Data from laboratory disaggregation experiments with sulfate polystyrene microplastics using a disaggregation roller tank that exposed aggregates to time-varying laminar shear in 2021

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Project
» Collaborative Research: The importance of particle disaggregation on biogeochemical flux predictions (Disaggregation)

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Abstract
These data include particle aggregate size, morphology, and fragmentation statistics obtained from laboratory experiments using a disaggregation roller tank that exposed aggregates to time-varying laminar shear. Particle aggregates were formed by rolling polystyrene microspheres at a slow constant rate. Laboratory experiments were conducted at Penn State University in 2021. Polystyrene aggregates were specifically studied to provide a controlled experiment to which we could compare disaggregation results of phytoplankton aggregates. The use of polystyrene allowed us to precisely control the surface bonding characteristics of the particle aggregates for consistent strength determination. Fragmentation was induced by oscillating the roller tank motion (following published methods) to create time-varying laminar shear with values relevant to turbulent shear in the open ocean. Aggregate sizes and morphologies were tracked in time using a bright side-illumination, a high-speed camera, and a particle tracking algorithm. Aggregates were tracked until they either left the camera's field of view or fragmented into two pieces. These data include capture of 51 fragmentation events. The fragmented aggregates ranged from 1 mm to 5 mm in major axis length, though deformed substantially prior to fragmentation due to shear exposure.

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Dataset Description

See the Related Datasets section for access to results of other disaggregation experiments conducted as part of this study.

These data were published in Song et al. (2023).
* This results publication includes additional supplementary material related to this dataset:
https://www.frontiersin.org/articles/10.3389/fmars.2023.1224518/full#sup...

Methods & Sampling

Polystyrene aggregates were prepared using surfactant-free monodispersed white sulfate latex beads

(Interfacial Dynamics Corp.) with a mean diameter of 3 microns. The microspheres were received in an 8% weight by volume solution. To prepare the experiments, 1 mL of the latex solution was diluted in 50 mL of deionized water. We then transferred these to the ~1L disaggregation tank and fully destabilized them by adding calcium chloride at a concentration of 0.5 M.

Polystyrene experiments were conducted with a particle concentration of ~6700 cells/ml. Cells were aggregated into large aggregates through differential sedimentation by rolling them for 2 days at a rotation rate of 2 rpm prior to creating laminar shear. To create laminar shear and induce disaggregation, the flow motion inside the rotating/oscillating tank was a superposition of a solid body rotation and a harmonic oscillatory flow. We provided an analytical solution to this viscous oscillatory flow in the attached publication. Given proper boundary conditions, this roller tank created calibrated laminar shear that is similar in magnitude to that in the ocean.

With high-speed imaging techniques, we captured the fragmentation of laboratory-made diatom aggregates exposed to the calibrated oscillatory flow. We have also developed a unique image processing method that enabled continuous tracking of particle positions, sizes, and morphologies, as well as the determination of individual aggregate breakup events. The image processing consisted of background removal, particle identification, particle matching, and breakup detection. The analytical solution of fluid flow allowed us to couple the hydrodynamic conditions to the recorded time history.

Instrument Summary:

The experimental facility consisted of a transparent acrylic cylindrical tank supported by four identical casters. The tank had an inner diameter of 100 mm and a wall thickness of 5 mm, with a total length of 300 mm. The tank was long enough to have a two-dimensional flow along the central tank cross-section. We controlled the rotation of this tank using an electric servo-motor (Dynamixel MX-28T, Trossen Robotics), programmed with Python. A timing belt drive system that connected the motor to one end of the tank precisely synchronized the rotation with a gear ratio of one. The motor had a resolution of 0.012 rad/s in rotation speed and 0.088º in operating angle. The optical transparency of the tank permitted illumination through the cylinder wall and the imaging of suspended particles through one end of the tank. An LED light panel (StudioPRO S-1200D, Fovitec) shone through a slit aperture (10 mm wide) to illuminate suspended particles along the central tank cross-section. We mounted a high-speed camera (FASTCAM Mini AX200, Photron) with its viewing axis perpendicular to the resulting light sheet. It captured particle motion through a macro lens with a 105 mm focal length (Sigma 105mm f/2.8 EX DG).

Data Processing Description

Data processing was conducted using custom-made codes to extract aggregate population statistics and individual characteristics from the high-speed videos acquired during experimentation. Data processing consisted of image background removal, particle identification, particle matching across frames, and breakup detection. The analytical solution of the fluid flow allowed us to couple the hydrodynamic conditions to the recorded time history. See the Supplemental Files section for data processing steps, which were written in Matlab R2018.

