Applications of Acoustics and Optics for the Characterization of Suspended Particulate Matter within an Estuarine Observing System

G. M. Cartwright
Virginia Institute of Marine Science

Follow this and additional works at: https://scholarworks.wm.edu/presentations
Part of the Environmental Sciences Commons

Recommended Citation
Cartwright, G. M. 'Applications of Acoustics and Optics for the Characterization of Suspended Particulate Matter within an Estuarine Observing System'. 6-4-2013. School of Marine Science, PhD Dissertation Defense Seminar, Virginia Institute of Marine Science, Gloucester Point, VA.
Application of Acoustics and Optics for the Characterization of Suspended Particulate Matter within an Estuarine Observing System

Dissertation Defense Presentation

Grace Cartwright
Department of Physical Sciences
June 4, 2013
Outline

Objective

Introduction

1.1 Observing Systems

1.2 Acoustic Sensors

1.3 Optical Sensors

York River Observing Systems
Acoustic Sensors (Concentration)
Acoustic Sensors (Settling Velocity)
Addition of Optical Sensors (Size Distribution and Settling Velocity)
Conclusions and Future Work
Outline

Objective

Introduction

1.1 Observing Systems

1.2 Acoustic Sensors

1.3 Optical Sensors

York River Observing Systems

Acoustic Sensors (Concentration)

Acoustic Sensors (Settling Velocity)

Addition of Optical Sensors (Size Distribution and Settling Velocity)

Conclusions and Future Work
1. Investigate the feasibility of a long-term, real-time Multi-Disciplinary Benthic Exchange Dynamic Observing Station

2. Better understanding and interpretation of the data collected specifically the Acoustic Doppler Velocimeter (ADV)
Outline

Objective

Introduction

1.1 Observing Systems

1.2 Acoustic Sensors

1.3 Optical Sensors

York River Observing Systems

Acoustic Sensors (Concentration)

Acoustic Sensors (Settling Velocity)

Addition of Optical Sensors (Size Distribution and Settling Velocity)

Conclusions and Future Work
Observing Systems – Why the York River Estuary?

Population Density

1960-2008

Percentage change
- 500.0 or more
- 250.0 to 499.9
- 69.6 to 249.9
- 0.0 to 69.5
- Less than 0.0
- Not comparable


Sea-level

Geologic History

Local Storm Inundation research and Land Loss Projections

Local Wetlands research

Local Fisheries research

Additional monitoring projects

(Wilson and Fischetti, 2010)
Study Site

**York River Estuary**

- **Clay Bank (CB)**
  - Physical
  - 2007-Present

- **Gloucester Point (GP)**
  - Biological
  - 2006-2009

---

Conceptual Model for Sediment Transport in the York River Estuary

(Dickhudt et al, 2009)
Outline

Objective

Introduction

1.1 Observing Systems

1.2 Acoustic Sensors

1.3 Optical Sensors

York River Observing Systems

Acoustic Sensors (Concentration)

Acoustic Sensors (Settling Velocity)

Addition of Optical Sensors (Size Distribution and Settling Velocity)

Conclusions and Future Work
ACOUSTIC DOPPLER VELOCIMETER (ADV)

Two State-of-the-Art Commercial Instruments

Nortek Vector (6 MHz)
Sontek ADVOcean (5 MHz)

(Nortek, 2005; Nortek, 2008)
Calibration Cruise Profiler
Tripod Mounted

2 minute burst every 15 minutes
ADV Calibration for Sediment Concentration

TSS (pump samples) vs. in-situ ADV backscatter

- **July & August only**
  - $y = e^{(0.039x - 1.1)}$
  - $R^2 = 0.817$

- **All samples**
  - $y = e^{(0.034x - 0.87)}$
  - $R^2 = 0.614$

- **All except Jul & Aug**
  - $y = e^{(0.033x - 0.96)}$
  - $R^2 = 0.701$

(Cartwright et al., 2009)
Settling Velocity Calculated from ADV Data

Assume:

\[ \langle w' C' \rangle = W_s < C > \]

(Fugate & Friedrichs, 2003)

\[ \text{Slope} = w_s = 1.5 \text{ mm/s} \]

