# Environmental Optical Sensors for AUVs and Other Compact Platforms

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# Collaborators

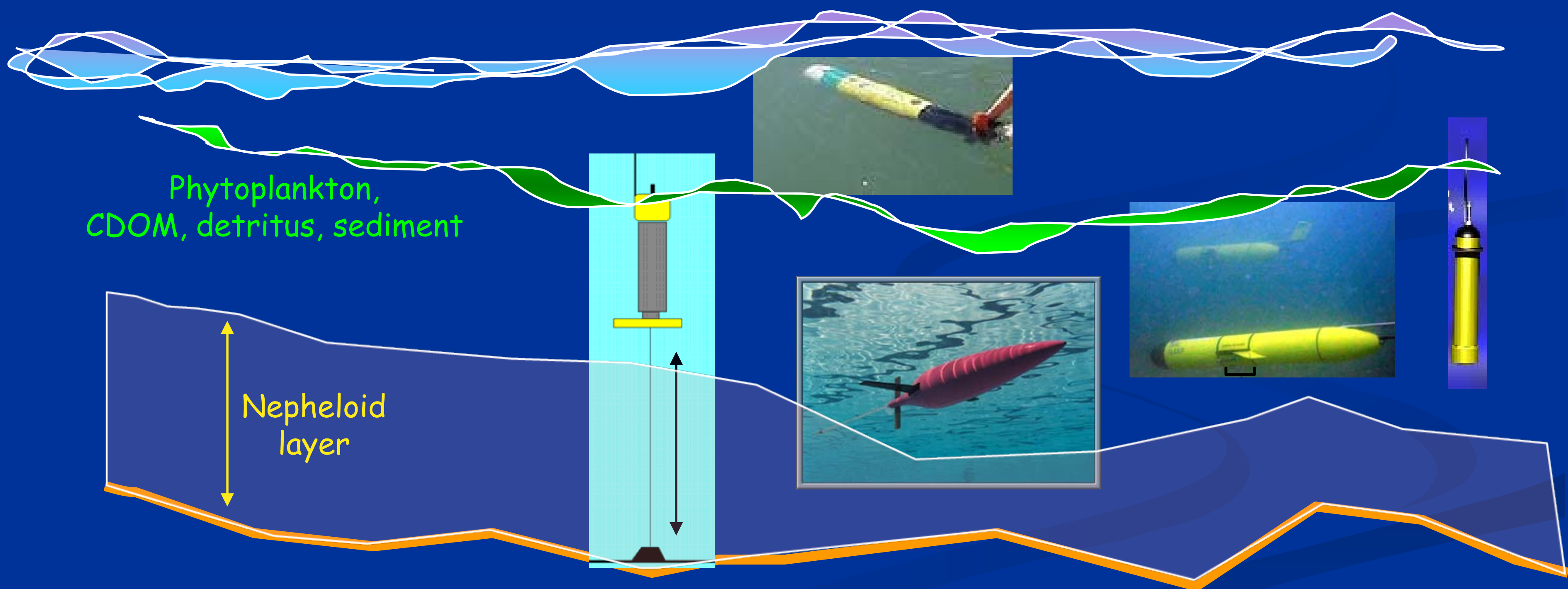
- **Casey Moore, Ron Zaneveld, Andrew Barnard, and Scott Freeman**
  *WET Labs, Inc.; Philomath, OR and Narragansett, RI*

- **Oscar Schofield**
  *Rutgers University; New Brunwick, NJ*

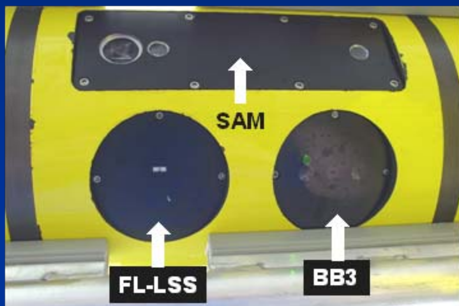
- **Jim Sullivan**
  *University of Rhode Island; Narragansett, RI*

# Optical Sensors on Compact Platforms: Science Applications

Science driver: Distribution and dynamics of biogeochemical properties in the ocean over unprecedented space and time scales

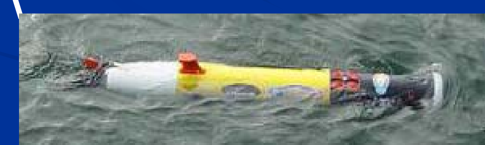


# Optical Sensors on Compact Platforms: Navy Applications




Environmental optical data

Divers
Active EOID
Passive EOID

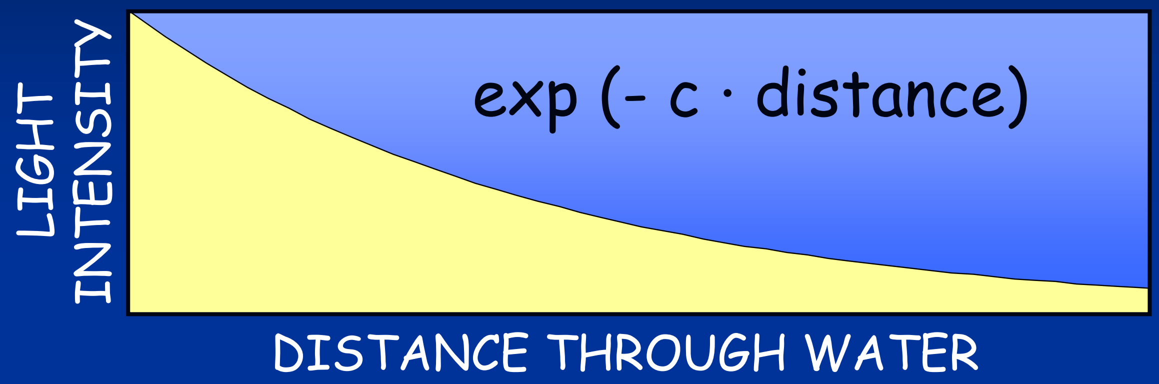


- Mine counter measure (MCM) operations
- Harbor security operations
- Debris field mapping

# Navy MIREM Training Exercise

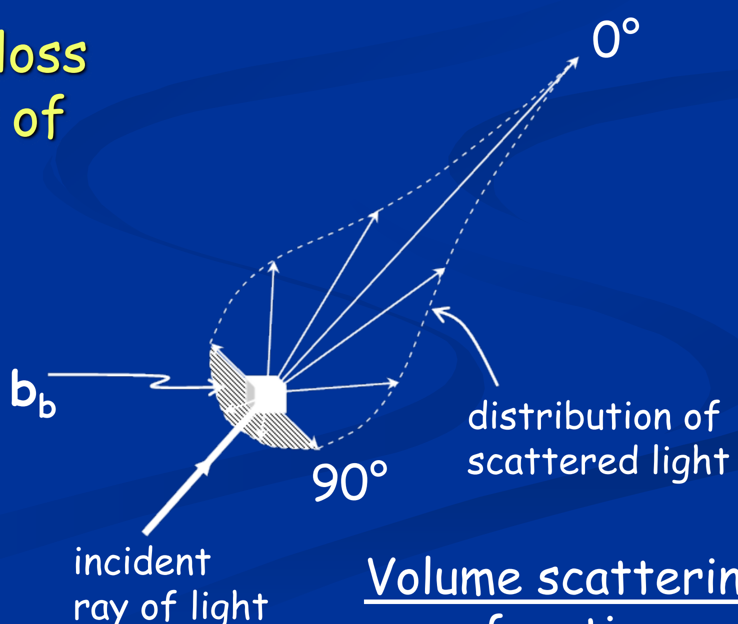
## Applied Problem: What can the towed system see in the optically complex coastal ocean?

