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Observations and best-fit modeling of settling and suspension of multiple sediment particle types: York River, Virginia

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Observations and best-fit modeling of settling and suspension of multiple sediment particle types: York River, Virginia

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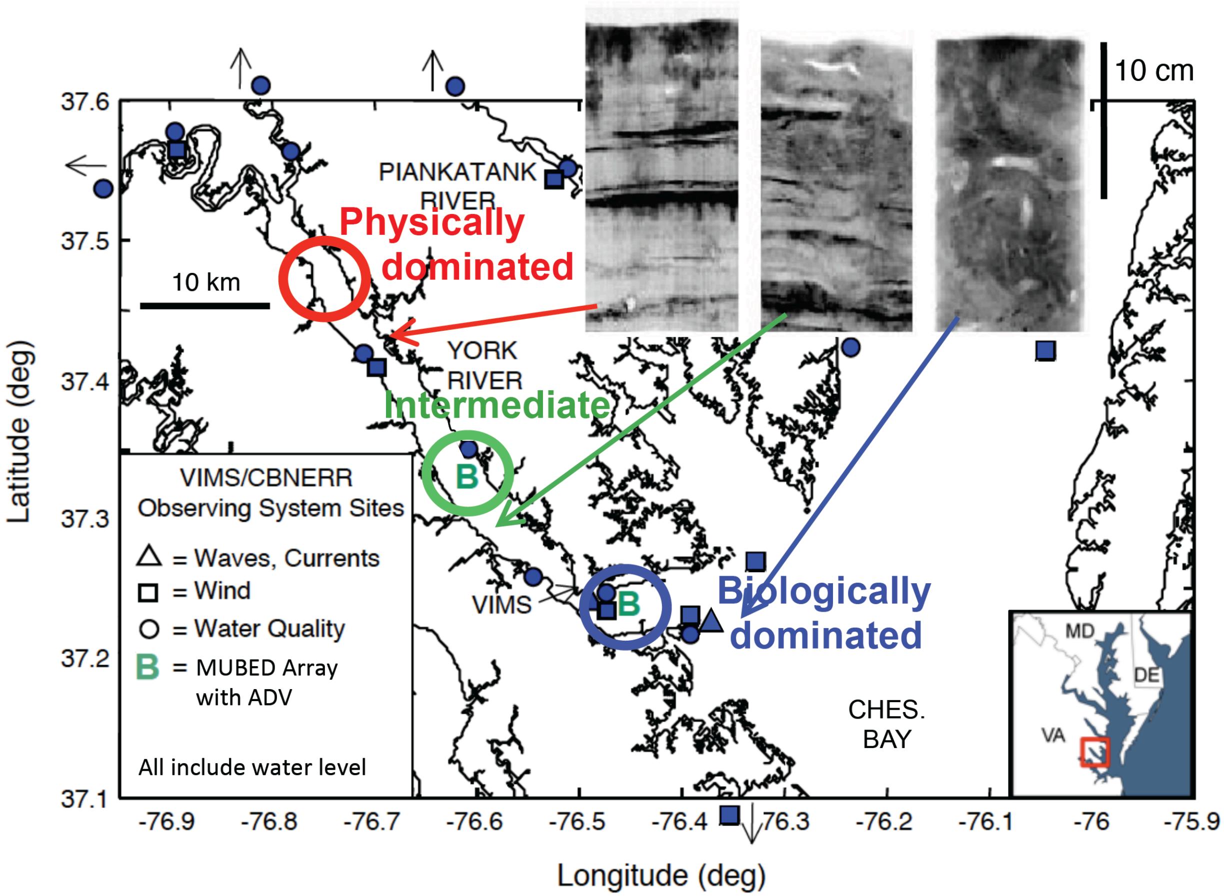
Motivation: Suspended particle settling velocity is one of the largest unknowns which limits accurate prediction of sediment transport in muddy coastal environments.



(X-rays courtesy of L. Schaffner)

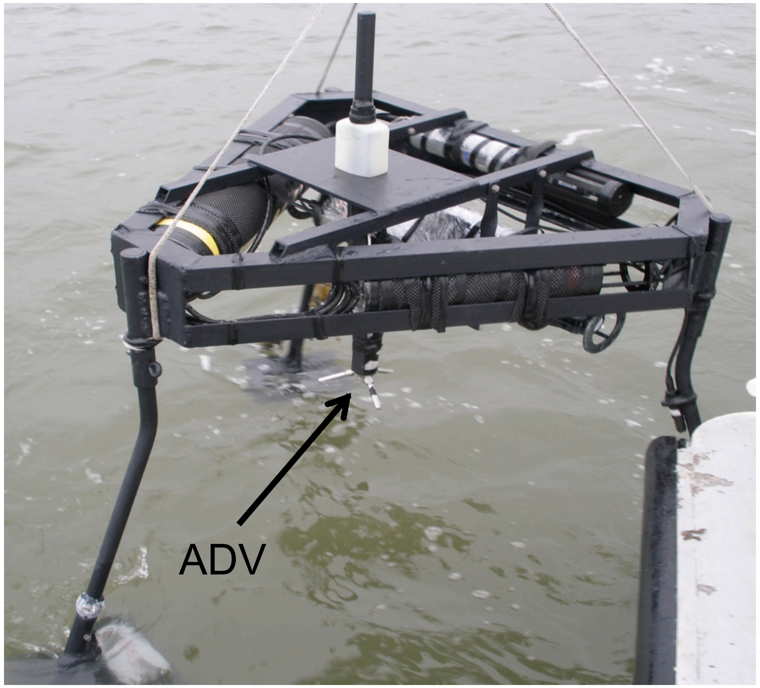
Physical-Biological Gradient found along the York estuary :

-- In the middle to upper York River estuary, disturbance by sediment transport reduces macrobenthic activity and sediment layering is often preserved. (e.g., **Clay Bank – "Intermediate Site"**)

-- In the lower York and neighboring Chesapeake Bay, layering is often destroyed by bioturbation. (e.g., **Gloucester Point** – **"Biological Site"**)

-- NSF Multi-Disciplinary Benthic Exchange Dynamics (MUBED) ADV tripods provide observations along gradient.

