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Swimming in Turbulent Waters: a New Mechanism for Phytoplankton Patchiness in the Ocean[1]

ROMAN STOCKER, Massachussetts Institute of Technology

Marine phytoplankton are responsible for nearly half of the world's oxygen production and comprise the base of the Oceans' food web. The spatial distribution of these unicellular organisms is observed to be heterogeneous at nearly all scales; the largest accumulations extend hundreds of kilometers, while the smallest span only a few millimeters. This endemic patchiness has profound consequences on trophic dynamics and biogeochemical cycles in the Ocean; a mechanistic understanding of the underlying processes is a primary research goal in oceanography. Many phytoplankton species, particularly those responsible for harmful algal blooms, are motile, propelling themselves through water at low Reynolds numbers. Yet, motility is rarely taken into account when considering the mechanisms that drive patchiness. In this study we find two simple ingredients are sufficient to generate striking heterogeneity in the distribution of motile phytoplankton: asymmetric cell morphology and hydrodynamic shear, both of which are ubiquitous in the ocean. For example, cells can be asymmetric due to uneven distribution of organelles or flagella, while shear in the Ocean occurs at all scales, from large-scale currents to small-scale turbulence. We propose a new mechanism - gyrotactic trapping - whereby motile asymmetric cells in shear preferentially accumulate in specific regions of the flow. We present experimental and theoretical evidence demonstrating that gyrotactic trapping can produce patchiness over a wide range of scales, from kilometer-scale thin phytoplankton layers to patchiness at the Kolmogorov scale, both of which are routinely observed by oceanographers. We find that the intensity, time scale, and location of the resultant accumulations are a function of two dimensionless numbers, containing properties of both the cells and the flow. These findings demonstrate that cell motility can shape principal features of the marine environment and provide oceanographers with quantitative tools to predict phytoplankton distributions in the Ocean.

[1] In collaboration with William Durham, Massachusetts Institute of Technology and Eric Climent, Institut de Mecanique des Fluids de Toulouse.