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

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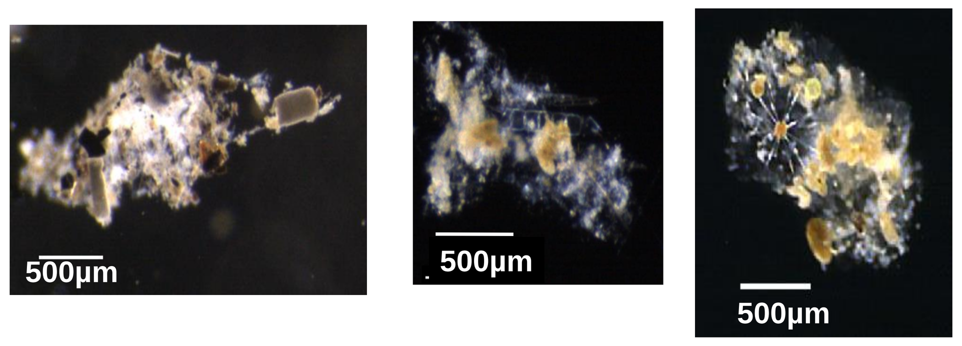
Introduction



Marine aggregates

- Significant contribution to the global carbon flux
- Sinking velocity and carbon content are size-dependent

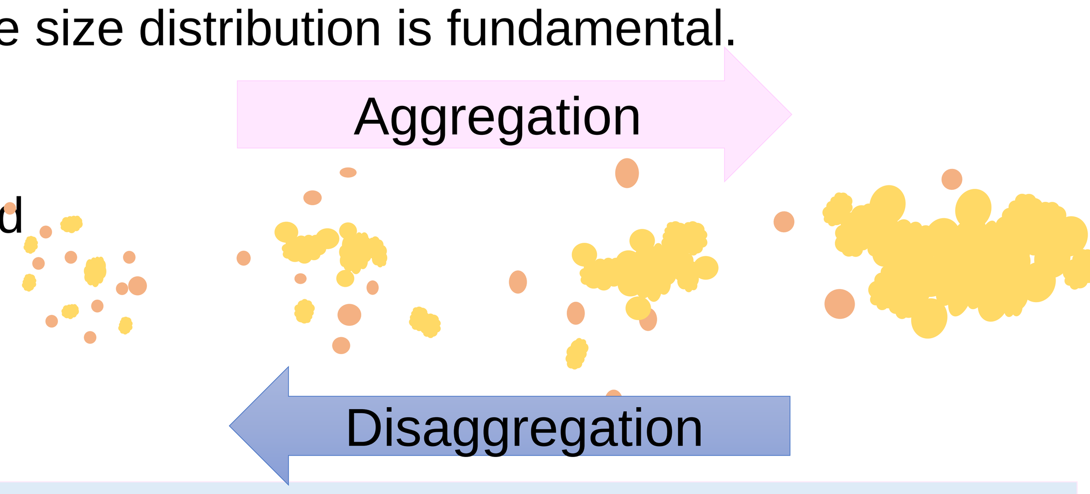
➡ Understanding physical mechanisms to control aggregate size distribution is fundamental.

Turbulence and aggregates

Theoretical studies(1) and laboratory experiments showed

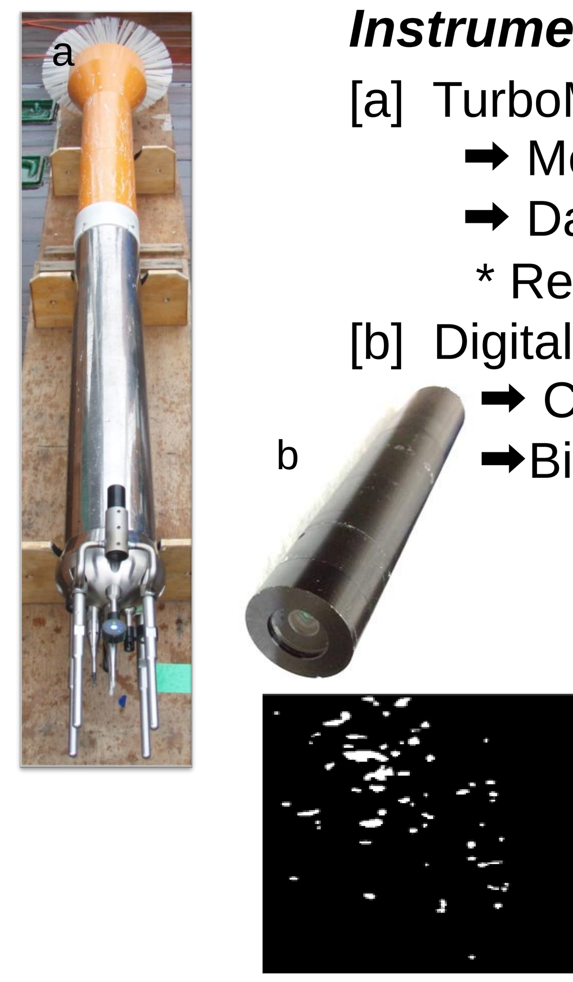
- Control aggregation / disaggregation process
- Set upper limits in aggregates size

