

Turbulence controls size distribution of aggregates: in-situ observations by a microstructure profiler

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Abstract

Marine aggregates are ubiquitous particles formed from the accretion of smaller biogenic and non-biogenic components. Visible aggregates, known as marine snow, are typically in the 0.5 to few mm size range. Aggregates are well recognised as hotspot of microbial and planktonic activities. Aggregates formation is an important pathway for transferring materials and carbon flux from surface to the deep ocean. Because aggregate sinking velocity and carbon mass content is size dependent, understanding the physical mechanism controlling aggregate size distribution is fundamental to determining the biological carbon pump efficiency. Turbulence is a physical mechanism in the aggregates formation and destruction. However, the relative roles of turbulence in aggregates formation and destruction have not been fully tested in observational studies. In this study, we analysed simultaneous in-situ observations of turbulence and aggregate in the various aquatic systems. A microstructure profiler, TurboMAP-L, was used to collect shear data and a digital still logger camera was used to collect images of aggregates. Digital images were subsequently used to determine aggregates abundances and size distributions. Direct comparison of turbulence intensity and aggregate size distributions show that turbulence below $\tau=10^{-6}$ [W/kg] enhances aggregation, increasing average particle size; greater turbulence causes particle breakup, limiting the average maximum aggregate size and decreasing the slopes of size distributions. This indicates the role of turbulence controlling aggregate size distributions. We also present fluorescence data collected by TurboMAP-L and focus on difference of aggregates size distributions among different aquatic systems.

Turbulence controls size distribution of aggregates:

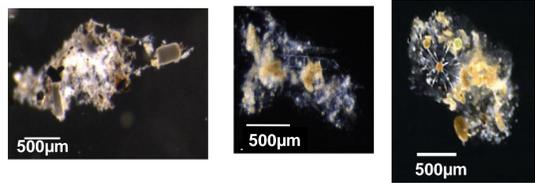
in-situ observations by a microstructure profiler



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Introduction



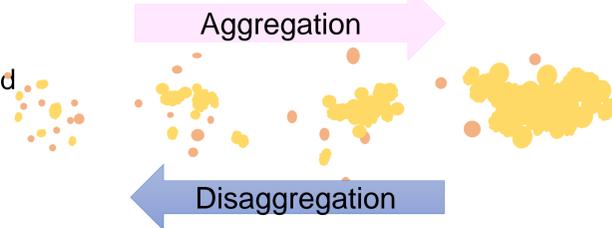
Marine aggregates

- Significant contribution to the global carbon flux
- Sinking velocity and carbon content are size-dependent
- ➔ Understanding physical mechanisms to control aggregate size distribution is fundamental.

Turbulence and aggregates

Theoretical studies⁽¹⁾ and laboratory experiments showed

- Control aggregation / disaggregation process
- Set upper limits in aggregates size
- ➔ **Not clarified from observational data**



Aim of this study

To illustrate the roles of turbulence in formation/ disruption of aggregates, using **in-situ observational measurements of aggregates and turbulence**.

Method



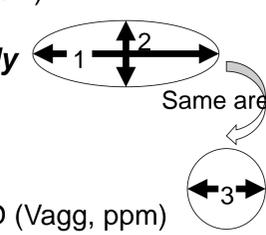
Instruments

- [a] TurboMAP-L (TML, free-fall microstructure profiler)
- ➔ Measurement: shear, temperature, conductivity, fluorescence (*), turbidity
 - ➔ Data collected at various aquatic systems (0 – 100 m)
 - * Resolves mm scale
- [b] Digital Still Logger camera (DSL camera) mounted on TML⁽²⁾
- ➔ Collects images of aggregates in **free-fall mode**
 - ➔ Binary images collected by DSL camera (2cm × 2cm)

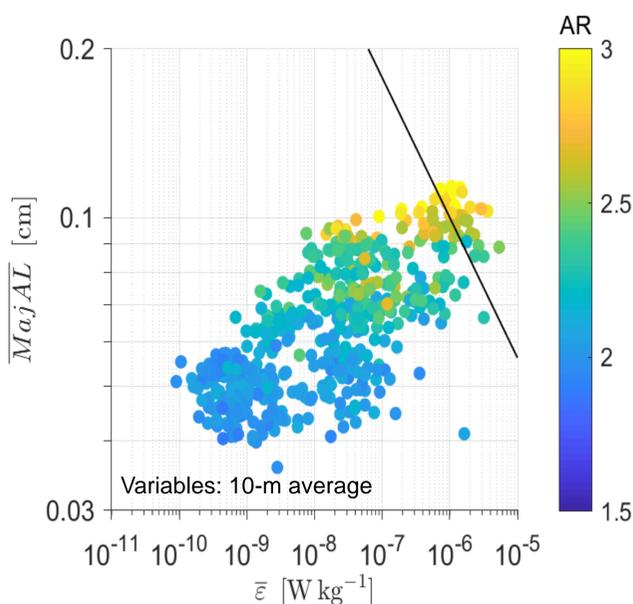


Aggregates properties used in this study

1. Major axis length (MajAL, mm)
2. Minor axis length (MinAL, mm)
3. Equivalent spherical diameter (ESD, mm)
4. Volume concentration, estimated from ESD (V_{agg} , ppm)
5. Aspect ratio (MajAL/MinAL, AR)