BCO-DMO Processing Description

The data included here consist of disaggregation events collected of aggregate made with a single, sterile strain of diatoms. Marine aggregates typically involve more than one type of phytoplankton along with other organic detritus and possibly inorganic minerals, all of which can affect aggregate strength. The facility used also uses oscillating laminar shear to induce disagregation. While laminar shear is excellent for repeatability and for determining local shear rates around each aggregate, the use of laminar flow prevents us from studying fragmentation under the statistical variability of turbulence.

Experimentally, lighting nonuniformities and particle shadows can introduce uncertainty in the particle identification and matching process used with this method. Practically, this limits the particle concentration we can study as too many aggregates will obscure much of the illuminated central tank cross-section. Additionally, discontinuity caused by particle shadows limited the number of frames we could track particles so we could not obtain the entire history of shear and morphology from the very beginning of the tank oscillation.

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Parameters

Parameters for this dataset have not yet been identified

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Instruments

Dataset-specific Instrument Name	FASTCAM Mini AX200, Photron
Generic Instrument Name	high-speed camera
Generic Instrument Description	A high-speed imaging camera is capable of recording rapid phenomena with high-frame rates. After recording, the images stored on the medium can be played back in slow motion. The functionality in a high-speed imaging device results from the frame rate, or the number of individual stills recorded in the period of one second (fps). Common video cameras will typically record about 24 to 40 fps, yet even low-end high-speed cameras will record 1,000 fps.

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Project Information

Collaborative Research: The importance of particle disaggregation on biogeochemical flux predictions (Disaggregation)

Coverage: Northeast United States Continental Shelf

NSF abstract:

Particle settling is one of the major ways that material in surface waters reaches the deep ocean. Particulate matter in the open ocean consists primarily of organic material from plankton and other biological detritus, which can readily aggregate to form large flocs. A combination of physical, chemical, and biological processes transforms these flocs as they settle, redistributing material throughout the water column and potentially sequestering elements such as carbon in the deep ocean. The impact of these transformations is affected by the sinking speed of these flocs, with larger and denser particles settling faster than smaller, less-dense ones. One of the key questions facing oceanographers today is what controls particle settling speed (for example, particle size, shape, and density). There is considerable evidence that particles readily break apart as they settle, decreasing their average size and settling speed, but it is not yet understood what conditions cause these disaggregation events. This work will measure the breakup characteristics of organic settling particles both in the laboratory and at sea to quantify the importance of these breakup processes relative to particle transport. The work will be done at the Pennsylvania State University in collaboration with the University of Georgia to target the development of future marine particle disaggregation models for use by the oceanographic community.

This research will play an important role in determining the importance of disaggregation on the vertical transport of particulate matter in the ocean. The project will quantify the breakup of organic marine aggregates due to fluid forces caused by turbulence or swimming organisms. Phytoplankton will be cultured and formed into aggregates in the lab prior to disaggregation using calibrated turbulence. The size, shape, and structure of these aggregates before and after breakup will be quantified using high-speed visualization and holographic imaging. In addition to the laboratory measurements, a deployable instrument that can disrupt particles in-situ and measure their size and shape will be built and deployed in the North Atlantic during the spring bloom of phytoplankton. Detailed measurements of particle concentrations, breakup characteristics, organic content, and ambient turbulence as a function of depth in the water column will be collected. This work will represent the first study of marine aggregate breakup in-situ. Specifically, the project will clarify: (1) under what conditions disaggregation is important, (2) how strong different types of natural marine aggregates are and how their strength varies with size, composition, and morphology, and (3) how aggregate size, composition, and structure influences the distribution of its breakup mass. This project will advance the career of a doctoral student and engage numerous undergraduate researchers with the field of ocean science.

This award reflects NSF's statutory mission and has been deemed worthy of support through evaluation using the Foundation's intellectual merit and broader impacts review criteria.

Additional Project Output (supplement to Data Collections section below):

Model Code Description:

Adrian Burd's Research Lab. (2023). BurdLab/Dissaggregation: Disaggregation (Disaggregation). Zenodo. https://doi.org/10.5281/zenodo.8226166

Associated Github Repository: https://github.com/BurdLab/Dissaggregation/tree/Disaggregation

This is the initial release of model code for particle aggregation and disaggregation in the ocean. The referenced Github Repository contains Matlab code to calculate the evolution of the particle size distribution in a single layer of the water column. The code numerically solves the aggregation-disaggregation mass balance equations using a so-called sectional approach developed by Gelbard and Seinfeld (J. Colloid and Interface Sci., 68:363-382, 1979). The model allows for particle aggregation, disaggregation, and sinking, and also changes in aggregate size from cell growth (see SetUpCoag.m), and will form the basis of a suite of particle aggrgation/disaggregation models. All documentation is provided within the code itself. Please see Associated Github Repository link above for detailed description and files.

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Funding

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NSF Division of Ocean Sciences (NSF OCE)	OCE-1948283

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