➡ 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

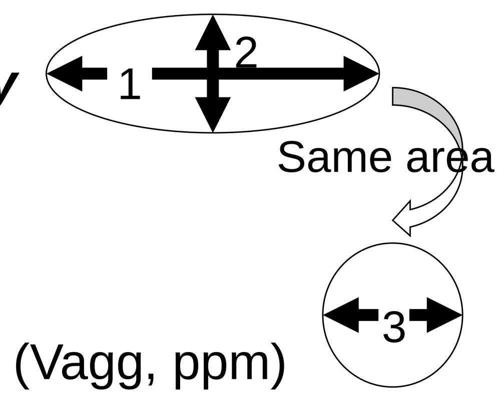


Instruments

[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

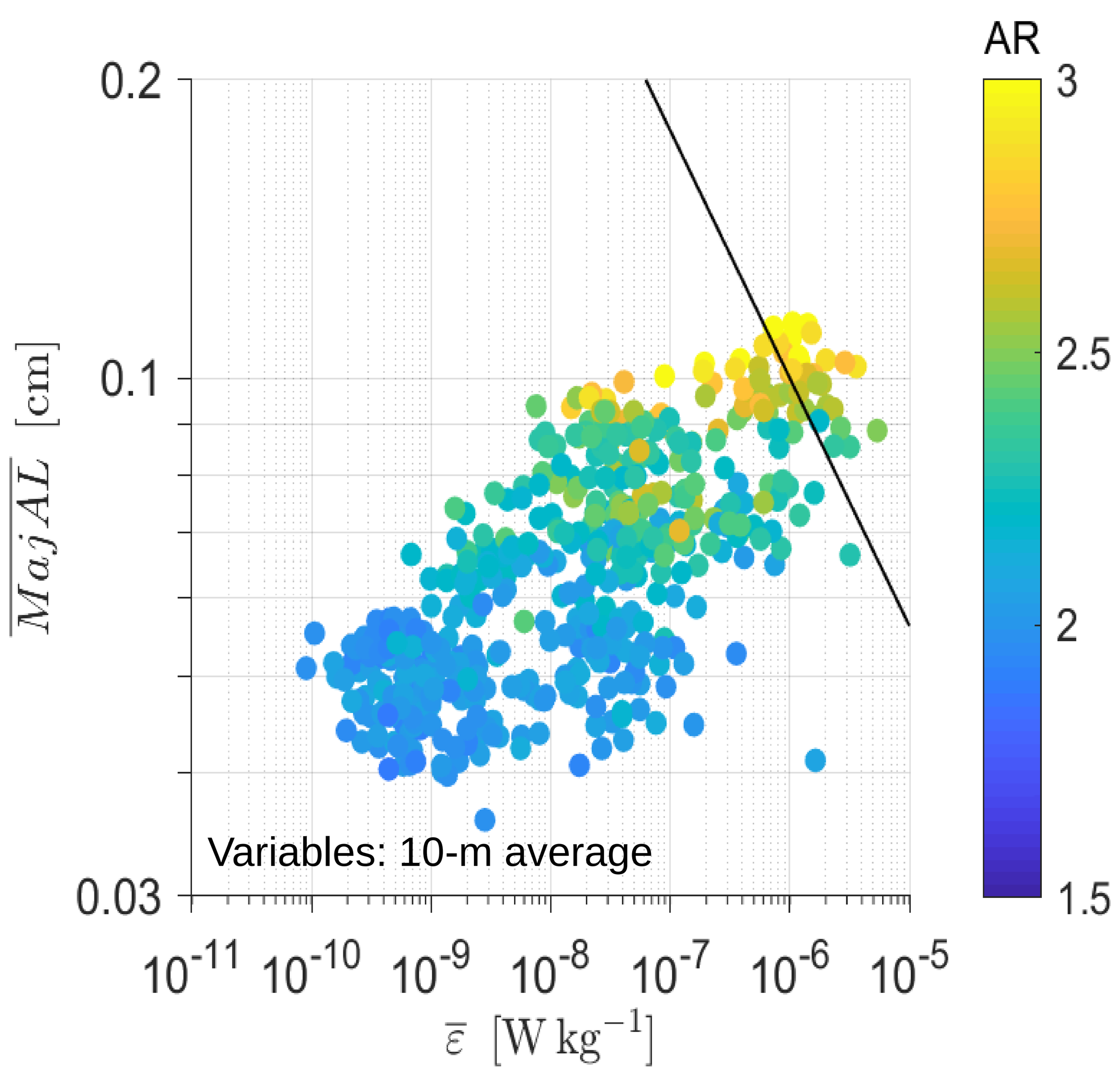
[b] Digital Still Logger camera (DSL camera) mounted on TML(2)
➡ Collects images of aggregates in **free-fall mode**
➡ Binary images collected by DSL camera (2cm × 2cm)

