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ADDED VALUE OF COMBINING MULTIPLE OPTICAL AND ACOUSTIC INSTRUMENTS WHEN CHARACTERIZING FINE-GRAINED ESTUARINE SUSPENSIONS

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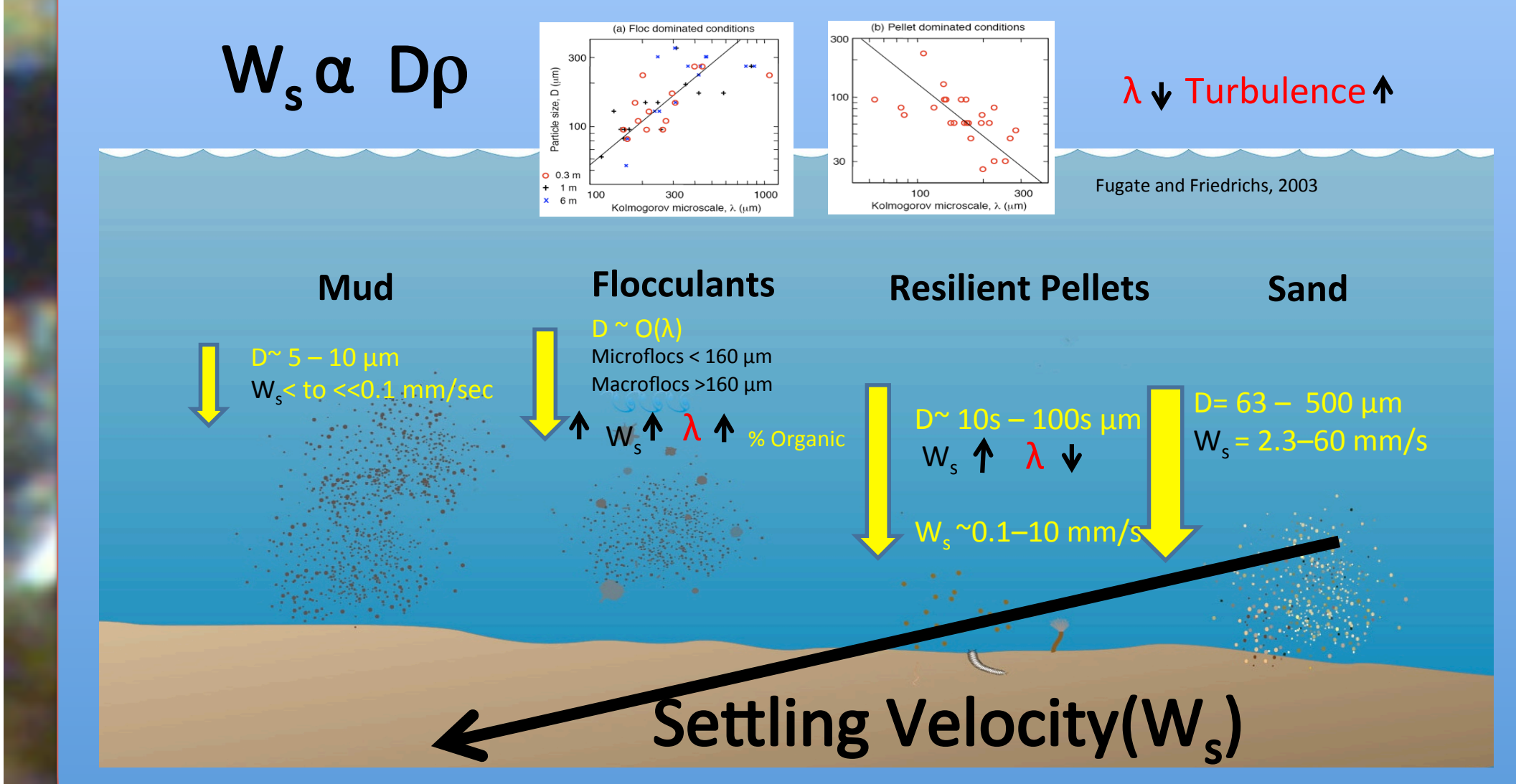
ABSTRACT

Various optical and acoustic instruments have specific advantages and limitations for characterizing suspensions, and when used together more information can be obtained than with one instrument alone. The LISST 100X, for example, is a powerful tool for estimating particle size distribution, but because of the inversion method used to determine the size distribution, it is difficult to distinguish two dominate populations that peak close to one another, especially among larger grain sizes. In the York River estuary, VA, additional information obtained through the deployment of a RIPScam camera system and an ADV along with the LISST 100X allowed differentiation between populations of resilient pellets and flocs in suspension close to the bed and how the populations varied over a tidal cycle. A second example of instrument pairing providing additional information was the use of a PICS video imaging system in the York River to verify the conditions under which use of the ADV Reynolds flux method was valid for estimating settling velocity of suspended particle populations.

