In-situ observations of marine aggregate using imaging systems

[課程博士・論文博士共通]

博士学位論文内容要旨
Abstract

専　攻 Major	応用環境システム学専攻	氏　名 Name	竹内茉莉香
論文題目 Title	*In-situ* observations of marine aggregate using imaging systems (光学機器を使用した海洋微小凝集体の現場観測)		

Marine aggregates are formed through the coagulation of small 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 recognized as hotspots of microbial and planktonic activities. In addition, aggregates formation is an important pathway for transferring organic matter from surface to the deep ocean, hence the impacts of aggregates in carbon flux is significant. Since carbon mass content, chlorophyll-*a* concentration, and aggregate sinking velocity are size dependent, aggregate size distribution is fundamental to better understand the contribution of aggregate in the ecosystems and future environmental changes. Numerous studies have been conducted at laboratories and theoretical ways to demonstrate size distribution of aggregate through aggregation and destruction of cultured aggregate or idealized particles, however, the size distribution of naturally occurring aggregate has not fully investigated in observational studies. In this study, I will present the relationships between size distribution of aggregate and i) turbulence and ii) chlorophyll-*a* using observational data. Furthermore, I will explore the seasonal variation of aggregate from long term monitoring. Introducing the ideal way of aggregate measurements in the field will be presented in the end.

A mini CMOS camera (DSLII 190, Little Leonard Inc.) was mounted on a microstructure profiler (TurboMAP-L, JFE Advantech Co., Ltd.) and collected images of aggregates simultaneously with microscale variations. Observations were conducted at 10 locations since 2008. Images that DSL camera collected were subsequently used to determine aggregates size distributions. Fluorescence and turbulence were simultaneously measured by a microstructure profiler, TurboMAPL.

Three physical mechanisms are known to form aggregate; Brownian motion, differential sedimentation and turbulence. Brownian motion is a main driver to form small aggregate through collisions of small particles (<1μm). The influences of differential sedimentation is relatively small under turbulent condition. Thereby, turbulence is expected to be the major driver to form aggregate in upper ocean. In order to reveal the relationship between turbulence and aggregation, turbulent kinetic energy dissipation rate (ε, W kg^{-1}) estimated from shear data and major axis length of aggregate (*MajAL*, cm) was directly compared. Each variables was averaged over 10 metres. Direct comparison of average turbulence kinetic energy dissipation rate ($\bar{\varepsilon}$, W kg^{-1}) and average *MajAL* ($\overline{MajAL}$,cm) had positive correlation in log-scale (r^2 = 0.52, n =567, p<<0.01), showing that aggregate becomes large with turbulence. Majority of $\overline{MajAL}$ remained smaller than Kolmogorov scale (the smallest eddy size), suggesting that aggregate size is limited by Kolmogorov scale. It also showed 90 of

$\overline{MaJAL}$ was smaller than 0.1 cm which is Kolmogorov scale at ε = 10^{-6} W kg^{-1}. This demonstrates that turbulence below $\bar{\varepsilon}$=10^{-6} W kg^{-1} enhances aggregation, increasing average particle size; greater turbulence causes particle breakup, limiting the average maximum aggregate size. Since ε is smaller than 10^{-6} W kg^{-1} in most water column, turbulence has a significant influence on formation of aggregate in the most of water column in the world. $\overline{MaJAL}$ was also compared with total concentration of aggregate (V_{agg}, ppm). V_{agg} indicates the fraction of water that is occupied with aggregate. Log_{10} ($\overline{MaJAL}$) and $log_{10}(V_{agg})$ also showed positive correlation (r^2 = 0.81, n =567, p<<0.01). The collision rate of aggregate increase when water is more occupied with aggregate, leading formation of large aggregate. Morphological change has also been investigated in this study. The comparison between average aspect ratio and $\bar{\varepsilon}$ showed negative correlation, suggesting that aggregate becomes elongated under strong turbulence.

Doubell et al., (2009) suggested that number of aggregate in the images increased when laser fluorescence probe on TurboMAP-L showed locally strong signals. Since laser fluorescence probe resolves ~2mm scale, they hypothesized that such strong signals were obtained from hitting individual aggregate. Secondly, I will present the relationship between aggregate and fluorescence. In order to compare the strong signals of laser fluorescence and aggregate, strong signals that exceeded threshold (1.5 × 1 metre moving average) were integrated over 10 metres (*ILFI*, μg L^{-1} /10m). *ILFI* was then compared with total volume concentration of aggregate (V_{agg}, ppm). Smaller V_{agg} was found in open water than coastal water, showing that water is less occupied with aggregate in open water. It also showed smaller V_{agg} in open water for given *ILFI*. This suggests that individual aggregate in open water contains more phytoplankton. Thereby phytoplankton is densely concentrated in open water and may support ecosystems. Open water environments such as Kuroshio extensions are known to be oligotrophic. Highly dense phytoplankton in induvial aggregate in open water may be playing an important role as source of nutrient and food for other living organisms.

The observations by DSL camera and TurboMAP-L show snapshot of aggregate distribution in water column, but do not provide time series data to resolve the seasonal variation. Long term monitoring of aggregate by a cabled observatory system (OCEANS) was conducted to explore the seasonal variation of aggregate. OCEANS was fixed at the sea bed (~20 m from surface) in Habu port of Oshima island. Data was continuously collected since 2014. Two periods (October-January in 2015 and 2016) were selected to compare in this study. Strong influence of open water from Kuroshio extension was found in 1st period and 2nd period had coastal water feature. The frequency of aggregate appearance was higher in 1st period. In 1st period, relatively larger aggregate with more transparent exopolymer particles (TEPs) was observed. Smaller aggregate with less TEPs was dominant during coastal water came in. Since other plankton abundance is also available, further investigation for the biological interaction between aggregate and other organisms is required for better understanding of ecosystems.

Observation of naturally occurring aggregate was successfully conducted by DSL camera, TurboMAP-L, and OCEANS, since DSL camera mounted on TurboMAP-L allowed non-disruptive measuring of aggregate in free fall mode and OCEANS was fixed at the seabed. In the end of this thesis, comparison between size distribution of aggregate obtained by DSL camera and holographic cameras are shown. Holographic cameras were lowered by cabled attached on the research vessel. Because of this, rocking motion of vessel caused sudden upward and downward motion of holographic cameras. The upward velocity of holographic cameras even reached 1 m s^{-1}. Size distribution clearly showed that aggregate was destroyed during the measurements by holographic cameras. Since holographic cameras are powerful tools to scan the water column with high resolution images, developing a new deployment method that allows non-disruptive measurements of aggregate such as free fall mode is highly required.