Class notes, SMS-618, Particle Dynamics.
Class # 1: Logistics and overview of particles in aquatic environments.

Questions for us to solve as a group (spend 5minutes on them individually, and we will then discuss them in a group):

- What is a particle?

- What particles do we find in aquatic environments?

- What are the sources/sinks of particles in aquatic environments?

- What are the processes that affect their transport and transformation?

- What properties of these particles do/should we care about?

What is a particle?

A particle is a coherent unit (we can tag it and follow it) which moves (sinks, floats) with significant velocity relative to the fluid in which it is immersed. The material forming the particle is termed ‘dispersed phase’ in contrast to the fluid around the particle is termed ‘continuous phase’. If the dispersed material is in liquid state the particle is called a ‘drop’ while if it is in a gas phase it is termed a ‘bubble’. Rigid particles, comprising most sold particles, can withstand large normal and shearing stresses without appreciable deformation or flow.

We consider only cases where the fluid around the particle can be considered a continuum (e.g. is not grainy), hence the scale of the particle much be much larger than the scale of water molecules (0.275nm). In air one may use the mean-free-path of air molecule as the scale to consider. Particle motion relative to its environment may be due to inertia, density differences, or self propulsion.

A dynamic consideration of the size of a particle is one for which the Brownian motion is smaller than its own motion (e.g. due to settling). Assuming a spherical particle and a the settling velocity of a small particle is (we will derive it in the future):

$$v \approx \frac{2(\rho_p - \rho_f)gR^2}{9\mu} ms^{-1}$$

Where μ is the fluid viscosity while ρ_f is its density.
Using values for water (ρ_f ~1000kg/m^3, μ =0.001kgm^{-1}s^{-1}, and assuming the particle to be clay-like (ρ_p ~2650kg/m^3), we obtain

$$v \approx 3.6 \cdot 10^6 R^2 ms^{-1}\ .$$

The velocity due to Brownian motion over the length scale of a particle can be obtain from a scaling argument,

$$v \approx \frac{D}{2R} ms^{-1}$$

Where D is the diffusivity of the particle due to Brownian motion:

$$D = \frac{kT}{6\pi\mu R} m^2 s^{-1}$$

With k=1.4 10^{-23}JK^{-1} being Boltzmann’s constant. For oceanic temperatures (300K>T>273K) we find:

$$v \approx \frac{kT}{12\pi\mu R^2} ms^{-1} = \frac{1.1 \cdot 10^{-19}}{R^2} ms^{-1}$$

Equating the two, to find the size that separates the regime where Brownian motion dominates (which we will call ‘dissolve’) to that where sinking does:

$$R^4 = 3 \cdot 10^{-26} m^3 \rightarrow R = 0.4 \mu m\ .$$

Hence from both considerations of continuum of the fluid and from defining particles as not being significantly impacted by Brownian motion, $D > 0.2 \mu m$.

Some texts (e.g. Clift et al., 1978) do not consider swimming organisms as particles. In our class we will, with the caveat that their swimming velocities are small compared to the movement of the water (hence still part of the plankton). The velocities associated with the small eddies in the surface ocean are on the order of 1 cm/s (e.g. Jumars et al., 2009). The fastest bacterial swimming speeds are on the order of 10 μm/s. Flagellates/cilliates swimming speeds can go up to mm/s. Macro-zooplankton can swim significantly faster and will thus be ignored in our class.

References:

Clift, R. J. R. Grace and M. E. Weber, 1978, *Bubbles, Drops and Particles*, reprinted by Dover in 2005.

Jumars, P.A., J.H. Trowbridge, E. Boss, and L. Karp-Boss, 2009. Turbulence-plankton interactions: a new cartoon. Marine Ecology 30, pp. 133-150.