Characterization of Sediment Properties with Optics

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Why does sediment matter?

- Suspended sediment blocks light.
- Suspended sediment carries pollutants.
- Deposited sediment takes up space.

Why use optics?

- Collection of sediment is difficult:
  - Extreme environments;
  - Extreme conditions.
- Characterization of sediment is time-consuming:
  - Filtration;
  - Weighing;
  - Size distribution;

Sediment in an extreme environment!

Two Goals

- Review basic principles linking sediment and optical properties.
- Present an application of these principles, which is part of Jing Tao's PhD project.

Important Sediment Properties

$$\text{vertical flux} = w_s C = \frac{(\rho_s - \rho) g D * D}{18\mu} C$$

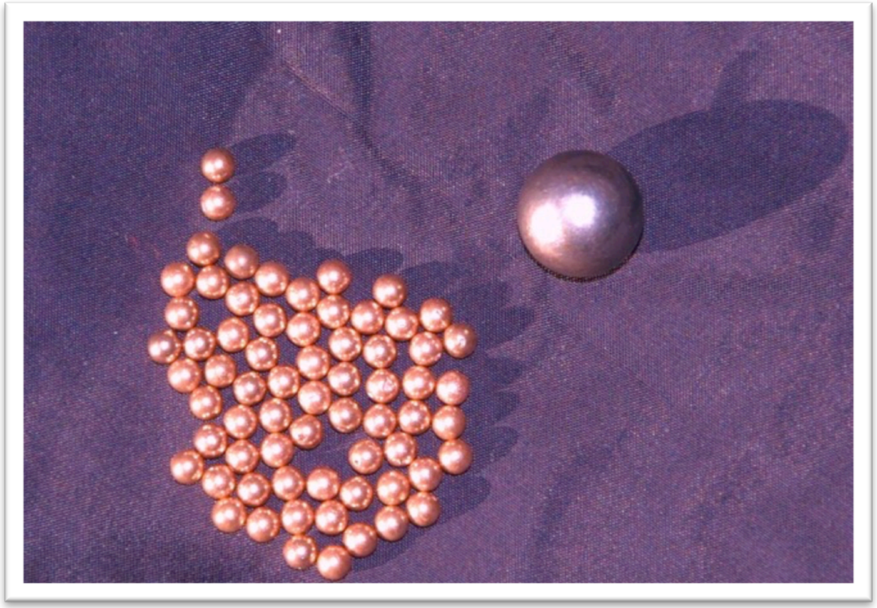
- Sediment Mass Concentration
- Particle Size
- Particle Composition

Three Principles

- Marine particles are typically aggregated, so total suspended mass scales with particle area.
- Particle beam attenuation depends on particle size relative to wavelength.
- Backscatter ratio depends on the index of refraction.

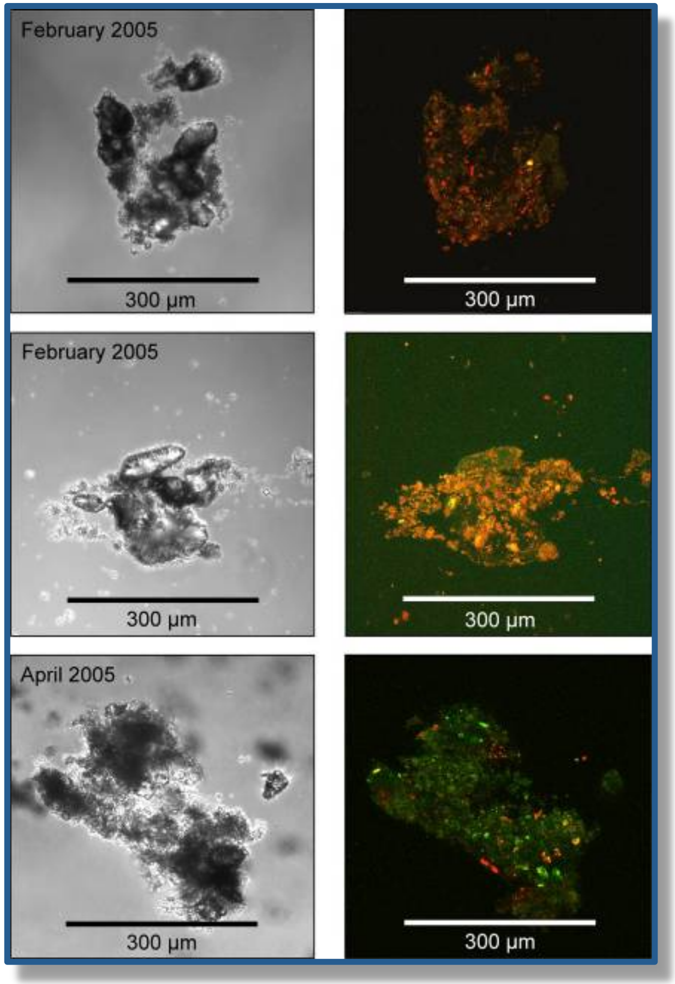
For solid particles, conversion from an optical property to mass depends on size

- Optical attenuation scales with particle area.
- For solid particles, mass is proportional to particle volume.
- For solid particles, the ratio of attenuation to mass scales as 1/D.

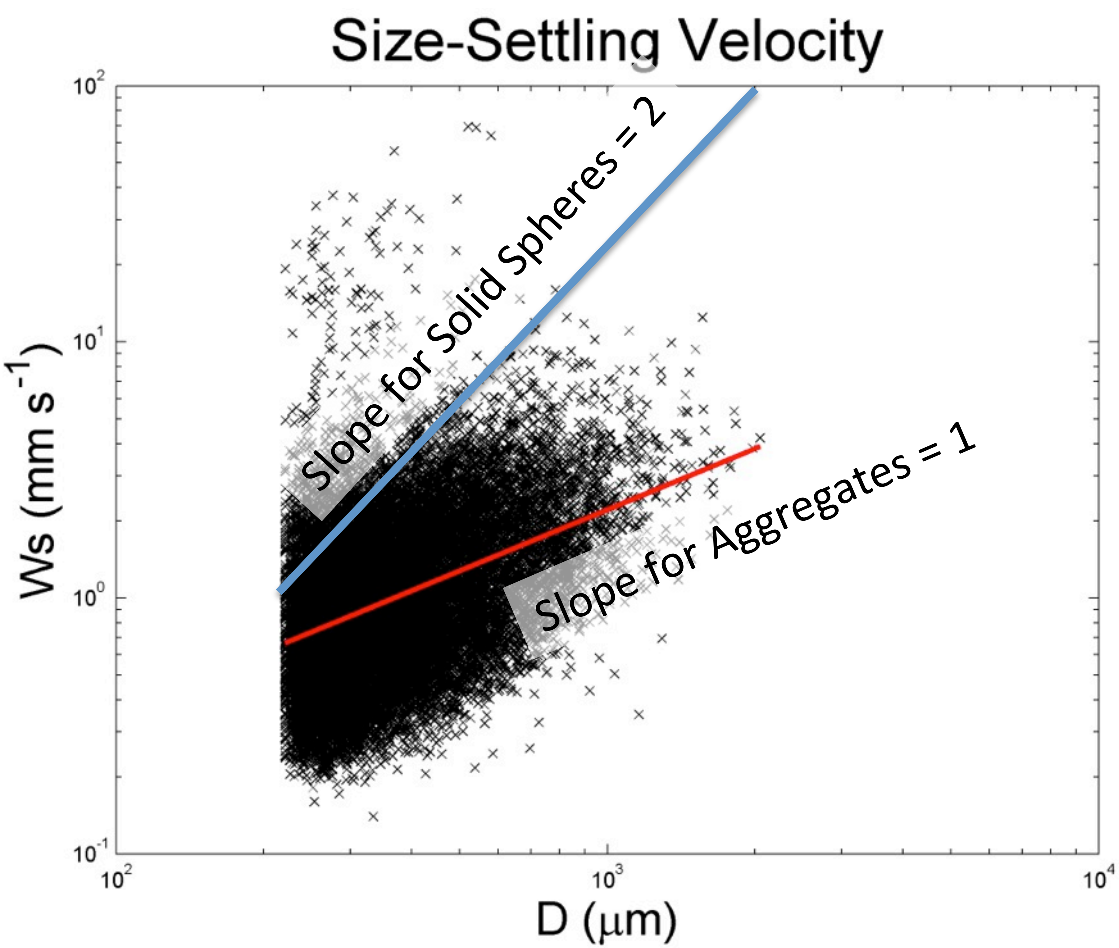


But natural particles are not solid, constant density spheres.

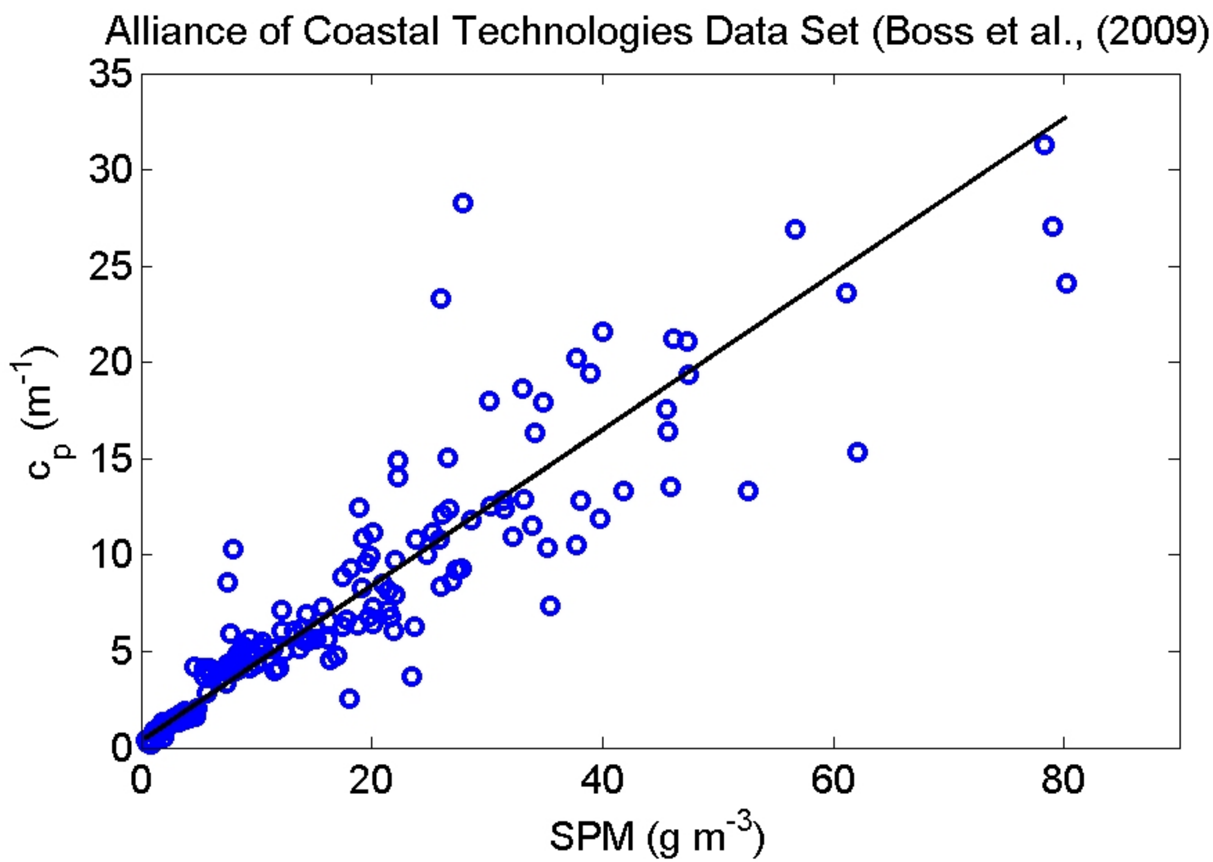
- Much particulate matter in coastal waters is contained in particle aggregates.
- In aggregates, the mass, on average, is proportional to particle area.



