Surfing on turbulence : A strategy for plankton navigation

Rémi Monthiller[1], Aurore Loisy[1], Mimi A. R. Koehl[2], Benjamin Favier[1] and Christophe Eloy[1]

[1] Aix Marseille Univ, CNRS, Centrale Marseille, IRPHE, Marseille, France
[2] Department of Integrative Biology, University of California, Berkeley, CA 94720-3140, USA
remi.monthiller@gmail.com

Living in a turbulent environment, navigation is a challenging task for motile planktonic organisms (plankters). Yet vertical migration is essential to many of them. For example, copepods (crustaceans that are a critical link in aquatic food webs) move upwards at night to feed in surface waters, and downwards during the day to escape visual predators [1], [2]. Being equipped with flow sensors, can these plankters use local hydrodynamic cues to migrate faster through turbulence?

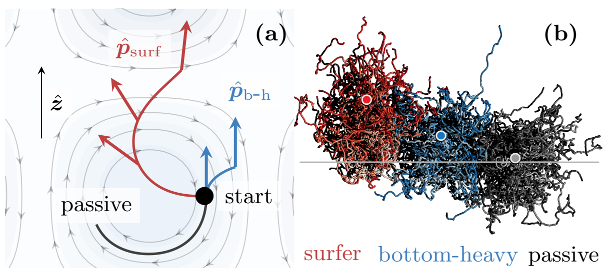

Figure 1. Plankters can exploit velocity gradients to "surf" on the flow: (a) 2D Taylor-Green vortex flow; (b) 3D turbulent flow. We compare the trajectories of surfers (red) to those of bottom-heavy swimmers (blue), which always swim upwards. We also show trajectories of passive particles (black). In (a), arrows show the swimming direction. In (b), the gray line shows the depth of the initial positions and circles show the average final vertical position for the same turbulent flow and initial conditions.

To address this question, we consider plankters swimming at constant speed whose goal is to move upwards. We propose a robust analytic behavior that allows plankters to choose their swimming direction according to local flow velocity gradients (Illustrated in Fig. 1a) formulated as follows:

$$\hat{\boldsymbol{p}}_{\rm surf} = \frac{\boldsymbol{p}_{\rm surf}}{|\boldsymbol{p}_{\rm surf}|}, \quad \text{with } \boldsymbol{p}_{\rm surf} = \left[\exp\left(\tau \boldsymbol{\nabla u}\right)\right]^T \cdot \boldsymbol{z}. \tag{1}$$

With $\hat{\boldsymbol{p}}_{\rm surf}$ the chosen swimming direction, $\boldsymbol{\nabla u}$ the measured flow velocity gradients, $\boldsymbol{z}$ the target direction and τ the sole free parameter of the strategy. Testing this behavior in 3D simulations of turbulence [3] (cf. Fig. 1b), we show that plankters can "surf" the flow and reach net upwards velocity up to twice their swimming speed. We assess the expected benefit of (active) orientation control over (passive) bottom-heaviness and show that it is advantageous across a wide range of marine habitats.

References

1. S. A. Richards, H. P. Possingham & J. Noye, Diel vertical migration: modelling light-mediated mechanisms, *J. Plankton Res.*, **19**, 2199 (1996).
2. M. G. Hadfield & M. Koehl, Rapid behavioral responses of an invertebrate larva to dissolved settlement cue, *Biol. Bull.*, **207**, 28 (2004).
3. Y. Li, E. Perlman, M. Wan, Y. Yang, C. Meneveau, R. Burns, S. Chen, A. Szalay, G. Eyink, A public turbulence database cluster and applications to study Lagrangian evolution of velocity increments in turbulence, *J. Turb.*, **9**, 31 (2008).