Assessment of a New Method for Estimating Density of Suspended Particles

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LONG-TERM GOALS

The goal of the proposed work is to investigate the accuracy of a new method for estimating the bulk density of suspended particles in situ and non-invasively. The new method uses the commercially available LISST-100x particle size analyzer paired with a digital floc camera. It would enable collection of high temporal resolution estimates of particle bulk density.

OBJECTIVES

The research has three objectives:

1. Use existing archived field data from a variety of studies to compare the two methods for estimating particle bulk density.
2. Carry out laboratory studies to assess the accuracy of the two methods in a controlled environment.
3. Gather new field data with which to compare the two methods.

APPROACH

The research compares and contrasts two methods for estimating suspended particle bulk density. An established method uses the size and settling velocity to estimate particle density (e.g., Fennessy et al., 1994; Hill et al., 1998; Hill et al., 2011). With this method Stokes Law (or a modified form for larger

Reynolds number particles) is re-arranged to yield particle apparent density (dry mass to wet volume ratio) according to the following equation:

$$\rho_a(DVC) = \rho_s - \rho = \frac{18 w_s \mu}{g D^2} \qquad (1)$$

In Equation 1, $\rho_a(DVC)$ is the apparent density of particles estimated with the size-settling velocity method (kg m^{-3}). The *DVC* refers to the digital video camera used to measure size and settling velocity (see below). The variable ρ_s is the particle density (kg m^{-3}), ρ is the density of water (kg m^{-3}), w_s is particle settling velocity (m s^{-1}), μ is the dynamic viscosity of water (kg m^{-1} s^{-1}), g is gravitational acceleration (m s^{-2}), and D is particle diameter (m). The sizes and settling velocities of suspended marine particles are observed with underwater video in a settling column that is closed to the environment during video observations (the Digital Video Camera, or DVC; *cf.* Hill et al., 2011) and open to the environment during the intervening periods. Median bulk density of particles in suspension is calculated from the population of particles observed in 4 frames separated by 1 s that are extracted from 1-min video clips.

The proposed new method makes use of a key result of our recent ONR-funded OASIS research. In that work, we demonstrated that optical beam attenuation per unit of suspended particle mass is relatively insensitive to particle size, which renders the particle optical beam attenuation coefficient (c_p) proportional to suspended sediment mass despite the variations in particle size that are typical of coastal waters (Boss et al., 2009; Hill et al., 2011). By extension, the ratio of c_p to suspended particle volume should be proportional to suspended particle density.

The particle optical beam attenuation coefficient is estimated with the Sequoia Scientific LISST- 100x. Particle volume is measured with the LISST 100x and a custom-built Digital Floc Camera (DFC). The LISST estimates particle volumes for particles with diameters from ~1.25-250 μm, and the DFC estimates volumes of particles with diameters larger than ~50 μm. Although the DFC is not commercially available, there are new commercial sensors that can provide similar data for large suspended particles. The LISST and DFC data are merged to produce a spectrum of particle volumes for diameters from ~1.25-10^4 μm (cf. Hill et al., 2011).

The proposed new method offers several potential advances. It is not labor-intensive; it can be carried out with commercially available instruments; and it can provide remote estimates of particle density at high temporal frequencies. Testing it against the established method is being carried out under this project.

WORK COMPLETED

The two methods for estimating density have been applied to 8 data sets from a variety of coastal settings. A method for estimating particle size dependent densities based on the work of Hill et al. (2011) and Maggi (2013) has been developed and applied to estimation of revised apparent bulk densities from the DVC. These new estimates have been compared to the new method under consideration in the proposal.

RESULTS

MSc student Alex Hurley has compared the two methods for estimating suspended particle bulk density for the following data sets: OASIS 2007 and 2011; New River Inlet, Willapa Bay, 2009; Bay of Fundy Aquaculture site, 2010, 2011 and 2012; and Minas Basin, 2013. The methods, in general, do not agree (Figure 1). Most DVC density estimates are low relative to the LISST-DFC estimates *($\rho_a(LD)$)*, and they vary less. Agreement degrades as median particle sizes decrease (Figure 2). We attribute disagreement between the methods to size bias with the video method. The lower limit of resolution of the DVC is relatively large (~250 µm), so when particles in suspension are on average significantly smaller than this lower size limit, density estimates from this method are low. Larger particles have lower densities because they are flocculated.