# "Environmental Optical Data"




**attenuation** (c) – the rate of light loss through water from the processes of scattering (b) and absorption (a)

$$c = a + b$$




Volume scattering function

# Scattering and Particle Composition

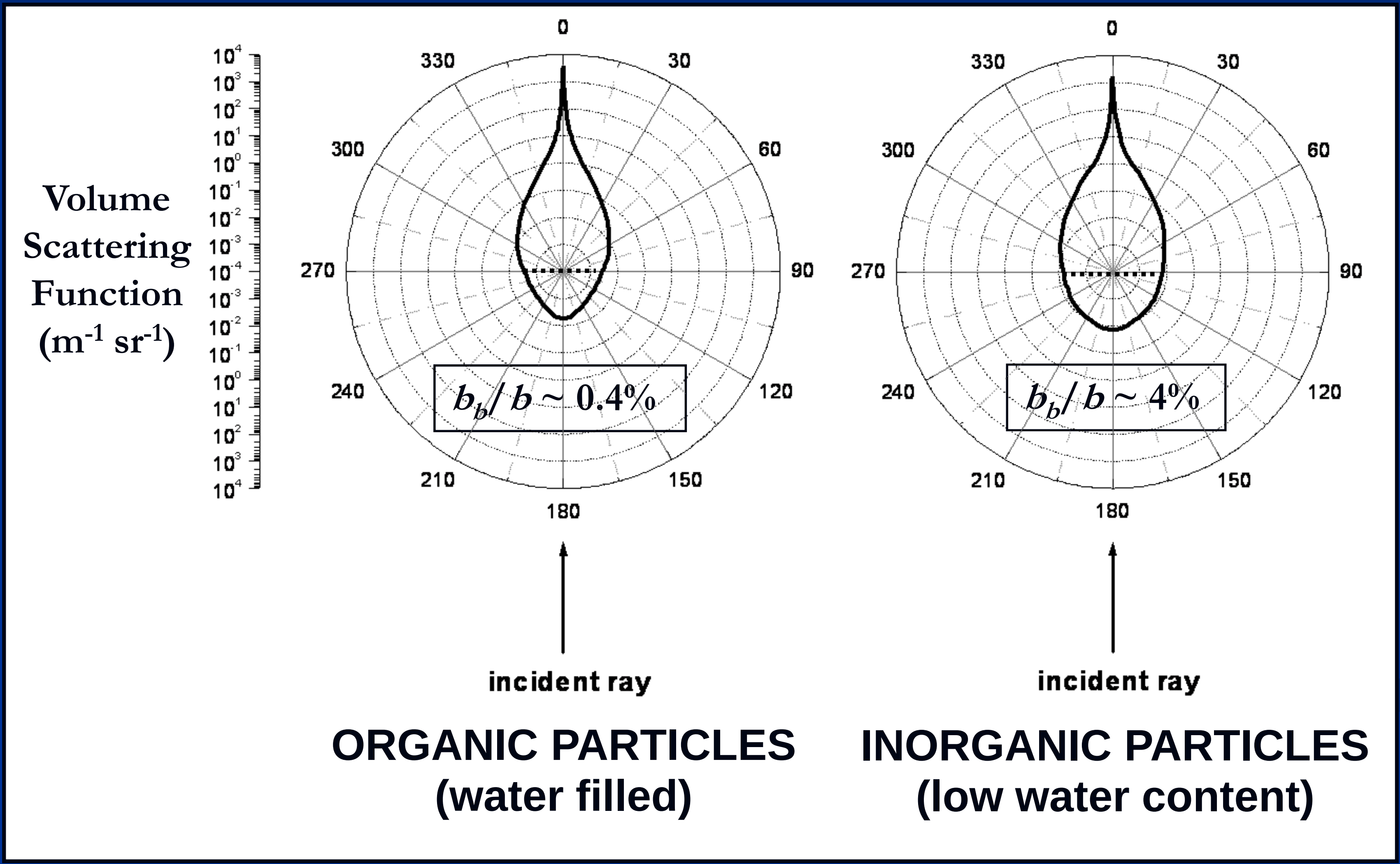


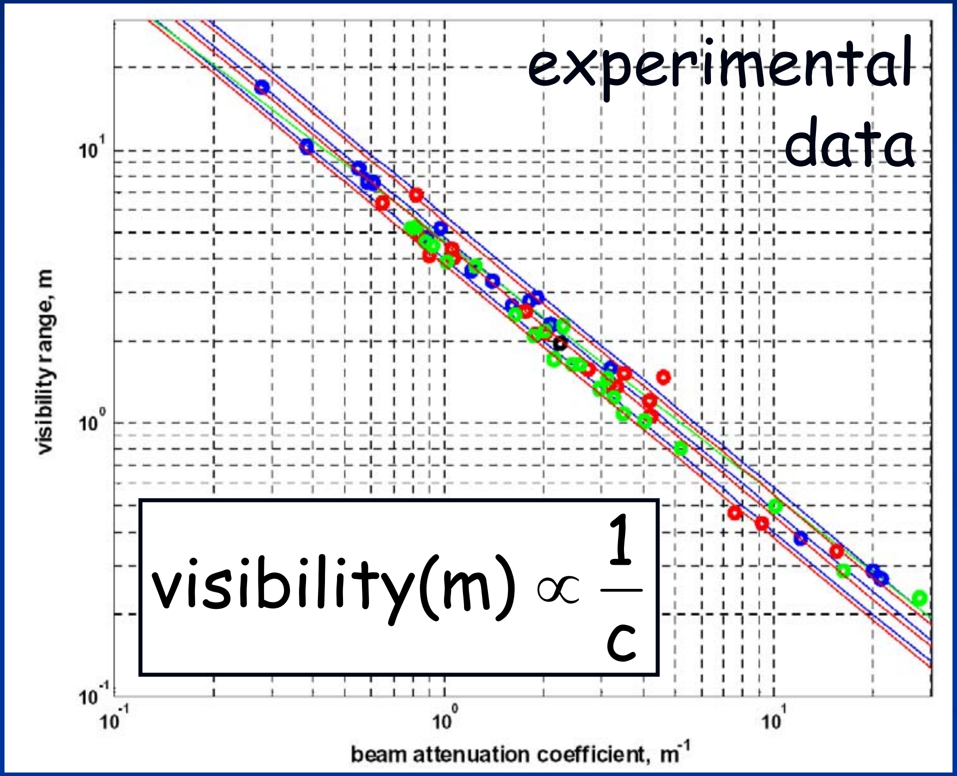
**Table 1. Some biogeochemical properties derived from optical properties.**