MOTIVATION

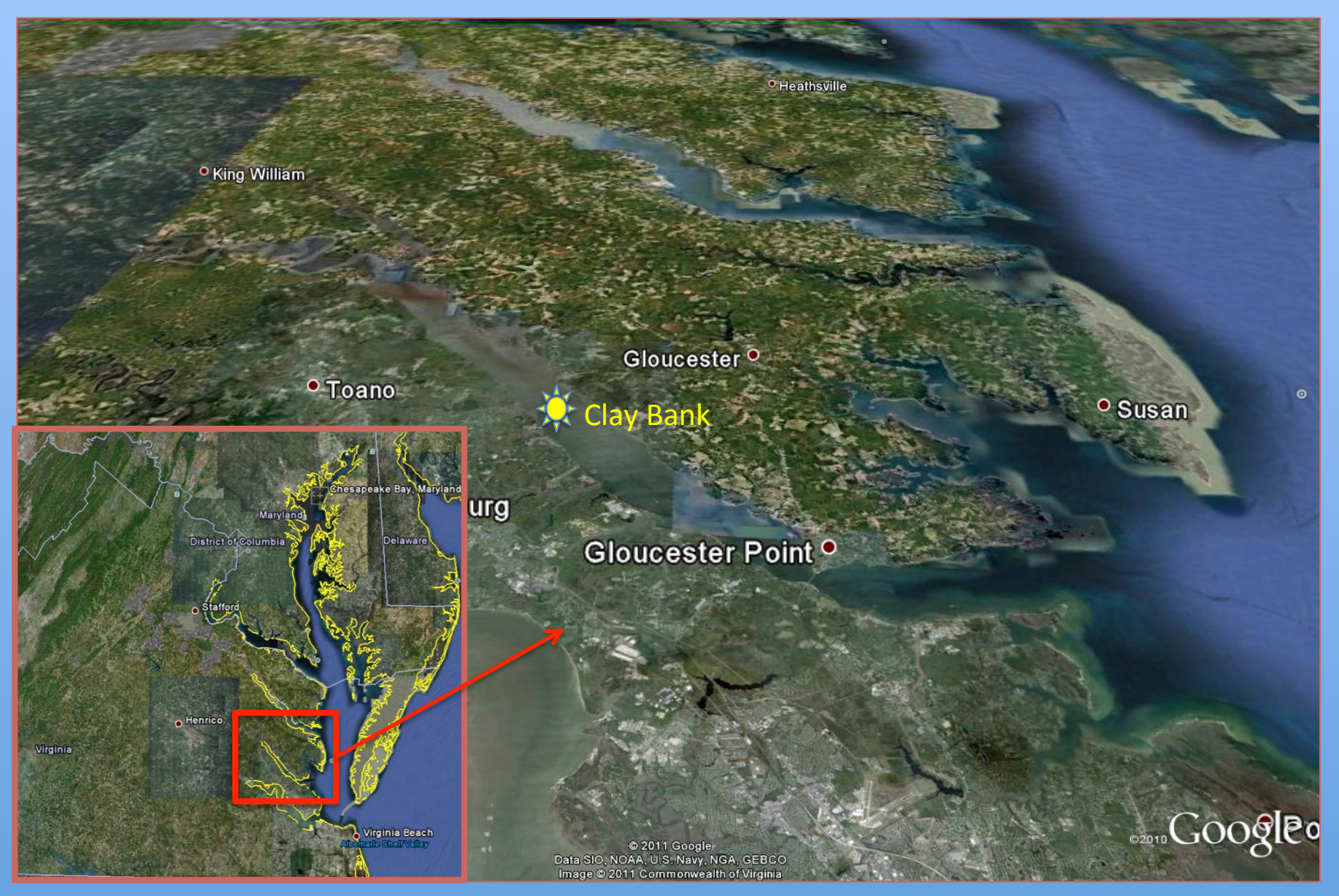
Identify the contribution of multiple particle types to the suspended distribution and thus to the effective settling velocity (W_s as measured by the ADV)



Important in modeling water clarity response to sea level rise and it's effect on ecosystems

Anderson, 2001; Sanford et al, 2005; Taghon et al , 1984; Wheatcroft et al , 2005

STUDY SITE



- Clay Bank area on York River Estuary
- A micro tidal (0.7 to 1 meter) tributary of the Chesapeake Bay, VA
- In secondary channel at ~5 meter depth

(Site of long term, 2007-present, Observing System)

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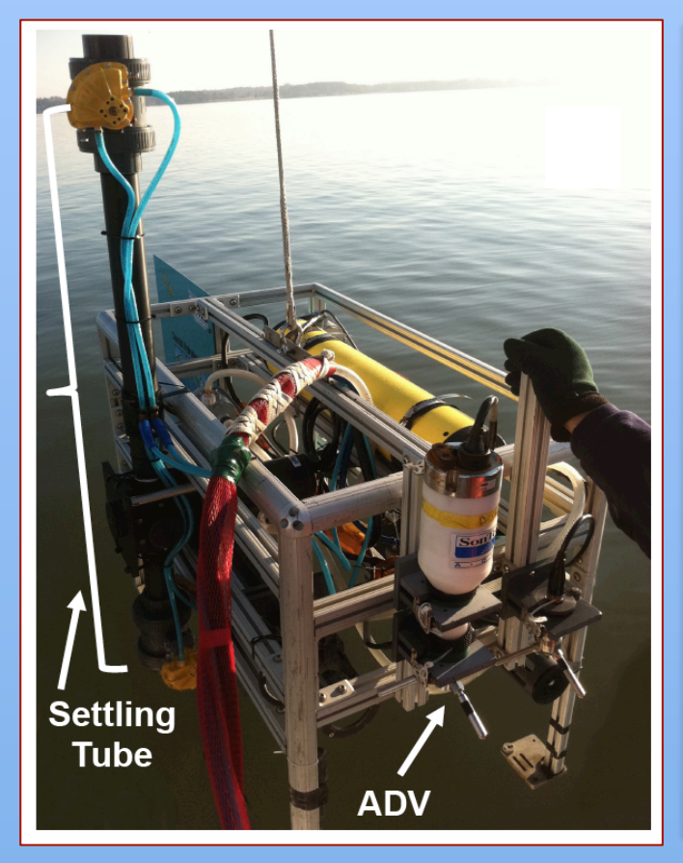
Verification