Schaffner et al., 2001; Friedrichs, 2009; Cartwright et al., 2009; Dickhudt et al. 2009; and Cartwright et al., 2011



Advantages of using Acoustic Doppler Velocimeters (ADVs) for continual observations in fine sediment environments:

-- Acoustics often survive long-term biofouling.

-- Provides estimates for:

- Suspended Sediment Concentration (c): from Acoustic Backscatter
- Effective Settling Velocity (w_{seff}): $\langle w'c' \rangle / c_{set}$
- Bed Stress (τ_b): $\rho * \langle u'w' \rangle$

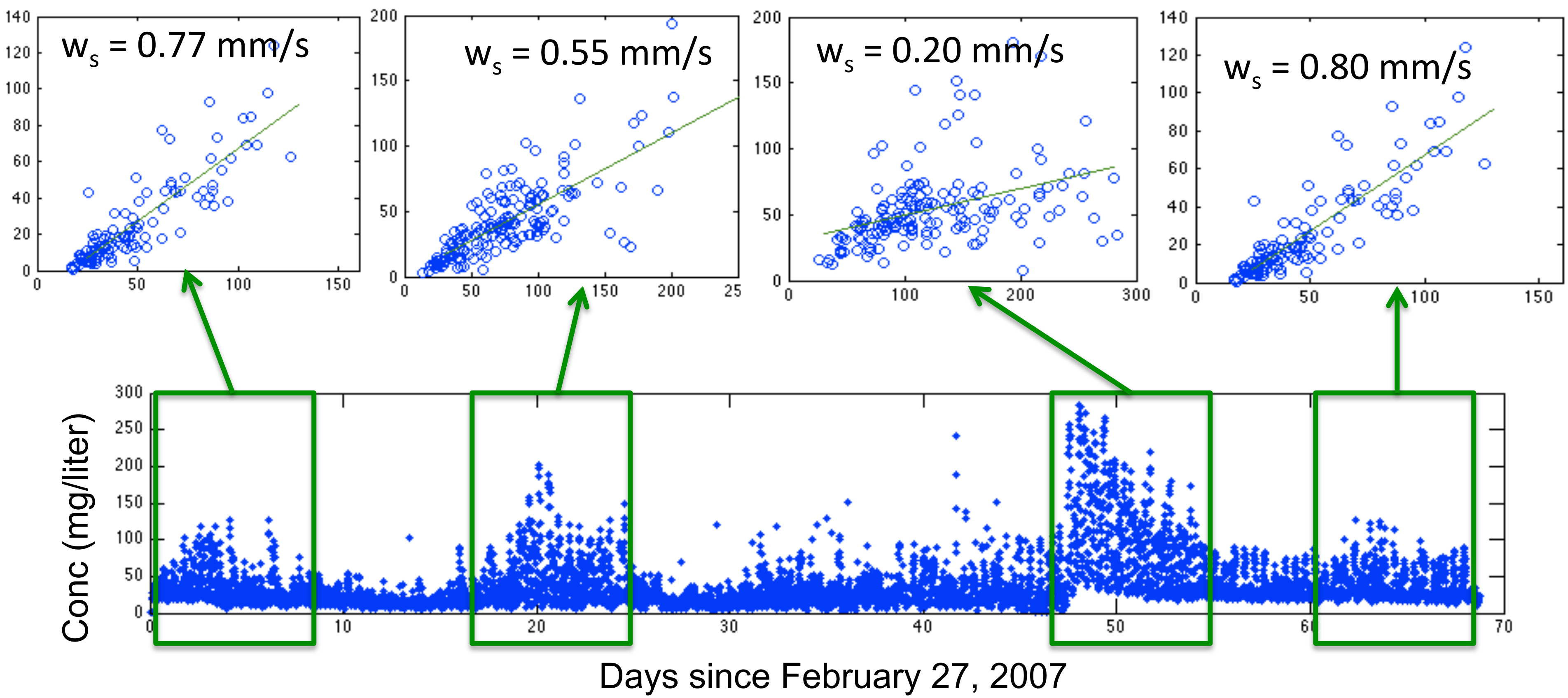
(Photos by Cartwright)

Fugate and Friedrichs ,2002; Friedrichs et al., 2009; Cartwright, et al. 2009 and Dickhudt et al., 2010

Example Settling Velocity from ADV Data at **Clay Bank ("Intermediate")** site <w' C' > vs. <C>

Plot <C> (mg/liter) on x-axis and <w' C' > (mm/s times mg/l) on y-axis, and slope gives w_s

