Finding food in a frenzy

The importance of turbulence in ecological modelling

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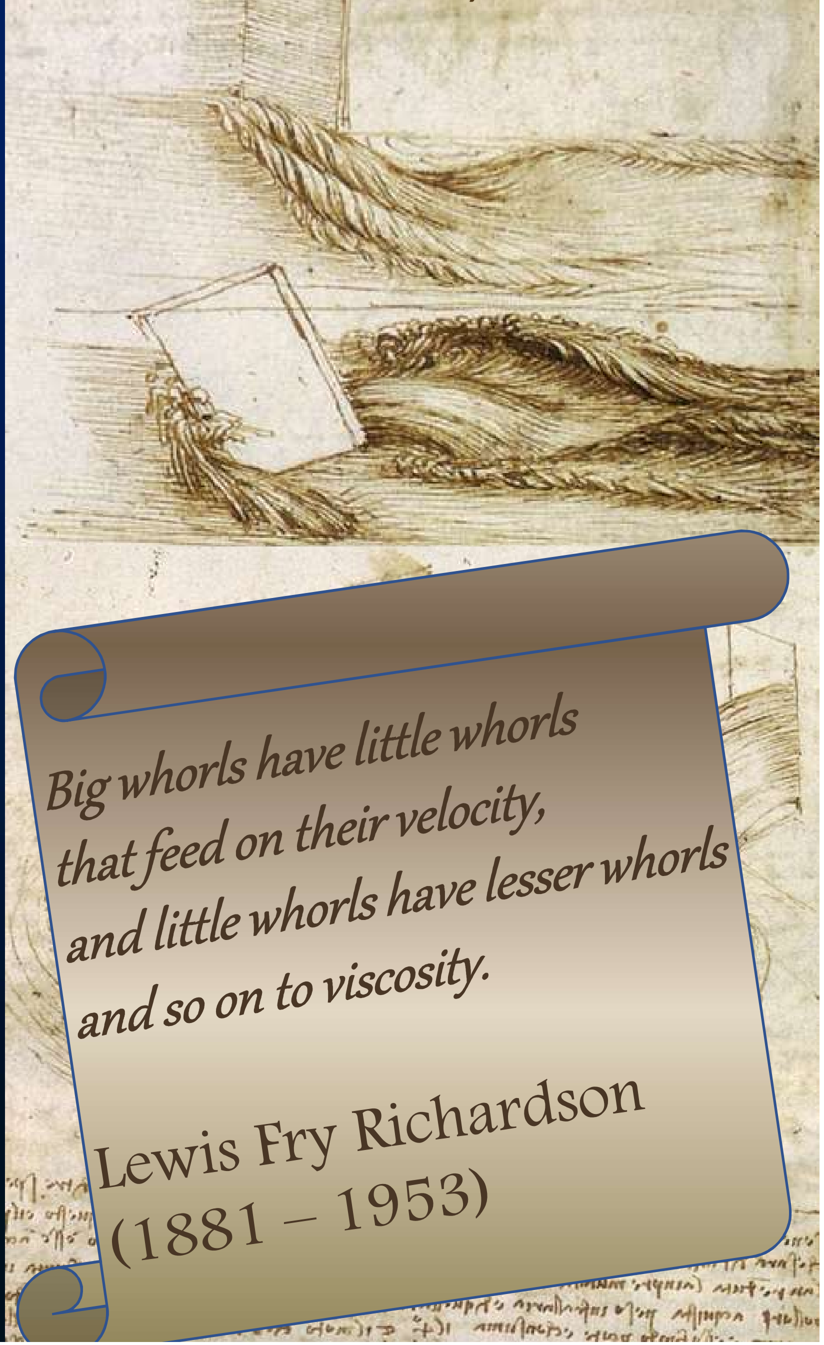
Credit: Sea Soup by Scott Luís Masson

