

Optical Constituents at the Mouth of the Columbia River: Variability and Signature in Remotely Sensed Reflectance

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LONG-TERM GOALS

The goal of our research is to improve our ability to assess and predict the distribution of water column optical properties in the coastal region.

OBJECTIVES

Our research in the New River Inlet and in the mouth of the Columbia River has four primary objectives:

1. Measure the variability of optical properties in-space and time;
2. Relate this variability to the concentration and dynamics of dissolved and particulate materials, including variability in the particle size distribution;

3. Relate the optical properties to the ocean reflectance, so algorithms to invert surface color to in-water constituents can be tested and improved;
4. Investigate sediment parameters that optimize fit between derived suspended sediment distribution in the Columbia River mouth and the distribution produced by Delft-3D.

APPROACH

As part of the ONR-funded DRI entitled “RIVET”, a team from Dalhousie University (Paul Hill and PhD student Jing Tao), Bedford Institute of Oceanography (BIO, Tim Milligan and Brent Law), and University of Maine (Emmanuel Boss) carried out a suite of measurements to characterize the evolution of particle and optical properties in the New River Inlet and in the Columbia River plume, moving from Astoria, Oregon through the mouth and onto the continental shelf just beyond the river-mouth bar.

Our work on in situ optical and particle properties in New River Inlet was coordinated with the work being carried out on physical processes and remote sensing during the RIVET project. Our sampling effort consisted of deploying 2 instrument packages to measure particle size and optical properties at a series of stations located along the New River and through the mouth. The instruments on the profiling packages are described below. A third drifting package was deployed to measure hyperspectral upwelling radiance and downwelling irradiance. Water samples were collected and filtered for analysis of particulate mass and organic carbon. Finally, a size settling velocity camera was deployed on the bottom over a tidal cycle.

In the Mouth of the Columbia River portion of the RIVET project, two general categories of measurements were gathered from the R/V Point Sur. First, profiles of water-column particle and optical properties were made at the points of release of several types of Lagrangian drifters, and then the drifters were followed, with profiles of water-column particle and optical properties collected amongst the drifters and at locations of drifter recovery. Second, profiles of particle and optical properties were collected on along-river transects in the mouth. Measurements were made primarily with a profiling instrument package (Figure 1).

The package comprised the two packages from RIVET 1 (see above) bolted and hose-clamped to one another. The particle package, constructed at BIO, carried the new Machine Vision Floc Camera (MVFC), a Sequoia Scientific LISST 100x Type B, an RBR CTD, and two pressure-actuated, self-closing Niskin bottles. The Niskin bottles were set to trip at 5-m and 10-m depths. Surface samples were collected with a “glug” bottle during deployment of the instruments. The optical package carried a WetLabs ac-9 absorbance and attenuation sensor with a 10-cm pathlength, a WetLabs Eco bb2fl that measures backscattering at 532 and 650 nm and CDOM fluorescence, a WetLabs WetStar CDOM fluorometer, a Sequoia Scientific flow control switch, and a SeaBird 37 CTD. The flow-control switch allows the ac-9 to collect 0.2- μ m-filtered and raw water samples on the up- and down-cast respectively. The difference between optical properties in raw and filtered water gives calibration-independent particulate absorption and attenuation (this switch is a novel technical advancement, funded by this project and subsequently commercialized by Sequoia Scientific).

Water samples were filtered through 8- μ m Millipore SCWP filters and through Whatman GFF glass-fiber filters. The former were used to estimate suspended particulate mass (SPM) and disaggregated

inorganic grain size (DIGS) distributions. The latter will be used to calculate organic fraction, characterised by loss on ignition.

Water leaving radiance was characterized two ways by Emmanuel Boss. In the Columbia River a WaterInSight WISP-3 was used to measure reflectance from the water surface. The WISP--3 contains three hyperspectral radiometers, measuring respectively the downwelling radiance, the upwelling radiance, and the diffuse downwelling irradiance. From the signal of these three radiometers the reflectance ('the color') of the water can be determined. In New River Inlet and the Columbia, Boss also used a new iPhone app developed by his student, Thomas Leeuw, at the University of Maine. It also measures reflectance, from which in-water turbidity is estimated.

