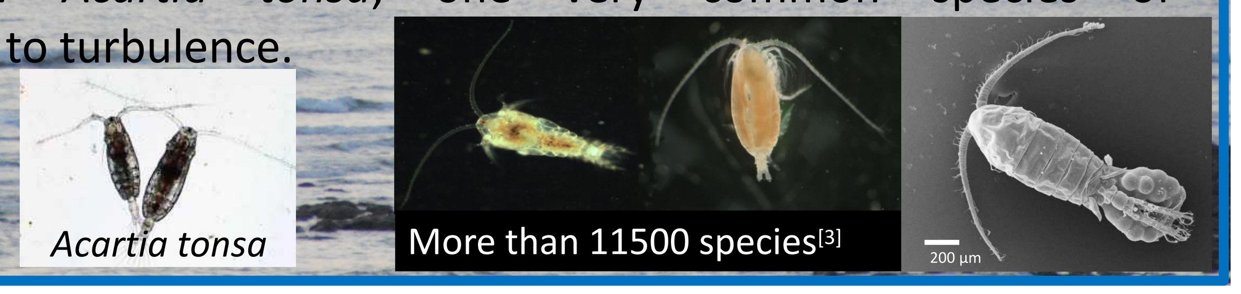
Copepods in a turbulent environment : experimental study of velocity and acceleration using high speed cameras

C. Le Quiniou[1], F. G. Schmitt[1], Y. Huang[2], E. Calzavarini[3], et S. Souissi[1]
[1]*Laboratoire d'Océanologie et de Géosciences, CNRS, Univ. Lille, Univ.Littoral Côte d'Opale, Wimereux, France*
[2]*Marine Environmental Laboratory, Xiamen University, Xiamen, China*
[3]*Unité de Mécanique de Lille - Joseph Boussinesq, Université de Lille, Lille, France*

Framework and objectives

Plankton differ from nekton by their inabilities to overcome flow currents, even though some species have remakable swimming abilities. Copepods are tiny crustaceas able to swim as fast as 40 cm.s^{-1} with instantaneous accelerations up to 10g[1] even though for short time spans. In the natural environment, turbulence is ubiquitous and must have led copepods to develop adaptation strategies depending on the turbulence intensities[2].

By means of a well controlled experimental approach, this work aims at identifying how *Acartia tonsa*, one very common species of copepods, adapt to turbulence.