UNIVERSITY OF BATH

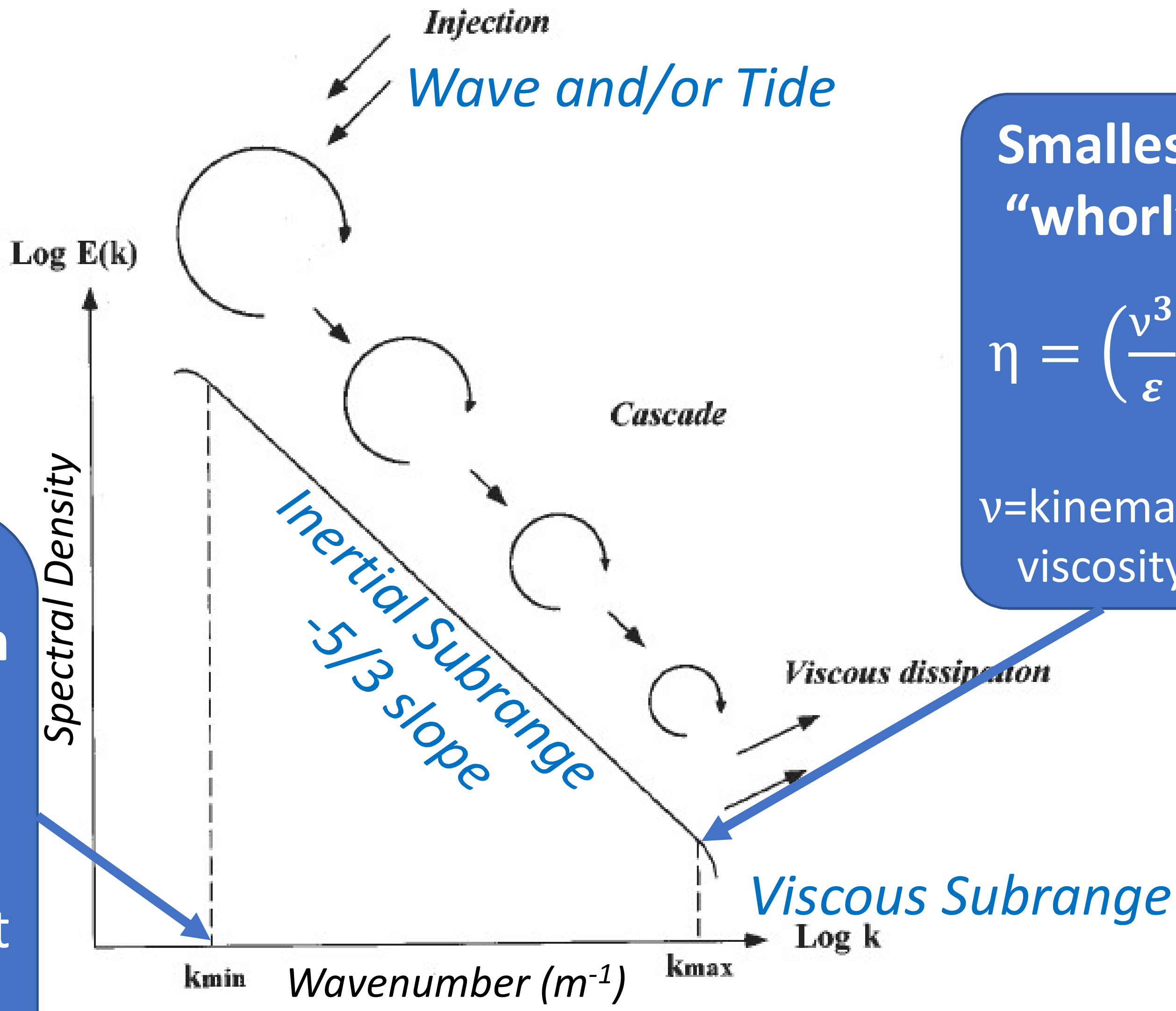
What is turbulence?

- Random, chaotic motion (both speed & direction) of a fluid over time at the smallest scales of fluid flow (Stevens *et al*, 1999).
- Generated by wind-stress at the surface or by bottom friction at the seabed.
- Eddies cascade down in size, becoming smaller and smaller until kinetic energy is dissipated as molecular waste heat
- Measured as rate of turbulent kinetic energy is dissipated to heat (ε [$m^2\ s^{-3}$])

Studies of Water Passing Obstacles and Falling by Leonardo da Vinci



Frequency Spectrum of Turbulent Velocity Cascade



Smallest "whorl"