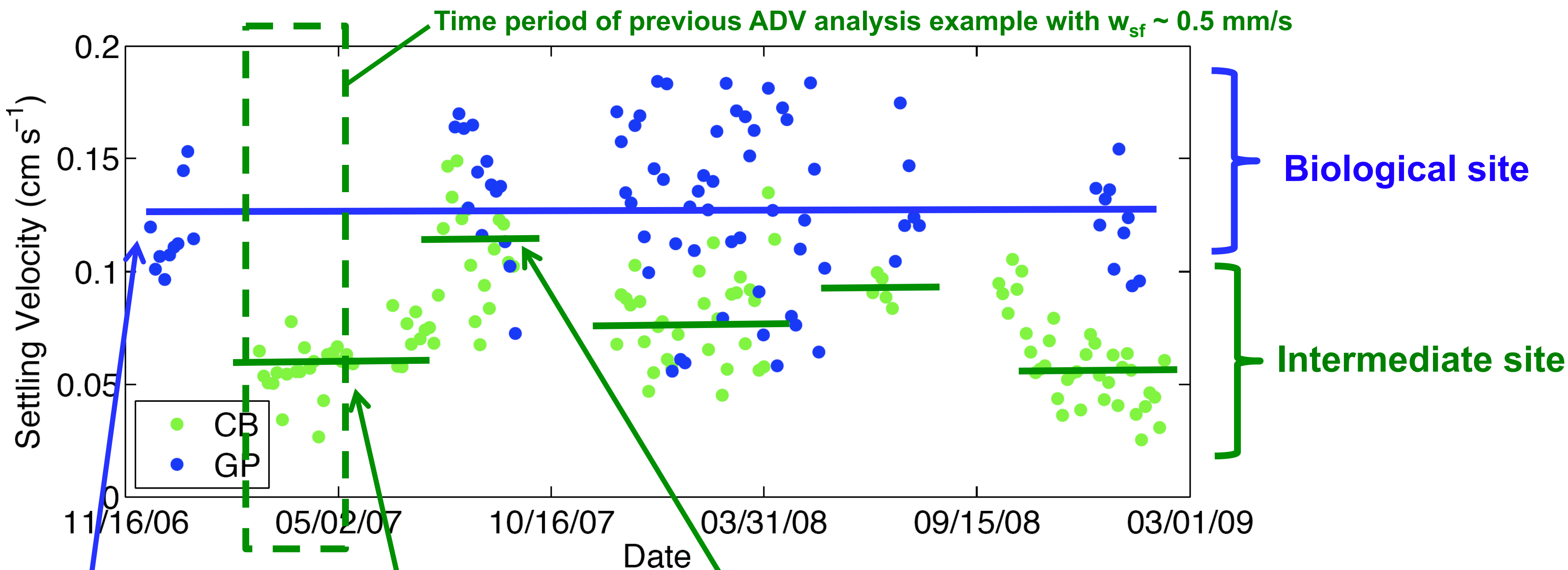
w' = vertical turbulent velocity, C' = turbulent concentration fluctuation
< > = burst average, w_s = sediment settling velocity, <C> = burst-average TSS

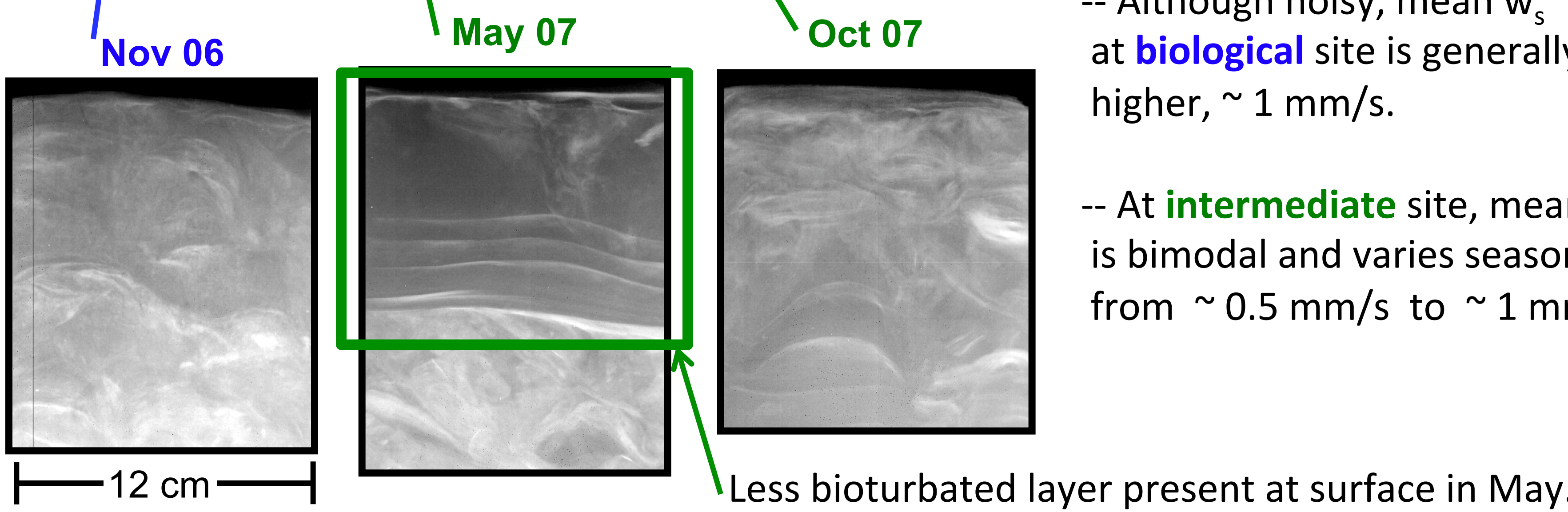


During Feb to May 2007, flocs appeared to dominate, with **$w_{sf} \approx \sim 0.5$ mm/s**