Results



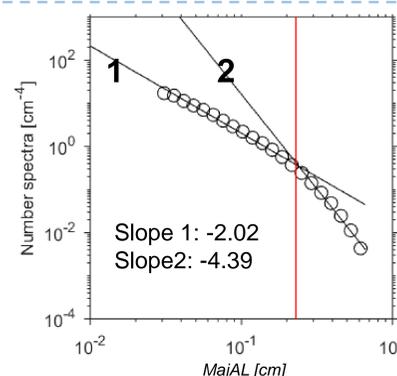
MajAL vs TKE dissipation rate (ϵ)

- Positive correlation ($r^2 = 0.52$, $n = 567$, $P < 0.001$)
- ϵ ranged 10^{-10} – 10^{-5} Wkg^{-1}
- $MajAL <$ the Kolmogorov length scale (the smallest eddy scale, $\eta = (v^3/\epsilon)^{1/4}$) up to $\epsilon = 10^{-6}$ Wkg^{-1}

Aspect ratio (AR) vs TKE dissipation rate (ϵ)

- Smaller AR: spherical
- Larger AR: elongated

- ① $\epsilon < 10^{-6}$ Wkg^{-1} : turbulence enhances **aggregation**
- ② 10^{-6} $Wkg^{-1} \leq \epsilon$: **disaggregation** is dominant
- ③ Aggregate size is limited by the Kolmogorov scale length
- ④ Large aggregates are more stretched under strong turbulence

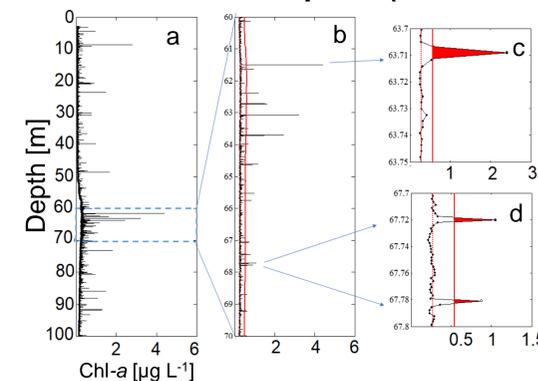


Size distribution

- All 10 surveys showed 2slopes size distribution
- Slope1: -2.5 to -1.6 (Ave. -2.0)
- Slope2: -5.7 to -3.6 (Ave. -4.4)
- Slope1 to 2 occurred at ~ Kolmogorov length scale

- ① Aggregate size is limited by Kolmogorov scale length
- ② Size spectrum have two slopes (~ -2 and -4)

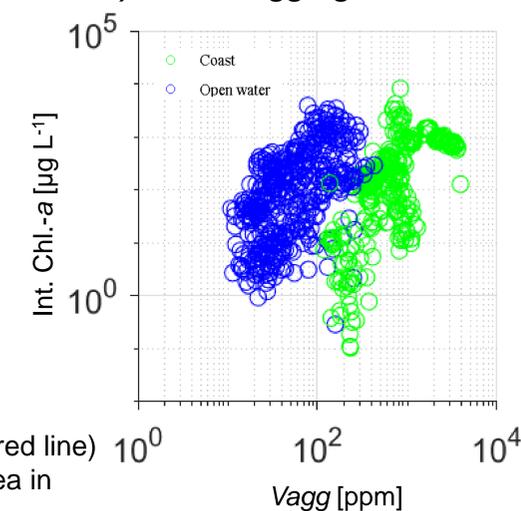
Laser fluorescence probe (mm scale resolution) detects aggregates



[a] Locally strong signals (Eg. 60-70 m)

[b] Threshold at 1.5 x 1-m moving average (red line)

[c, d] Integrate signals exceed threshold (area in red) over 10m.



Integrated Chl-a (Int.Chl-a) vs aggregate volume concentration (Vagg)

- Open water: $r^2 = 0.30$ ($p < 0.01$)
- Coastal water: $r^2 = 0.45$ ($p < 0.01$)

For given Int.Chl-a, V_{agg} (open water) $<$ V_{agg} (coastal water)

- ➔ Open water : dense phytoplankton per aggregate
- Coastal water: less phytoplankton + more non-fluorescent matter

Conclusion

The in-situ observational data demonstrated that ① $\epsilon \leq 10^{-6} Wkg^{-1}$: aggregation is dominant ② $10^{-6} Wkg^{-1} < \epsilon$: break up aggregates ③ Kolmogorov scale: upper limit of aggregate size.

Turbulence intensity at the majority of world ocean remains $\epsilon \leq 10^{-6} Wkg^{-1}$ (3). Thus, turbulence-enhanced formation / disruption of aggregates is an important physical mechanism that drives vertical flux of aggregates in the world ocean.

References & Acknowledgement

1. Jackson, G. A. Comparing observed changes in particle size spectra with those predicted using coagulation theory. *Deep. Res. Part II* **42**, 159–184 (1995) | 2. Doubell et al., An advanced laser-based fluorescence microstructure profiler (TurboMAP-L) for measuring bio-physical coupling in aquatic systems. *Journal of Plankton Research* **31**, 1441–1452, (2009) | 3. Lueck, R. G., Wolk, F. & Yamazaki, H. Oceanic velocity microstructure measurements in the 20th century. *J. Oceanogr.* **58**, 153–174 (2002)

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