INSTRUMENTS to measure Settling Velocity (Ws)



Reynolds Flux method

$$\langle w'C' \rangle = Ws \langle C \rangle$$

Upwards turbulent sediment flux = Downwards gravitational Settling

Modified Reynolds Flux method

$$Ws = \frac{\langle C \rangle - C_{background}}{\langle w'C' \rangle}$$

Remove background concentration, $C_{background}$
(lowest concentration measured during study period-at slack)
< > represents burst averaged data
C' is fluctuations in conc about burst mean
w' is fluctuations in mean velocity in z direction

Figure 1. Profiler with LISST and PICS (Fugate and Friedrichs, 2002; Cartwright et al, 2013)

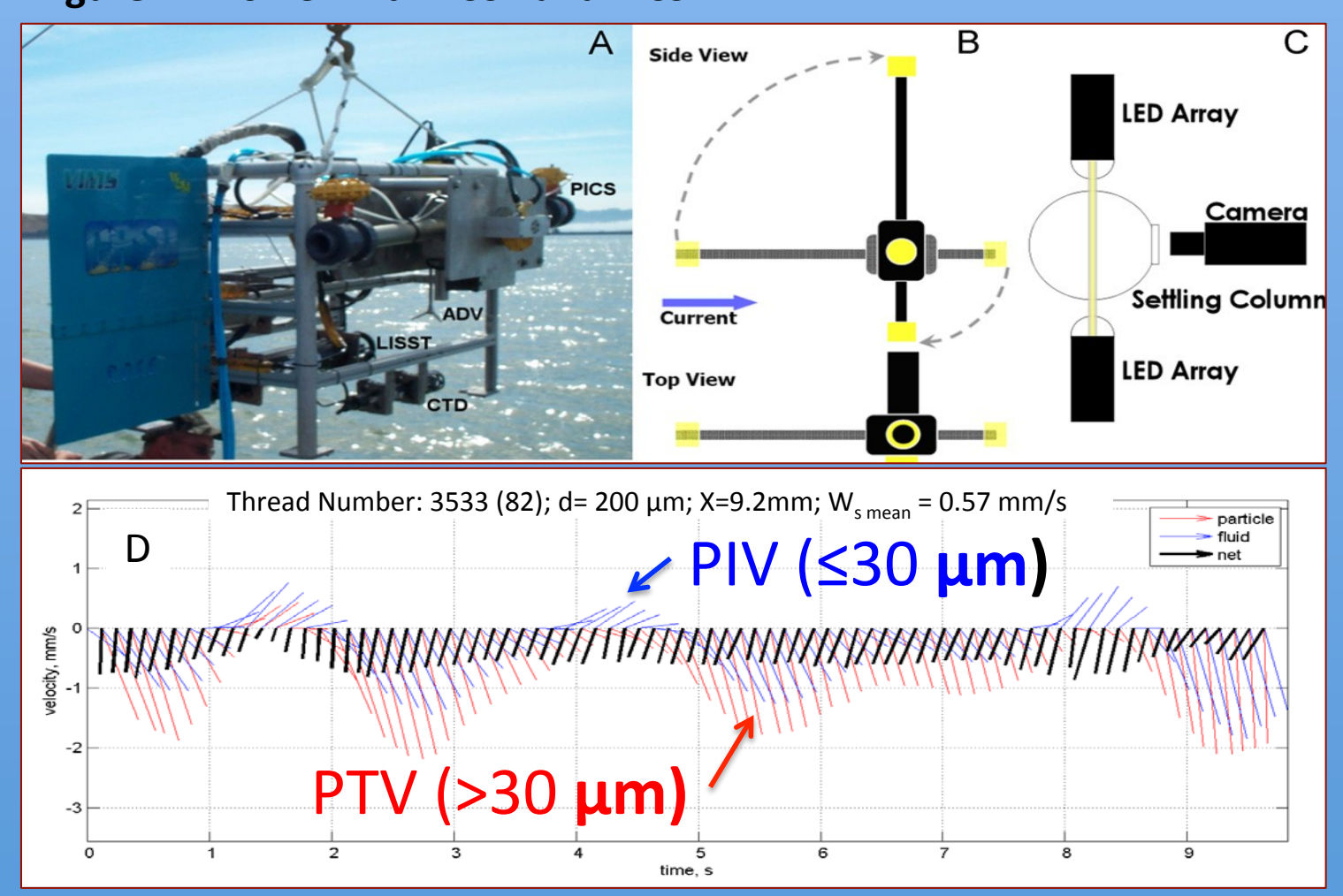


Figure 2. A-C) PICS setup and operation. D) Example PICS data tracking a particle through 82 frames and removing fluid velocity for average size and settling velocity (and post processed density).