$$\eta = \left(\frac{\nu^3}{\varepsilon}\right)^{\frac{1}{4}}$$

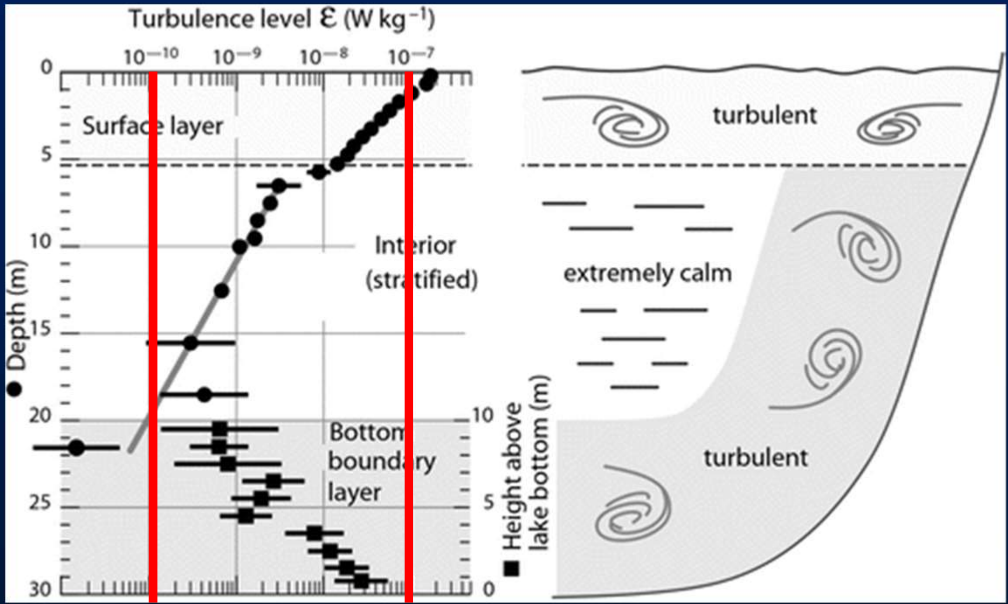
ν=kinematic viscosity

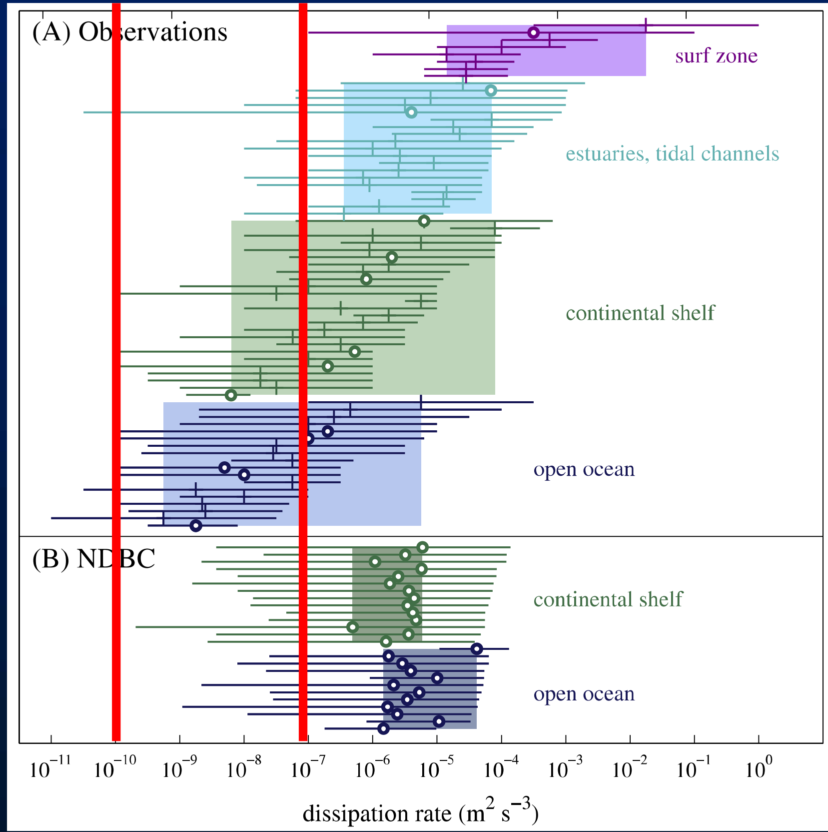
Kolmogorov Length
the smallest scale of turbulent eddies where they begin to be smoothed out by viscosity

Seuron et al, 1999

MOTO MOTT

Most Of The Ocean, Most Of The Time (Franks, 2018)



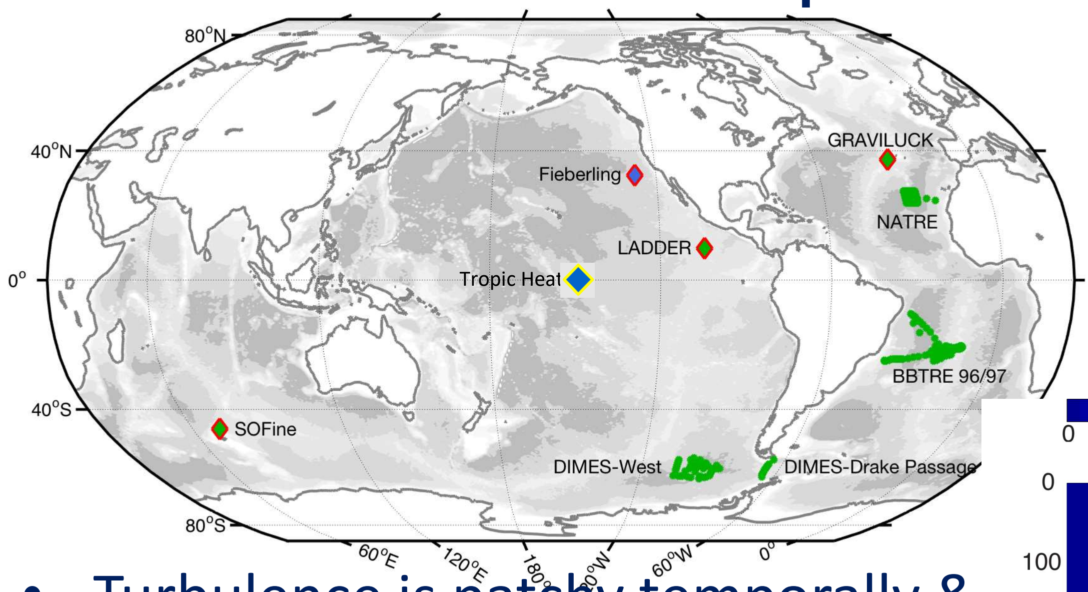


$$10^{-10} < \varepsilon < 10^{-7}\ m^2/s^3$$

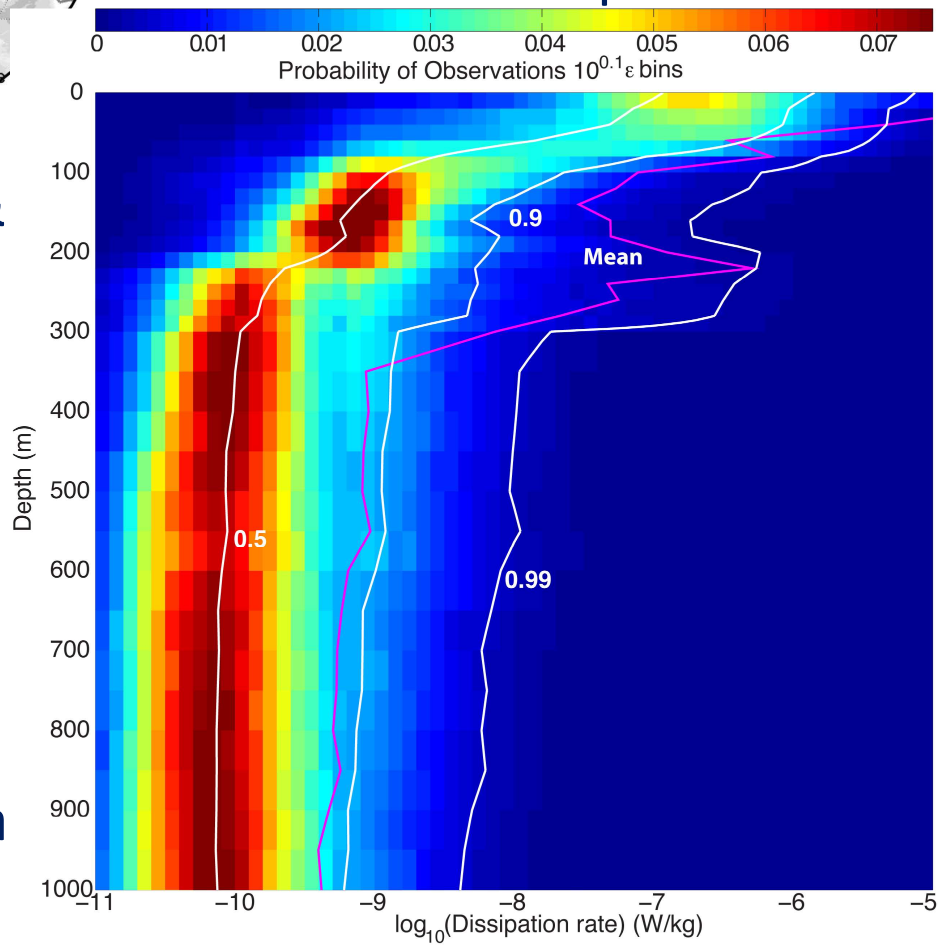
Wüest and Lorke (2003)