Biological site (GP) ADV Data:

-- Does not require unstratified conditions, only approximate suspension-settling balance.
-- Insensitive to ADV calibration for C; 50% change in calibration = 10% change in \( w_s \).
Outline

Objective

Introduction

1.1 Observing Systems

1.2 Acoustic Sensors

1.3 Optical Sensors

York River Observing Systems
Acoustic Sensors (Concentration)
Acoustic Sensors (Settling Velocity)
Addition of Optical Sensors (Size Distribution and Settling Velocity)
Conclusions and Future Work
Optical Instruments

Laser In-Situ Scattering Transmissometer (LISST-100X)

Range 2.5-500 μm

(LISST-100 User’s Guide; Cartwright et al., 2011)
Optical Instruments

Remote In-situ Particle Sizing Camera (RIPSCam)

Range 30 - >3000 μm

(Cartwright et al., 2011)
Optical Instruments

Particle Imaging Camera System (PICS)

Range 30 to ~1000 μm

Uses PTV/PIV To remove Fluid Velocity

Thread Number: 3533 (82); d = 200 μm; X = 9.2 mm; \( W_{\text{mean}} = 0.57 \text{ mm/s} \)

(Smith and Friedrichs, 2011; Cartwright et al, 2012; Smith and Friedrichs, 2012)
Example PICS Video Sequence (1 m depth)

10/06/2012 14:06:00 (frames 001-080) collected at 8 frames/sec

Fluid Velocity hinders sediment settling
Objective

1. Investigate the feasibility of a long-term, real-time Multi-Disciplinary Benthic Exchange Dynamic Observing Station

2. Better understanding and interpretation of the data collected specifically the Acoustic Doppler Velocimeter (ADV)
Outline

Objective

Introduction

1.1 Observing Systems

1.2 Acoustic Sensors

1.3 Optical Sensors

York River Observing Systems

Acoustic Sensors (Concentration)

Acoustic Sensors (Settling Velocity)

Addition of Optical Sensors (Size Distribution and Settling Velocity)

Conclusions and Future Work
York River Observing Systems

MUDBED Real-Time Communications From Clay Bank

Computers in lab for collecting real-time data

(Cartwright et al., 2009)
York River Observing Systems

VIMS

In lab for collecting real-time data

MUDBED Real-Time Communications From Clay Bank

(Cartwright et al., 2009)
York River Observing Systems

MUDBED Real-Time Communications From Clay Bank

VIMS Internet

Computers in lab for collecting real-time data

SUPPORTING CALIBRATION CRUISES

(Cartwright et al., 2009)
Higher Concentration Period at **Physical (CB)** site (ADV height ~ 35 cm)

- Current (cm/sec)
  - ~ 40 cm/s

- TSS (mg/liter)
  - ~ 100 mg/l

- Bed elev (cm)
  - ~ 20 cm change

(Days since February 27, 2007)

(Cartwright et al., 2009)
Higher Concentration Period at Physical (CB) site (ADV height ~ 35 cm)

\[ w_s = 0.77 \text{ mm/s} \]
\[ w_s = 0.55 \text{ mm/s} \]
\[ w_s = 0.20 \text{ mm/s} \]

\[ <w'C'> \text{ vs. } <C> \]

(Cartwright et al., 2009)
Objective

1. Investigate the feasibility of a long-term, real-time Multi-Disciplinary Benthic Exchange Dynamic Observing Station

2. Better understanding and interpretation of the data collected specifically the Acoustic Doppler Velocimeter (ADV)
Objective

1. Investigate the feasibility of a long-term, real-time Multi-Disciplinary Benthic Exchange Dynamic Observing Station

2. Better understanding and interpretation of the data collected specifically the Acoustic Doppler Velocimeter (ADV)

“The use of acoustics for estimating sediment concentration in flocculating cohesive suspensions is still problematic and requires fundamental studies on the interaction of sound with aggregated fine grained particles, before quantitative inversions can be formulated”