WORK COMPLETED

Paul Hill and Emmanuel Boss have completed analysis of particle and optical data from New River Inlet. Under the supervision of Paul Hill, Jing Tao has completed the analysis of MVFC and LISST data from the Columbia River to produce merged particle size distributions covering a diameter range of 3-1000 μm . Under the supervision of Emmanuel Boss, Jing Tao has also calculated dissolved and particulate attenuation, absorbance, scattering and backscattering coefficients at multiple wavelengths in the Columbia. She has used these data to calculate the slope of the particulate beam attenuation spectrum and the backscatter ratio. Vanessa Page, who is supervised by Brent Law at BIO, has completed the analysis of suspended particulate mass (SPM) estimated from the filter samples at both sites. Work on disaggregated inorganic grain size (DIGS) analysis is partially completed. Jing Tao presented preliminary results at the Ocean Sciences meeting in Honolulu in February, 2014.

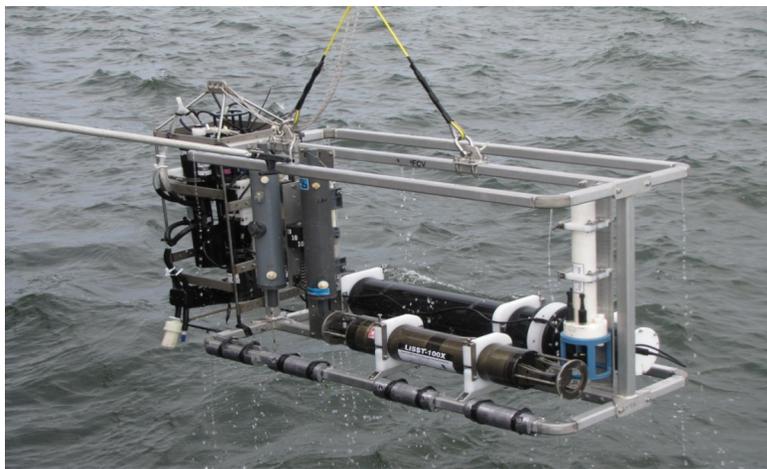


Figure 1. Particle and Optics Profiling package. On the right is an RBR CTD (white cylinder), a LISST-100x type B (green cylinder) and behind it the Machine Vision Floc Camera (large horizontal black cylinder). Niskin bottles designed to collect water at 5 and 10 m are on the left (gray cylinders) as is the Optical package which comprises a 10-cm-pathlength ac-9, a CDOM fluorometer, a SBE-37 CTD, and an automatic switch designed to make 0.2- μm filtered measurements when the package is raised between 8 and 1.5 m.

RESULTS

Our early analysis has focused on the hypothesis that the Columbia River plume contains abundant coarse silt and fine sand resuspended landward of the density front by strong nearbed currents. The resuspended silts and sands clear rapidly from the plume because of their relatively large settling velocities (Nowacki et al., 2012). The Nowacki et al. (2012) hypothesis was based on plume observations outside of the mouth of the Columbia River. Our measurements from inside the mouth support the hypothesis.

Several lines of evidence indicate the presence of resuspended single grains in the plume just seaward of the density front. Total area concentration (TAC) and suspended particulate mass (SPM) both reach maxima at River Km 0 (Figure 2), where Nowacki et al. (2012) propose that resuspension takes place. Concentrations fall rapidly seaward of Km 0. The beam attenuation spectrum is lower in the river than seaward of the mouth, which indicates a shift to smaller particles, which is consistent with sediment loss from the plume by rapid settling.

Analysis of in situ particle size distributions at River Km 0 and River Km -3 demonstrates that the increase in SPM is attributable to the presence of particles in the sand and silt size ranges (Figure 3). Solid particles in this size range are required to explain the rapid settling losses inferred by Nowacki et al. (2012).

In contrast with other coastal environments, the correlation between the beam attenuation coefficient and SPM is weak (Figure 4). The poor correlation arises because the TAC/SPM ratio in the MCR varies inversely with Sauter mean diameter (total volume concentration/ $1.5 \times \text{TAC}$), which means that in the MCR sediment mass is proportional to sediment volume (Figure 5). This proportionality holds for solid single grains but not for aggregated particles, for which sediment mass is proportional to sediment area (Boss et al., 2009; Hill et al., 2011; Slade et al., 2009). Further degrading the correlation between beam attenuation and SPM is correlation of TAC/SPM with the inverse of particle apparent bulk density (SPM/total volume concentration).