Fuchs and Gerbi (2016)

MOTO MOTT - Dissipation Statistics



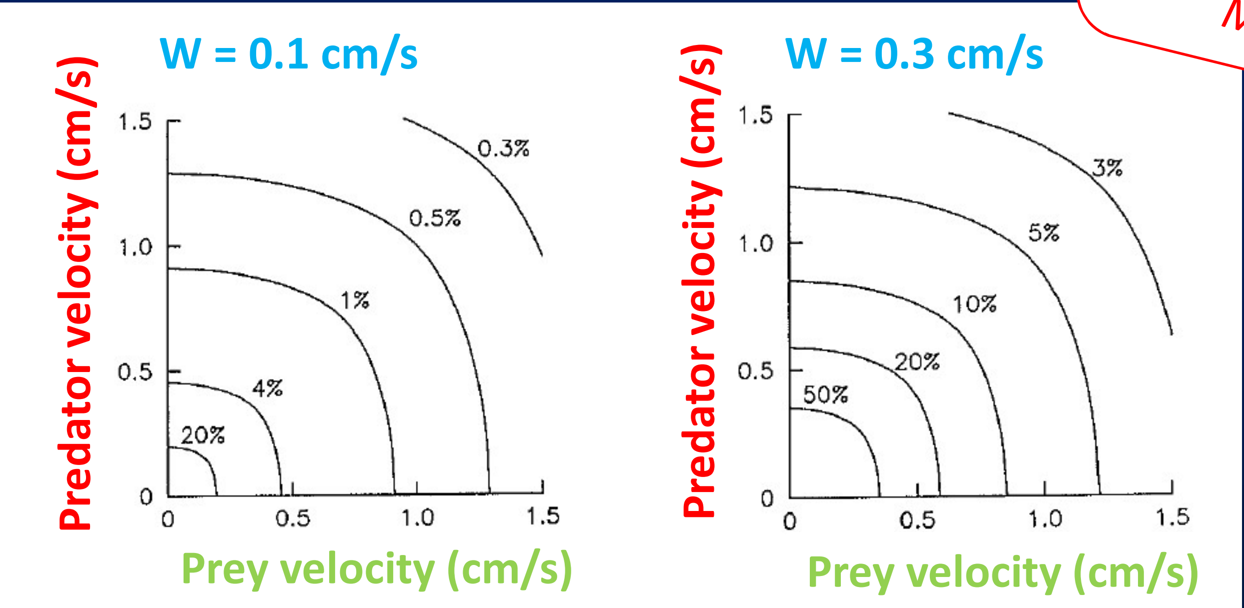
Franks (2018) used Waterhouse et al. (2014) 5200+ microstructure profiles to characterize the turbulence "climate" of the open ocean



- Turbulence is patchy temporally & spatially!
- Time between turbulent events is long compared to lifespans of many planktonic species (days to weeks)
- Most plankton rarely experience a turbulent event

Predators finding prey...

Increase in contact rate due to turbulence



UP TO 10X INCREASE FOR FISH LARVAE!

MacKenzie & Leggett, 1991

$Z = DA$

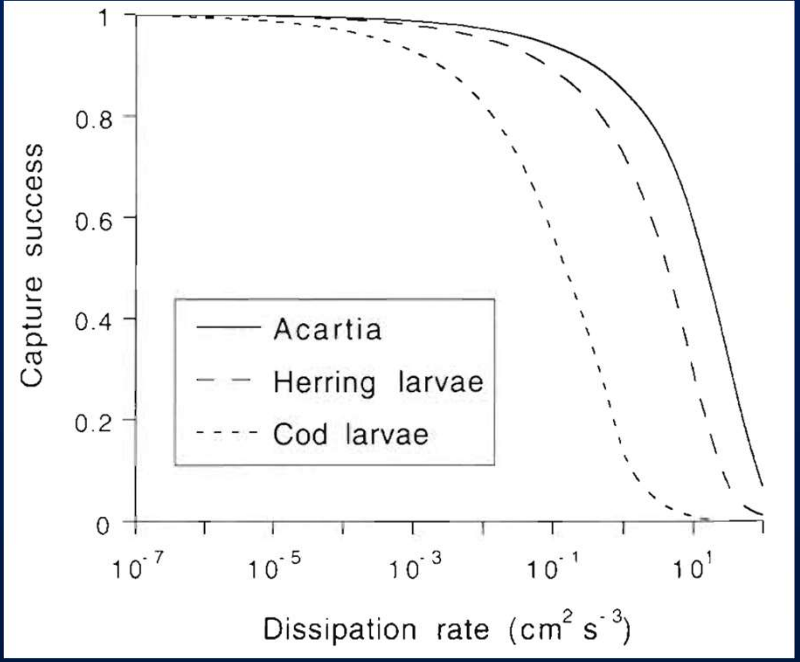
Z = contact rate
D = prey density per unit volume
A = predator velocity

