A MODEL OF PLANKTON DYNAMICS COUPLED WITH A LES OF THE SURFACE MIXED LAYER

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The dynamics of phytoplankton populations are not only determined by biological processes such as growth/mortality rates, nutrient levels and predator-prey interactions, but by the distributions of the micro-organisms, which are governed by the physical structures and motions of the ocean (Denman & Gargett 1995). These biological-physical interactions take place over a wide range of different scales, e.g. upwelling gyres over many kilometres are often nutrient rich and associated with high phytoplankton concentrations, whilst individual predator-prey encounters are governed by turbulent motion on the scale of millimetres. In this presentation the influence of physical processes on an intermediate scale (tens of metres), namely those associated with the large-eddy structures of turbulence in the surface mixed layer, on a simple ecosystem will be examined. The objective of the work will be to see what characteristics of the water motion, e.g. horizontal and vertical mixing, vortical structures, are associated with high levels of phytoplankton activity, and how these are correlated with local nutrient and predatory zooplankton concentrations.

The basis of the mixed layer model (assuming uniform density) is formed by a LES code (over a domain 120×120m horizontally and 50m deep), which integrates a spatially filtered form of the Navier-Stokes equations. The mesh size is $40\times40\times100$, implying a horizontal resolution scale of 3m and a vertical resolution scale of 0.5m. The sub-grid scales are parameterised using a standard Smagorinsky LES closure scheme. The applied boundary conditions are horizontal periodicity, whilst at the bottom zero stress and no-normal flow constraints are imposed. At the surface the no-normal flow is retained, but a specified wind stress is imposed in the positive x direction. The code has been validated by comparing the output with some published LES results of McWilliams *et al* 1997 (some examples will be shown). One unusual feature is the incorporation of a 'vortex force' term, brought about by a coupling of the Stokes-drift velocity associated with surface waves with the local vorticity. This 'vortex force' is thought to be the mechanism underlying the formation of Langmuir circulations (Craik & Leibovich 1976), a series of near surface counter rotating roll cells (called Langmuir cells), aligned roughly in the wind direction. Associated with these cells are upwelling and downwelling zones in which levels of vertical mixing are greatly increased. It has been speculated (Bees *et al* 1998) that such enhanced mixing rates, characteristic of 'Langmuir turbulence' will play a significant role in stimulating planktonic activity. The presentation will examine results derived from simulations with and without Langmuir circulations.

The biological model is formed from three coupled advection-diffusion equations for nitrate N, phytoplankton P and zooplankton Z (the sizes of the micro-organisms are assumed to be sufficiently small, <0.1 millimetres, to justify a continuum hypothesis and the treatment of their concentrations as scalar fields) of the form:

$$\frac{\partial N}{\partial t}+\boldsymbol{U}.\nabla N = D_N\nabla^2 N - \text{uptake by phytoplankton} + \text{recycled from phytoplankton growth inefficiency}$$

$$\frac{\partial P}{\partial t}+\boldsymbol{U}.\nabla P = D_P\nabla^2 P + \text{growth (based on light and } N \text{ levels)} - \text{grazing loss (based on Z concentration)}$$

$$\frac{\partial Z}{\partial t}+\boldsymbol{U}.\nabla Z = D_Z\nabla^2 Z + \text{grazing uptake (based on } P \text{ concentration)} - \text{mortality rate}$$

where $\boldsymbol{U}$ is the instantaneous (LES) turbulent velocity field. This model represents a somewhat simplified version of the ideas presented in Baird & Emsley (1999), in which full details of the various source/sink terms are appearing on the right hand side are discussed. Basically they represent parameterisations of processes that take place on the sub-grid scales. For instance the uptake term depends upon the nitrate storage capacity of the phytoplankton species of interest and the efficiency of the mass transfer of nitrate to the cells estimated by means of a turbulent Sherwood number. This is calculated by means of the horizontally averaged level of the kinetic energy dissipation rate ε at different depths. The growth rate term depends on the local light intensity as well as levels of nitrate concentration. Similarly the grazing rate terms are also calculated from estimates of the local turbulence characteristics parameterised by ε. Grazing levels are calculated from theoretical ideas discussed in Lewis & Pedley 2001 concerning predator-prey encounter rates and capture probabilities for isotropic turbulence. The diffusion coefficients are estimated from the local eddy viscosity assuming low (<1) values for various turbulent Schmidt numbers, suitable for this relatively course grid scale resolution. The model equations above are integrated subject to various boundary conditions (horizontally periodic, zero fluxes at the surface, whilst at the bottom a prescribed inward flux of nitrate, representing nitrate replenishment from the thermocline, and prescribed outward fluxes of P and Z), over a fixed period of time. Computational constraints limit this to about 10 hours, although longer runs are planned.

Vertical profiles of mean, variance, vertical flux and correlations between the various scalar fields, averaged over time and horizontally, will be presented. Also the nature of the instantaneous evolution of the planktonic concentrations will be examined. Particular attention will be paid to the characteristics of those flow features that correlate to high levels of phytoplankton growth and patch formation. The sensitivity to phytoplankton growth to both biological and physical parameters will also be discussed. Initial conditions play a crucial role. Results will be presented where the initial distributions of both P and Z are uniform in three dimensions. Later simulations will restrict the Z field to lie in certain regions where grazing potential is high. It may also be possible to look at what happens when the zooplankton are allowed to actively hunt their prey by swimming, and/or interspersing their time spent foraging with rest periods.

References

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