| Biogeochemical property | Optical Property | Example Reference(s) |
|---|---|---|
| Particulate Organic Carbon (POC) | 1) $c_p$ or $b_p$ | Peterson 1978; Gardner et al. 1993, 2001; Loisel and Morel 1998; Bishop 1999; Bishop et al. 2002; Claustre et al. 1999, 2000; Mishonov et al. 2003 |
| | 2) $b_{bp}$ | Stramski et al. 1999; Balch et al. 1999 |
| Total Suspended Matter (TSM) | 1) $c_p$ or $b_p$ | Peterson 1978; Gardner et al. 1993, 2001; Walsh et al. 1995; Prahl et al. 1997 |
| | 2) turbidity | Fugate and Friedrichs 2002 |
| Dissolved Organic Matter or Carbon (DOM, DOC) | 1) $a_g$ | Pages and Gadel 1990; Vodacek et al. 1997 |
| | 2) Fluorescence | Coble et al. 1993; Ferrari et al. 1996; Klinkhammer et al. 2000 |
| DOM composition[a] | 1) $a_g$, spectral shape | Carder et al. 1989; Blough and Green 1995 |
| | 2) Fluorescence, multi-spectral shapes | Coble 1996; Del Castillo et al., 1999; McKnight et al. 2001 |
| Chlorophyll | 1) $a_p$ | Bricaud et al. 1998; Claustre et al. 2000 |
| | 2) Fluorescence | e.g., Yentsch and Menzel 1963; Claustre et al. 1999 |
| Phycobiliproteins | Fluorescence | Cowles et al. 1993; Sosik et al. 2002 |
| Phytoplankon pigment ratios | $a_p$, spectral shape | Trees et al. 2000; Eisner et al. 2003 |
| Proteins | Fluorescence | Coble et al. 1993; Mayer et al. 1999 |
| Hydrocarbons | Fluorescence | e.g., Holdway et al. 2000 |
| Particle size distribution | 1) $c_p$, spectral shape | Morel 1973; Boss et al. 2001 |
| | 2) $\beta(\theta)$ | Brown and Gordon 1974; Zaneveld et al. 1974; Agrawal and Pottsmith 2000 |
| Particulate refractive index | 1) $\beta(\theta)$ | Brown and Gordon 1974; Zaneveld et al. 1974 |
| | 2) $c_p(\lambda)$, $b_{bp}$, and $b_p$ | Twardowski et al. 2001 |
| Sewage | Fluorescence | Petrenko et al. 1997 |
| Nitrate | UV absorption | Johnson and Coletti 2002 |

[a]For example – ratio of dissolved humic acid to fulvic acid, DOM molecular size distribution, DOM aromaticity, DOM source

For more details:
Twardowski, M.S., M. Lewis, A. Barnard, J.R.V. Zaneveld. 2005. In-water instrumentation and platforms for ocean color remote sensing applications. In: *Remote Sensing of Coastal Aquatic Waters*, R. Miller, C. Del Castillo, and B. McKee [Eds.], Springer Publishing, Dordrecht, Netherlands, pp. 69-100.

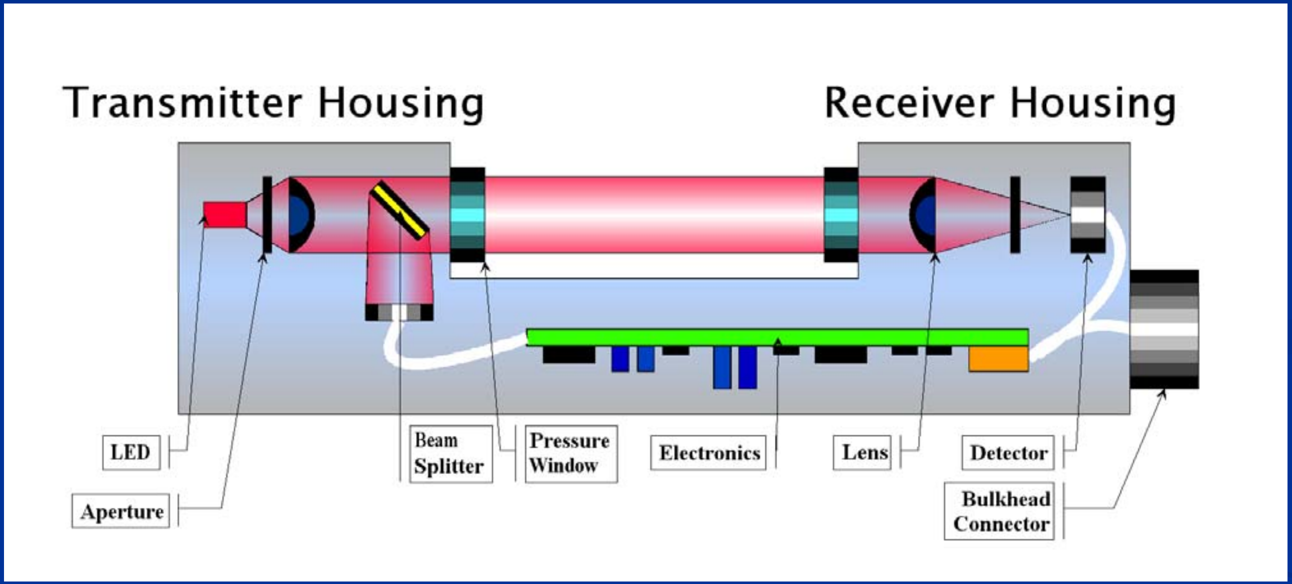
# Visibility and Attenuation

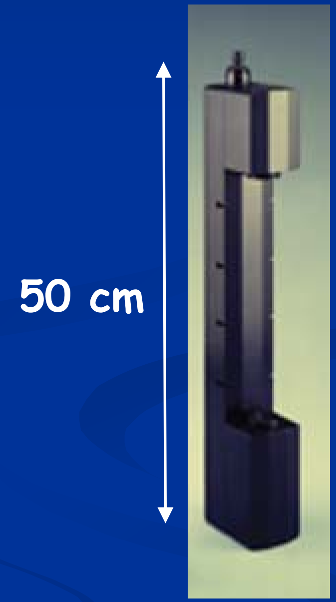



Zaneveld and Pegau (2003)