(Thorne and Hay, 2012)
Outline

Objective

Introduction

1.1 Observing Systems

1.2 Acoustic Sensors

1.3 Optical Sensors

York River Observing Systems

Acoustic Sensors (Concentration)

Acoustic Sensors (Settling Velocity)

Addition of Optical Sensors (Size Distribution and Settling Velocity)

Conclusions and Future Work
Acoustic Sensors (Concentration)

(Cartwright et al., 2012)
Acoustic Sensors (Concentration)

(Cartwright et al., 2012; Newbill, 2010)
Acoustic Sensors (Concentration)

(Cartwright et al., 2012; Newbill, 2010)
TSS (pump samples) vs. in-situ ADV backscatter

- July & August only
  
  $y = e^{(0.039x - 1.1)}$
  
  $R^2 = 0.817$

- All samples
  
  $y = e^{(0.034x - 0.87)}$
  
  $R^2 = 0.614$

- All except Jul & Aug
  
  $y = e^{(0.033x - 0.96)}$
  
  $R^2 = 0.701$

(Cartwright et al., 2009)
Comparison of Sontek ADVOcean and Nortek ADV Vector for measuring concentration

<table>
<thead>
<tr>
<th>ADV serial number</th>
<th>VCH 4844</th>
<th>VEH 4493</th>
<th>VCH 4854</th>
<th>VCH 4856</th>
<th>VCH 4921</th>
<th>B336</th>
<th>B337</th>
<th>B338</th>
<th>B339</th>
<th>B3084</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1: Inter-/intra-vendor, paint/no-paint</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Run 2: Inter-/intra-vendor, no-paint</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Run 3: Method Reproducibility</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run 4: Mud (silty-clay) calibration</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run 5: Sand calibration</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run 6: Mixed (sandy mud) calibration</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-situ calibration</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muddy flocs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Cartwright et al., 2013; Tait, 2012)
Comparison of Sontek ADVOcean and Nortek ADV Vector response to concentrations of sediment types

(Cartwright et al., 2013)
Comparison of Sontek ADVOcean and Nortek ADV Vector for measuring concentration in a silty clay

(Cartwright et al., 2013; Tait, 2012)
Comparison of Sontek ADVOcean and Nortek ADV Vector for measuring concentration in a silty clay

(Cartwright et al., 2013; Tait, 2012)
Comparison of Sontek ADVOcean and Nortek ADV Vector for measuring concentration

| ADV serial number | NORTEK | SONTEK | | |
|-------------------|--------|--------|--------|--------|--------|--------|--------|--------|
|                   | VCH 4844 | VEH 4493 | VCH 4854 | VCH 4856 | VCH 4921 | B336 | B337 | B338 | B339 | B3084 |
| Run 1:            | X       | X       | X       | X       | X       | X     | X     | X     |
| Inter-/intra-vendor, paint/no-paint |         |         |         |         |         |       |       |       |
| Run 2:            | X       | X       | X       | X       |         | X     | X     | X     |
| Inter-/intra-vendor, no-paint |         |         |         |         |         |       |       |       |
| Run 3:            |         |         |         |         |         | X     |       | X     |
| Method Reproducibility |         |         |         |         |         |       |       |       |
| Run 4:            |         |         |         |         | X       | X     |       |       |
| Mud (silty-clay) calibration |         |         |         |         |         |       |       |       |
| Run 5:            |         |         |         |         | X       | X     |       |       |
| Sand calibration |         |         |         |         |         |       |       |       |
| Run 6:            |         |         |         |         | X       | X     |       |       |
| Mixed (sandy mud) calibration |         |         |         |         |         |       |       |       |
| In-situ calibration |         |         |         |         |         | X     |       |       |
| Muddy flocs       |         |         |         |         |         |       |       |       |
| Offset in counts  | -3.97   | 3.38    | 0       | -0.82   | 4.96    | -32.75| -1.21 | -6.8  | 0     | -9.14 |
| needed to match reference ADV |         |         |         |         |         |       |       |       |
Comparison of Adjusted Sontek ADVOcean and Nortek ADV Vector response to concentration of various size classes

\[ y = A_2 x^2 + A_1 x + A_0 \]

\[ A_2 = 6.01 \pm 1.19 \times 10^{-3}, \quad A_1 = 7.38 \pm 3.84 \times 10^{-1}, \quad A_0 = 1.06 \pm 0.31 \times 10^2 \]