(Smith , 2010; Cartwright et al, 2013; Smith and Friedrichs, 2012)

As measured by:

Acoustic Doppler Velocimeter (ADV)

***Advantages*:**
- Non-intrusive single point velocity measurement
- Less susceptible to bio-fouling and can be used in higher concentration ranges than optical instruments
- Burst data used to estimate effective settling velocity (Ws), as well as flux, turbulence, stress, and concentration when calibrated
- Simple deployment and data processing.

***Disadvantages*:**
- Can not track individual or groups of particles – only valid for effective (bulk) Ws.
- Profiler must be stationary- profiler motion interferes with velocity calculations.

Verified using:

Particle Imaging Camera System (PICS)

Measurement range: >30 µm to ~ 3mm

***Advantages*:**
- Individual measured particle size and settling velocity allows estimation of particle density
- PTV/PIV removes fluid velocity allowing for Ws estimates in situ (stationary profiler not necessary)
- 30 sec of video allows averaging for better estimate of size and Ws
- Can capture large particles

***Disadvantages*:**
- Pixel size limits resolution of small particles
- Data processing time intensive
- Can not be used in high concentration regimes
- Currently not set up for autonomous deployment

METHOD--STUDY 1

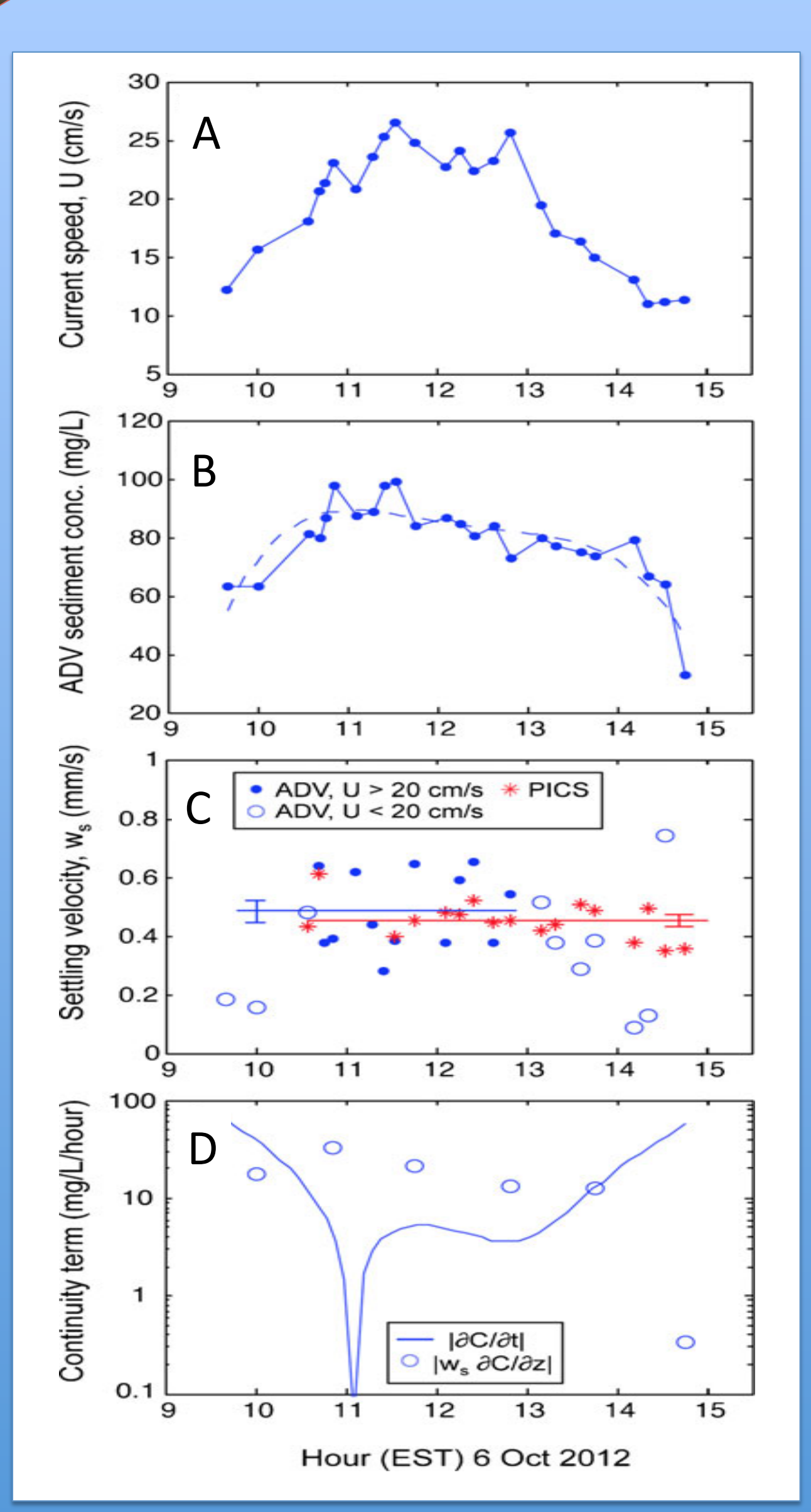


Figure 3. A) ADV current speed, B) ADV suspended concentration C) ADV and PIC settling velocity D) Continuity term