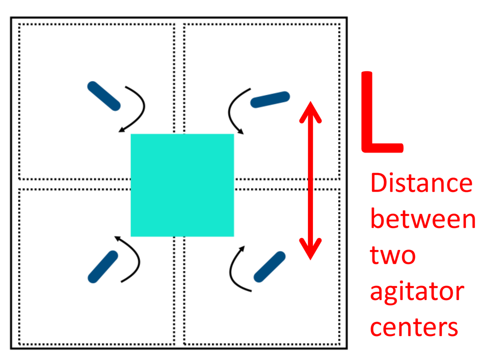


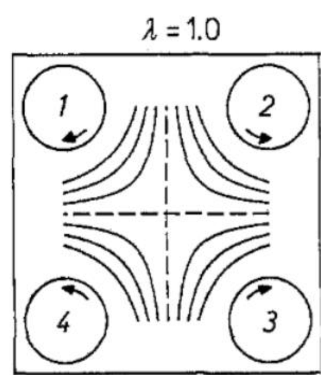
Experimental set-up

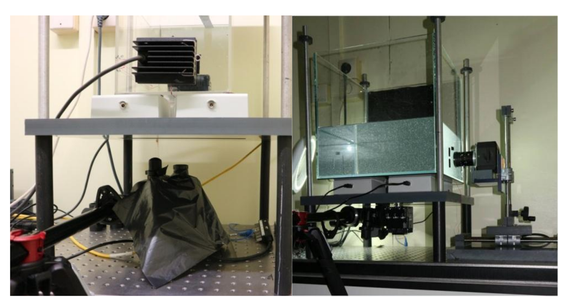
Pure extensional flow

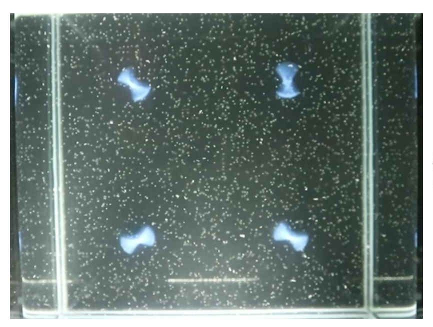
Turbulence was generated by four stirring arranged in a square pattern and each counter-rotating with respect to their next neighbors ('four-roll mill'[4,5]).

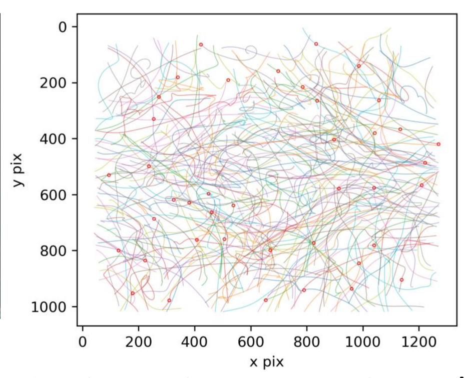
Trajectories were recorded using a high speed camera (1200 fps) with two IR lamps.





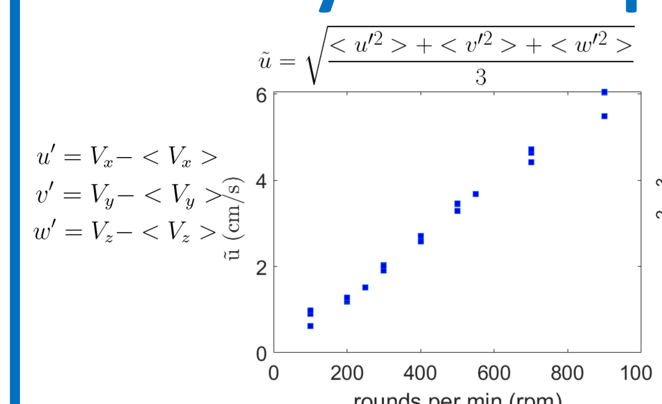


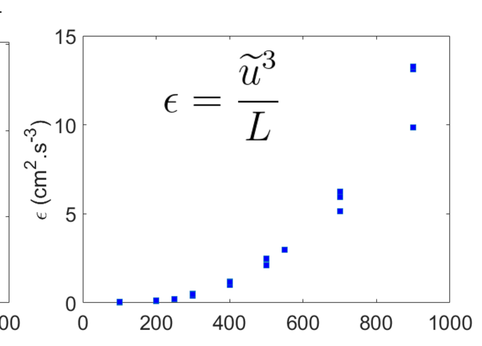




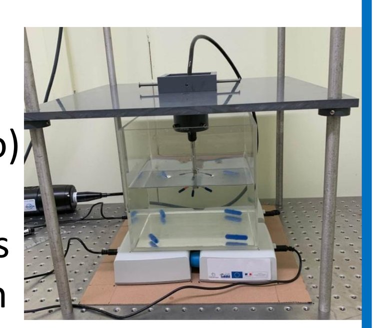
Trajectories reconstituted with TrackPY (Python)

