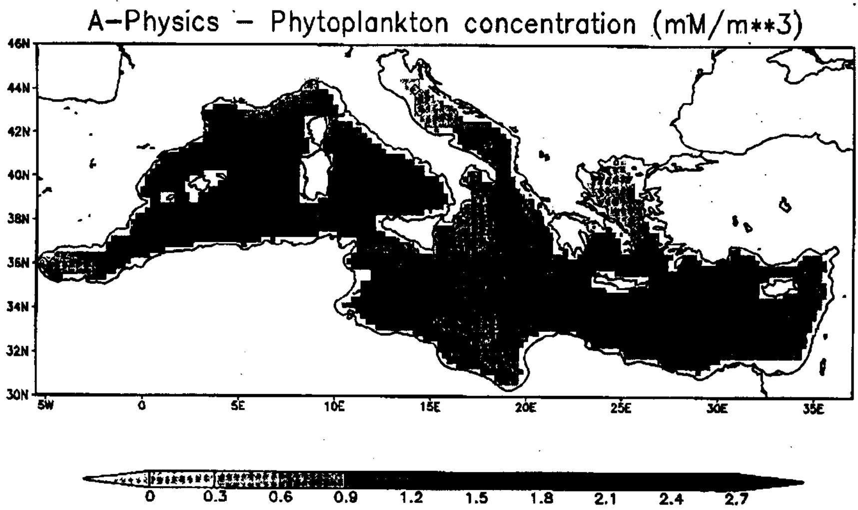
One of the major physical forces acting on the biological processes of the upper ocean is turbulent mixing, mainly produced by wind-stirring and internal wave breaking.[1] Turbulent eddies, and the associated overturning, displace phytoplankton and other biotracers along the water column. Conversely, density stratification inhibits vertical transport by reducing the length-scale of energy-containing eddies near the pycnocline. Wind stress and density fields are characterized by strong space and time variability, so that sophisticated turbulence closure schemes are needed in order to correctly describe subgrid-scale processes. Several attempts in this direction have been proposed in the literature, although most of them concern one-dimensional domains. On the other hand, 1-D models are forced to artificially increase vertical diffusion to compensate for the absence of vertical advection, and therefore a three-dimensional approach is preferable when the vertical dynamics have to be fully resolved.

The aim of this paper is to compare the effects of different vertical mixing parameters on the variability of the lower trophic levels in the Mediterranean pelagic ecosystem, by means of a three-dimensional coupled ecological–hydrodynamical model.[2] The hydrodynamic forces are obtained by means of a primitive equation model forced with climatological monthly mean winds, while ecological dynamics are described by use of an aggregated model, based on inorganic nitrogen, phytoplankton, and detritus.

We have compared a simple A-physics closure scheme (hereafter AP) with a more complex parameterization such as the one proposed by Pacanowski and Philander (hereafter PP[3]). Whereas in the AP scheme, constant eddy coefficients are used, in the PP parameterization momentum and tracer diffusivities vary in space and time depending upon vertical density gradient and velocity shear, through the dimensionless Richardson number.

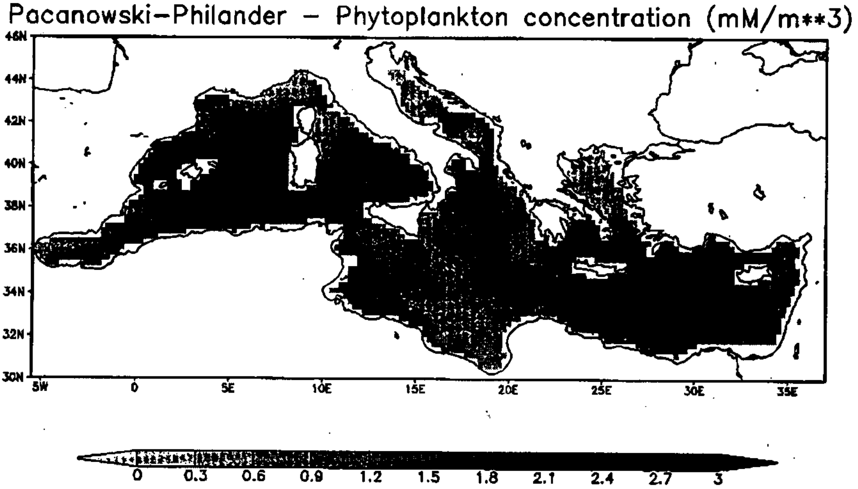
A well-developed surface mixed layer, together with a sharper vertical density gradient, is the most striking feature evidenced by PP when compared to AP results (FIGS. 1 and 2). The modified structure of the mixed layer can lead to detectable differences between the velocity patterns in the two simulations.