6 Hour Study Period bracket Flood (Oct 6, 2012)

Mounted on profiler resting on seafloor (Figures 1 and 2)
LISST100X - ~ 4 bursts/hr, 2 min@ 1 Hz (10 samples/record)
ADV- ~4 burst/hr, 2 min @ 10 Hz
PICS - 30 video corresponding to each ADV/LISST burst.
8 frames/sec

RESULTS

- Reduction of sediment concentration (Figure 3B) by 50% resulted in less than 1% change in ADV-based estimates of Ws (Using modified Reynolds flux equation).
- Modified Reynolds flux method (ADV) for estimating mean Ws was noisier than PICS settling column observations (Figure 3C).
- PICS observed mean settling velocities (0.45±0.02 mm/sec) were consistent with ADV-based effective estimates for cases with **U**>20cm/sec (0.48±0.04 mm/sec)
- PICS observed mean settling velocities were not consistent with ADV-based effective estimates for cases with **U**<20cm/sec
- For U> 20 cm/sec $|\partial C/\partial t| \leq |w_s\, \partial C/\partial z|$ provides appropriate sediment flux balance for ADV Ws calculation (Figure 3D)

(Cartwright et al, 2013)

Clarification

INSTRUMENTS to measure Particle Size Distribution

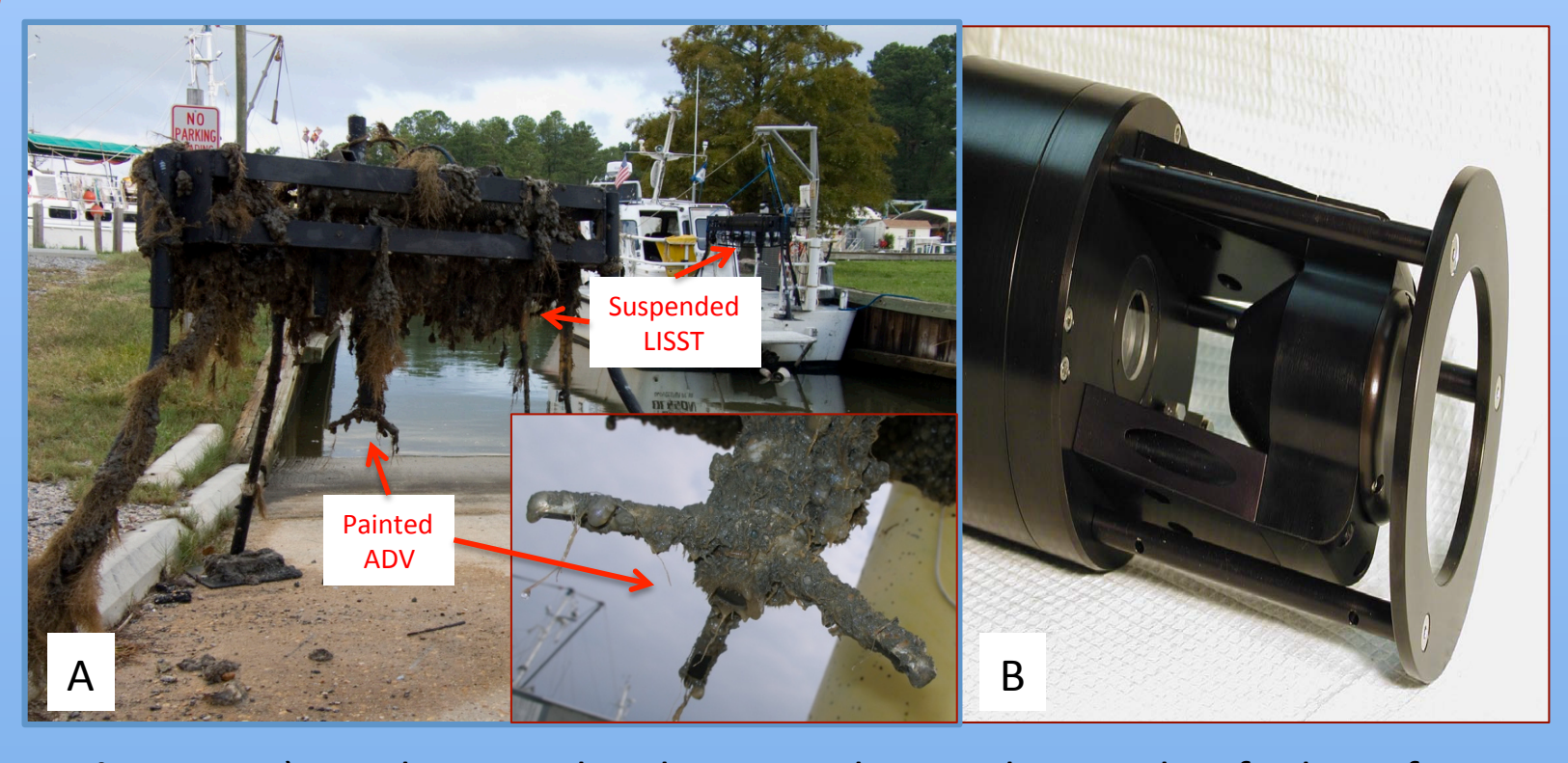


Figure 4. A) Benthic tripod with ADV and LISST showing bio-fouling after >3 months. B) Sequoia LISST 100X.