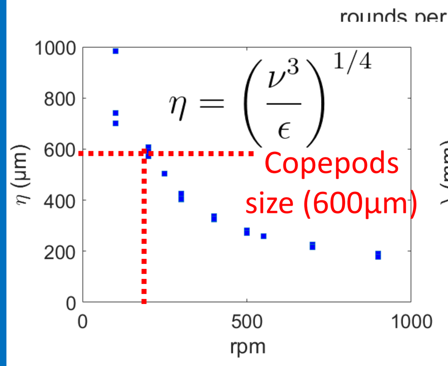
Fluid dynamics properties

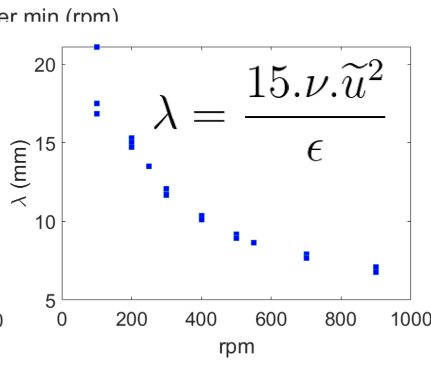


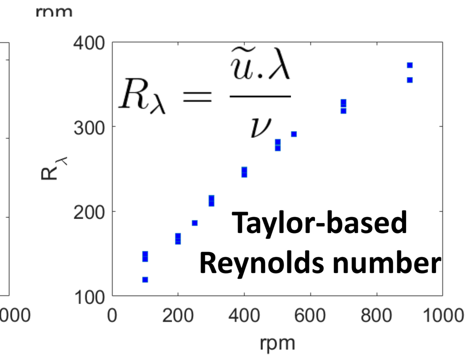


ADV (Nortek Vectrino) with particles of 10µm









Rounds per min	R_λ
100	140
200	170
300	210
500	280

Signal processing of the trajectories from high speed camera

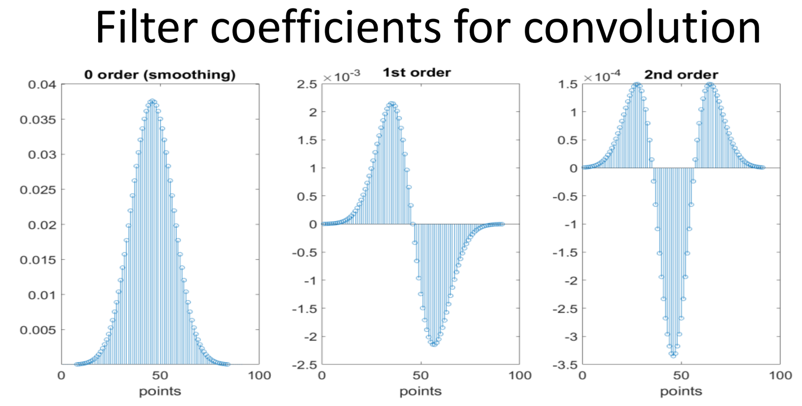
Gaussian kernel[6]

$$g(\tau) = \frac{1}{\sqrt{\pi.\omega^2}}.exp\left(-\frac{\tau^2}{\omega^2}\right)$$

τ_f = Filter length $\quad \tau_f = \sqrt{2}.\omega$

τ_f was chosen such as filtering the noise does not remove information at the Komogorov scale[7]

Filter coefficients for convolution



Derivatives = convolution with the derivatives of the kernel.

