

Physical process measurements of sediment suspension by vessel operations at Pearl Harbour, Hawaii

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Background

Vessel berthing operations generate near-bed flows that are often sufficient to erode and entrain bed sediments. These flows are generated by tugs, bow thrusters, and/or ship propellers providing propulsion and the flows around the ship hull while turning or underway. In addition to erosional stresses, these vessel-induced flows also produce vertical mixing. This process mixes the eroded sediment through entrainment, turbulent mixing, and/or vertical advection. Contaminants are predominately associated with the fine sediments. Therefore the mobilization of fine sediments in ports and harbours by vessel operations is a potentially significant process in describing contaminant transport and fate.

Two key physical parameters that influence the transport and fate of suspended fine sediments are the initial distribution of suspended sediment mass and the settling velocities of the suspended particles. The objectives of the research described herein are: 1) to quantify spatial and temporal distributions of suspended sediment in plumes generated by vessel operations, 2) to determine fine-sediment settling velocities within the vessel-generated plumes, and 3) to assess aggregation states and flocculation of suspended sediments within the plumes.

Methods

Field experiments were conducted on 28, 29, and 31 August 2012. On 28-29 August, a Tiger tug pushed against the pier pilings at Bravo and Oscar Piers, respectively, generating a prop jet which suspended sediments from the bed. In each case, the tug pushed against the pier in three intervals of 5 minutes separated by approximately 15 minutes for observations. During the observational period instrumentation was deployed from a barge. On 31 August, the team conducted measurements in plumes generated by two departing vessels in the vicinity of a pier. During these vessel operations, tugs assisted the departing naval vessels in leaving the pier or berth, turning the vessel, and getting underway during harbour departure.

The general approach in defining the characteristics of the sediment plumes and the suspended sediment within the plume was to first define the initial extent and concentration of the subsurface plume by acoustic backscatter. Then, periodically, a profiling frame was cast through the water column to permit suspended sediment sampling and measurements of temperature, salinity, suspended particle size, and settling velocity. The acoustic mapping and vertical casts of the profiling frame continued alternately until the sediment plume became very diffuse and difficult to discern from ambient conditions by acoustic backscatter.

Settling of cohesive sediments is governed by processes that are difficult to estimate from fundamental sediment properties. Cohesive sediments are known to aggregate (or stick together) to form flocs, composed of fine-grained sediments and organic matter. Floc size is governed by the balance between aggregation and disaggregation processes. Aggregation is influenced by processes causing particles to collide and the efficiency with which these particles stick together. Particle collisions are influenced by turbulence, differential settling, and Brownian motion; whereas aggregation efficiency is largely associated with surface characteristics of the particles (mineralogy, surface coatings, biological polymers, and water chemistry). Disaggregation is influenced by turbulent shear and interparticle bonding strength of the floc.

Flocs formed in suspension have large porosities, and a large fraction of floc volume is occupied by water. After flocs have settled to the sediment bed, the weight of overlying sediments collapses the floc structure and expels pore water. This process, known as consolidation, results in increased bed density and increased interparticle bond strength. If the consolidated bed is later exposed by erosion, a portion of the eroded sediment may not be completely disaggregated and instead is suspended as small fragments of the bed. These bed aggregates differ from the aggregates formed in the water column (flocs) as they are more tightly packed, have stronger interparticle bonds, and have greater particle densities.

The Particle Imaging Camera System (PICS) (Smith and Friedrichs, 2011) was deployed from a profiling frame to determine suspended sediment size, settling velocity, and particle density. Supporting instrumentation was also deployed on the profiling frame to include: 1) a YSI 600XLM sonde for measuring depth, temperature, and salinity, 2) a Laser In-Situ Scattering and Transmissometry particle size analyzer (LISST) for measuring particle size in the range of 7.5 to 1500µm, and a sampling port for pumped physical samples. The PICS is an ERDC-developed system for *in-situ* measurements of cohesive sediment settling velocities. The PICS collects digital video of particle settling within a small settling column and can be deployed in the field. Sample collection, optical and lighting design, and image acquisition were designed to produce high-quality, *in-situ* image sequences. Image sequences collected by PICS are analysed with automated particle tracking software to produce size, settling velocity, and density (inferred) distributions of particles suspended at the sampling location. Additional details of PICS, including system configuration and measurement uncertainty are provided by Smith and Friedrichs (2011).

Image analysis results in simultaneous measurement of particle size and settling velocity. Using these two measured parameters permits estimation of individual particle densities. This is accomplished by solving the settling balance for spherical particles with the Schiller-Naumann drag approximation (Graf, 1971). The estimated individual particle densities are used to classify particles by their aggregation state. Details of the image processing and analysis methods are provided in Smith (2010). Aggregation states include primary particles (individual mineral grains), bed aggregates (aggregations with density approximating that of the sediment bed), and flocs (lower-density aggregations formed in the water column). Flocs are associated with density between 1010-1200kg m⁻³, bed aggregates: 1200-1800kg m⁻³, primary particles: 1800-3000kg m⁻³. A single 30-second video may have hundreds to thousands of tracked particles.

Results

Periodically during the roving ADCP surveys, the motor barge stopped and held position over the sediment plume for conducting water column casts. During these casts, size and settling velocity data, temperature/salinity data, and physical samples were acquired at approximately 2-3m vertical intervals. The settling velocity data within 20 minutes of plume generation were pooled to evaluate the initial distributions of suspended sediment size, settling velocity, and aggregate state.

The pooled distributions indicate that most particles are aggregated fine sediments. The range of primary, disaggregated particles in the PICS data was 0.1 to 1.0 percent, compared to dense bed aggregates (11 to 41 percent) and low density flocs (57 to 89 percent). The minimum resolvable particle size by PICS is approximately 30µm, but the LISST can resolve particles as small as 7.5µm. The LISST data was analysed to determine that 7-9 percent of the suspended particle volume was in the size ranges of 7.5 to 30µm. The apparent densities of the suspended aggregates suggest that the initial suspension of sediment should not be represented as single, disaggregated sediment grains. Instead, the settling velocities of sediment suspended by the vessel operations should be represented as multiple classes of aggregates with settling velocities consistent with the observations in the plume. The mass-weighted frequency distributions of settling velocity are broadly spread, with the suspended population spanning more than two orders of magnitude in settling velocity. A four sediment class representation was developed. By this representation, a numerical model could represent the diverse population of particles evident in the plume.

References

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