Figure by G. Cartwright

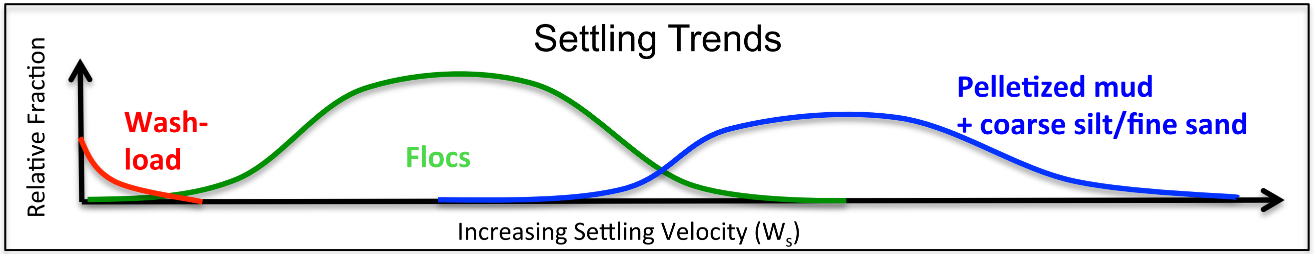
3-day Mean w_s Determined from Fits to <w'C'> = w_s<C> using ADVs





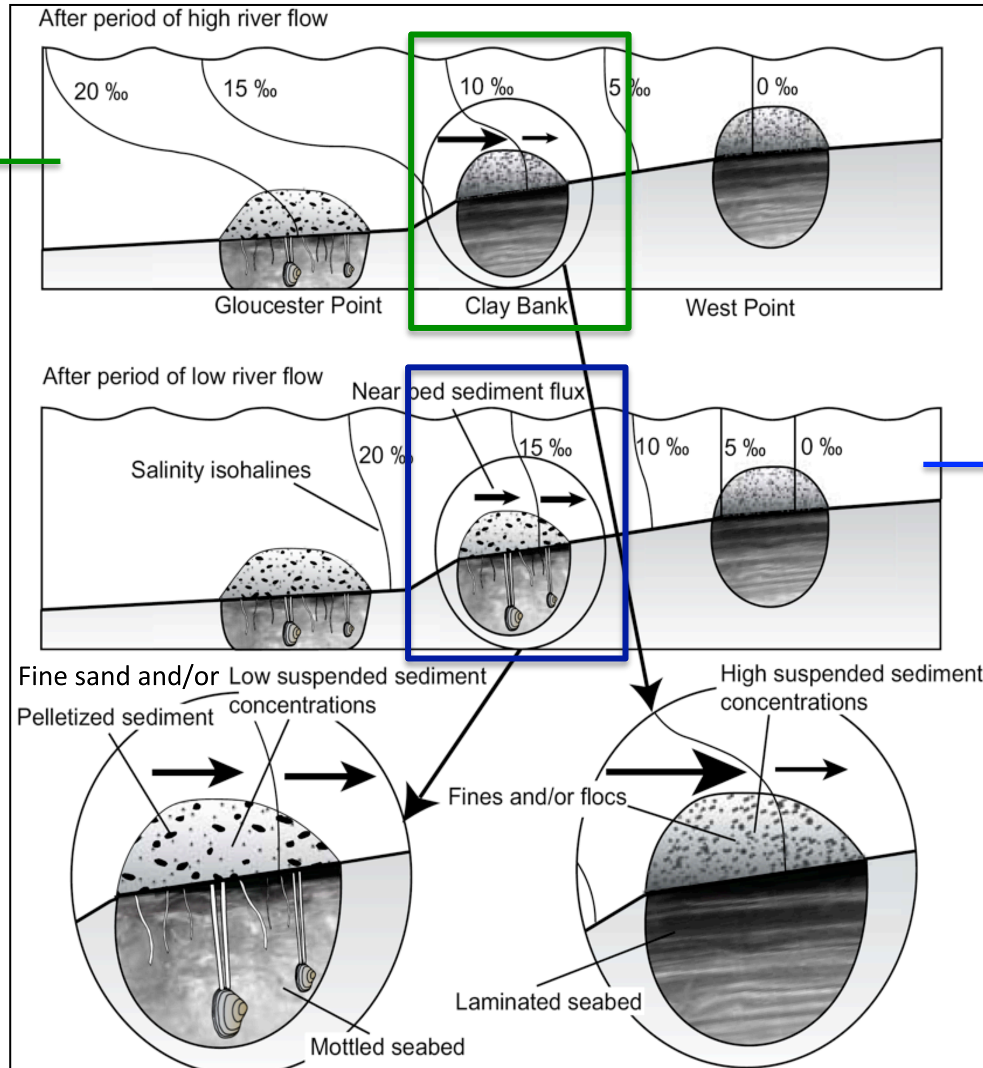
-- Although noisy, mean w_s at **biological** site is generally higher, ~ 1 mm/s.

-- At **intermediate** site, mean w_s is bimodal and varies seasonally, from ~ 0.5 mm/s to ~ 1 mm/s.



Conceptual Model:

- After HIGH river flow
- Stratified lower estuary
- Transport convergence
- Mid-estuary ETM
- Trapping of flocs
- Dilution of pellets
- **LOW settling velocity**