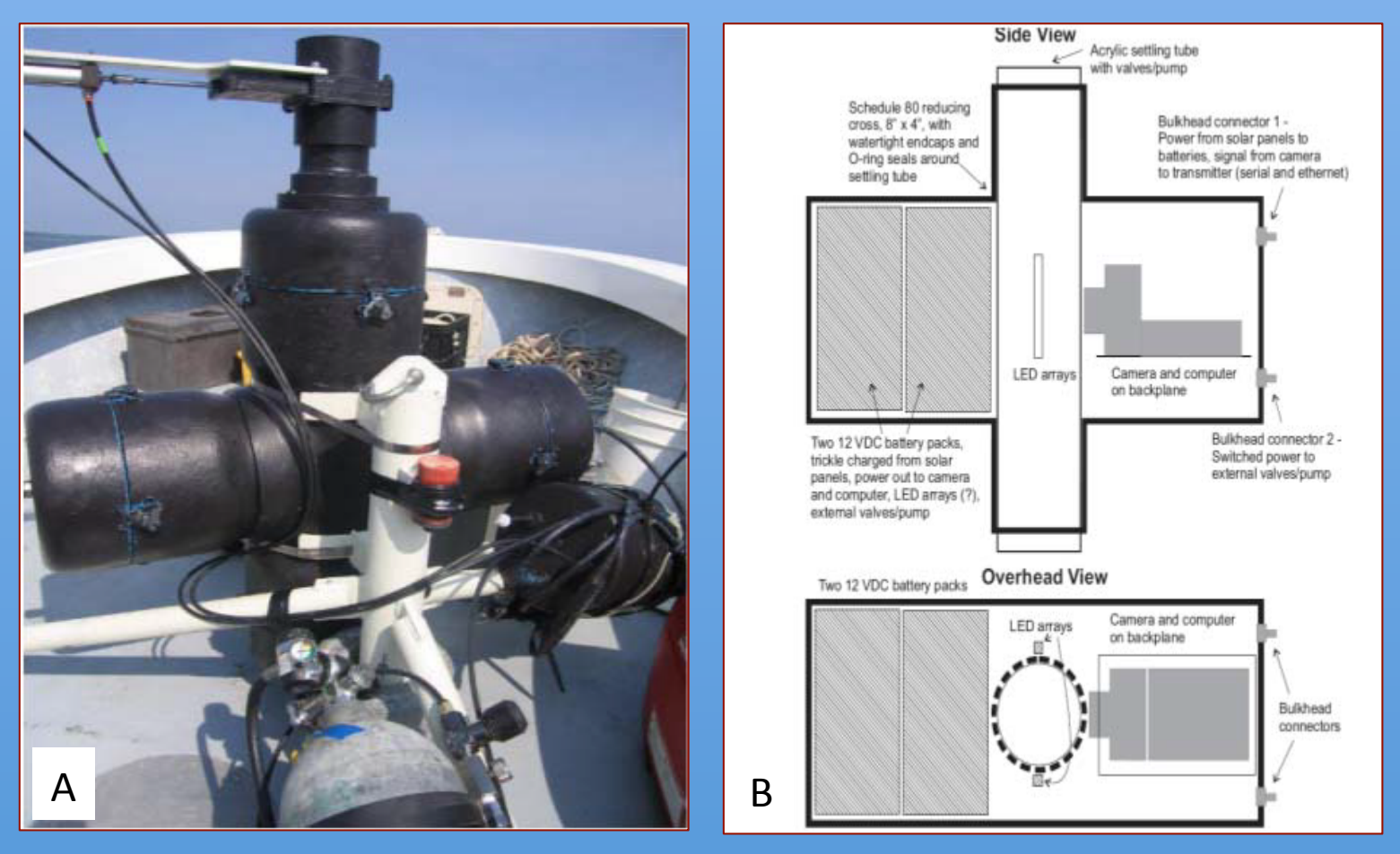


Figure 5. A) RIPScam mounted on benthic lander B) RIPScam schematic.

(Cartwright et al., 2011)

As measured by:

Laser In Situ Scattering Transmissometer (LISST 100X)

Measurement Range: 2.5 to 500 µm

***Advantages*:**
- Good resolution of smaller particle sizes (21 of 32 logarithmically spaced size classes <=100 µm)
- Simple deployment and data processing
- Can be deployed autonomously

***Disadvantages*:**
- Highly susceptible to bio-fouling when deployed autonomously
- Can not be used in high concentration regimes
- Poor resolution of large particles and limited range

As measured by:

Remote Imaging Camera System (RIPScam)

Measurement range: >30 µm to ~ 3mm

***Advantages*:**
- Can be deployed autonomously
- Can capture large particles

***Disadvantages*:**
- Highly susceptible to bio-fouling when deployed autonomously
- Pixel size limits resolution of small particles
- Limited memory
- Data processing time intensive
- Can not be used in high concentration regimes