(Cartwright et al., 2013)
Regression Curves

SAND

Reference corrected ABS (counts)

log_{10} Suspended Solids Concentration (mg/L)

Silty Clay

Reference corrected ABS (counts)

log_{10} Suspended Solids Concentration (mg/L)

In-situ Muddy Floc

Reference corrected ABS (counts)

log_{10} Suspended Solids Concentration (mg/L)

(Cartwright et al., 2013)
For a given mixed concentration, need to add power response then convert back to counts:

$$P_{mixed} = P_{mud} + P_{sand}$$

$$dB = 10 \log_{10} \frac{P}{P_0}$$

counts = dB * 0.4

(Prediction of Mixed Grain-Size Suspended Concentration)

(Cartwright et al., 2013)
Outline

Objective

Introduction

1.1 Observing Systems

1.2 Acoustic Sensors

1.3 Optical Sensors

York River Observing Systems

Acoustic Sensors (Concentration)

Acoustic Sensors (Settling Velocity)

Addition of Optical Sensors (Size Distribution and Settling Velocity)

Conclusions and Future Work
Acoustic Sensors (Settling Velocity)

Verified settling velocity using the Rapid Sand Analyzer

Quartz Sand

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>PHI</th>
<th>Micron</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.00</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>3.75</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>3.50</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>3.25</td>
<td>106</td>
<td></td>
</tr>
<tr>
<td>3.00</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>2.75</td>
<td>150</td>
<td></td>
</tr>
</tbody>
</table>

(Cartwright et al., 2012)
Acoustic Sensors (Settling Velocity)

(Cartwright et al., 2012)
Acoustic Sensors (Settling Velocity)

A

B

C

D

(Cartwright et al., 2012)
Outline

Objective

Introduction

1.1 Observing Systems

1.2 Acoustic Sensors

1.3 Optical Sensors

York River Observing Systems

Acoustic Sensors (Concentration)

Acoustic Sensors (Settling Velocity)

Addition of Optical Sensors (Size Distribution and Settling Velocity)

Conclusions and Future Work
Addition of Optical Sensors (Settling Velocity)

Particle Imaging Camera System (PICS)

(Fugate & Friedrichs, 2003) method

\[ \langle w' C' \rangle = W_s \langle C \rangle \]

New method

Remove background concentration, \( C_{\text{background}} \)

\[ W_s = \frac{\langle C \rangle - C_{\text{background}}}{\langle w' C' \rangle} \]

(Cartwright et al, 2013)
Addition of Optical Sensors (Settling Velocity)

Particle Imaging Camera System (PICS)

(Cartwright et al, 2013; Fall 2012)
Addition of Optical Sensors (Settling Velocity)

Particle Imaging Camera System (PICS)

(Cartwright et al., 2013; Fall, 2012)
Addition of Optical Sensors (Size Distribution and Settling Velocity)

Laser In Situ Scattering Transmissometer (LISST 100X) and Remote In-situ Particle Sizing camera (RIPScam)

EXAMPLE DISTRIBUTIONS

Dominant Floc size ~315 µm
Addition of Optical Sensors (Size Distribution and Settling Velocity)

Laser In Situ Scattering Transmissometer (LISST 100X) and Remote In-situ Particle Sizing camera (RIPScam)

EXAMPLE DISTRIBUTIONS

Slack after Ebb

Increasing stress toward Ebb

Dominant Pellet size
~102 µm

(LISST time = 29-Jul-2009 11:02:24 EST  Camera time = 1600 GMT)

LISST D16 = 23 µm
LISST D50 = 171 µm
LISST D84 = 315 µm
LISST Peak = 331 µm

RIPScam D16 = 300 µm
RIPScam D50 = 758 µm
RIPScam Peak = 1243 µm

(Log10) Particle Size (µm)

Volume Concentration (µl/L)
Addition of Optical Sensors (Size Distribution and Settling Velocity)