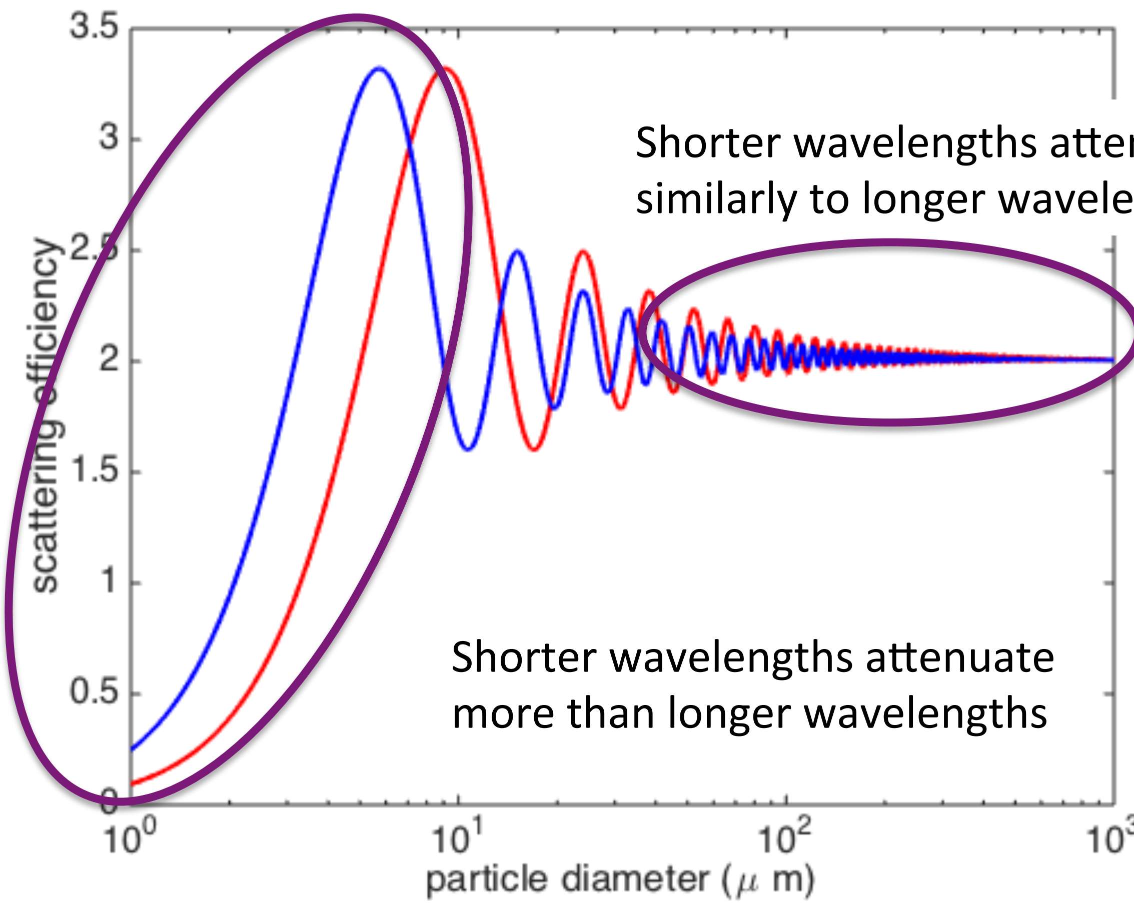
Size versus settling velocity data reveal aggregate properties.



Optical properties are good O(1) predictors of suspended particulate mass *(SPM)*.



Scattering efficiency versus diameter



Calculations from Slade's fastmie.m code

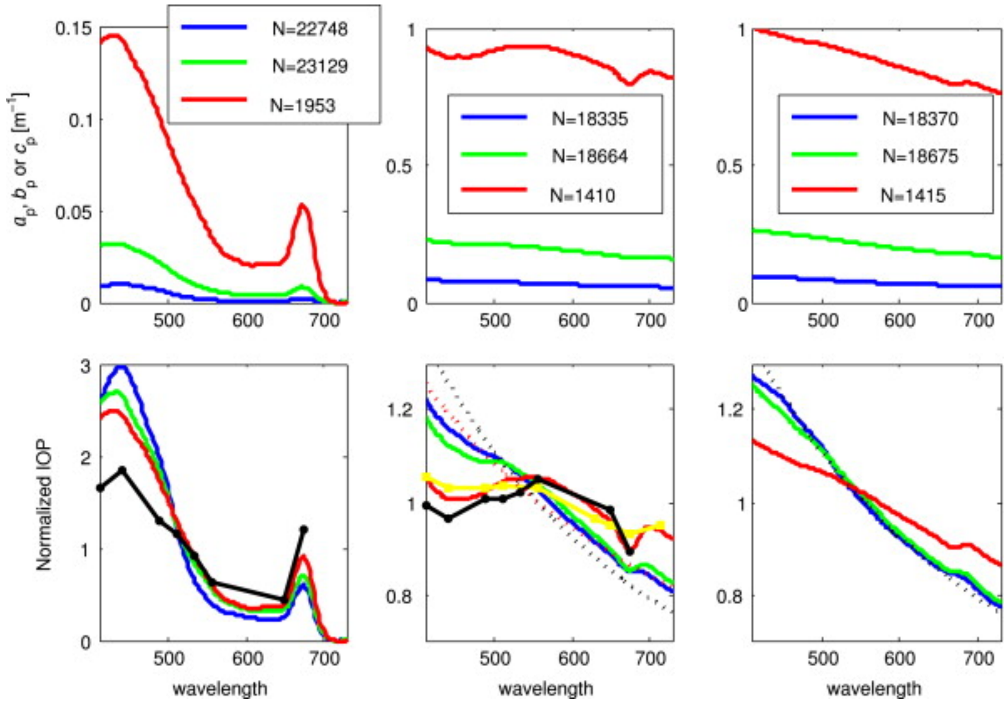


Fig. 4. Averaged particulate absorption (left), scattering (middle) and attenuation (right) spectra for Ca,AC-S<0.1Ca,AC-S<0.1 (blue), 0.1<Ca,AC-S<10.1<Ca,AC-S<1 (green) and 1<Ca,AC-S1<Ca,AC-S (red) (top panel) and their normalized shap...

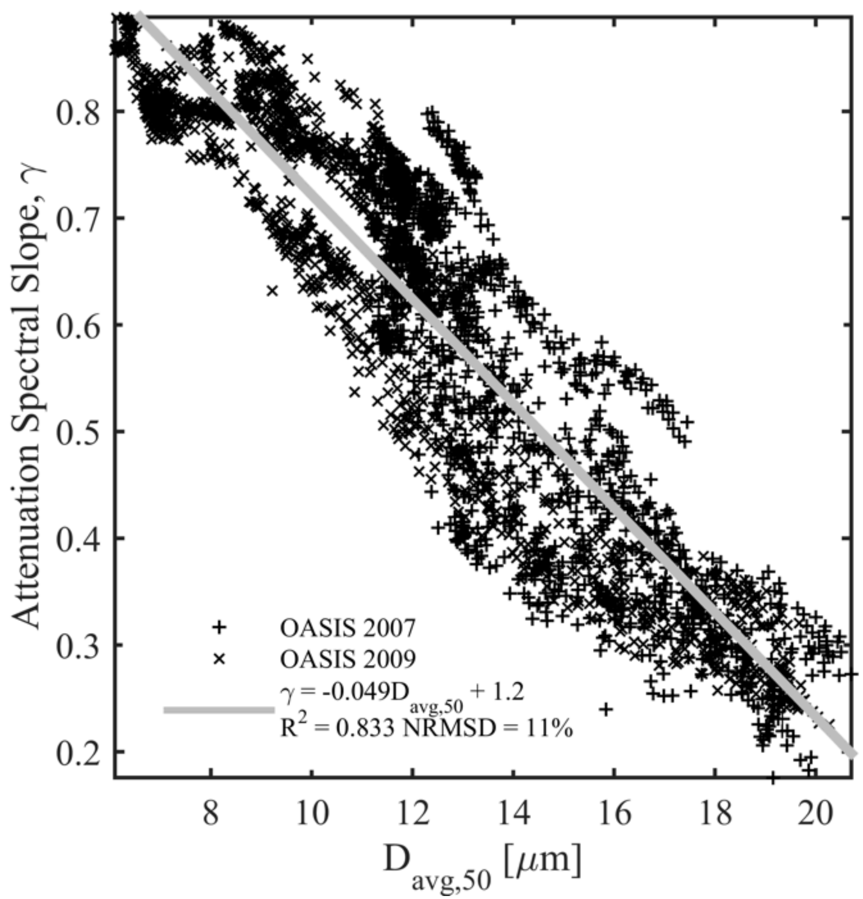
Emmanuel Boss, Marc Picheral, Thomas Leeuw, Alison Chase, Eric Karsenti, Gabriel Gorsky, Lisa Taylor, Wayne Slade, Josephine Ras, Herve Claustre