This latter effect also complicates the conversion of inherent optical properties to SPM in the New River Inlet.

Dependence of TAC/SPM on inverse apparent bulk density is caused by variable composition of component particles and/or variable particle packing geometry. If variable component particle composition affects TAC/SPM, then TAC/SPM is inversely correlated with backscatter ratio. In New River Inlet correlation between TAC/SPM is significant, but in the Columbia River, it is not (Figure 6). These results indicate that variable composition affects the conversion between optical properties and SPM, but in the Columbia River it does not.

These results support the hypothesis that relatively large sediment sizes are resuspended in the energetic mouth of the Columbia River. The presence of these particle sizes in suspension complicates the interpretation of optical properties because they decouple mass concentration from optical scattering and attenuation coefficients. As a corollary, models of optical properties will require multiple particle size classes, including aggregated fine sediment and solid silt and sand particles.

RELATED WORK

The in-situ measurements of particle size, beam attenuation (c_p), and settling velocity from this project are being combined with those from the another ONR funded project designed to explore methods for estimating particle density without collection of water samples. The efforts described here extend our work carried out in OASIS at Martha's Vineyard Coastal Observatory. The two 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 assess and predict the distribution of optical properties in the coastal region. Such information is needed to assess underwater visibility of relevance to both diving operations and underwater communication.

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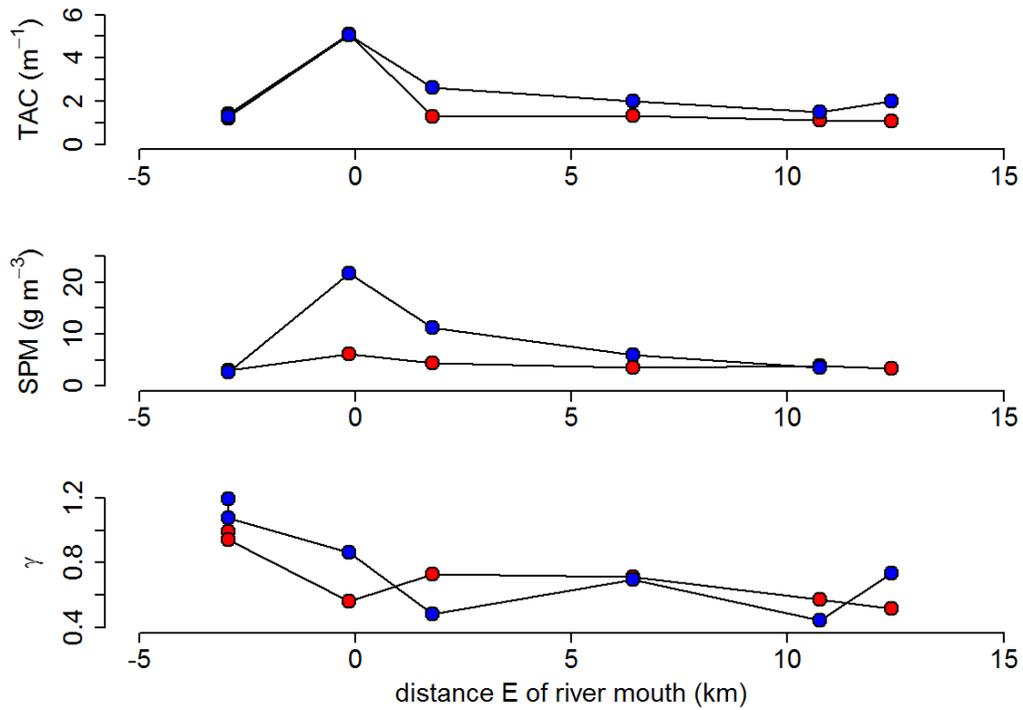


Figure 2. Total area concentration (TAC), suspended particulate mass (SPM) concentration, and the slope of the beam attenuation spectrum (γ) as a function of distance. Red symbols indicate surface measurements (~1 meter depth), and blue symbols are from 5 meters. TAC and SPM are highest at River Km 0, as hypothesized by Nowacki et al. (2012). TAC and SPM decline rapidly seaward of River Km 0. As TAC and SPM decrease, the slope of the beam attenuation spectrum increases, which is consistent with loss of larger particles by settling.