- proportionality (~4.8) determined by contrast threshold of human eye
- accuracy better than 10%
- backscattering is NOT a good visibility proxy

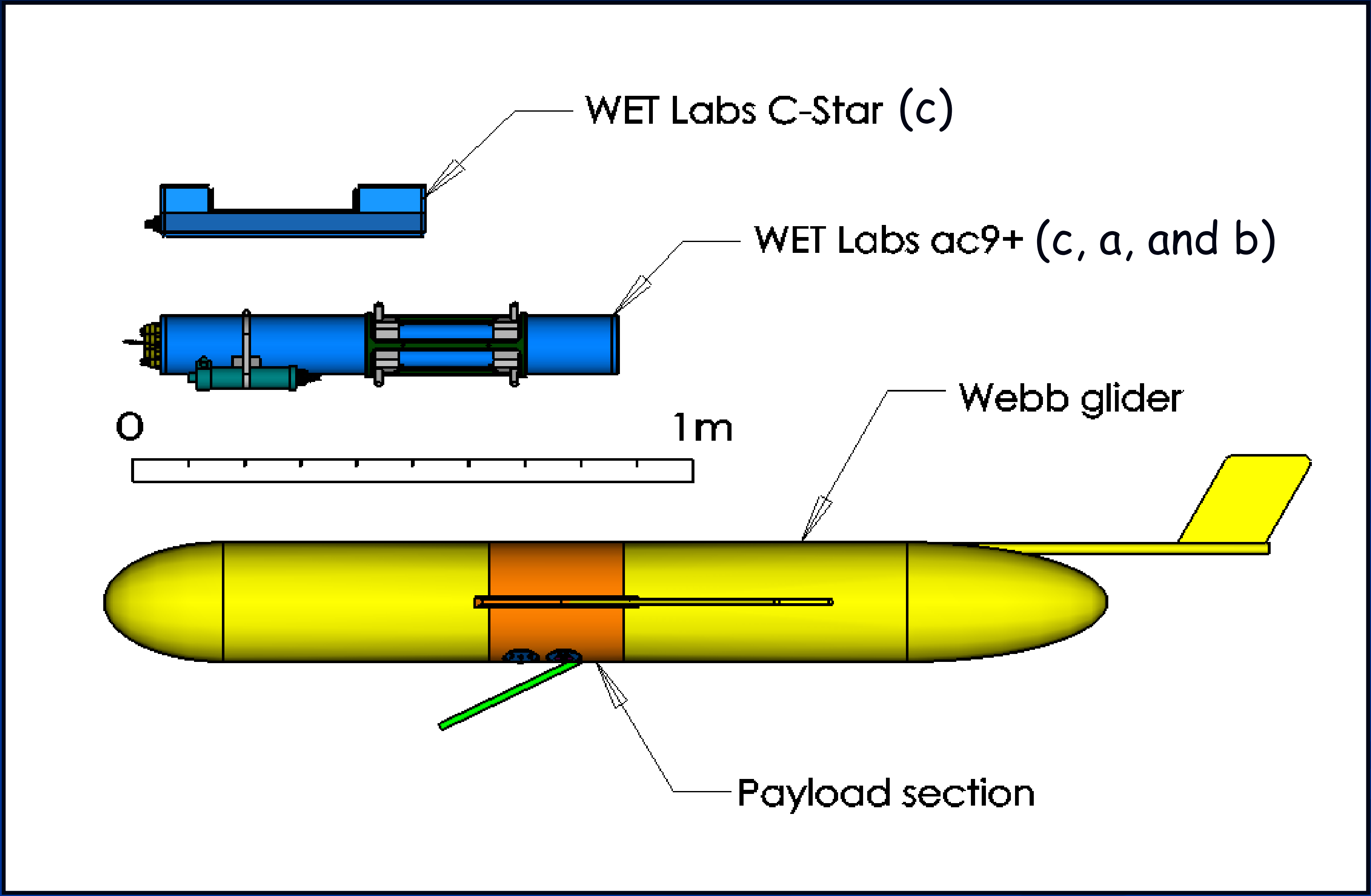
# COTS beam attenuation meter

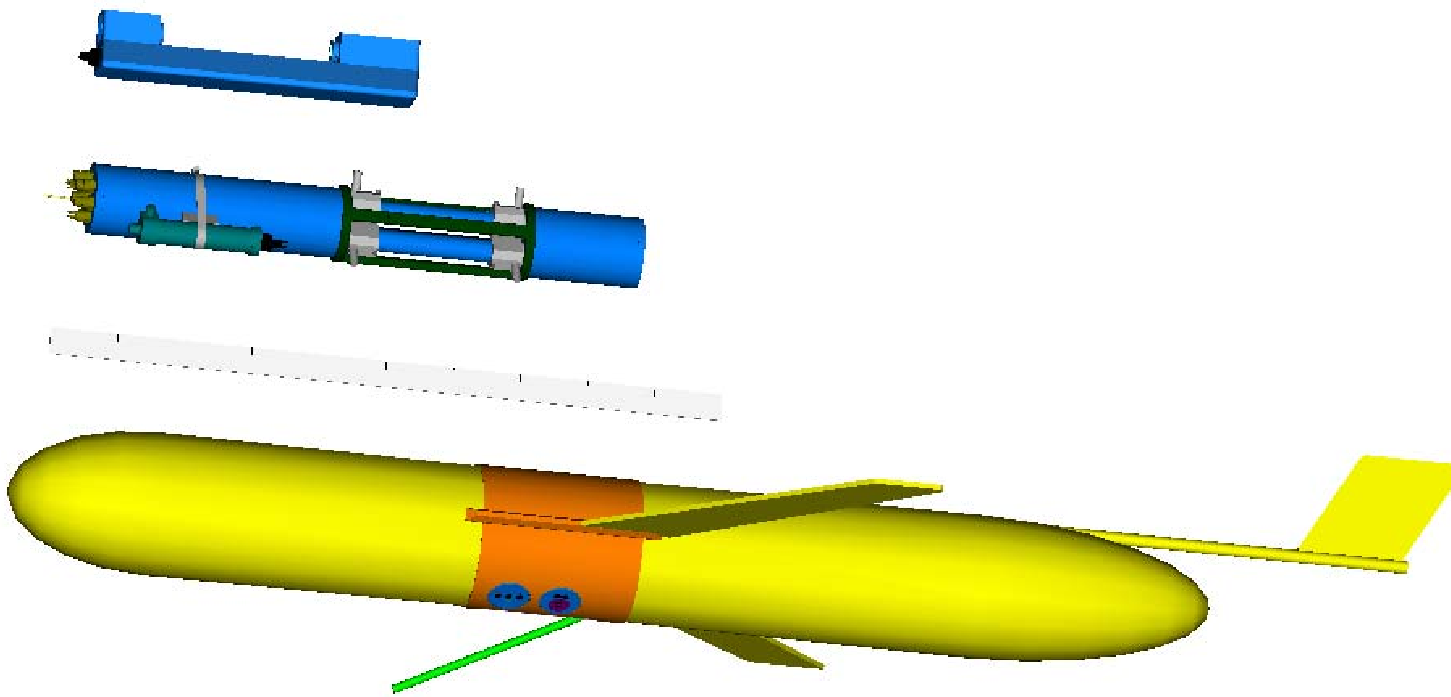


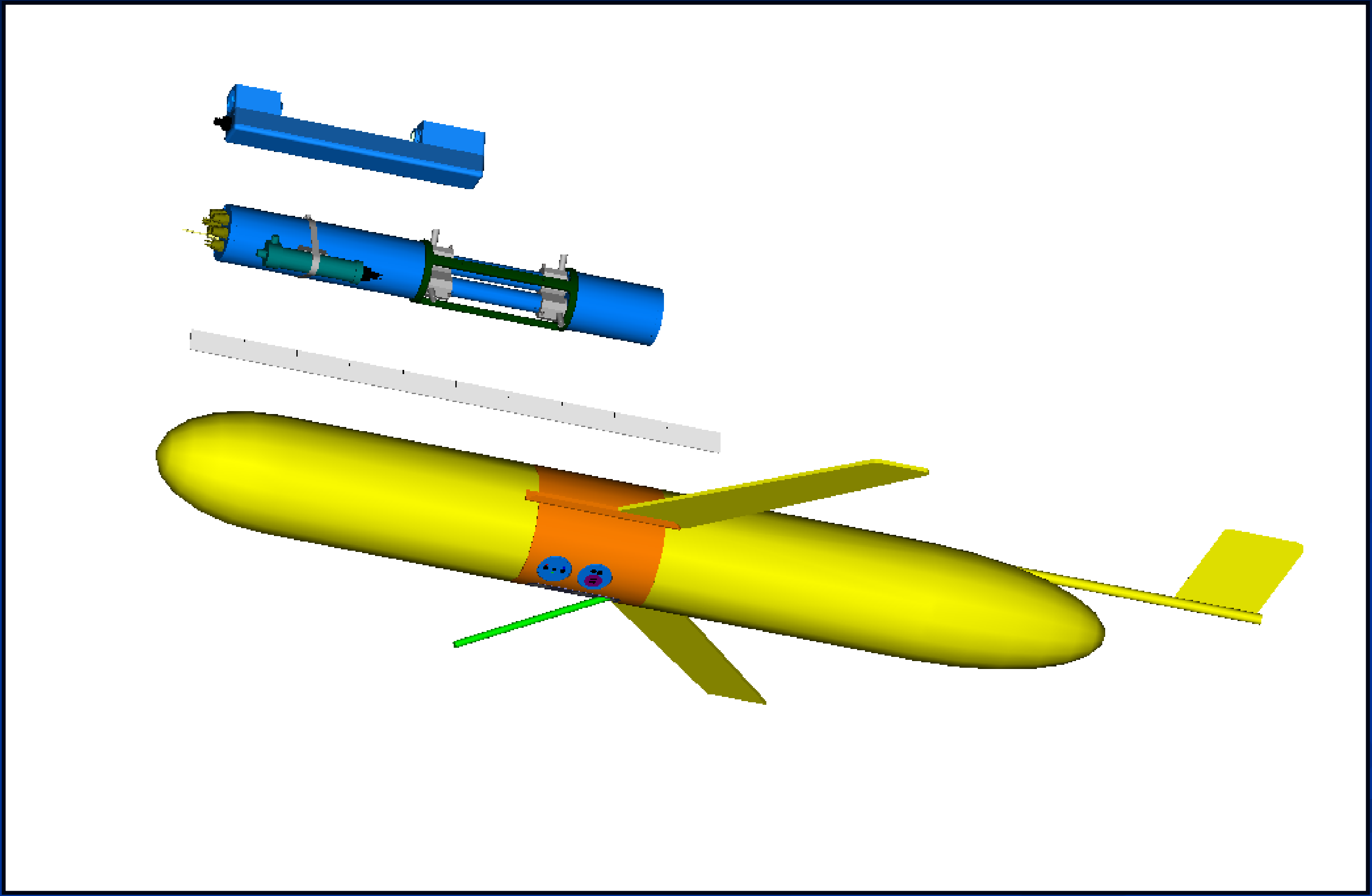