- Feeding rates typically derived from enclosure experiments without turbulence.
- Predators can rely on turbulence instead of metabolic energy to obtain prey.
- Turbulence also increases contact of nutrient donors and acceptors.
- Implications for reproduction / mating / larval dispersion

Rothschild and Osborn, 1988

Predators finding prey…

Ambush predators



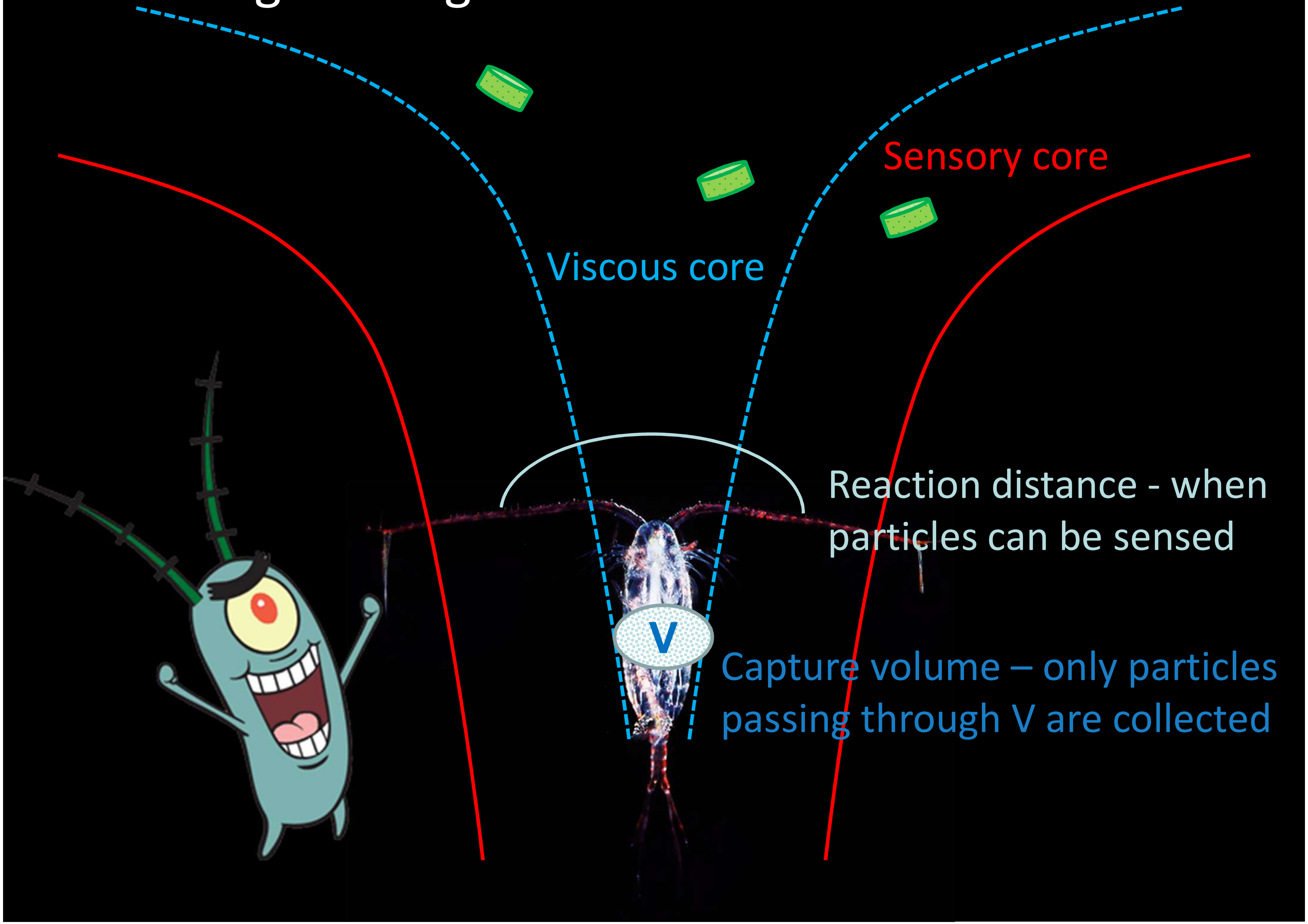
- Predator differences (reaction distance, reaction time) & behaviour (ambush vs cruise vs filter feeder)
- Turbulence can advect prey away & obscure detection of chemical trails (hunting for food & mating)

Turbulence matters to predators at the Kolmorogov range (0.03cm to 1cm)