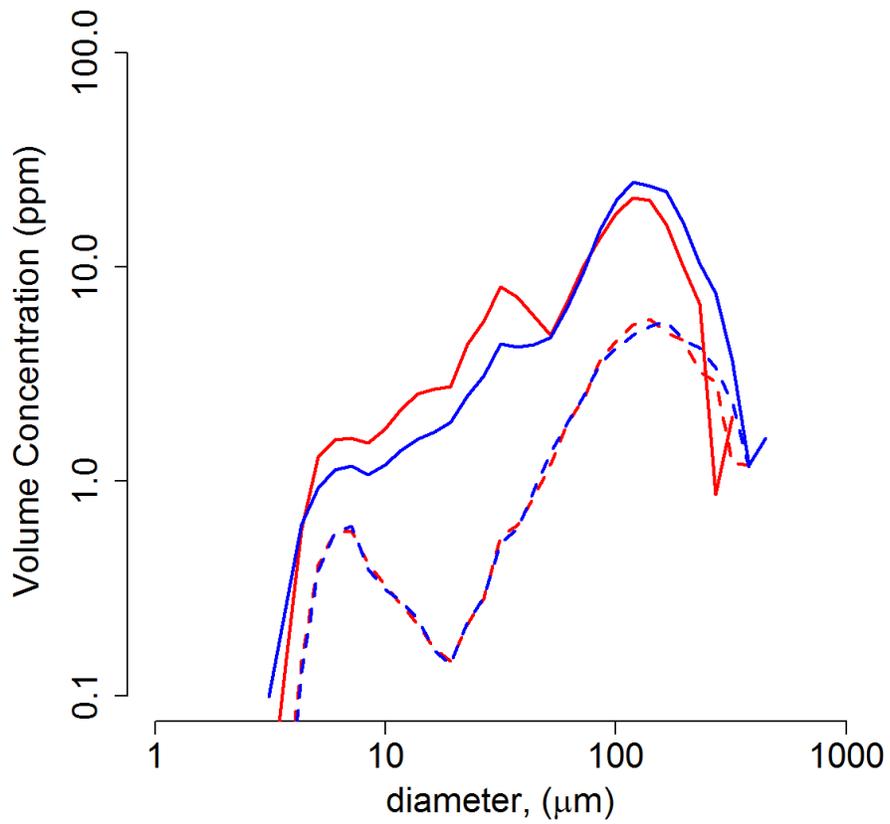


Figure 3. Particle volume concentrations versus particle diameter from River Km 0 (solid lines) and River Km -3 (dashed lines). Red lines are from the surface, and blue lines are from 5 m below the surface. The largest differences between the two sites are in the silt and fine sand sizes.