The characteristics of particulate absorption, scattering and attenuation coefficients in the surface ocean; Contribution of the Tara Oceans expedition

Methods in Oceanography, Volume 7, 2013, 52–62

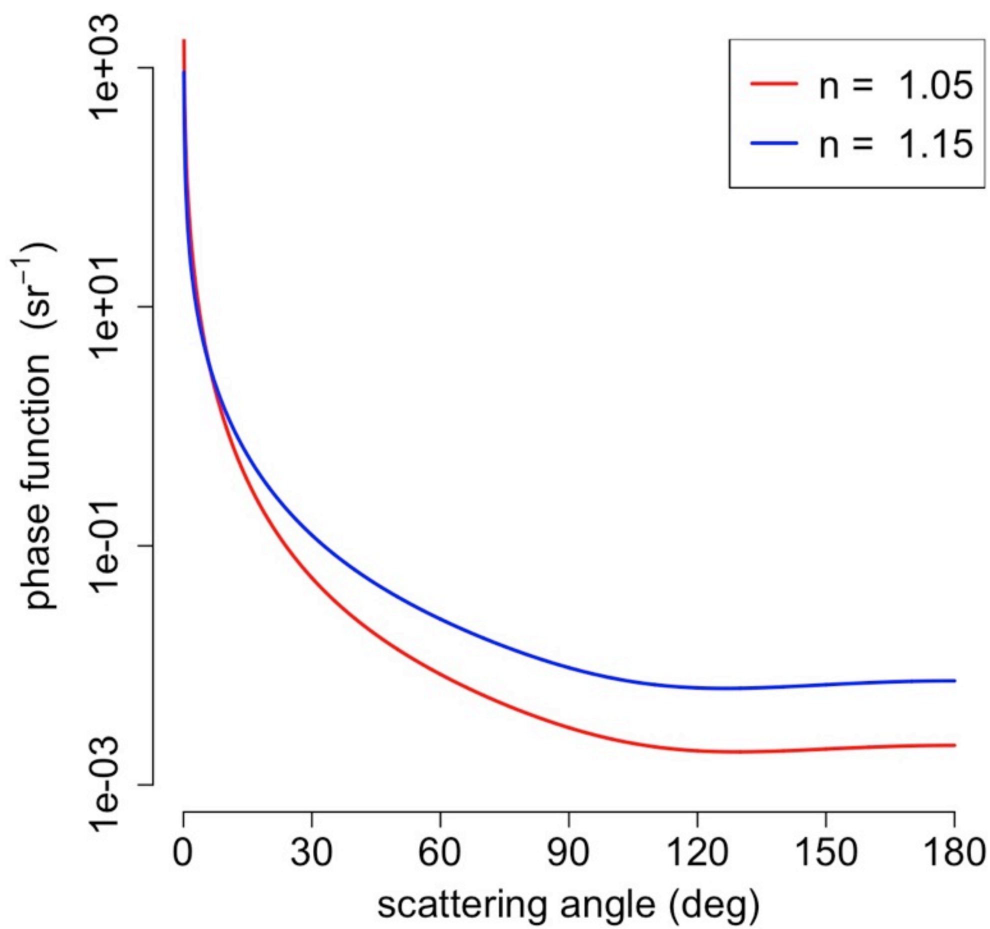
http://dx.doi.org/10.1016/j.mio.2013.11.002

Attenuation slope is inversely correlated with particle size.



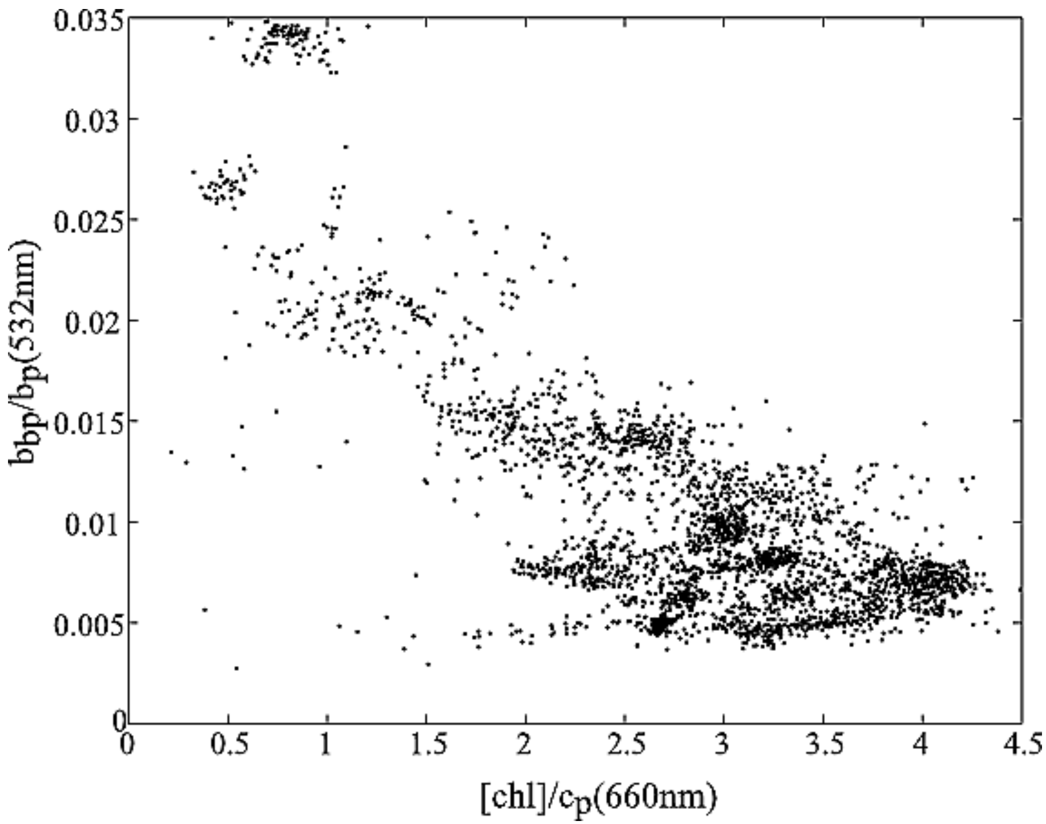
Slade and Boss, Applied Optics, 2015

Fournier-Forand Phase Function



Boss et al., 2004

Particulate backscattering ratio at LEO 15 and its use to study particle composition and distribution



Journal of Geophysical Research: Oceans
[Volume 109, Issue C1,](http://onlinelibrary.wiley.com/doi/10.1029/2002JC001514/full#jgrc9143-fig-0005) C01014, 21 JAN 2004 DOI: 10.1029/2002JC001514
http://onlinelibrary.wiley.com/doi/10.1029/2002JC001514/full#jgrc9143-fig-0005

Optical Parameters for Sediments

- Attenuation or backscatter coefficient for mass concentration
- Slope of attenuation spectrum for particle size
- Backscatter ratio for particle composition