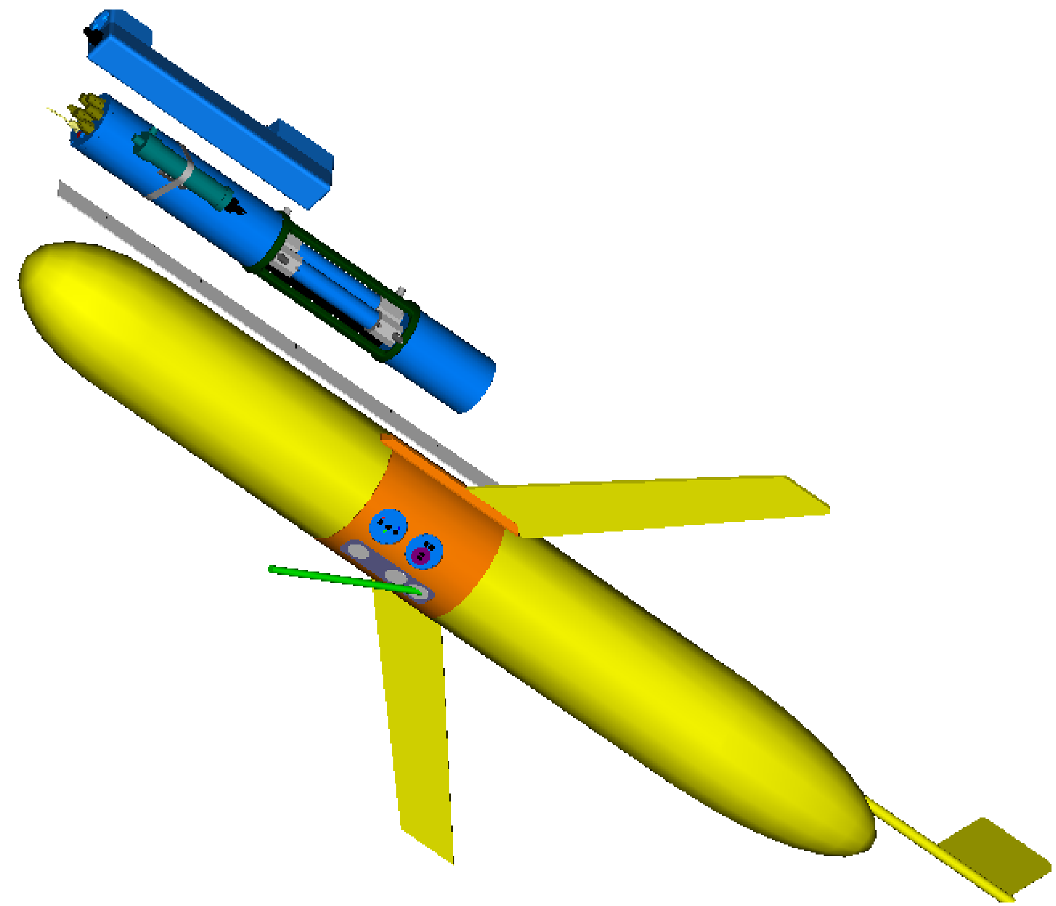

WET Labs c-star

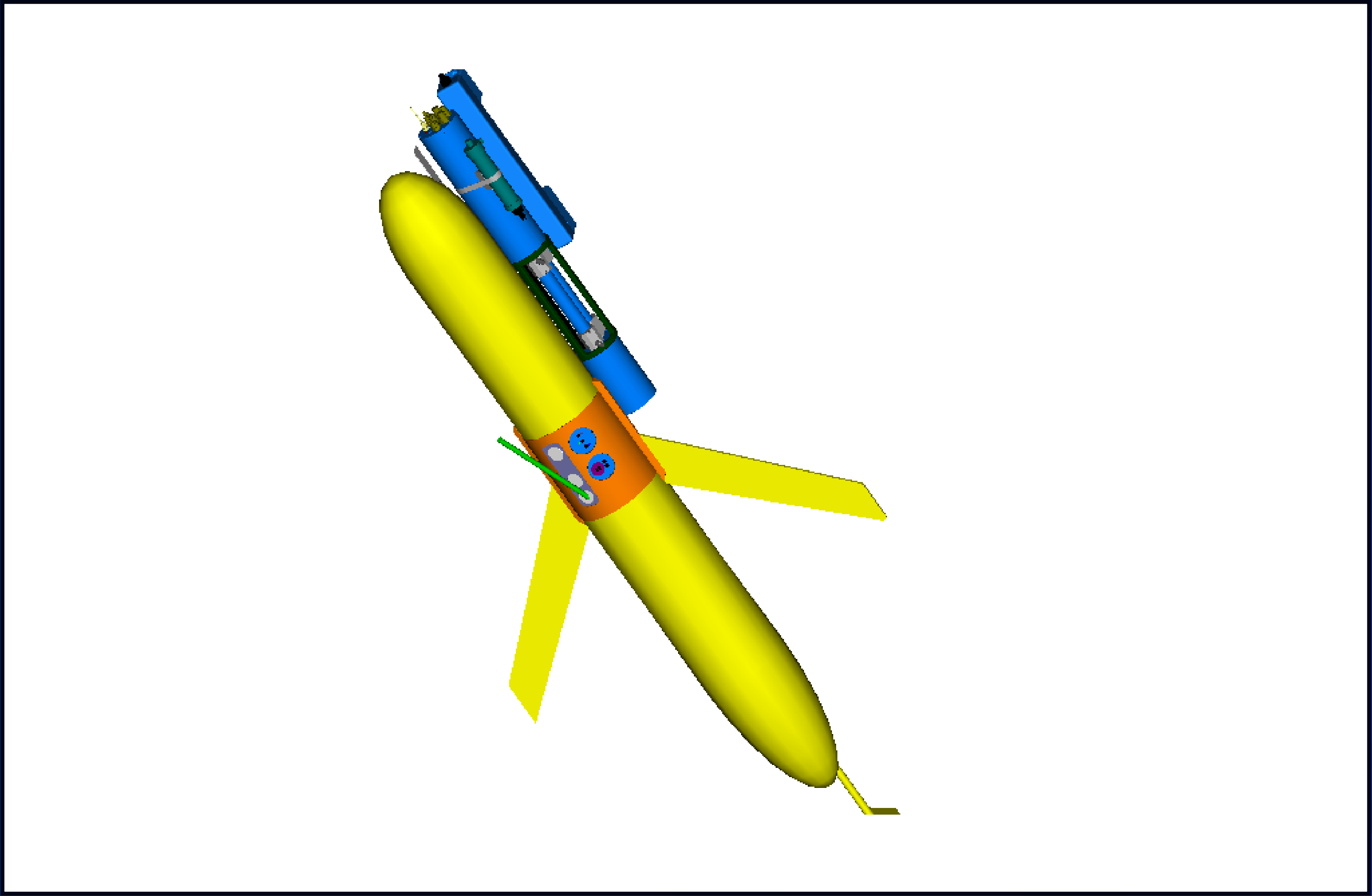
# Problems: size, hydrodynamics, power, maintenance…