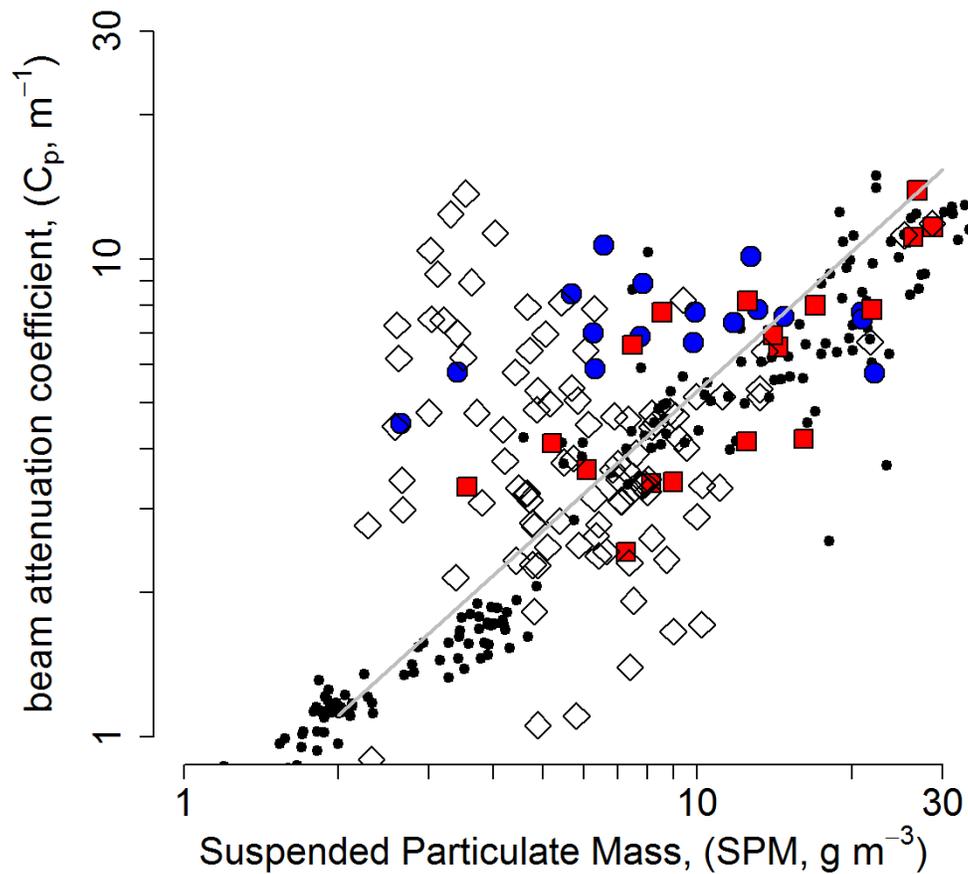


Figure 4: Beam attenuation coefficient (660 nm) versus suspended particulate mass concentration for 4 data sets. Open diamonds are from the mouth of the Columbia River, red squares are from the Martha's Vineyard Coastal Observatory (ONR-funded OASIS project), blue circles are from the New River Inlet (ONR-funded RIVET 1 project), and black dots are from a study funded by the Alliance of Coastal Technologies (ACT). OASIS and ACT data show good correlation between the beam attenuation coefficient and SPM. RIVET 1 and MCR data do not.