Study Site

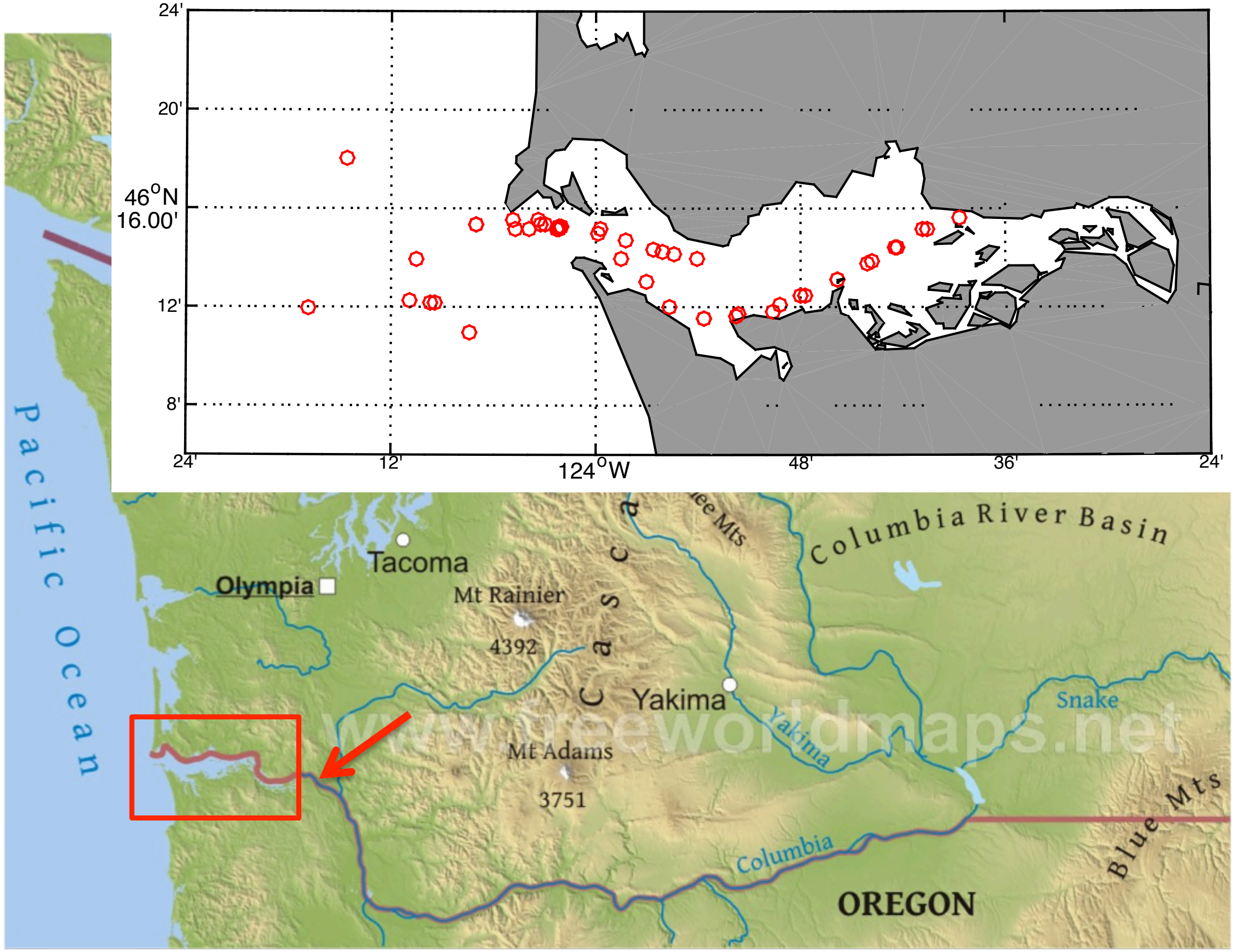
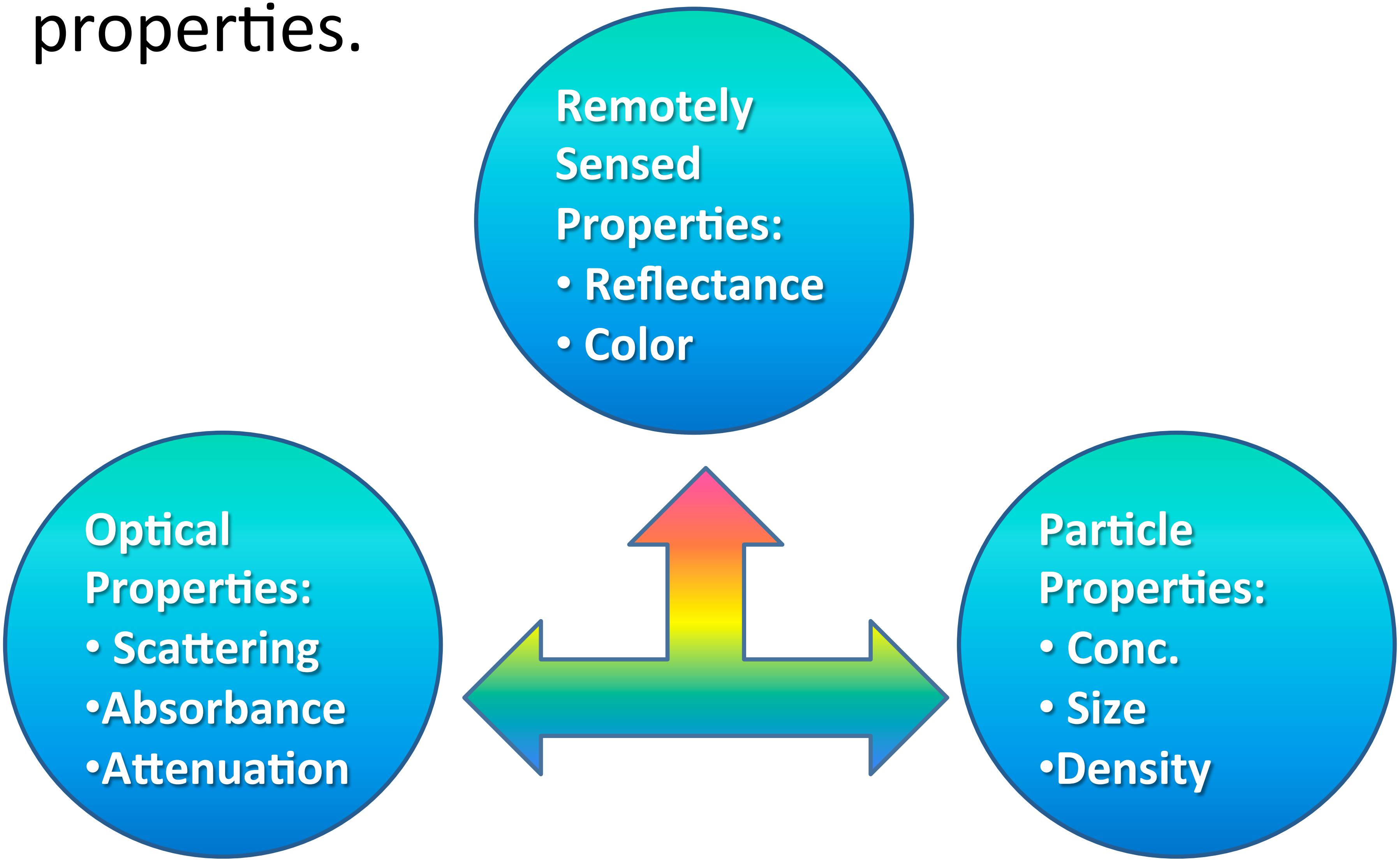


Fig. 1: Map of study sites in the Columbia River Mouth, USA.

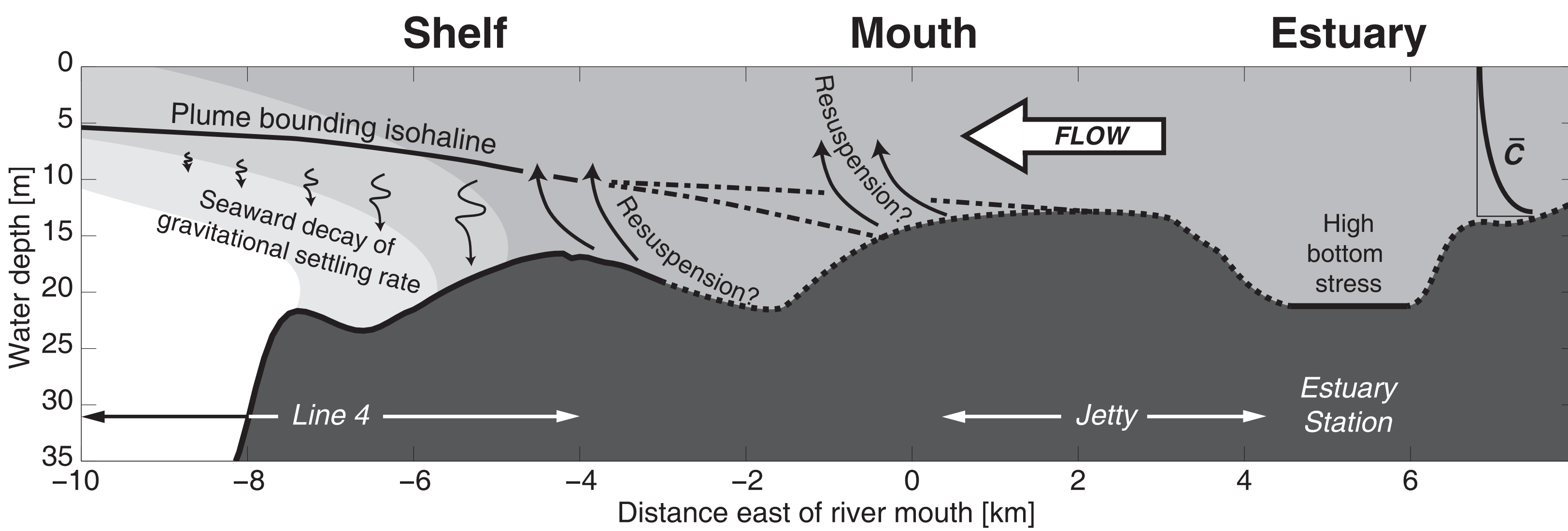
Mouth of the Columbia River

- Interesting dynamics
  - Big river
  - Big tides
  - Big waves
- Challenging conditions
  - Lack of observations
  - Ideal for new in situ and remote sensing technologies

Goal: Link particle dynamics, optical properties, and remotely sensed properties.



Much is already known about sedimentation in estuaries.



Nowacki et al. , 2012

Methods

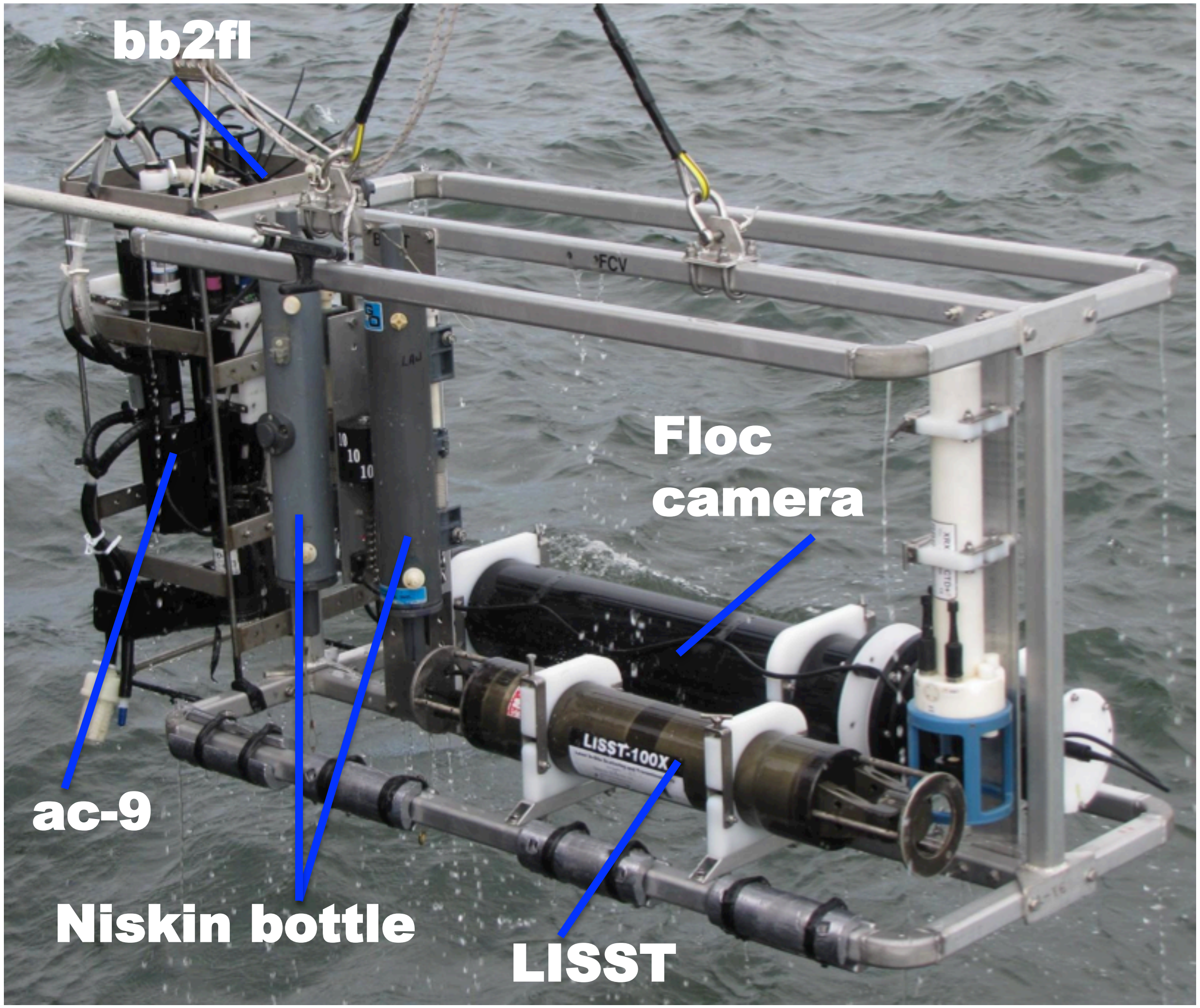


Fig. 2: Particle and Optics Profiling package.