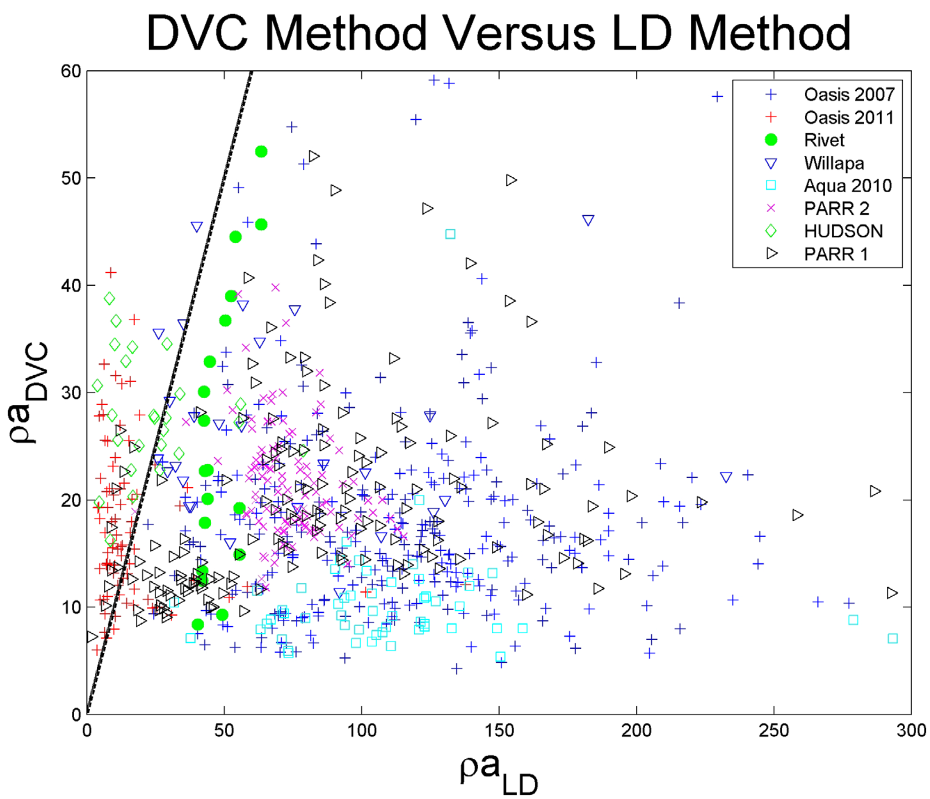

Figure 1. Comparison of apparent bulk densities with two methods. Different color symbols are for different data sets, and the black line plots a one-to-one relationship. There is no correlation overall between estimates of apparent density for the two methods. Densities estimated with the DVC are lower and more constant than densities estimated as the ratio of c_p to volume concentration.