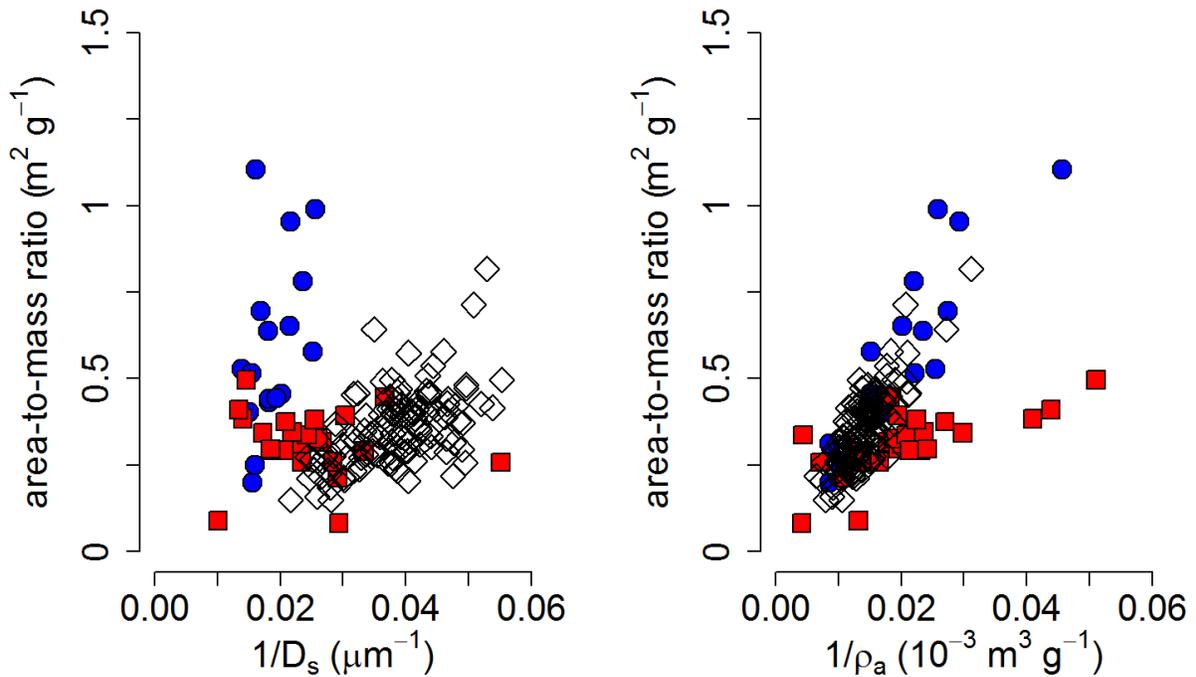


Figure 5. Area-to-mass ratio versus the inverse Sauter diameter and inverse apparent bulk density of sediment. Area-to-mass ratio determines the proportionality between the beam attenuation coefficient and SPM. Open diamonds are from the mouth of the Columbia River (MCR), red squares are from the Martha’s Vineyard Coastal Observatory (ONR-funded OASIS project), and blue circles are from the New River Inlet (ONR-funded RIVET 1 project). In OASIS and RIVET 1 area-to-mass ratio is not a function of particle size, but in MCR it is. This finding indicates the presence of solid particles in suspension. In OASIS area-to-mass ratio does not depend on apparent bulk density, but in RIVET 1 and MCR it does. This finding indicates that there is variability either in the composition or packing geometry of particles in RIVET 1 and MCR.

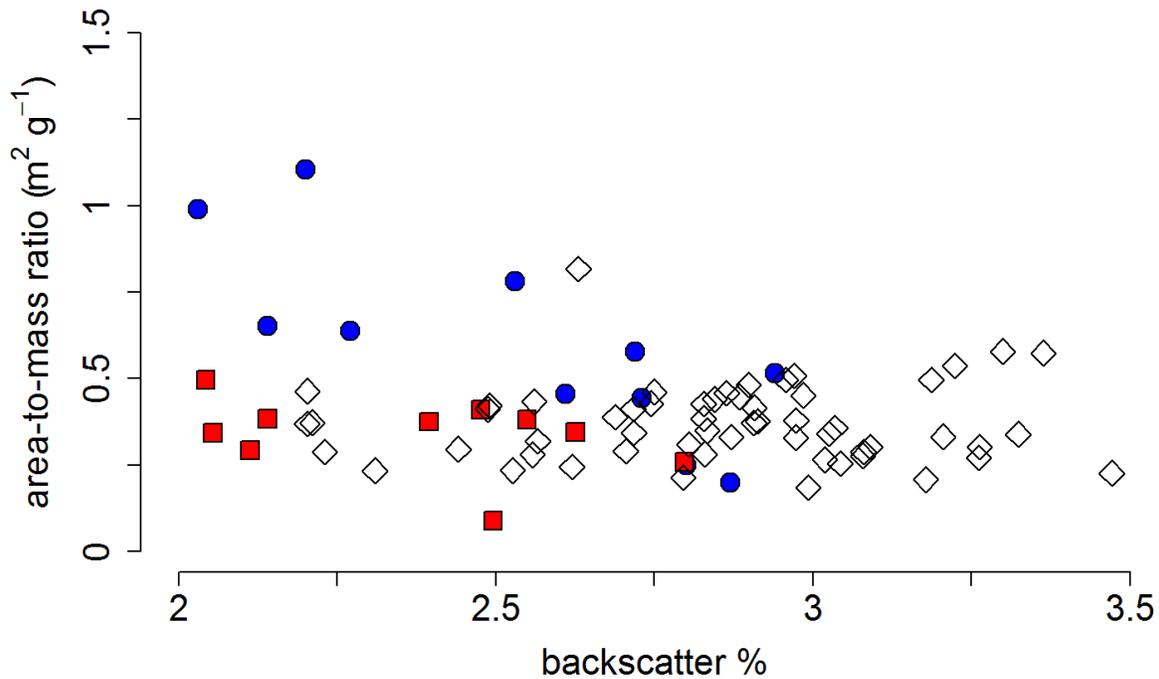


Figure 6. Area-to-mass ratio versus backscatter ratio. Area-to-mass ratio determines the proportionality between the beam attenuation coefficient and SPM. Open diamonds are from the mouth of the Columbia River (MCR), red squares are from the Martha’s Vineyard Coastal Observatory (ONR-funded OASIS project), and blue circles are from the New River Inlet (ONR-funded RIVET 1 project). In RIVET 1 area-to-mass ratio negatively correlated with backscatter ratio, but in MCR and OASIS it is not. This finding indicates compositional variability underlies dependence of the area-to-mass ratio on inverse apparent bulk density of particles in New River Inlet. The lack of correlation between area-to-mass ratio and backscatter ratio in MCR indicates that packing geometry of particles underlies the dependence of area-to-mass ratio on the inverse apparent bulk density of particles there.