Velocity and acceleration components of polystyren particles

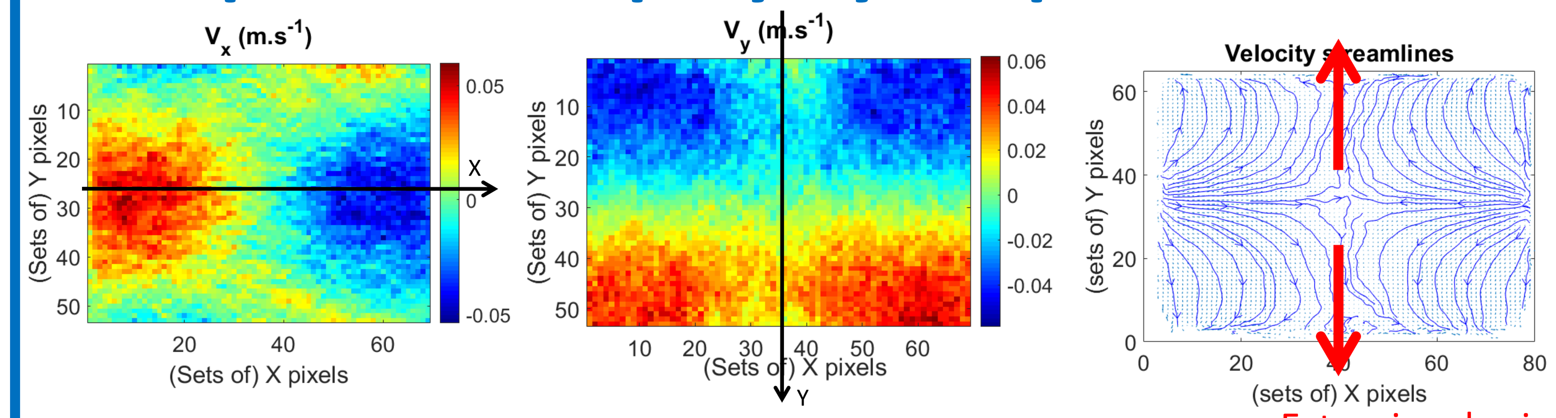


Figure 1: Eulerian vision of the lagrangian tracking

Velocity components of particles in the flow (diameter 600µm) at different intensites

$$V_y = \langle V_y \rangle + v' \qquad A_y = \langle A_y \rangle + a'_y$$

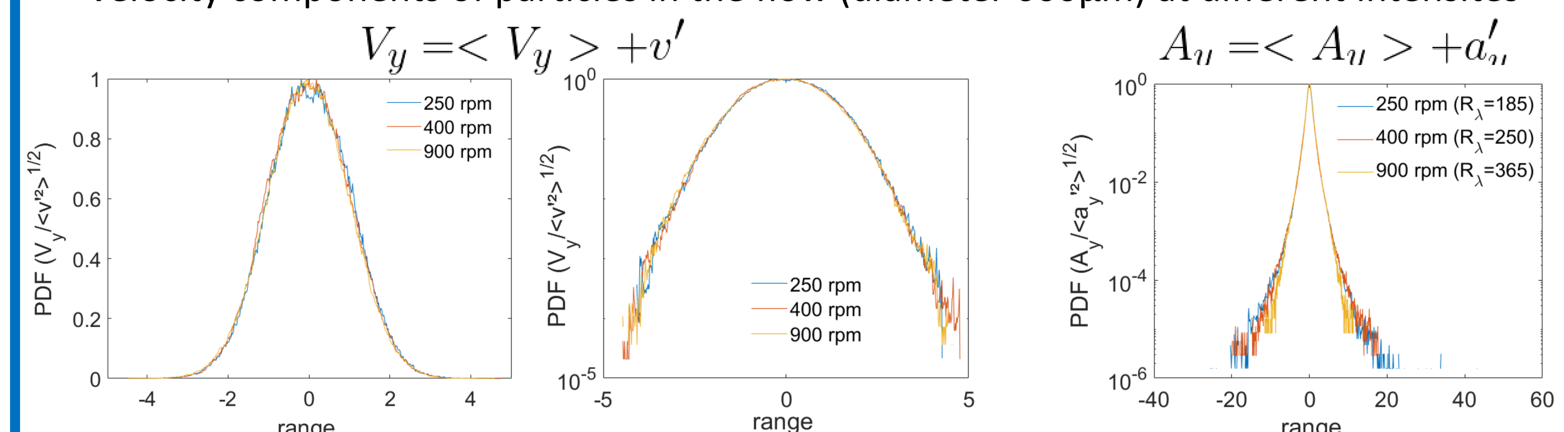


Figure 2 : Y components PDF (normalized by the standard deviation) of velocity (Left : Linear scale, Right : Logaritmic scale) and acceleration at different turbulence intensities