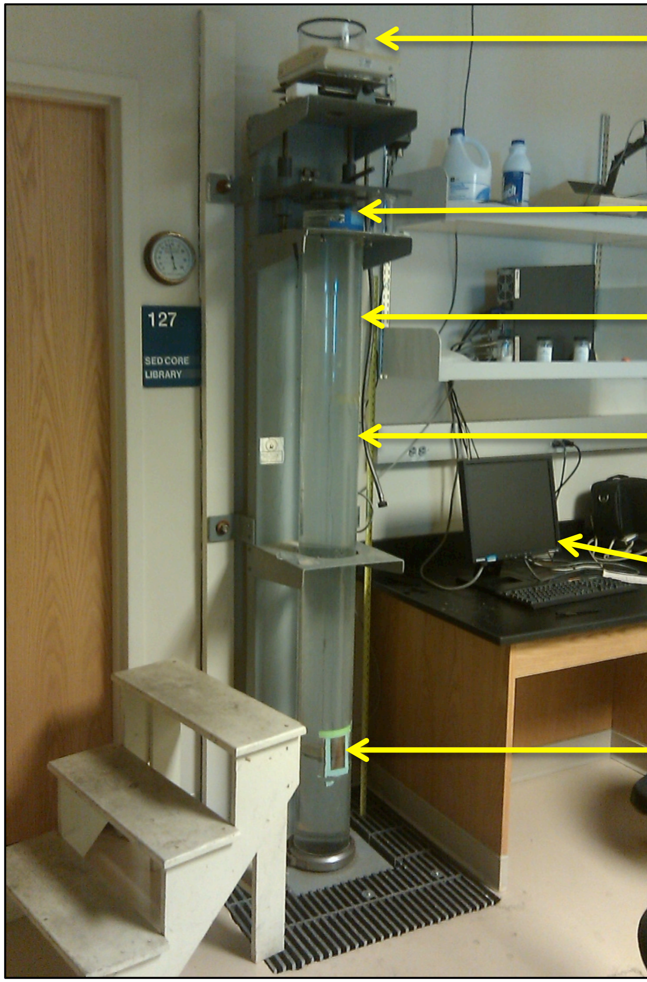


- After LOW river flow
- Little or no stratification
- Transport divergence
- No mid-estuary ETM
- Winnowing of fines
- Concentration of pellets
- **HIGH settling velocity**

(Friedrichs, 2009), (Cartwright et al., 2009), (Dickhudt et al. 2008), and (Schaffner et al., 2001)

Rapid Sediment Analyzer (RSA)

Typically used to analyze coarse grain material based on particle settling velocities.
Used here to determine settling velocities for Pellet-Silt-Sand Mixtures



Balance connected to computer

Sediment drop and start button

Thermometer to measure water temp.

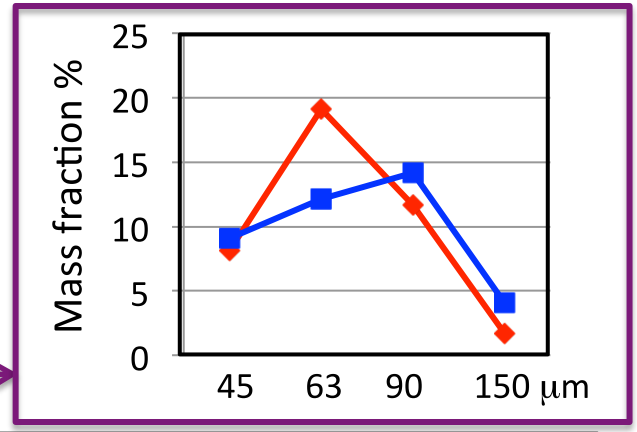
Settling tube filled with water

Computer records weight and settling time

Metal plate connected to balance
(~150 cm from sediment top)

1) Gentle sieve method for down to 45 μm (by L. Kraatz) applied to sediment samples collected from 1-2 cm in the seabed during slack tide following both neap and spring tides in May 2010:

Tide	%Pellets (dry wgt.)	% Sand + Coarse Silt (dry wgt.)	% Mud < 45 μm (dry wgt.)	%water (by vol.)	%organic (dry wgt.)
Neap	8%	23%	69%	65%	10%
Spring	15%	23%	62%	66%	6%



2) RSA measured settling velocity for gently sieved particles captured on 45 μm sieve