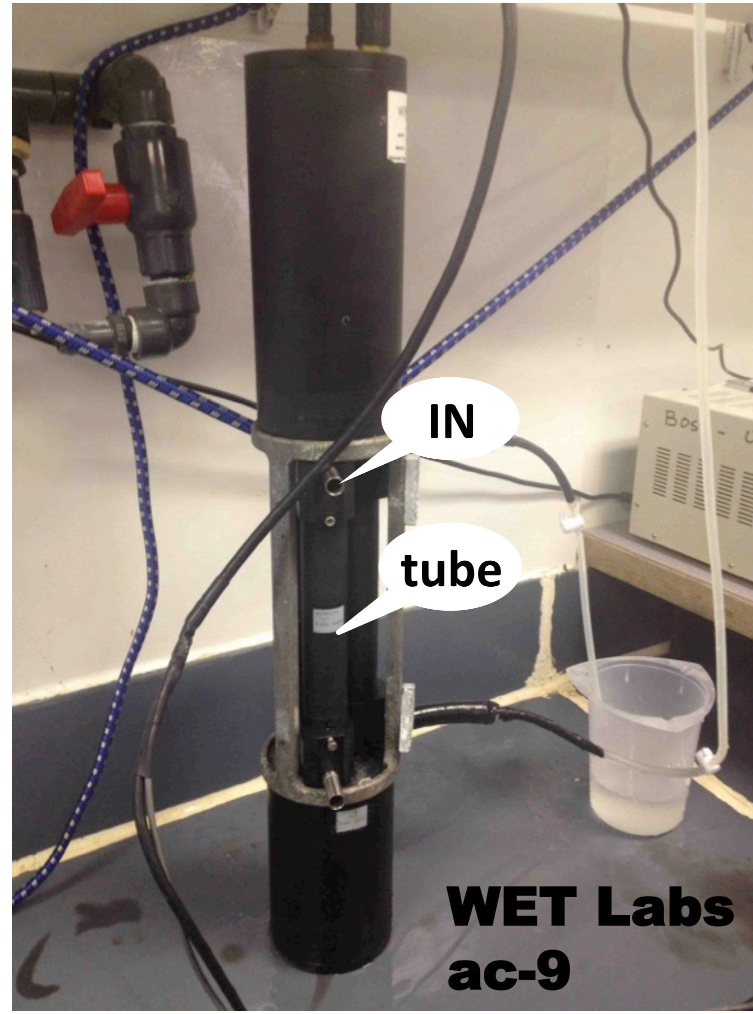
- **Floc camera**
  - Area conc. →PSDs (large)
- **Sequoia LISST-100B**
  - PSDs (small)→Area conc.
  - Beam attenuation (c_p)
- **Niskin bottles**
  - water sample (SPM)
- **ac-9**
  - a: absorption
  - c: attenuation
- **bb2fl**
  - Backscattering(b_{bp}) at 532, 650 nm

Instruments

- Sequoia LISST: PSDs; c_p(650 nm)
- ac-9: c_p (650 nm)

Acceptance angles:

- LISST-B: 0.0262°
- ac-9: 0.9328°

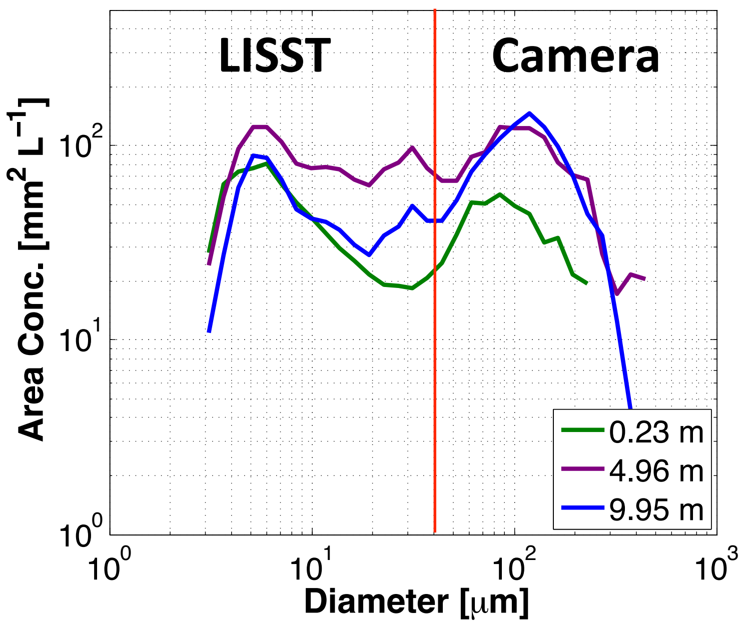


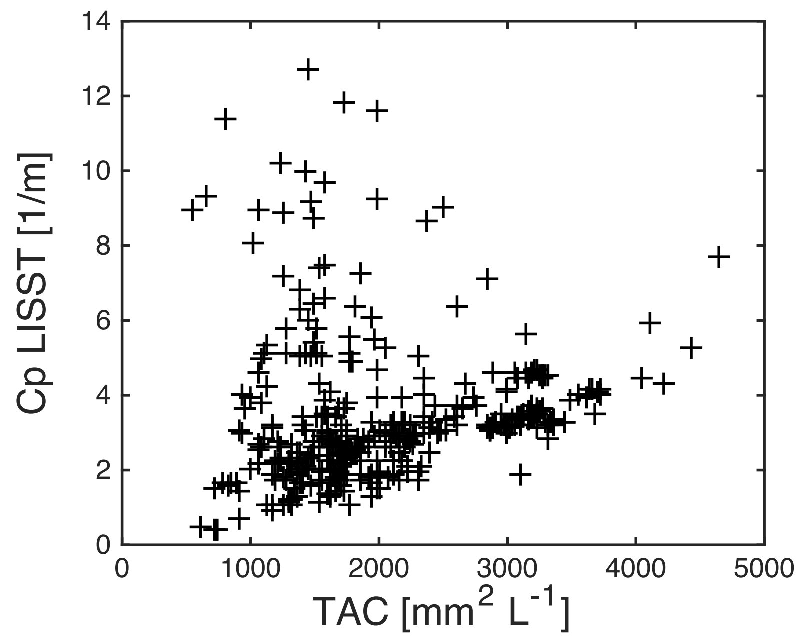
ac-9 has larger acceptance angle than LISST and measures mixed water

Results

- Part I
  - Identify Schlieren effect in c_p derived from LISST, WetLabs ac-9 and b_{bp} derived from and bb2fl
- Part II
  - Variability of particle and optical properties

TAC vs. C_p


LISST
Camera
Area Conc. [mm2 L-1]
Diameter [μm]
0.23 m
4.96 m
9.95 m
10^0
10^1
10^2
10^3


Cp LISST [1/m]
TAC [mm2 L-1]
0
1000
2000
3000
4000
5000
2
4
6
8
10
12
14

Schlieren

In pycnocline, the density gradients have varying refractive indices, thereby causing light scattering.