Size effects

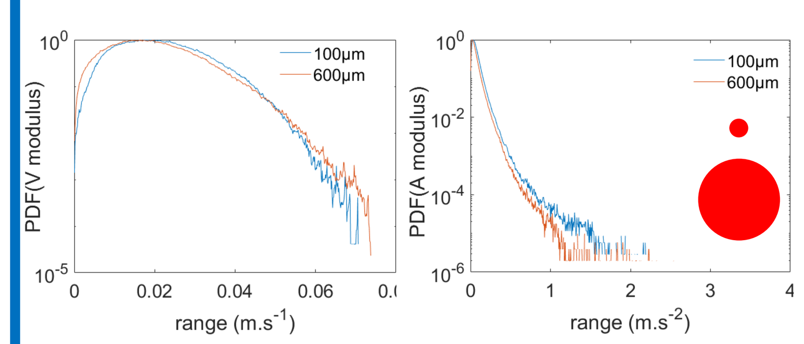


Figure 3 : Comparison between particles of different diameter at R_λ=190 (250 rpm). Left : Velocity modulus. Right : Acceleration modulus.

No shape effects

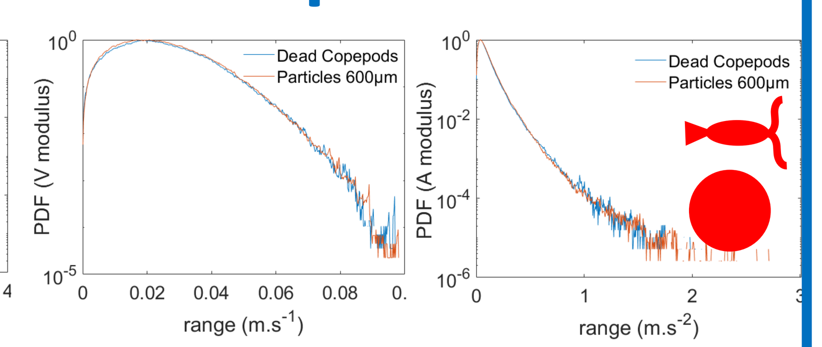


Figure 4 : Comparison between dead copepods and particles of same size at R_λ=210 (300 rpm). Left : Velocity modulus. Right : acceleration modulus.

Differences between alive and dead copepods are visible in the probability density functions

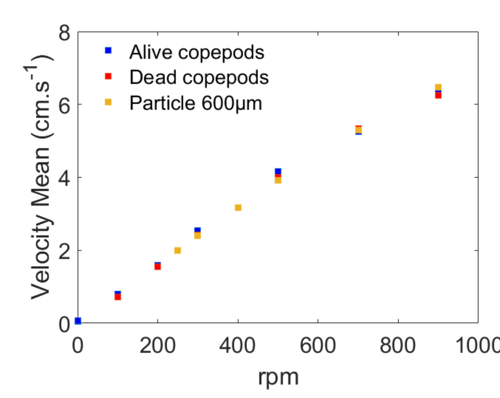
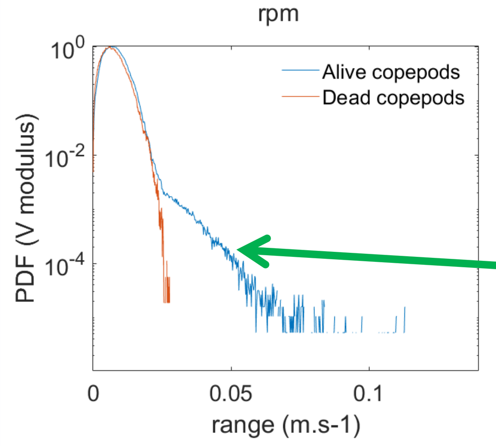
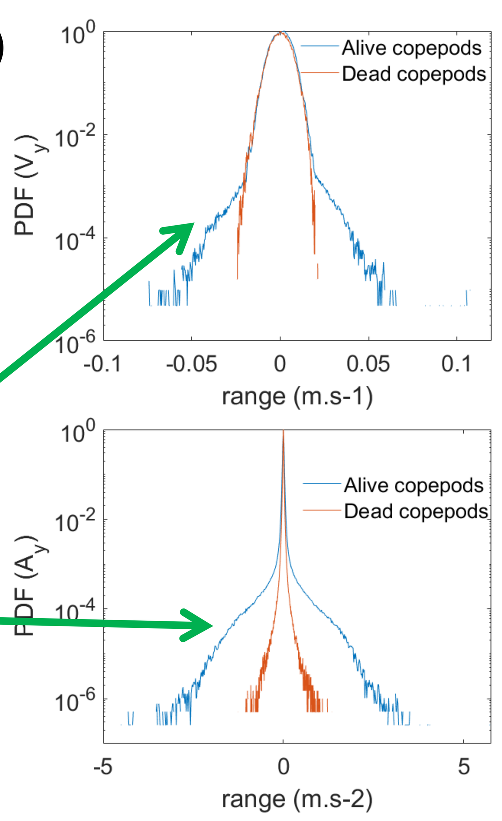