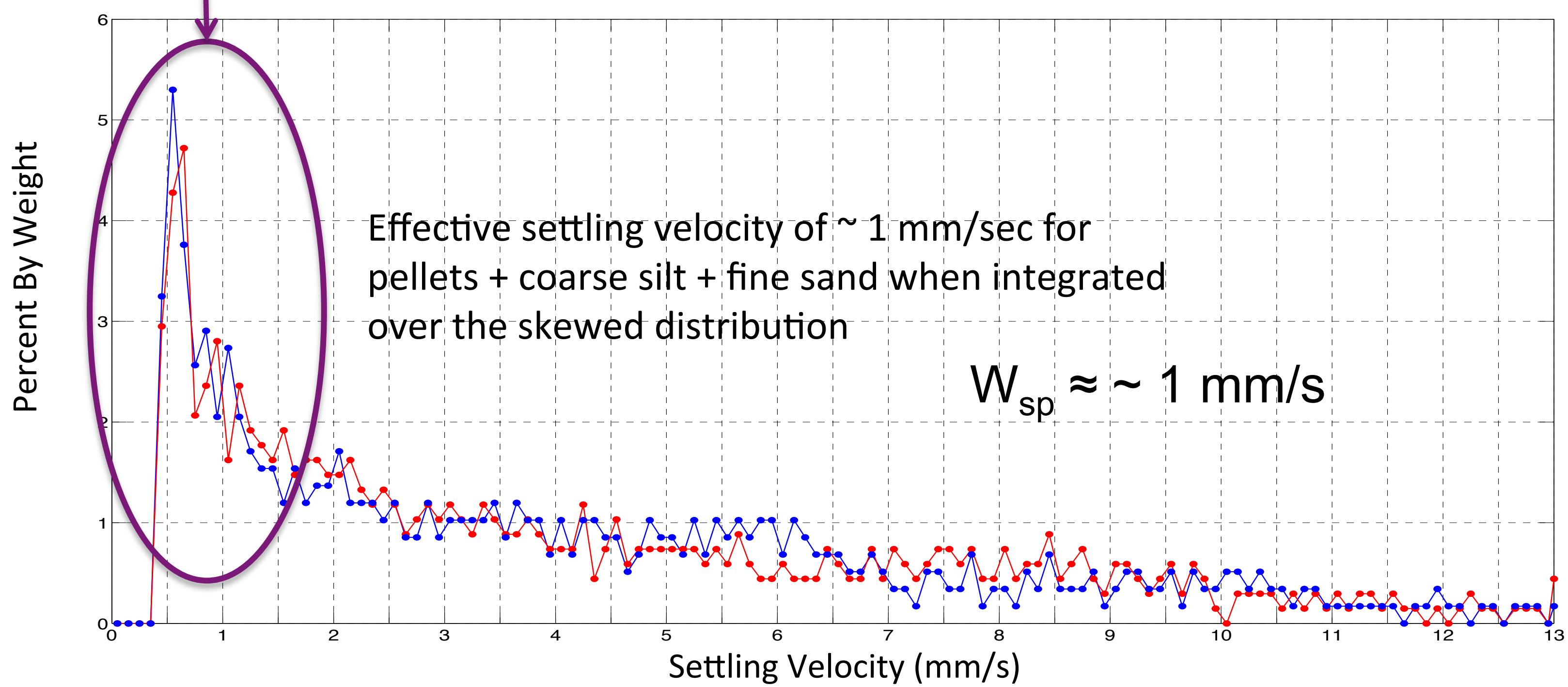
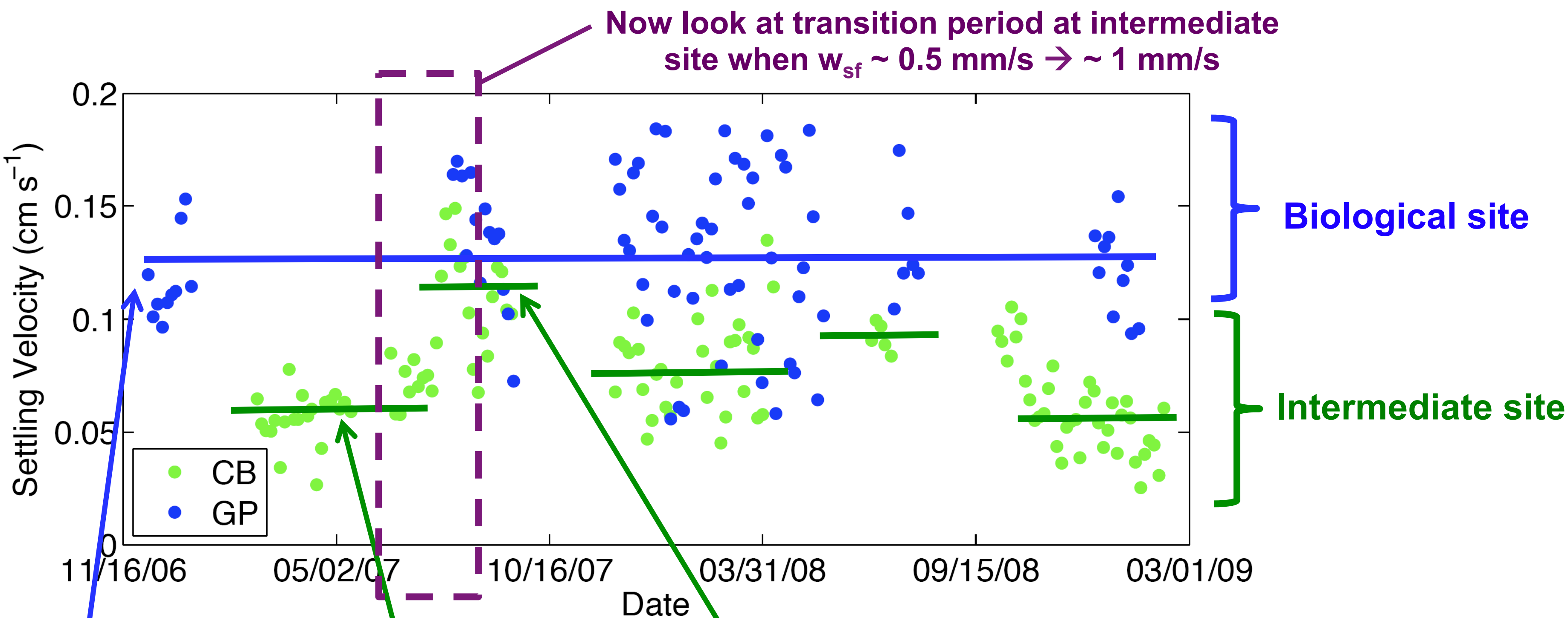
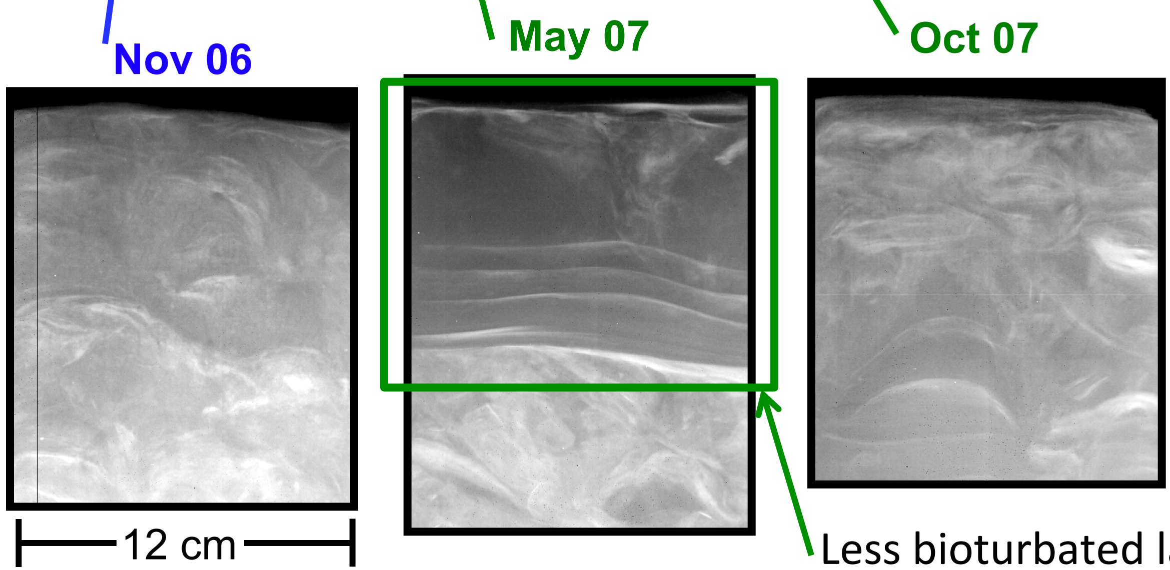