- Mikkelsen et al., 2008

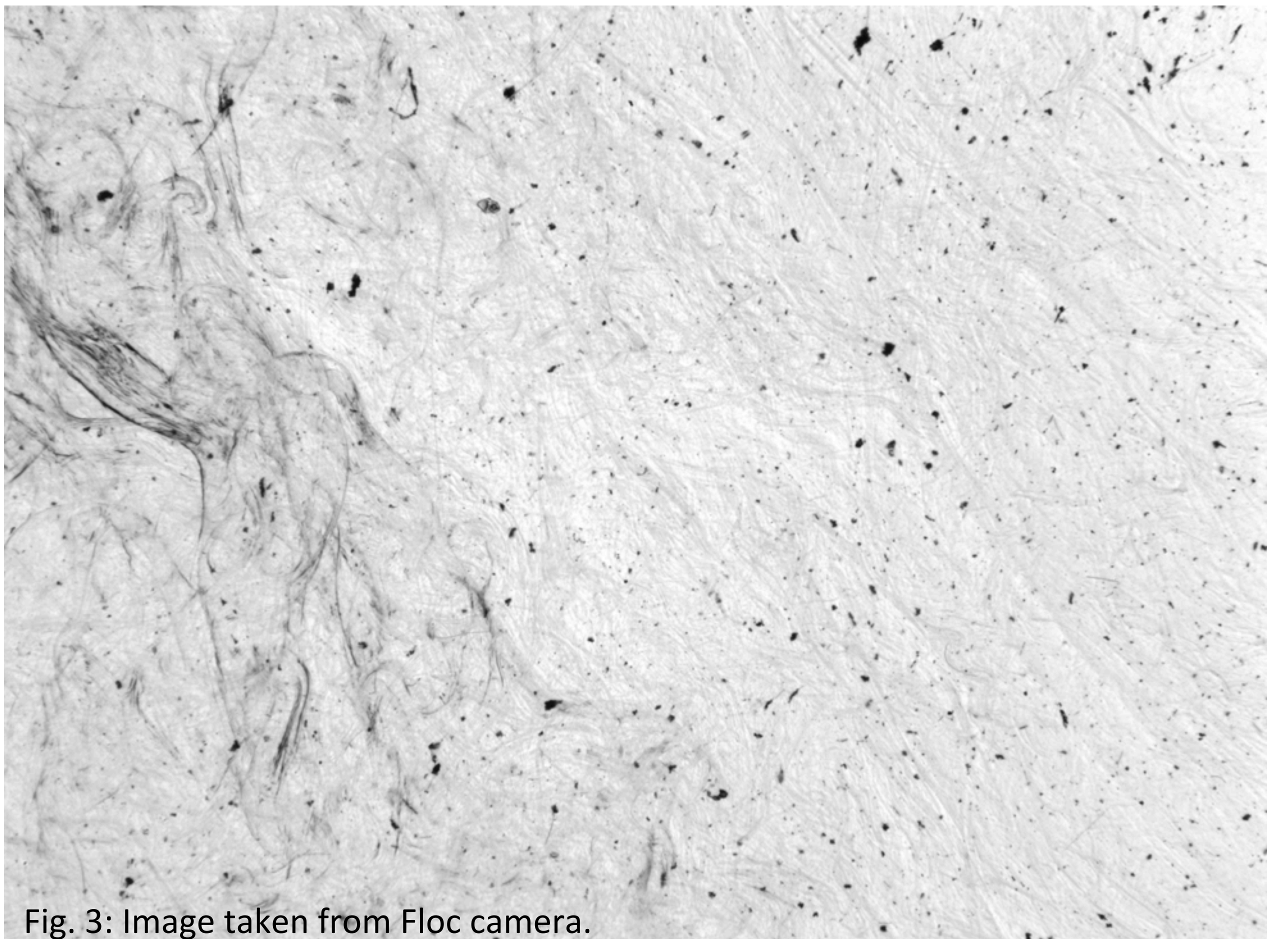
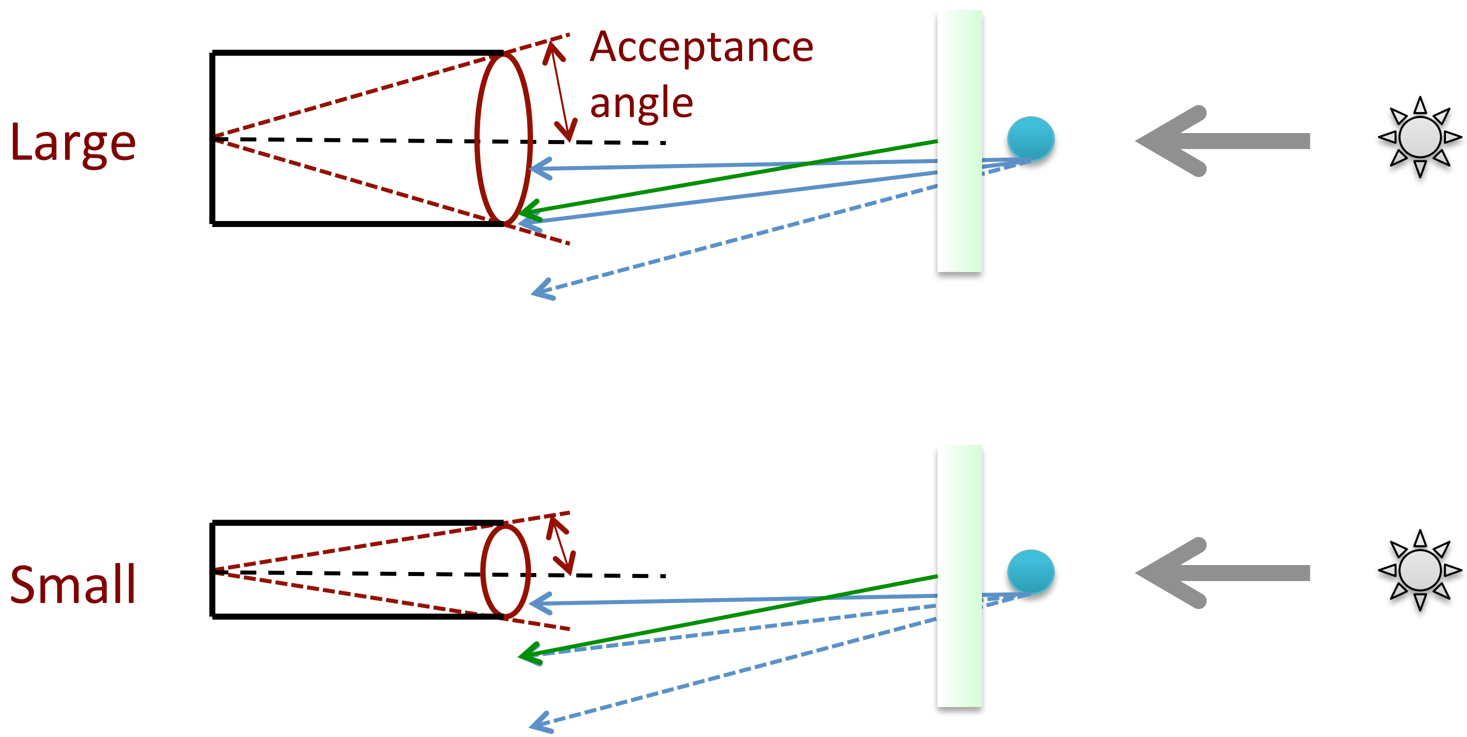


Fig. 3: Image taken from Floc camera.

How c_p responds to acceptance angle?

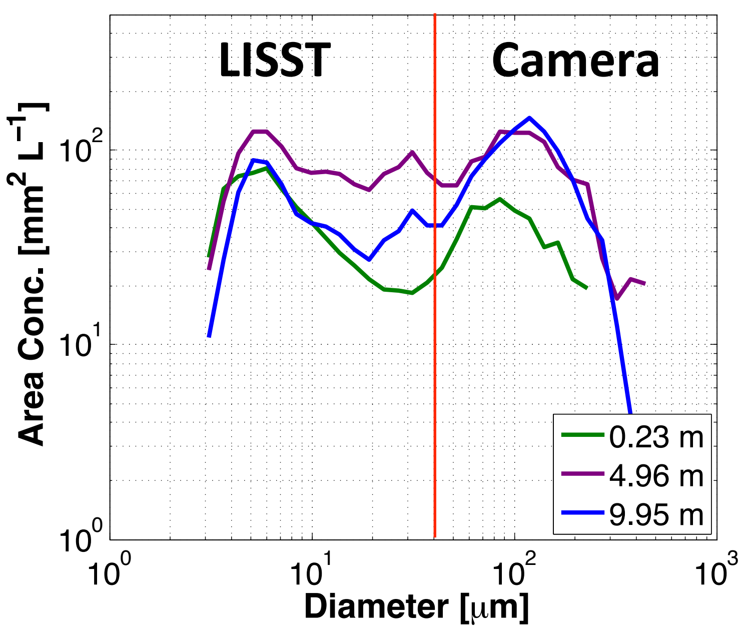


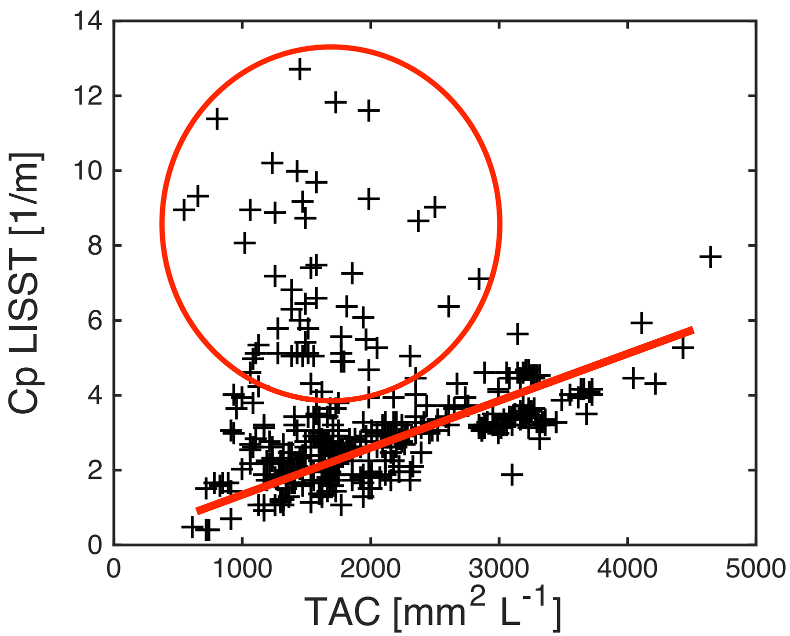
Acceptance angles:

- LISST-B: 0.0262°
- ac-9: 0.9328°

Acceptance angle ⬇ → beam attenuation (c_p) ⬆

TAC vs. C_p


LISST
Camera
Area Conc. [mm2 L-1]
Diameter [μm]
0.23 m
4.96 m
9.95 m

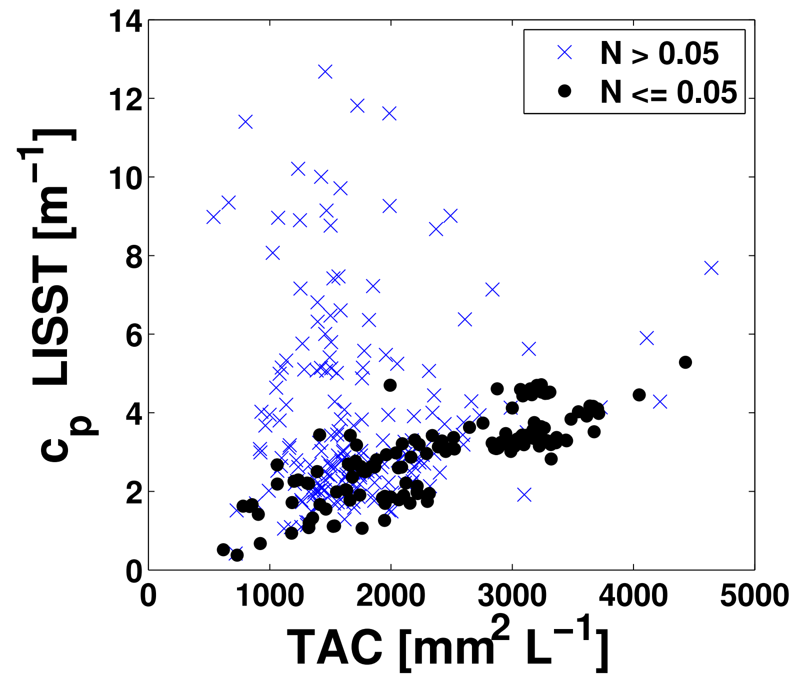

Cp LISST [1/m]
TAC [mm2 L-1]