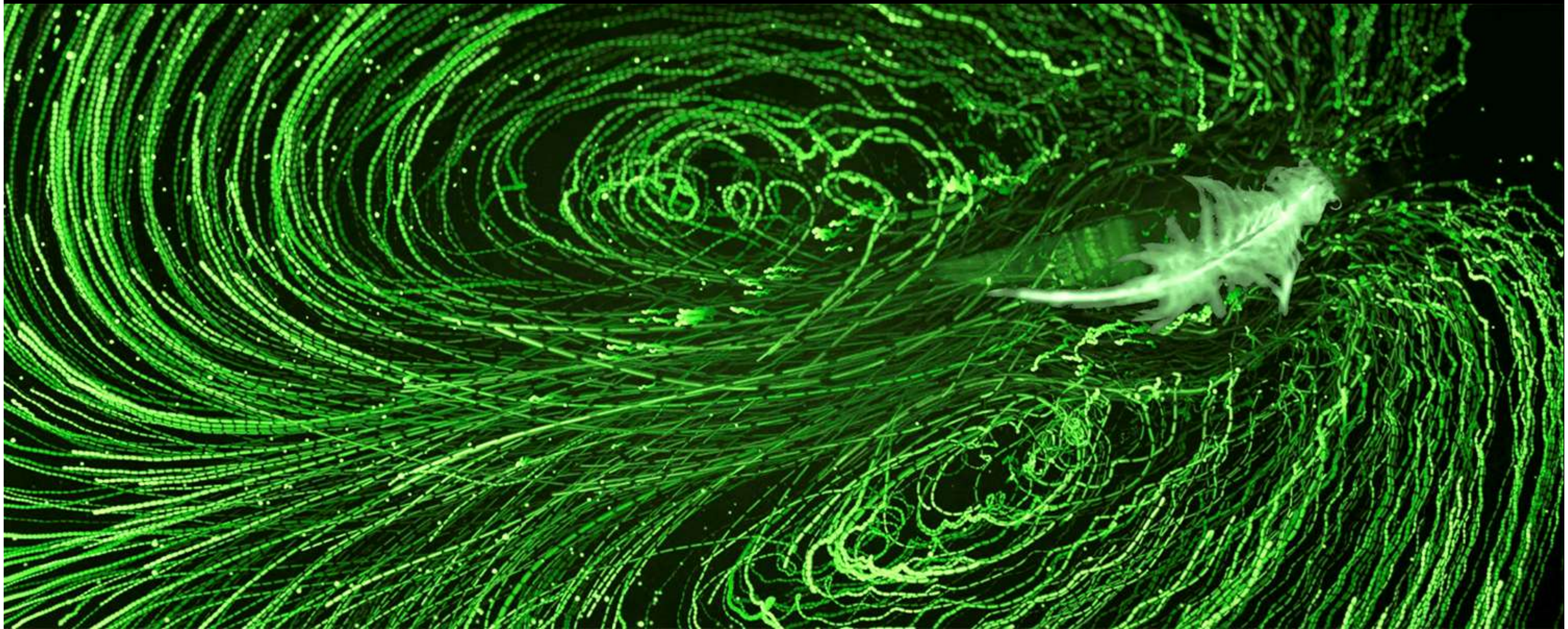
Turbulence strongly affects **ambush** predators & predators with long-reaction distance / slow swimming speeds.

Kiørboe and Saiz, 1995

Generating feeding currents...



“With our knowledge of vertically migrating populations of animals, it is likely that copepods, krill and some species of gelatinous zooplankton and fish have the potential to be strong sources of biogenic mixing.”
Katija, 2012



A tethered brine shrimp generates flow when swimming, made visible via a time lapse of particles suspended in the water