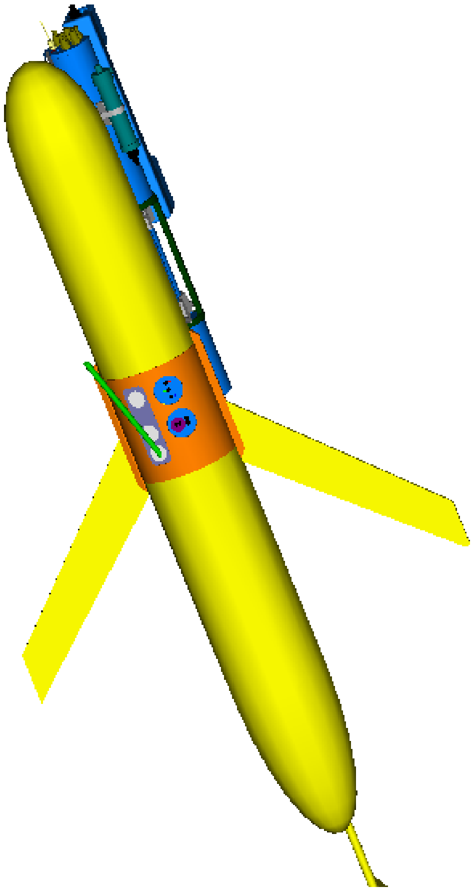


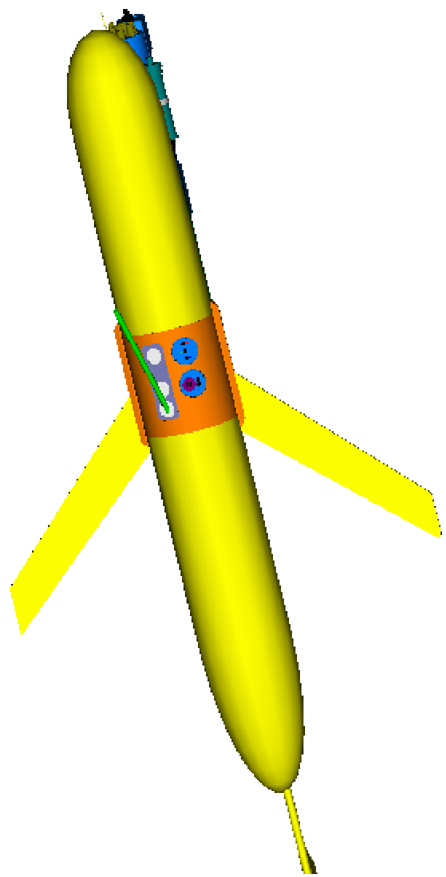


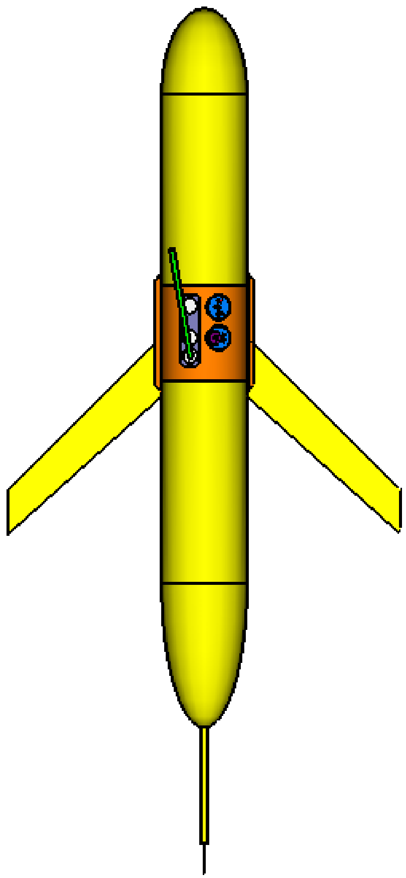