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 (Vagg, ppm)
5. Aspect ratio (MajAL/MinAL, AR)

Results



$\overline{MajAL}$ vs TKE dissipation rate (ε)

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

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

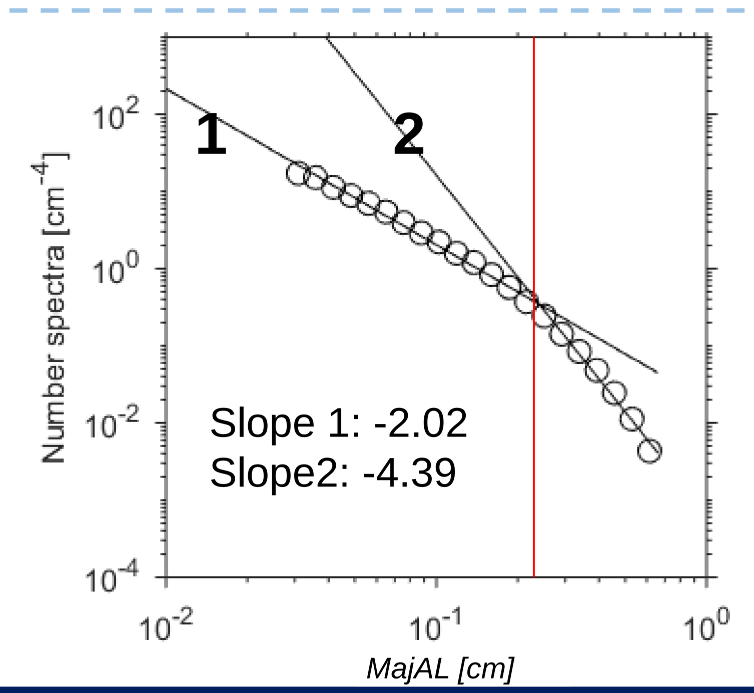
- Smaller AR: spherical
- Larger AR: elongated