Laser In Situ Scattering Transmissometer (LISST 100X) and Remote In-situ Particle Sizing camera (RIPScam)

Example Distributions

Slack after Ebb

Increasing stress toward Ebb

Dominant Floc size ~205 µm

(Cartwright et al., 2011)
Optical Sensors (In-situ Size Distribution)

ADV Settling Velocity and LISST Volume Concentration

Date (July 28, 2009 (17:00 EST) - July 29, 2009 (18:00 EST))

- **Settling Velocity, \( ws \) (mm/s)**
  - Ratio calc method
  - Slope calc method

- **Volume Conc (ul/L)**
  - 87.9 µm
  - 280 µm

**Pellets (~102 µm)**
- Increase stress
- Increase eff. \( W_s \)
- Increase vol conc

**Flocs (~315 µm)**
- Decrease stress
- Decrease eff. \( W_s \)
- Increase vol conc

**Pellets**
- Increase stress
- Increase vol conc

**Flocs**
- Decrease stress
- Decrease vol conc

**Optical Sensors**
- In-situ Size Distribution

**Se=ling Velocity, \( ws \) (mm/s)**
- Slack
- EBB
- Slack
- Flood
- Slack
- Ebb
- Slack
- Flood
- Slack
Outline

Objective

Introduction

1.1 Observing Systems
1.2 Acoustic Sensors
1.3 Optical Sensors

York River Observing Systems
Acoustic Sensors (Concentration)
Acoustic Sensors (Settling Velocity)
Addition of Optical Sensors (Size Distribution and Settling Velocity)
Conclusions and Future Work
• The York River estuary is an excellent site for a fine sediment observing system. As well as being easily accessible, there are strong gradients in concentration, particle types, and biological influences.

• ADVs are well suited for use in our “MUDBED” observing system. ADVs can be used to measure velocity, turbulence, sediment concentration and settling velocity, and they are resistant to biofouling.

• ADVs can estimate settling velocity (i) by direct Doppler measurement of settlement, which works for sand in the lab, and (ii) by dividing turbulent flux by concentration, which works for mud in the field.

• But backscatter from ADVs is sensitive to particle type, with greater response to larger, denser particles. Also, ADVs are not interchangeable, and response varies by vendor and by individual instrument.

• ADVs have different offsets in their backscatter response, which can be corrected by comparing multiple ADVs to the same sediment at the same concentration and defining a reference unit for each vendor.
Conclusions (p. 2 of 2)

• But the slope of ADV backscatter response to sediment concentration still depends on (i) whether grain size changes with concentration, and (ii) whether or not attenuation is occurring.

• ADV response to mixed grain-sizes can be estimated by adding together the expected acoustic response to each grain size in power units before transforming the sum to logarithmic count units.

• Optical instruments (which can only be deployed for short periods) can be used to better understand the complexity of mixed grain sizes because optics can measure particle size distribution.

• Optics plus ADVs shows that smaller but denser pellets are suspended in phase with bottom stress. When stress decreases, pellets drop out, and larger, fragile, less dense flocs dominate at slack tide.

• Like ADVs, optics-based video settling tubes can also measure settling velocity in-situ, and agreement between both methods (after removing background concentration) was demonstrated for the first time.
Proposed Chapter 6 - Optical Sensors (In-situ Settling Velocity)
3-day Mean $w_s$ Determined from Fits to $<w'C'> = w_s<C>$ using ADVs

---

Although noisy, mean $w_s$ at biological site is generally higher.

At physical site, mean $w_s$ is bimodal and varies seasonally.

Less bioturbated layer present at surface in May.
Acoustic Sensors (Laboratory suspended sediment conc)

Acoustic Response to Natural Sediment to Determine Suspended Sediment Concentration

Multiple scattering and Particle-particle interactions tend to dominate attenuation

Grain-size diameter (μm)

Absorption tends to dominate attenuation

Dis-aggregated Mud$_{d50}$

10 MHz transition between absorption and single scattering

CB Sand$_{d50}$

FP Sand$_{d50}$

5 MHz transition between absorption and single scattering

(Jackson and Richardson, 2007; Wright et al, 2010)