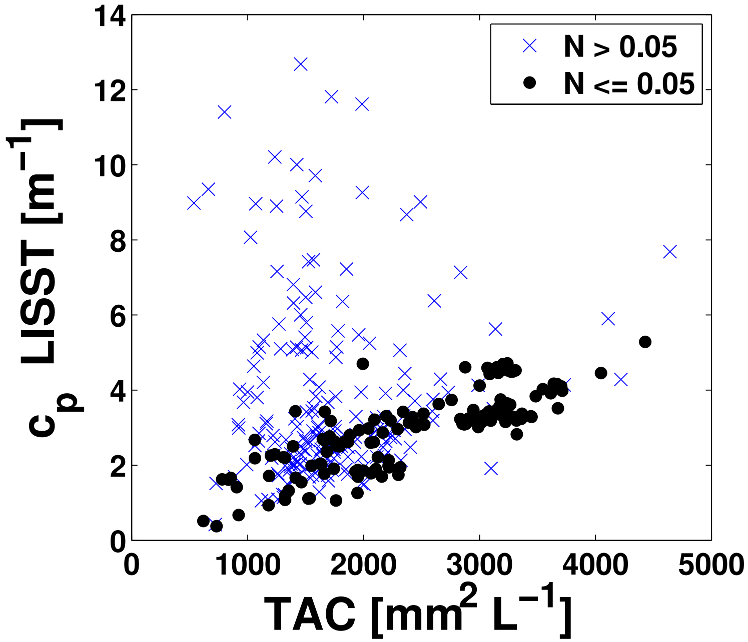
Buoyancy Frequency N

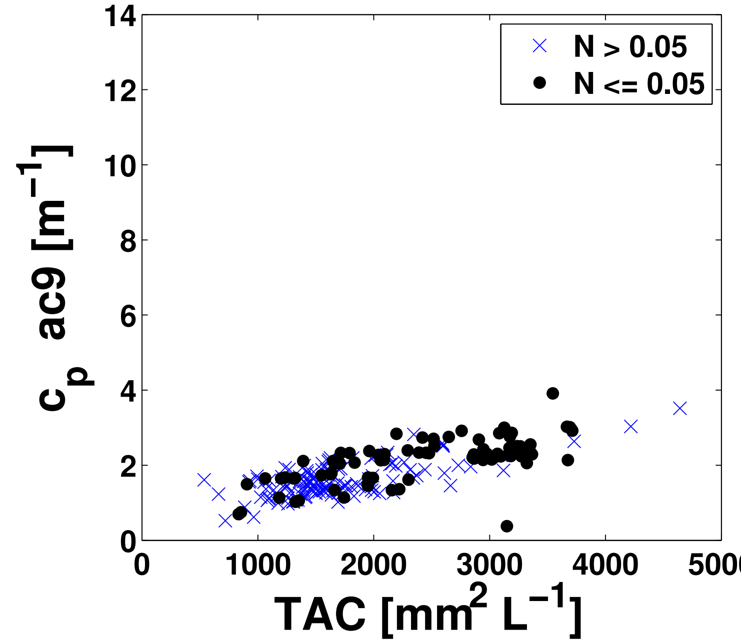
- Buoyancy Frequency, N (Mikkelsen et al., 2008)

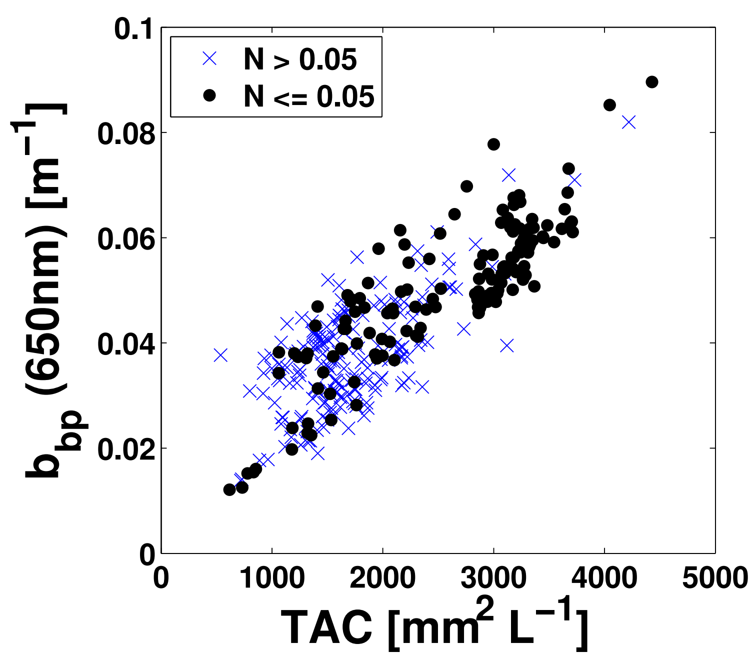
$$N = \left(-\frac{g}{\rho_0}\frac{\partial \rho}{\partial z}\right)^{0.5}$$

  - g is gravitational acceleration
  - the ρ_0 is the average density
  - $\partial \rho / \partial z$ is the vertical density gradient