Credit: Isabel Houghton

Turbulence obscures hydromechanical signals

Mesodinium pulex
detecting, chasing and
consuming protist prey

Jakobsen et al. 2006

Prey avoiding turbulence…

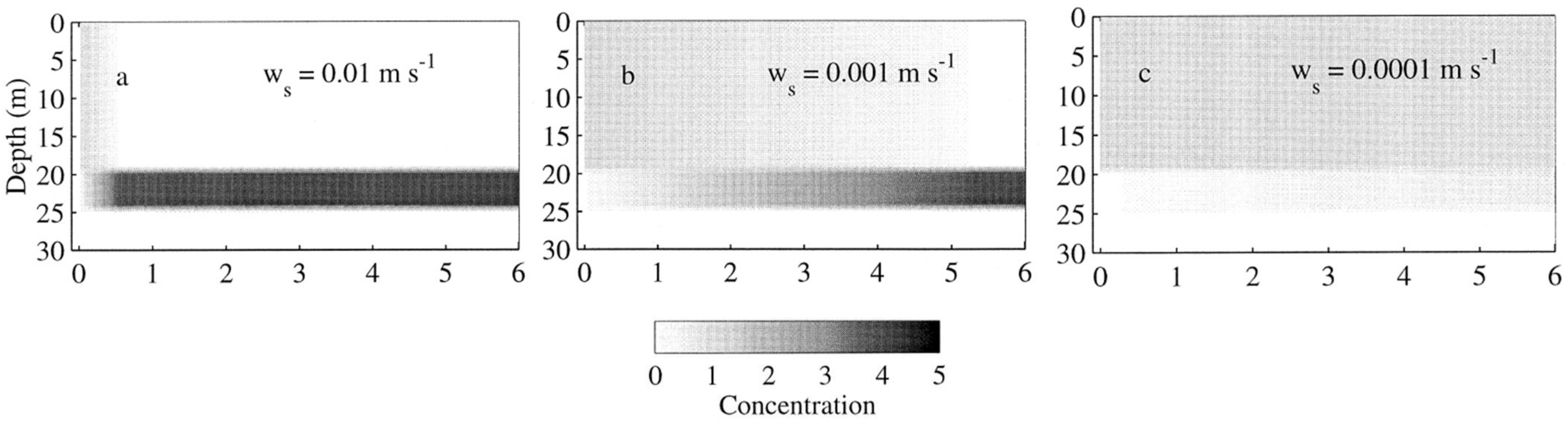
$e = \beta C$

contact rate

behaviour

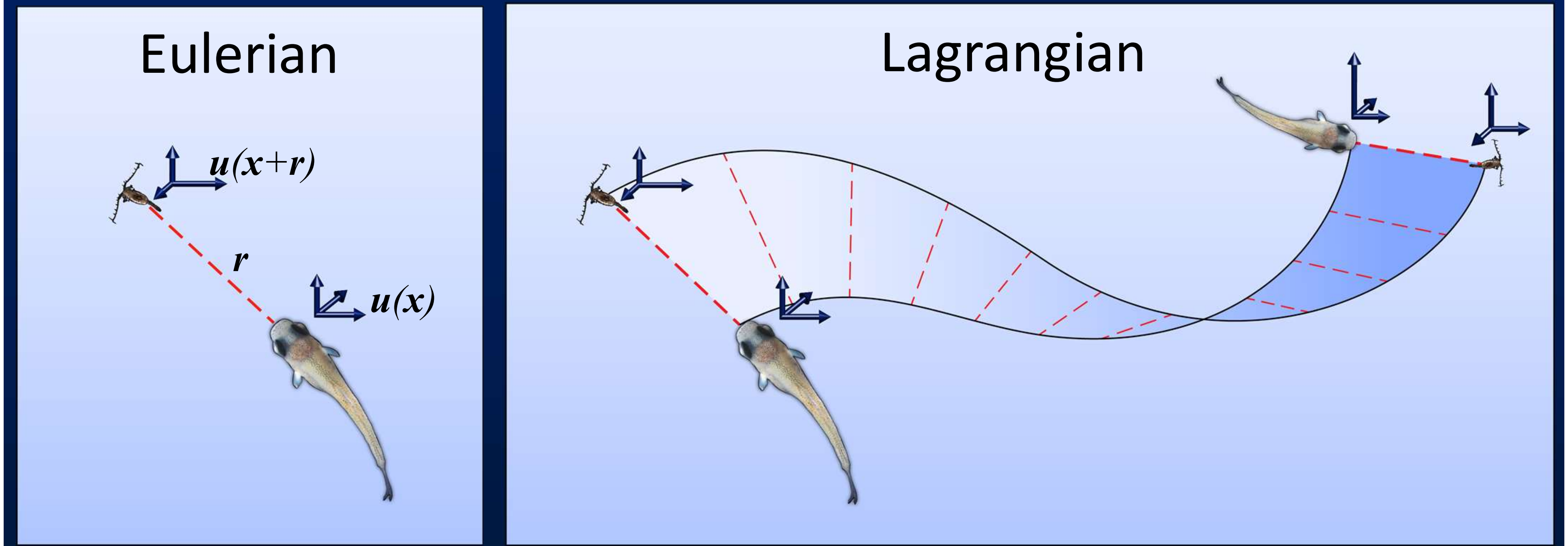
prey concentration

- Increase in contact rate is often attributed to behaviour in lab experiments
- No refuge from turbulence & small tanks restrict range
- Organisms swim down away from upper mixed layer, concentrating themselves into a thinner layer



Franks, 2001

Eulerian vs Lagrangian?

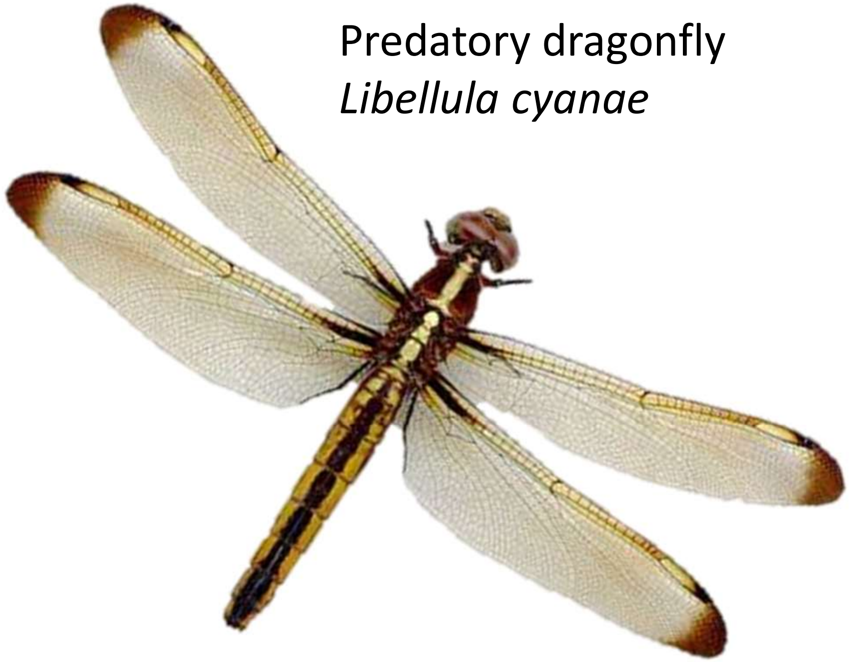


- Shift from Eulerian-based to Lagrangian systems to understand turbulence effects on plankton
- Can take a long time for particles to separate
- Behaviour may be more important

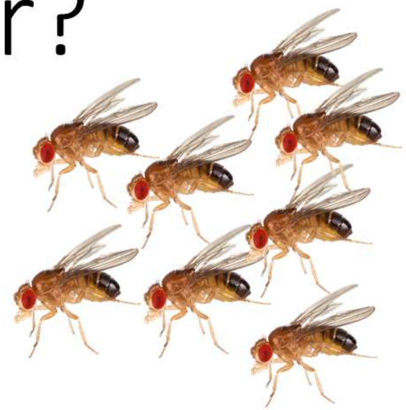
Franks, 2018

Combes et al, 2011

What about in the air?