METHOD--STUDY 2

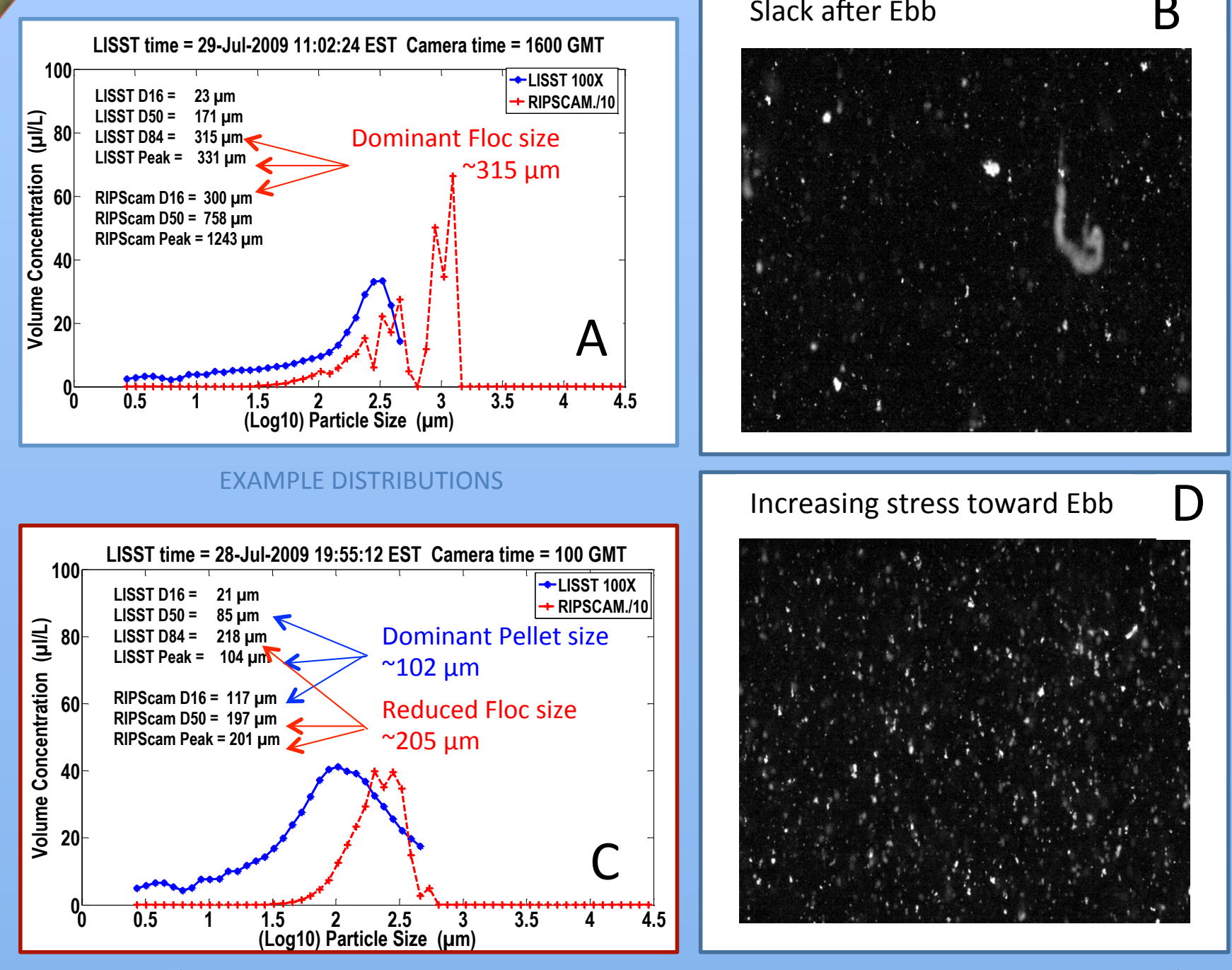


Figure 6. A)Example LISST and RIPScam distributions during a low stress period B) Image from RIPScam during low stress periodC)Example distributions during increasing Stress period D)RIPScam image from increasing stress period.

25 Hour Study Period (July 28-29, 2009)

Mounted on bottom landers (Figures 4 and 5)
LISST100X - 15 min burst interval, 100 records@ 1 Hz (10 samples/record)
ADV- 15 min burst interval, 2 min @ 10 Hz
RIPScam - 1hr burst interval, 5 flash exposures @ 1 min intervals (focal depth ~1mm)

RESULTS

Example Distributions

Low Stress Period (Figures 6 A-B)
- LISST peak and D84 agrees with RIPScam D16 suggest dominant floc size of ~315 µm
- LISST D50 influenced by a range of smaller flocs still in suspension
- RIPScam D50 skewed by a single large particle (whose size is better described by RIPScam peak = 1243 µm)

Increasing stress period (Figures 6 C-D)
- Broader LISST distribution suggests multiple particle types in suspension
- LISST D50 and peak and RIPScam D16 suggest dominant particle size in suspension is ~102 µm (resilient pellets)
- LISST D84, RIPScam D50 and peak suggest a second particle size of ~205 µm (floc size reduced by turbulence)