Figure 5 : Mean values (Left, up) of velocity modulus at different turbulence intensities and its PDF at R_λ=140 (100 rpm) (Left, down) ; PDF of the Y component (Right) of velocity and acceleration at R_λ=140

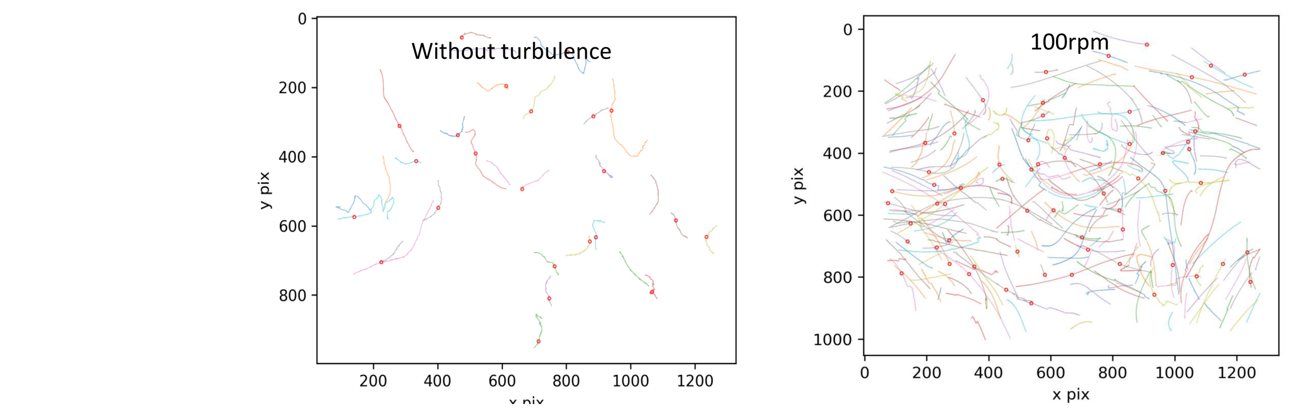


Effect of swimming behavior

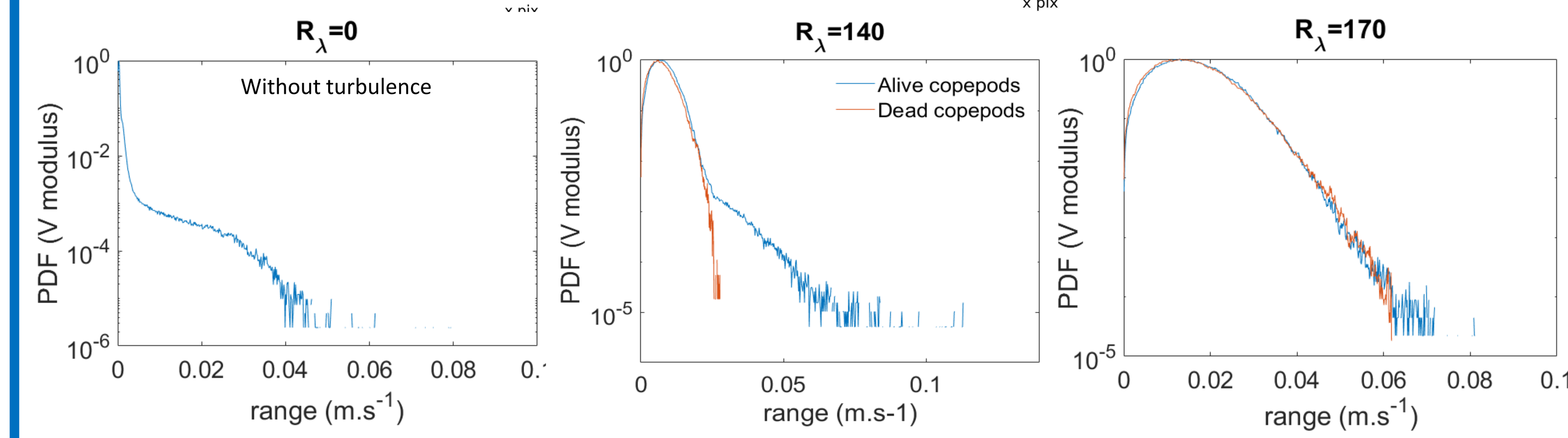
→Is it the case at any turbulence intensity?