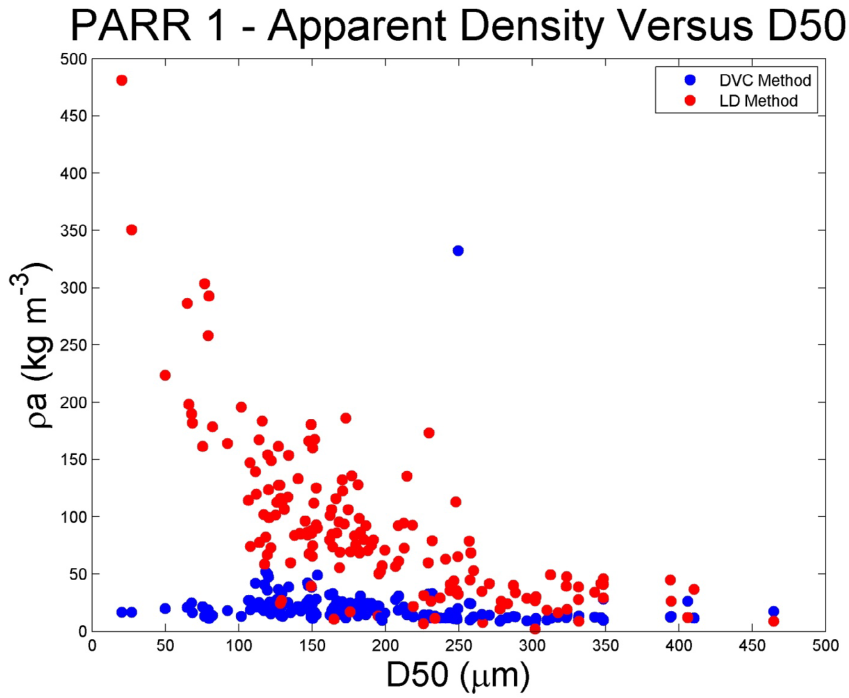

Figure 2. Apparent bulk density versus volume median diameter for the PARR data set collected near an aquaculture site in the Bay of Fundy. Apparent bulk densities from the DVC method (blue circles) do not vary with median diameter. Apparent bulk densities estimated with the ratio of c_p to volume concentration vary as the inverse of median diameter, as expected for flocculated particles. The different behaviors suggest that the DVC method is biased to larger particles.

To contend with the size bias of the DVC, we used its data to develop a density model that covered the size range of the LISST and DFC (Hill et al., 2011; Maggi, 2013). The volume concentration in each size class of a given distribution is multiplied by the modeled density for that size class to produce a mass concentration. These mass concentrations are summed and divided by total volume to produce an apparent bulk density for the suspension.

Apparent bulk densities estimated with the DVC density model, $\rho_a(DVCm)$ are linearly correlated with the ratio of the beam attenuation coefficient to suspended volume concentration (Figure 3). In essence what this linearity reveals is proportionality between mass and the beam attenuation coefficient. The different slopes in the two OASIS data sets shown indicates that the coefficients of proportionality between the beam attenuation coefficient and suspended mass concentration are different.

RELATED WORK

The in-situ measurements of particle size, beam attenuation (c_p), and settling velocity for this project were gathered with support from 4 other ONR funded projects and 4 projects funded by Fisheries and Oceans Canada. The LISSTs used in this project were purchased with Canadian funds, one from a project on oil-mineral aggregation (NSERC, Hill) and one on particle transport away from finfish aquaculture sites (DFO, Law).

IMPACT/APPLICATIONS

This proposal seeks to improve our ability to estimate particle density in situ at high frequency. Such information is needed to predict particle settling velocities, which affect underwater visibility and rate of burial of objects on the seabed.

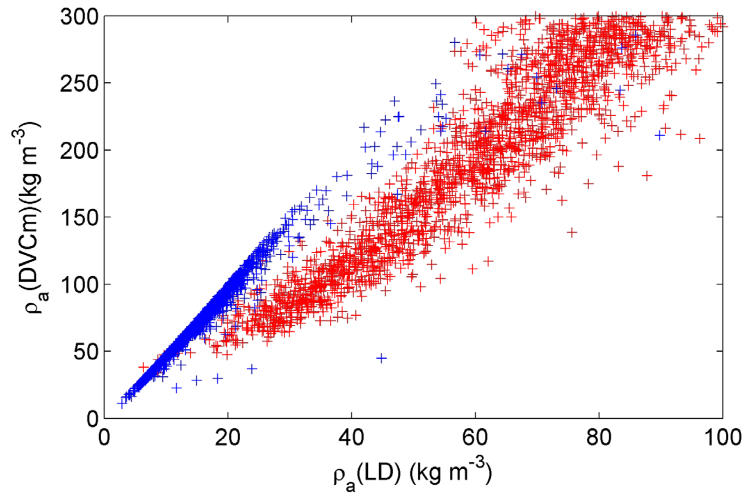

Figure 3. Comparison of apparent bulk density from two methods. The estimate of density on the x axis is simply the ratio of c_p to volume concentration. The estimate on the y axis is derived from a density model for all particle sizes based on the size-settling velocity data from the DVC. The red symbols are from the OASIS 2007 experiment and the blue symbols are from the OASIS 2011 experiment. The linear correlation between density estimates indicates that mass estimated from the DVC data and model are proportional to c_p. The different slopes for the two data sets indicates that the beam attenuation per unit of mass differs between the two data sets.

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