Critical turbulence revisited

The impact of geophysical turbulence on three-dimensional plankton distribution patterns

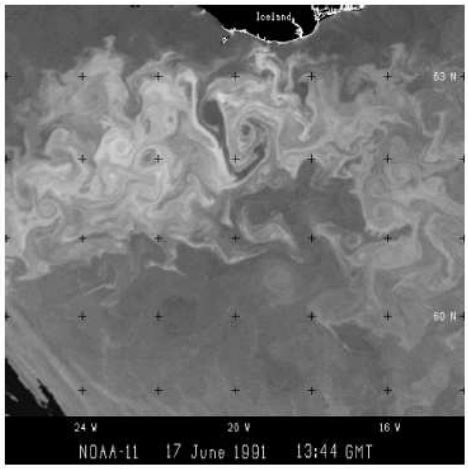
Anne Willem Omta and Bas Kooijman

Institute for Molecular Cell Biology, Vrije Universiteit, De Boelelaan 1081, 1081 HV Amsterdam, The Netherlands

anne.willem.omta@falw.vu.nl

Henk Dijkstra

Institute for Marine and Atmospheric Research Utrecht (IMAU), University of Utrecht, The Netherlands



Introduction

Spatial heterogeneity or 'patchiness' in phytoplankton distributions is ubiquitous in the marine biosphere. Until recently, the focus was on the effect of horizontal stirring and mixing on plankton patchiness [1]. Vertical transports, however, play a crucial role by supplying nutrients (that are necessary for plankton growth) from the deep ocean. To investigate the relationship between such vertical transports and plankton distributions, we simulated a phytoplankton population in a submesoscale eddy in which strong vertical transports are generated through baroclinic instability [2] (see Fig.1).

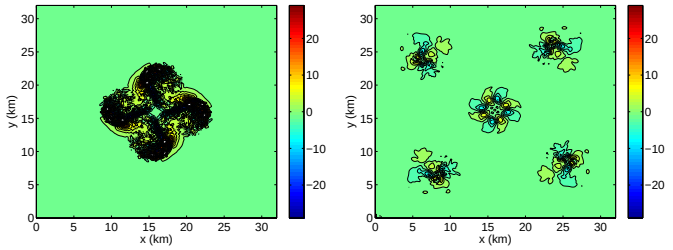


Fig.1 Horizontal cross-sections of the vertical velocity at 20 m depth after 3.6 days (left panel), 12 days (right panel).

Coupled model

We make use of a plankton model coupled to a high-resolution three-dimensional nonhydrostatic flow model. In the plankton model, there are three state variables: living biomass, biomass detritus, and nutrient. The local biomass growth rate depends on the nutrient concentration and the light intensity according to SU-kinetics [3]. Because no maintenance and reserves are included, the model can be counted as one of the Monod-family of models.

Results

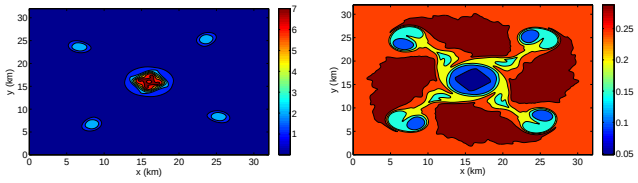


Fig.2 Horizontal cross-sections of the density at 20 m depth after 12 days, with a surface light flux of 50 mol/(m^{2}d) (left panel), 2 mol/(m^{2}d) (right panel).

The simulated plankton distributions turn out to depend strongly on the light intensity and local vertical transport (see Fig.2). With simpler two- and one-dimensional models (see Fig.3), we found out that these two regimes can be understood using an extension of the critical turbulence concept [4]. If the plankton is nutrient limited, then the growth is highest in regions with strong mixing, but if the plankton is more light limited, then strong vertical mixing leads to a low growth. Nevertheless, such vertical mixing does bring up nutrients that diffuse into the areas adjacent to the region of high mixing. Here, the conditions for plankton growth are optimal: a high nutrient concentration and a low vertical mixing.

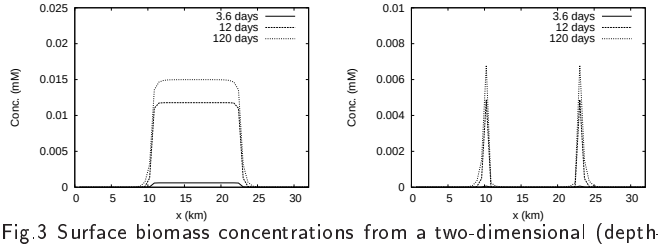


Fig.3 Surface biomass concentrations from a two-dimensional (depth-horizontal) model with vertical mixing K in 'eddy region': K=0.01 m^{2}s^{-1} (left panel), K=1.0 m^{2}s^{-1} (right panel)

References

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[3] Kooijman, Dynamic energy and mass budgets in biological systems, 2nd edition (2000), Cambridge University Press

[4] Huisman et al., Critical depth and critical turbulence: two different mechanisms for the development of phytoplankton blooms, Limnology & Oceanography 44: 1781–1787 (1999)

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