Predatory dragonfly
Libellula cyanae



Fruitfly prey
Drosophila melanogaster

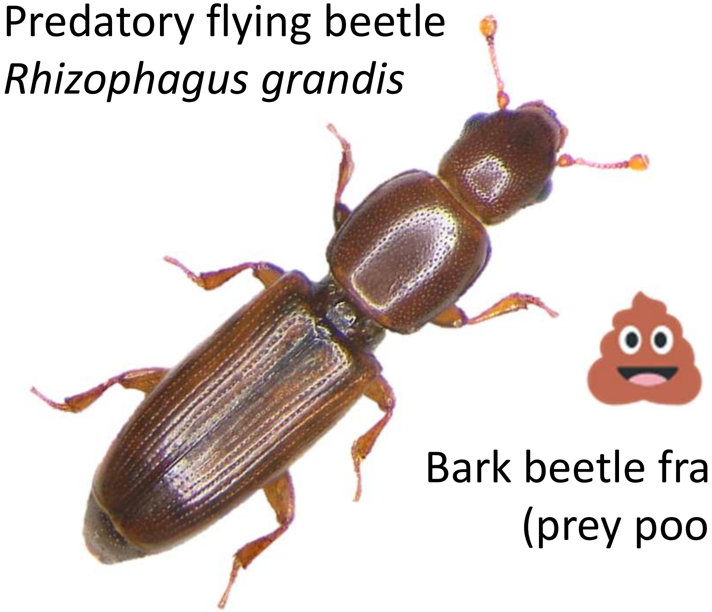
"*prey density explains the most variability in success rate*"

- Insect distribution & dispersal is affected by wind.
- Windbreaks cause wind reduction, microclimates,
- Nature of windbreak is affected by vegetation diversity.
- Wingless insects / small insects depend on wind to carry them to new sites & settle in areas with low windspeeds
- Better for flying insects to stay within boundary layer where windspeeds < insect flight speed.

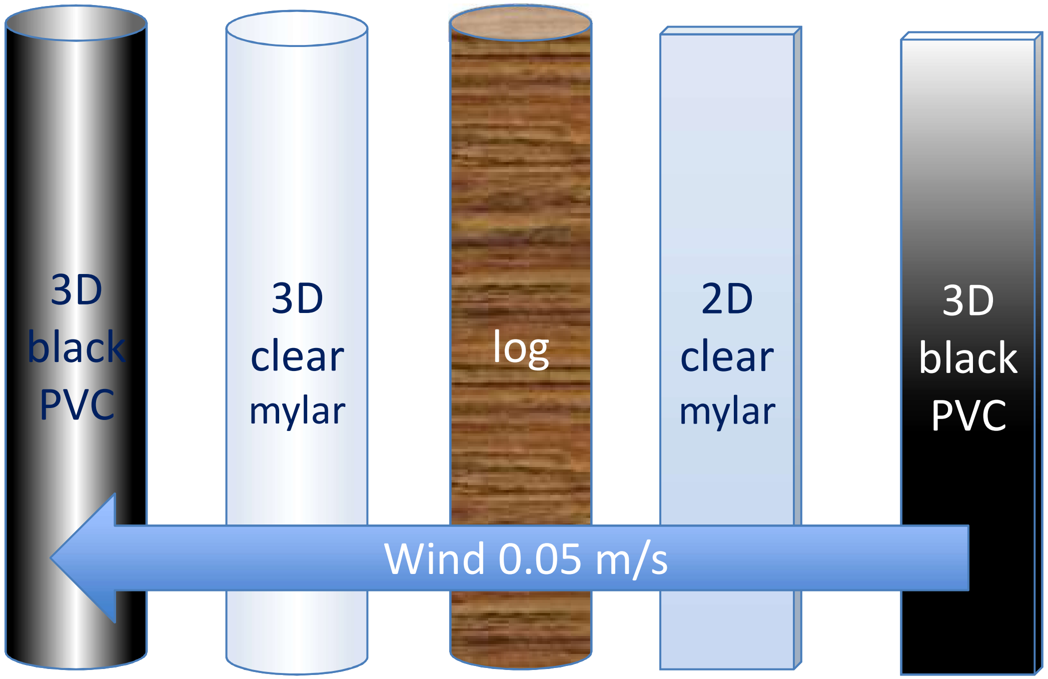
What about in the air?

Wyatt, Phillips and Grégoire, 1993

Predatory flying beetle
Rhizophagus grandis



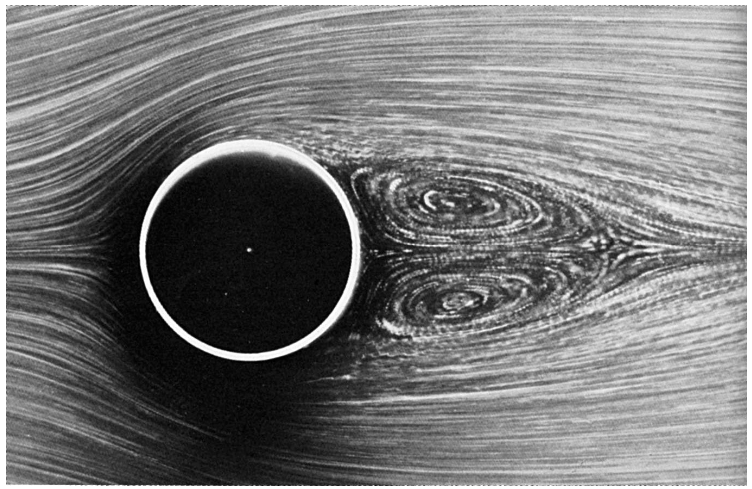
Bark beetle frass
(prey poop)



- Frass on 2D attraction same as frass alone (low) => Not visual

- High attraction to frass on 3D structures

- Response to odour AND turbulent eddies downwind of 3D structure



Take home thoughts…

- Organism feeding rates & velocities may be under / over represented if obtain from a laboratory experiment that omitted turbulence or over-exposed test organisms.
- The extent that turbulence affects predator-prey interactions depends on predator behaviour (ambush / suspension / cruising; reaction distance; perception distance; handling times).
- Turbulence can affect prey distribution both directly and indirectly