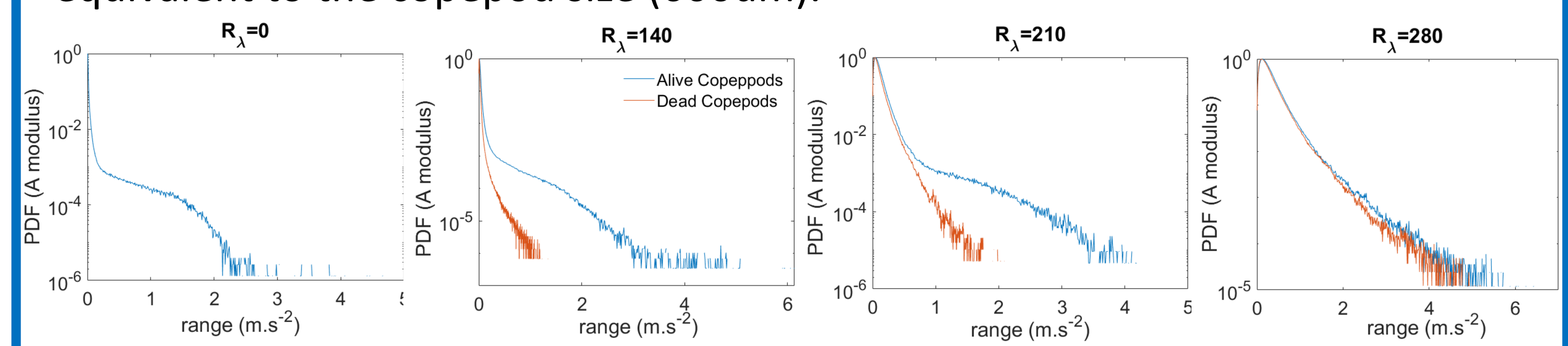
Copepods behavior induced by turbulence



Copepods (red dots) along their trajectories with or without turbulence



When looking at velocity modulus, the difference between Alive and Dead copepods disappears between R_λ = 140 and R_λ = 170. The value of R_λ at which the transition occurs, seems to correspond to the Kolmogorov scale equivalent to the copepod size (600um).



In the acceleration, the difference between Alive and Dead copepods disappears between R_λ = 210 and R_λ = 280, so to say at higher intensity of turbulence than for the velocity.

Swimming behavior is observed up to a certain value of turbulence. The swimming behavior is longer detected in the acceleration signal.

Main messages

- In a controlled turbulent environment, generated by a newly designed experimental setup, it has been possible to follow copepods behavior at different R_λ.
- Swimming behavior of copepods depends on the turbulence intensity : when turbulence is too high copepods let themselves to be carried by the flow without swimming. The highest value up to which they are able to swim under turbulence seems to correspond to the maximum value they can achieve without turbulence.
- For a large range of intensities, copepods show some swimming abilities. These results are in agreement with previous works[8]. Differential geometry will be used to analyze radial and tangential accelerations.
- Perspectives : Does the transition occur at the same intensities when copepods are feeding (in presence of phytoplankton)?

References

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Acknowledgements

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