The geostrophic adjustment of the density field under the effect of a sheared-wind force, produces a horizontal buoyancy gradient due to the pycnocline slope, which is stronger in PP with respect to the AP case. The increased horizontal density gradients are in turn responsible for an enhanced vertical shear in the horizontal velocity components, according to the thermal wind equations[4]:



A-Physics – Phytoplankton concentration (mM/m**3)

FIGURE 4. Spatial distribution of phytoplankton average concentration (upper 200 meters) for A-physics parameterization. Streamfunction is superimposed as a contour line.



Pacanowski–Philander – Phytoplankton concentration (mM/m**3)

FIGURE 5. Spatial distribution of phytoplankton average concentration (upper 200 meters) for PP parameterization. Streamfunction is superimposed as a contour line.

$$-f\frac{\partial v}{\partial z} = \frac{g}{\rho_0}\frac{\partial \rho}{\partial x} \qquad -f\frac{\partial u}{\partial z} = \frac{g}{\rho_0}\frac{\partial \rho}{\partial y}$$

where u and v are the horizontal components of mean velocity, f is the Coriolis parameter, g the gravitational acceleration, ρ the density, and ρ_0 a constant reference density.

This affects the geostrophic vorticity field, which is intensified in both cyclonic and anticyclonic gyres. A direct effect on tracer transport is therefore observed: the intensified large-scale flow makes the advective transport prevailing on the horizontal diffusive transport inside the gyres, and the tracers are advected along streamlines rather than across them. In this way the gyres behave as a "tracer trap," modifying space and time tracer distribution. Looking at the space variability of phytoplankton concentration in the upper layer, the PP physics produces more pronounced gradients, giving rise to a sort of patchy distribution on a synoptic scale, particularly evident in the eastern basin (FIGS. 4 and 5). Also, in the gyre area, tracers have a higher residence time. Because FIGURES 4 and 5 refer to the surface layer, these effects are more easily recognizable in the cyclonic gyres, characterized by upwelling phenomena, than in the anticyclonic one. Ekman suction pumps nutrients (inorganic nitrogen) in the cyclone's core, making them available to phytoplankton uptake. In PP simulation nutrients are trapped in the gyre for a longer time, while in the AP case the horizontal turbulent diffusion is more effective in spreading them outside. As a consequence, when we adopt the PP parameterization, phytoplankton growth inside a cyclone is more rapid and effective, as shown in FIGURE 3 for the Rhodes gyre. We can finally argue that different choices of turbulence closure schemes result in significatively different space-time distributions of modeled biological variables.

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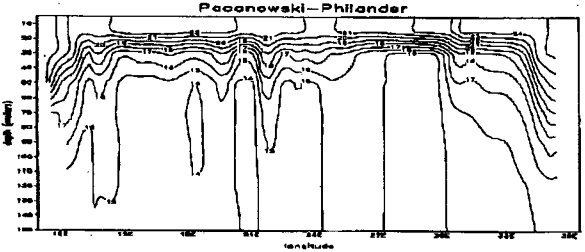

FIGURE 1. Temperature as a function of depth and longitude along a zonal section in the levantine basin as simulated by PP parameterization.

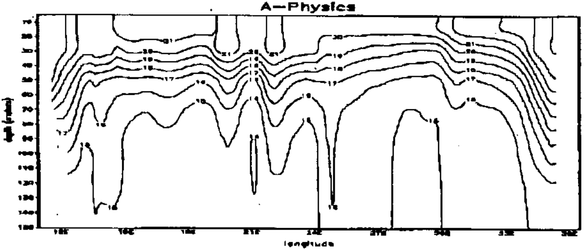

FIGURE 2. Temperature as a function of depth and longitude along a zonal section in the levantine basin as simulated by AP parameterization.

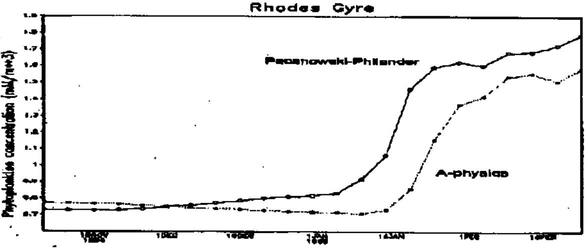

FIGURE 3. Time evolution of phytoplankton average concentration (upper 200 meters in the Rhodes gyre core).