Table from work by L. Kraatz

3-day Mean w_s Determined from Fits to $\langle w'C' \rangle = w_s \langle C \rangle$ using ADVs





-- Although noisy, mean w_s at **biological** site is generally higher, ~ 1 mm/s.

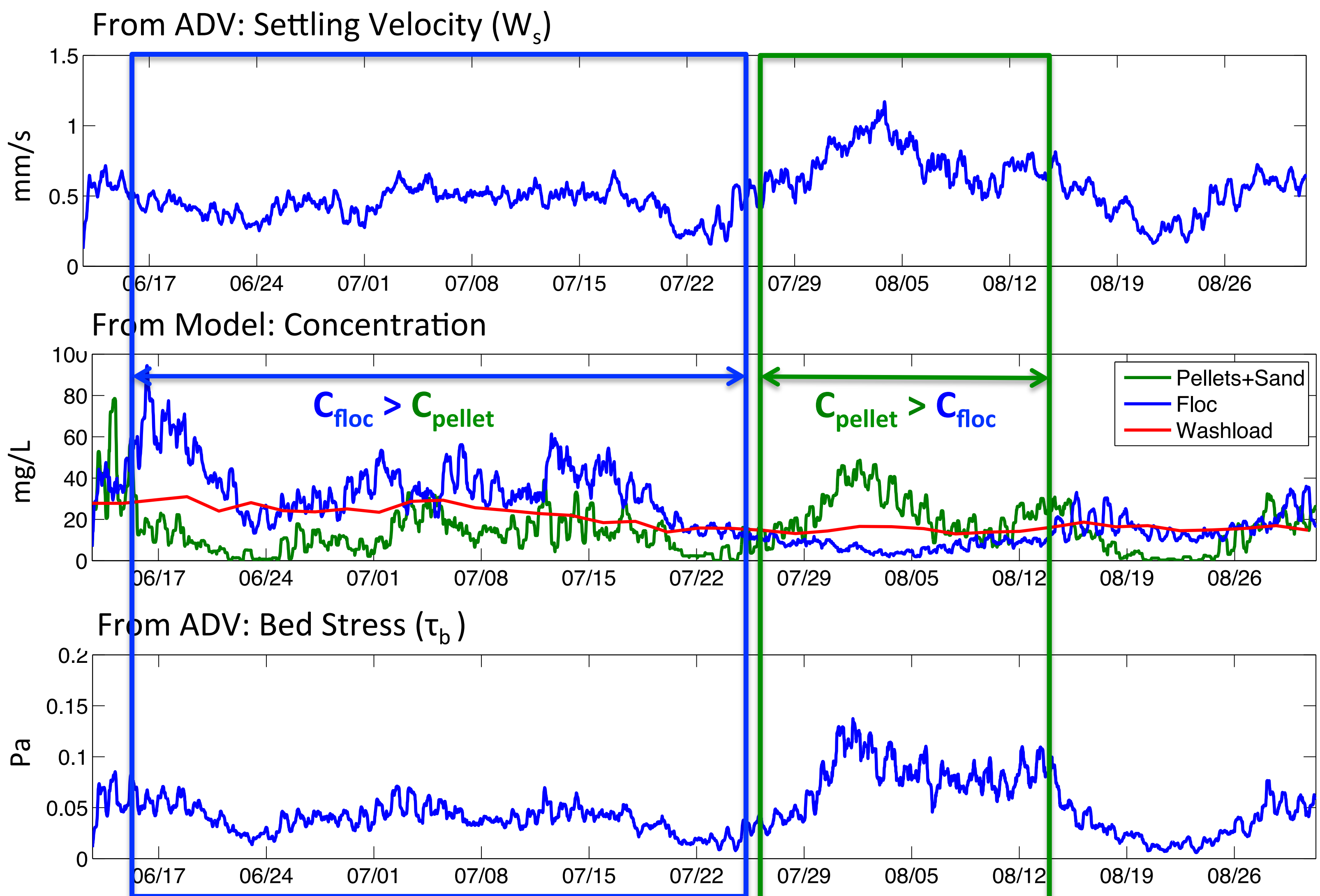
-- At **intermediate** site, mean w_s is bimodal and varies seasonally, from ~ 0.5 mm/s to ~ 1 mm/s.