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

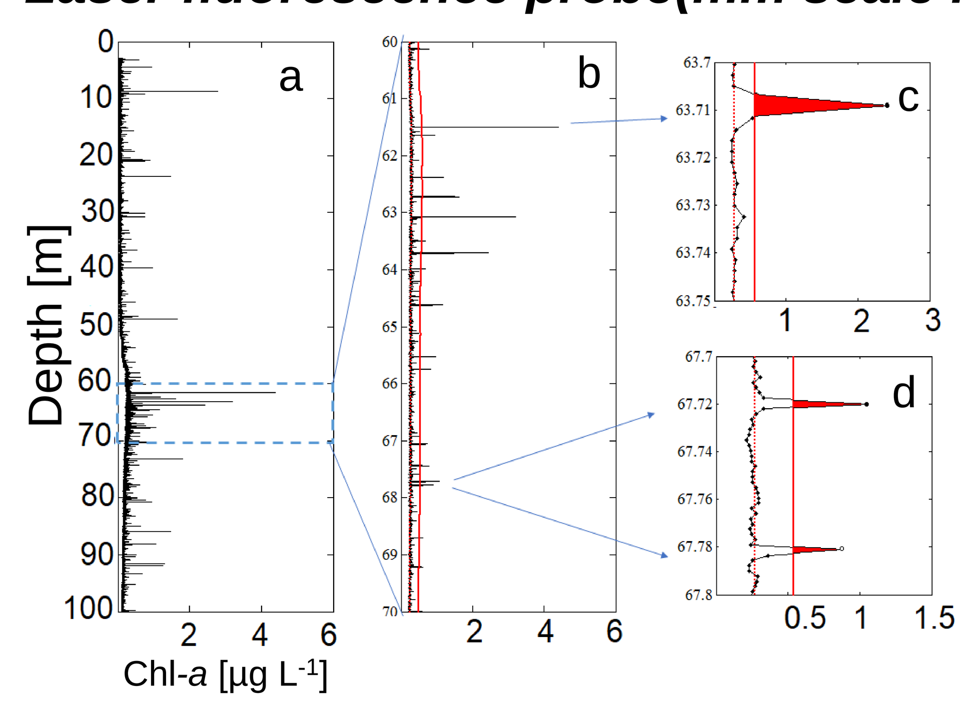
Size distribution

- 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

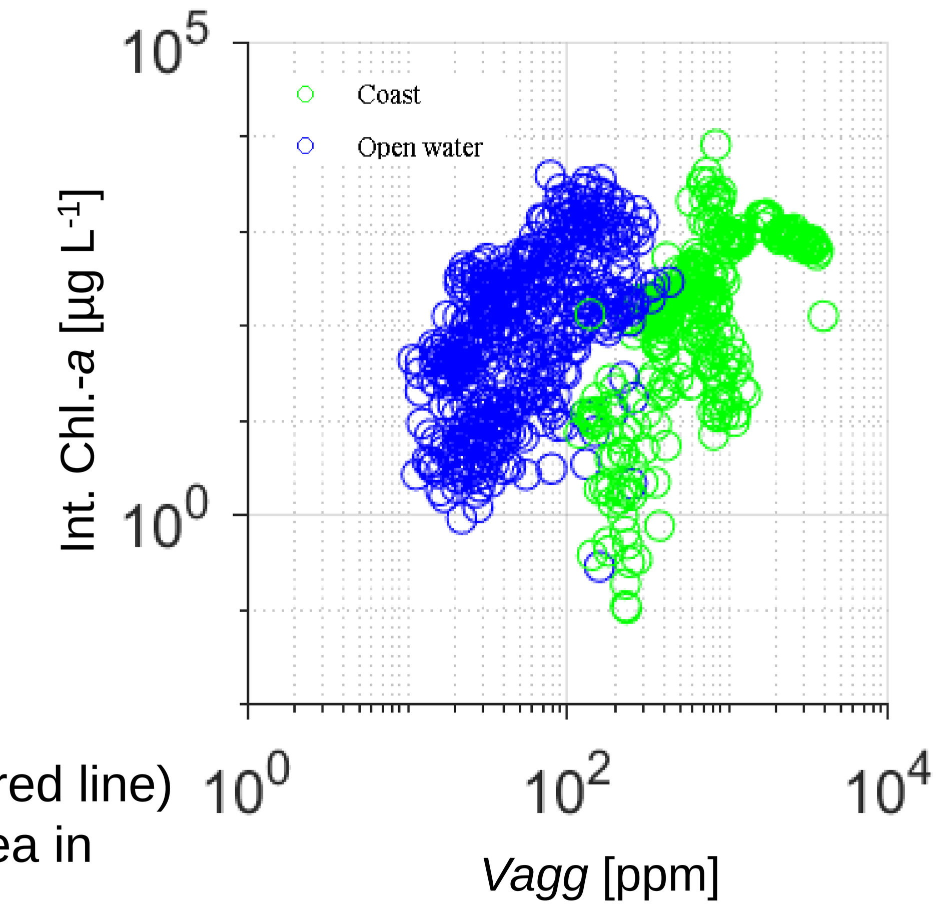
① Aggregate size is limited by Kolmogorov scale length
② Size spectrum have two slopes (~ -2 and -4)



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: r2 = 0.30 (p< 0.01)
- Coastal water: r2 = 0.45 (p<0.01)

For given Int.Chl-*a*, Vagg (open water) < Vagg(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 **$\varepsilon \le 10^{-6}$Wkg^{-1}** : aggregation is dominant ② 10^{-6}Wkg^{-1} < ε : break up aggregates ③ Kolmogorov scale: upper limit of aggregate size.

Turbulence intensity at the majority of world ocean remains **$\varepsilon \le 10^{-6}$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

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