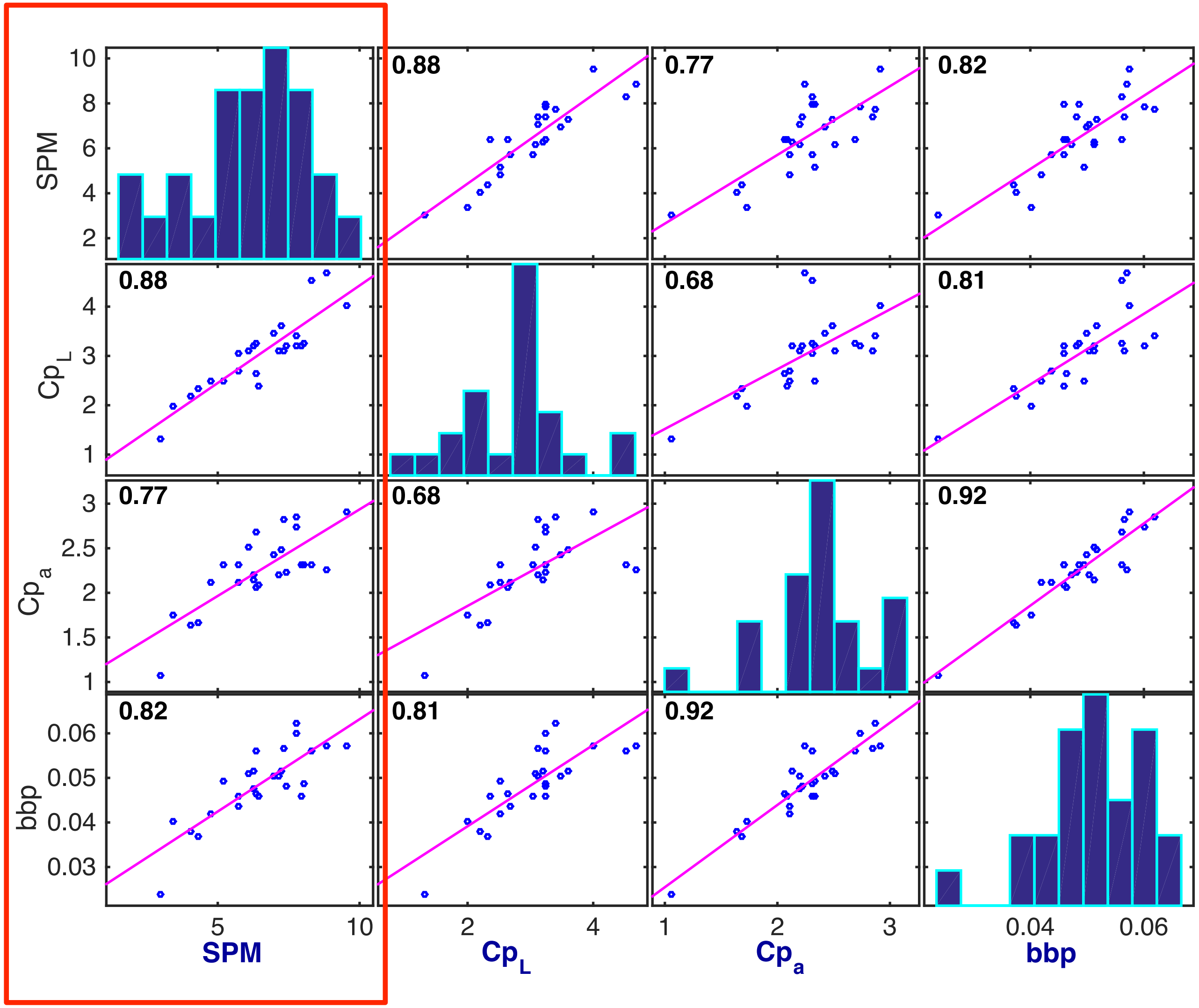




ac-9 has larger acceptance angle than LISST and measures mixed water

C_p (LISST) and C_p(ac-9) and b_{bp} correlated well with SPM

N = 0.05 s^{-1}

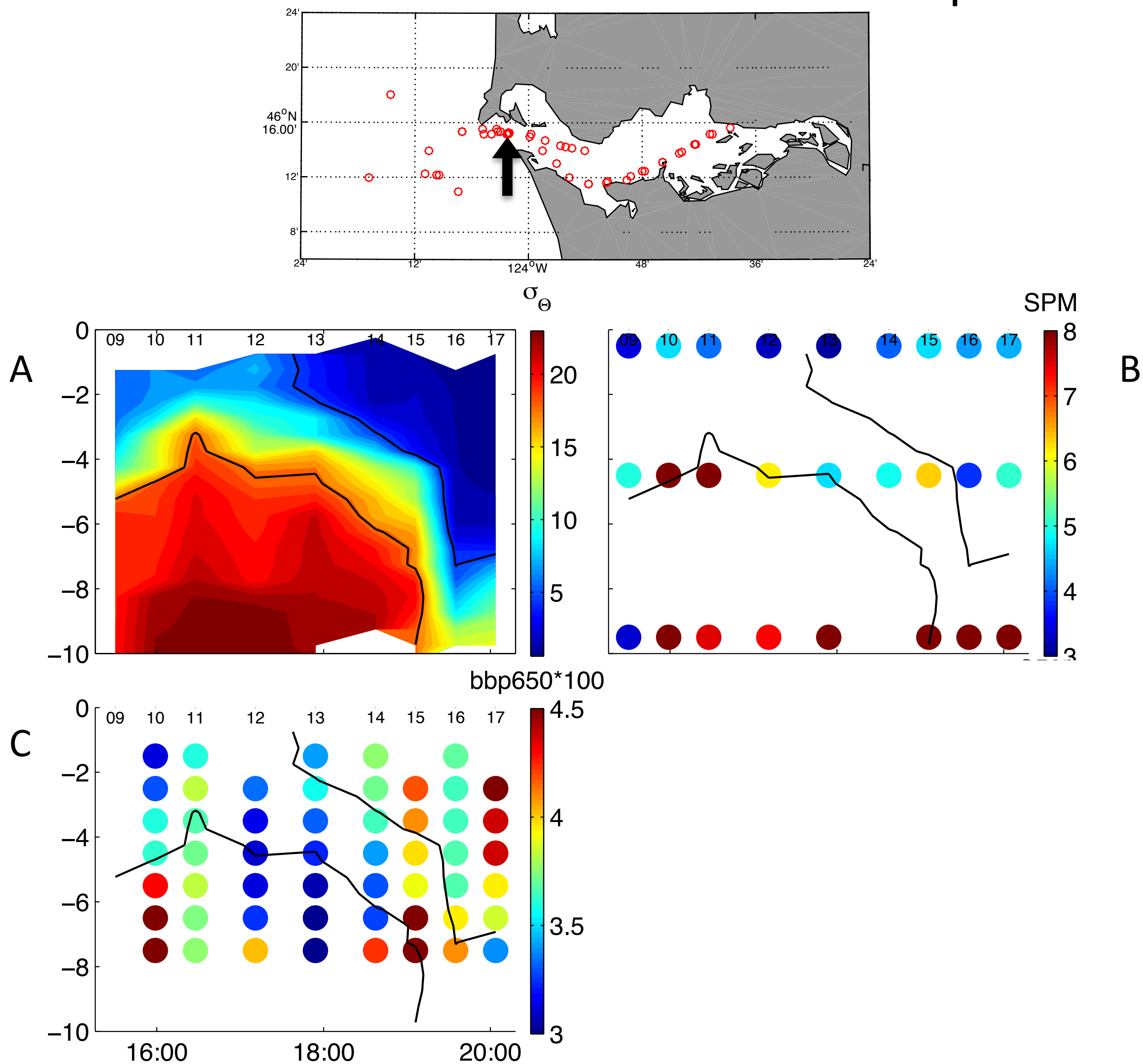


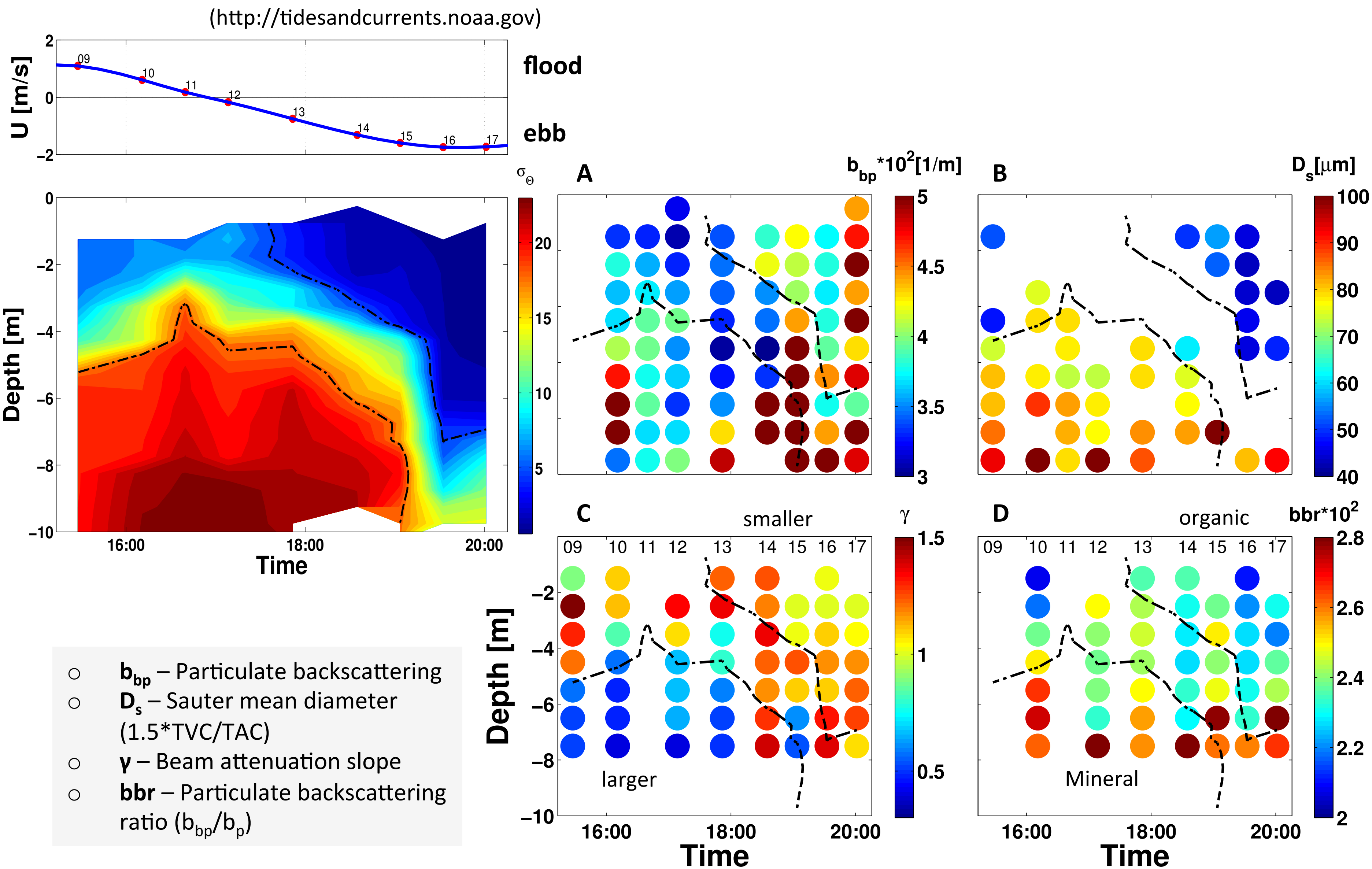
Results

- Part I
  - Identify Schlieren effect in c_p derived from LISST, WetLabs ac-9 and b_{bp} derived from and bb2fl

- Part II
  - Variability of particle and optical properties

Estimated SPM from b_{bp}





(http://tidesandcurrents.noaa.gov)
U [m/s]
flood
ebb
09
10
11
12
13
14
15
16
17
Depth [m]
Time
16:00
18:00
20:00
σ_Θ
A
$b_{bp}*10^2$[1/m]
B
D_s[μm]
C
smaller
larger
γ
D
organic
Mineral
$bbr*10^2$
b_{bp} – Particulate backscattering
D_s – Sauter mean diameter (1.5*TVC/TAC)
γ – Beam attenuation slope
bbr – Particulate backscattering ratio (b_{bp}/b_p)

Summary

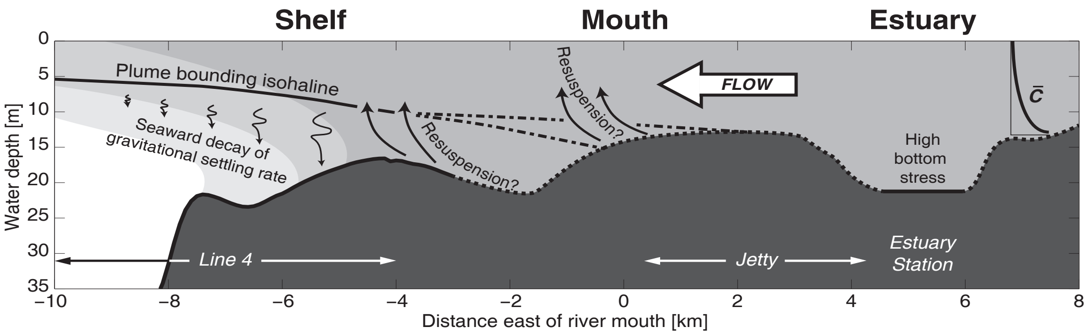
- Attenuation and backscatter coefficients are good proxies for mass concentration.
- Slope of attenuation spectrum is a good proxy for particle size.
- Backscatter ratio is a good proxy for particle composition.

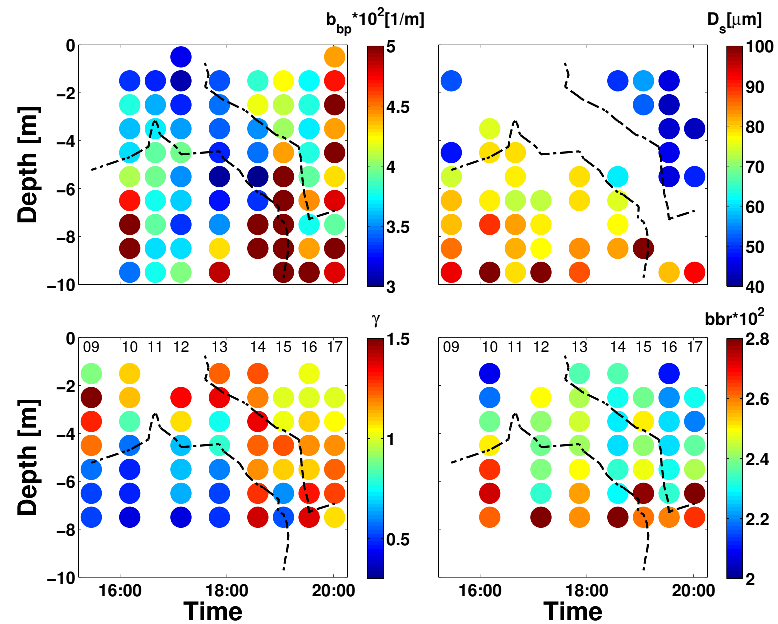
Summary

- Schlieren produces an increase in c_p derived from LISST. N is a good tool to eliminate inaccurate estimates of c_p .
- The schlieren do not affect the c_p and b_{bp} derived from WetLabs ac-9 and bb2fl.

Summary

- An accurate understanding of key sediment properties can be developed with optical measurements.






Thank you!