Using RSA settling velocities in very simple model

Assume: Effective settling velocity composed of Pellets+Silt/Sand and Flocs: $W_s = W_{sp} * C_p + W_{sf} * C_f$

From RSA: W_{sp}= ~ 1 mm/s; From ADV: W_{sf}= ~ 0.5 mm/s; Assume C at slack is washload

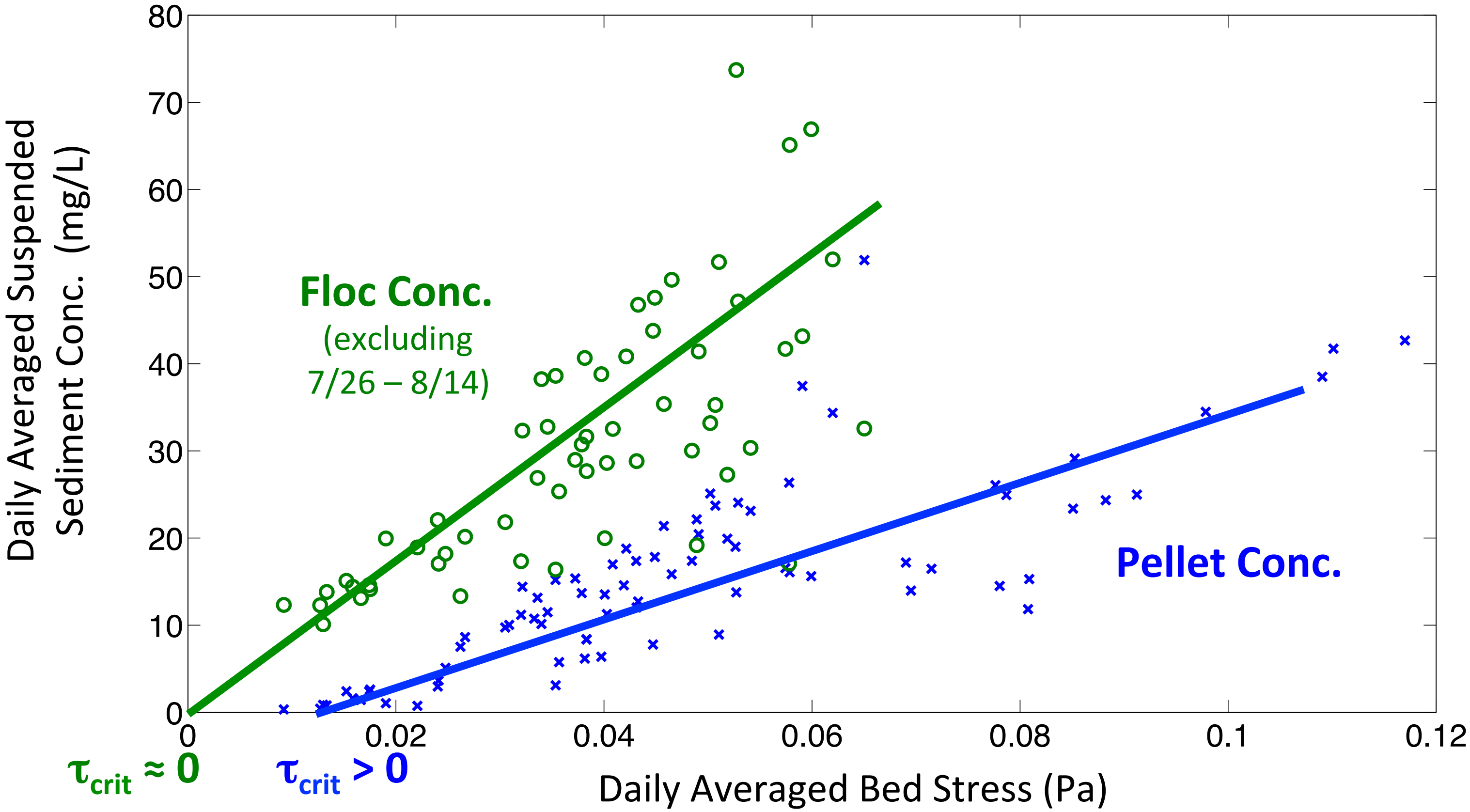
W_s =effective settling velocity(from ADV), W_{sp} =settling velocity of Pellets+ Sand, W_{sf} =settling velocity of flocs, C_p= Conc. Pellets+Sand, C_f = Conc. Flocs



June 12, 2007-August 31, 2007

Dyer, 1999; Friedrichs et al., 2008; Cartwright et al., 2011

A closer look at particle type relationship with bed stress (τ_b)
June 12, 2007-August 31, 2007



-- Flocs and pellets have distinct relationships between stress and suspended sediment concentration.

-- Flocs appear easier to resuspend than pellets (i.e., floc erodibility is higher than pellet erodibility).

-- Pellets have a critical threshold stress for resuspension, flocs do not (i.e., floc line intersects zero).

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Conclusions and future work:

- In estuaries, ADVs allow continual, long-term observation of bed stress, fine sediment concentration, and total effective settling velocity (w_s), all while resisting biofouling.
- In the middle York River estuary, stratification traps flocs (w_{sf} ~ 0.5 mm/s), whereas mixed conditions disperse flocs, leaving behind a pellitized lag (w_{sp} ~ 1 mm/s).
- A very simple model assuming (i) wash load + (ii) flocs + (iii) pellets/silt/sand can be applied to ADV data to estimate the time-varying concentration of each particle class.
- The ADV-based model indicates flocs are much easier to suspend than pellets (i.e., floc erodibility is higher than pellet erodibility).
- The ADV-based model also indicates that pellets have a critical threshold stress for resuspension ($\tau_{crit} > 0$), whereas flocs have no significant critical erosion stress ($\tau_{crit} \approx 0$).
- Our future work will include (i) fine-tuning the RSA method, (ii) using vertically stacked ADVs, (iii) deploying a new particle settling camera, and (iv) using adjoint data assimilation to allow more sophisticated best-fit models.

Questions?

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