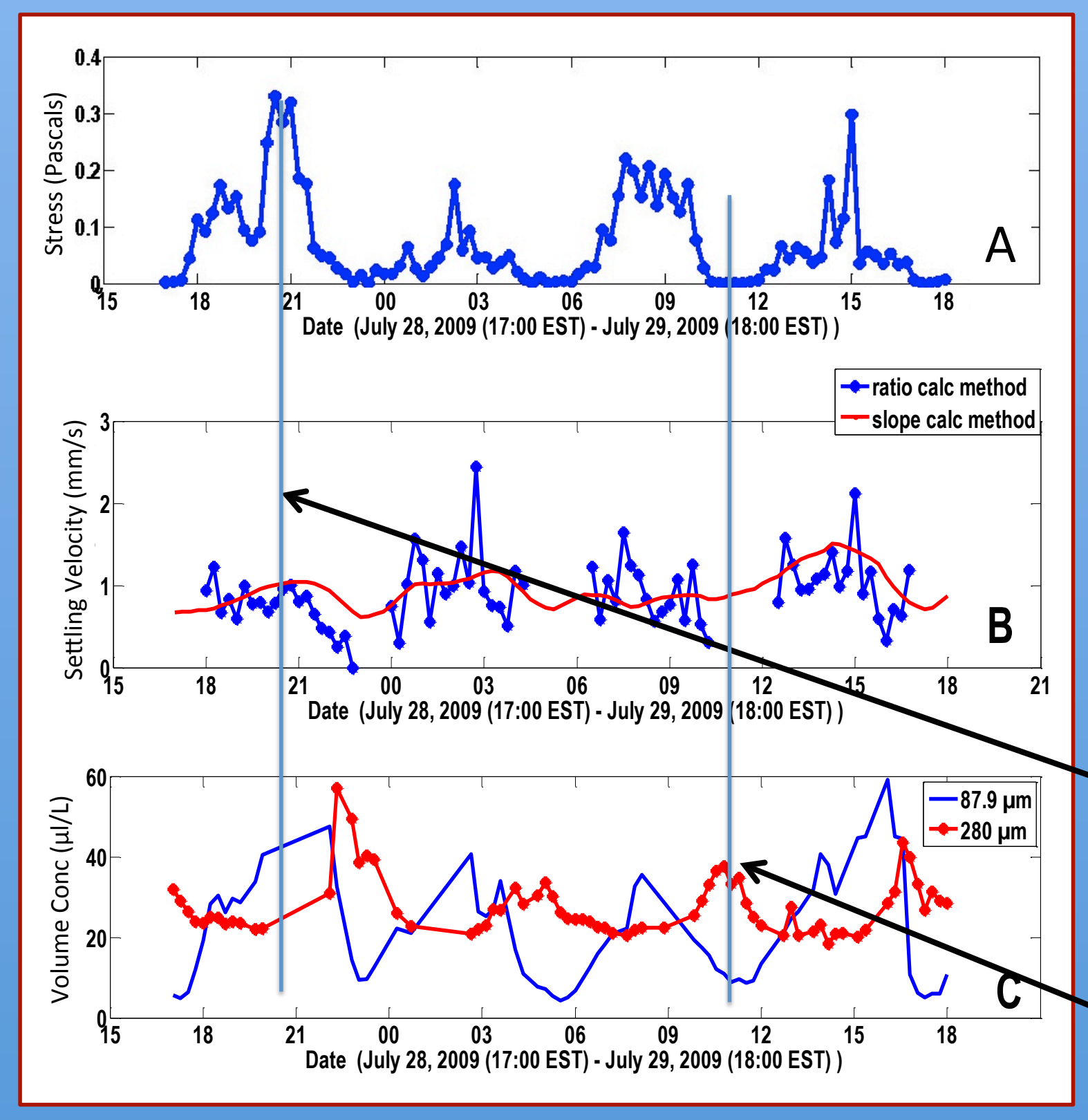


Figure 7. A) Stresses calculated from ADV bursts B)Settling velocities calculated From ADV bursts. Slope calc method is running average of previous 5 bursts. C) Blue line is volume concentration of LISST bin closest to pellet size determined in Figure 6 for increasing stress period. Red line is bin size closest to the dominant floc size determined low stress period.

(Cartwright et al., 2011)

ADV Settling Velocity and LISST Volume Concentrations

PELLETS (~102 µm)
- Increased stress
- Increased ADV effective Ws
- Increased LISST volume concentration of comparable 'pellet' size class

LARGEST Dominant Floc size (~315 µm)
- Decrease stress
- Decrease ADV effective Ws
- Increased LISST volume concentration of comparable 'floc' size class

CONCLUSIONS

- Using multiple instruments with various capabilities provides a more complete picture of the particle size distribution and their associated settling velocities.
- Both PICS and ADV in study 1 do a reasonable job of describing the mean/effective Ws when U>20 cm/s. At slower velocities suspended sediment suspension is insufficient to provide valid ADV estimated Ws via the modified Reynolds flux method.
- ADVs, however, provide long term continuous estimates of Ws when it is impossible to deploy other instruments (For example during episodic events)
- PICS overestimates the mean or effective Ws because it is limited by pixel resolution. ADVs are likely biased towards particles which are larger and denser and thus produce stronger acoustic backscatter.
- Combination of the LISST, which is better at resolving smaller particles, and the RIPScam, which is better at resolving larger particles, does a reasonable job in describing the "total" distribution. However neither of these instruments are capable of direct measurement of Ws.
- Addition of LISST-ST to PICS can help resolve contribution of the smaller particles particularly in the low stress periods.

Background photo provided by Kelsey A. Fall. Particles collected on a 63 micron sieve from sediment trap deployed on Clay Bank tripod Aug-Nov 2013. Total sediment captured in trap was composed of 98.4% mud (68.7% clay, 29.7% silt) with 7.8 % of this mud fraction packaged as resilient pellets.

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