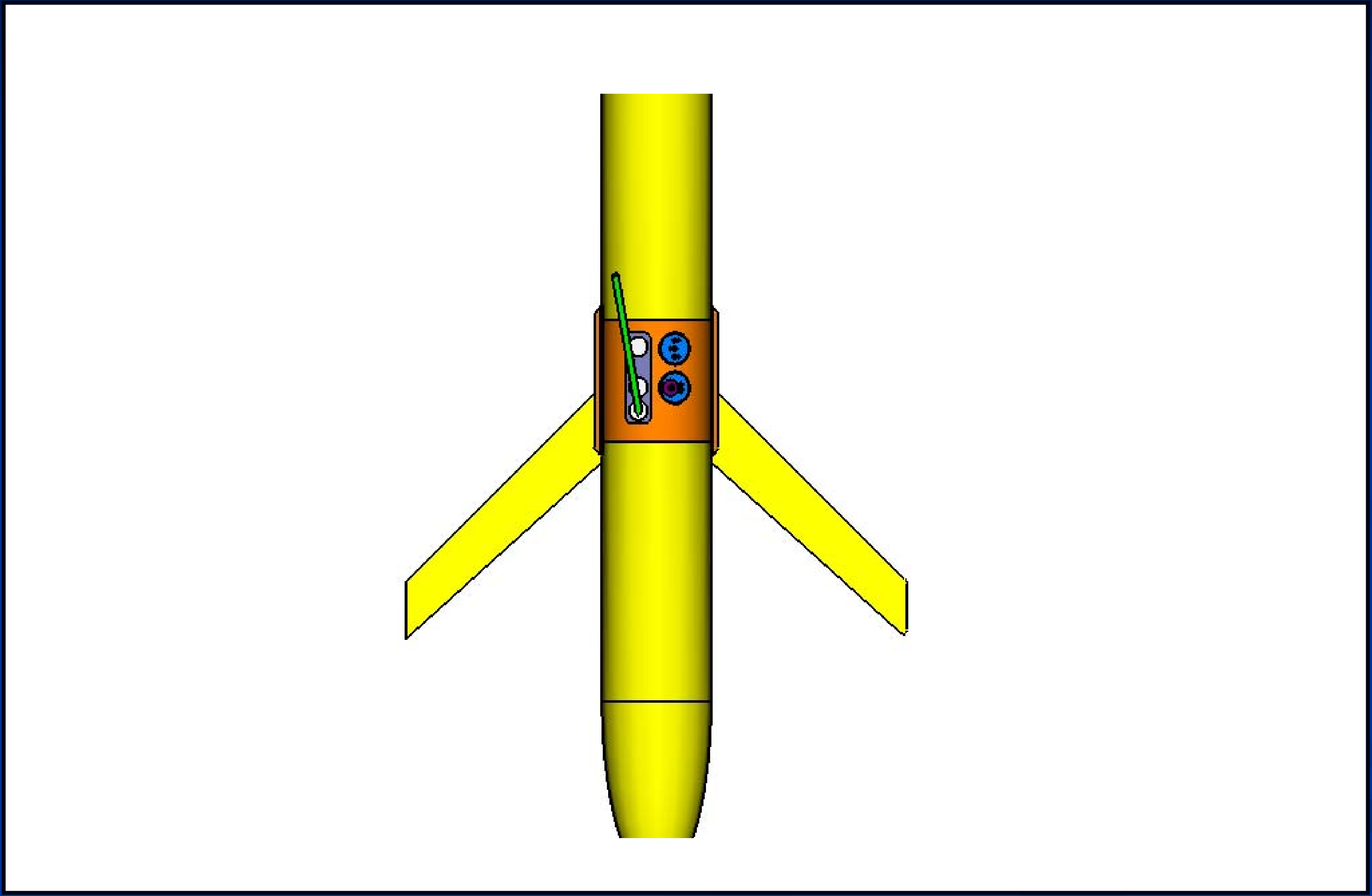


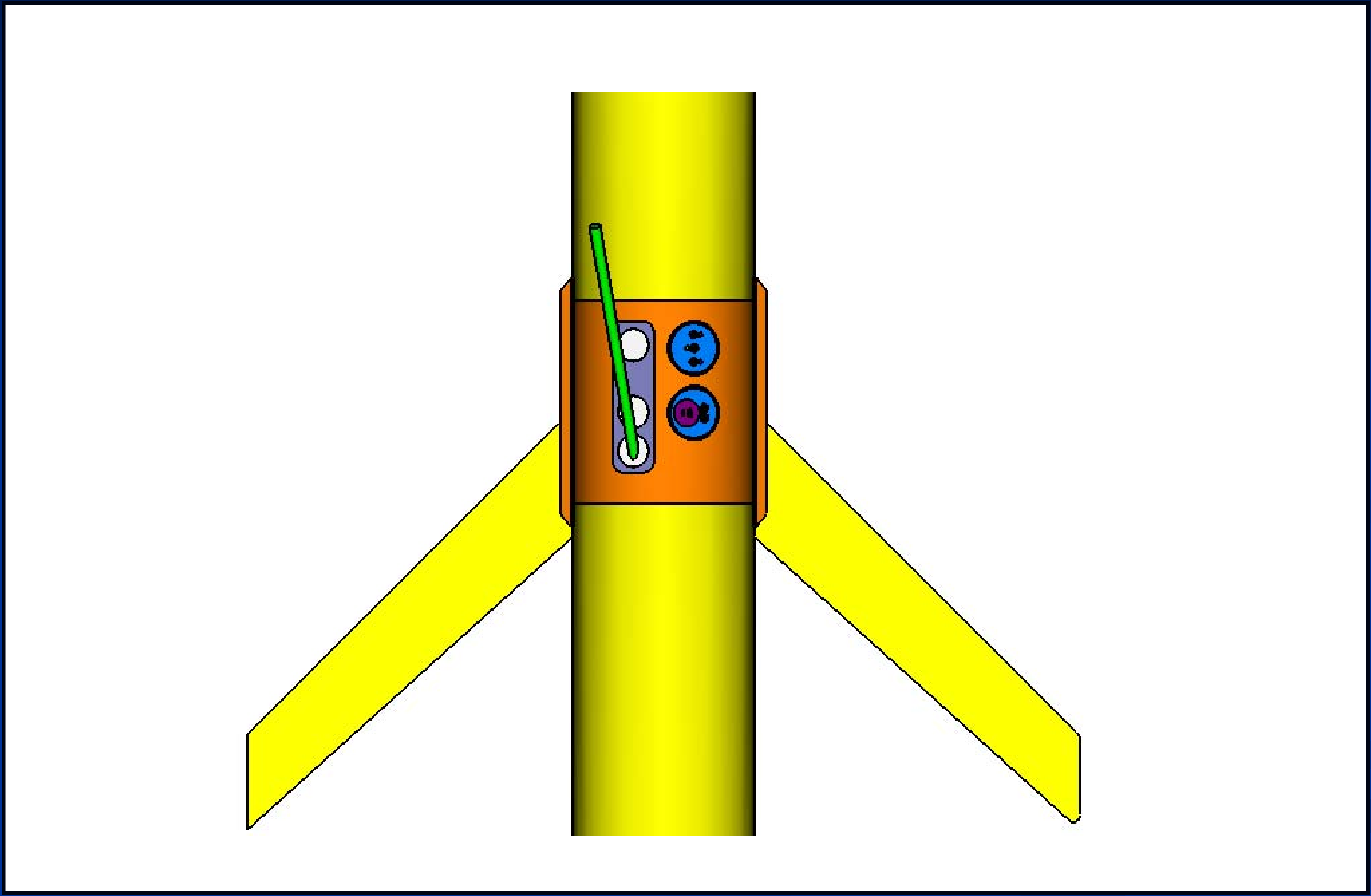


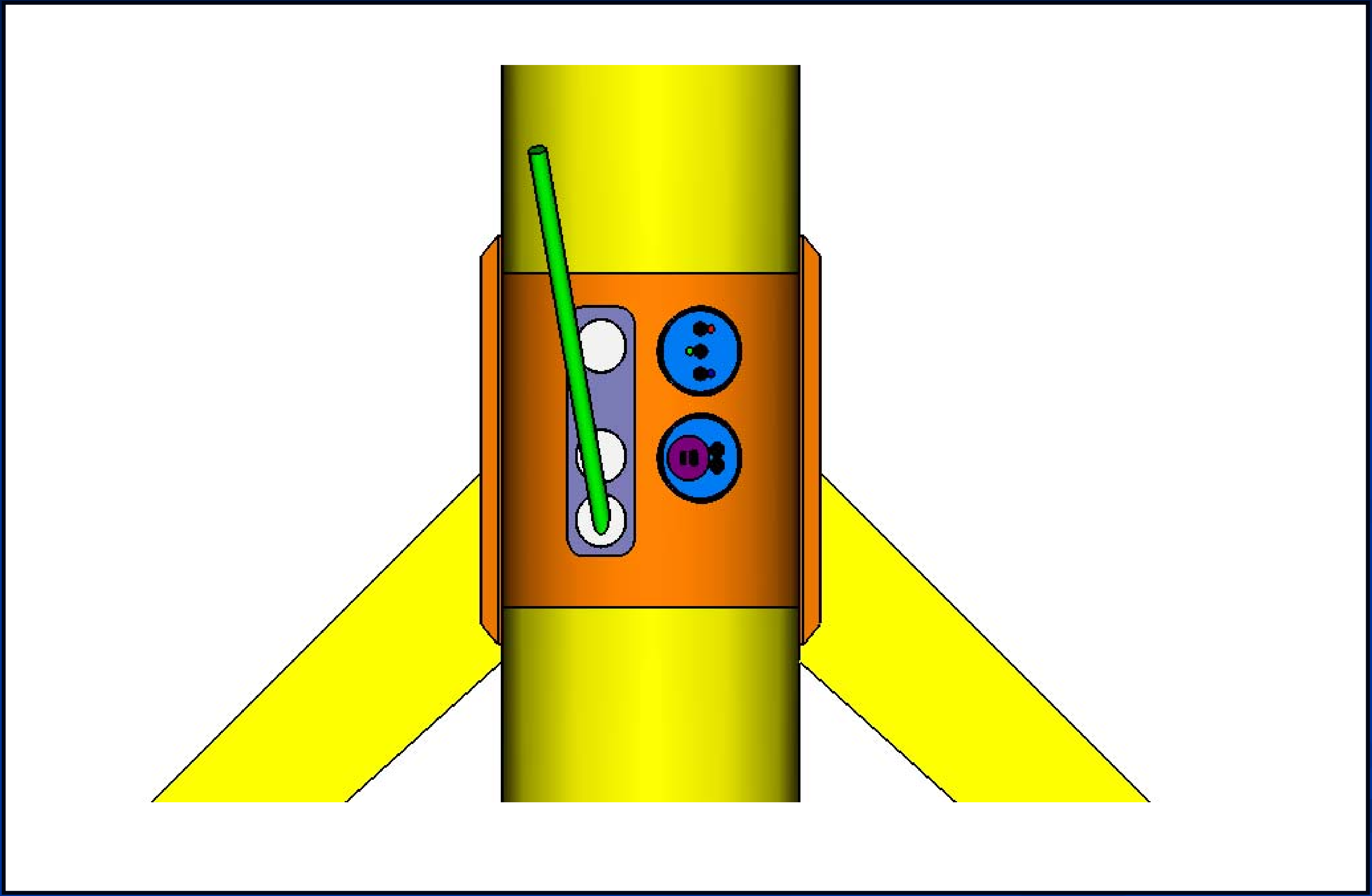


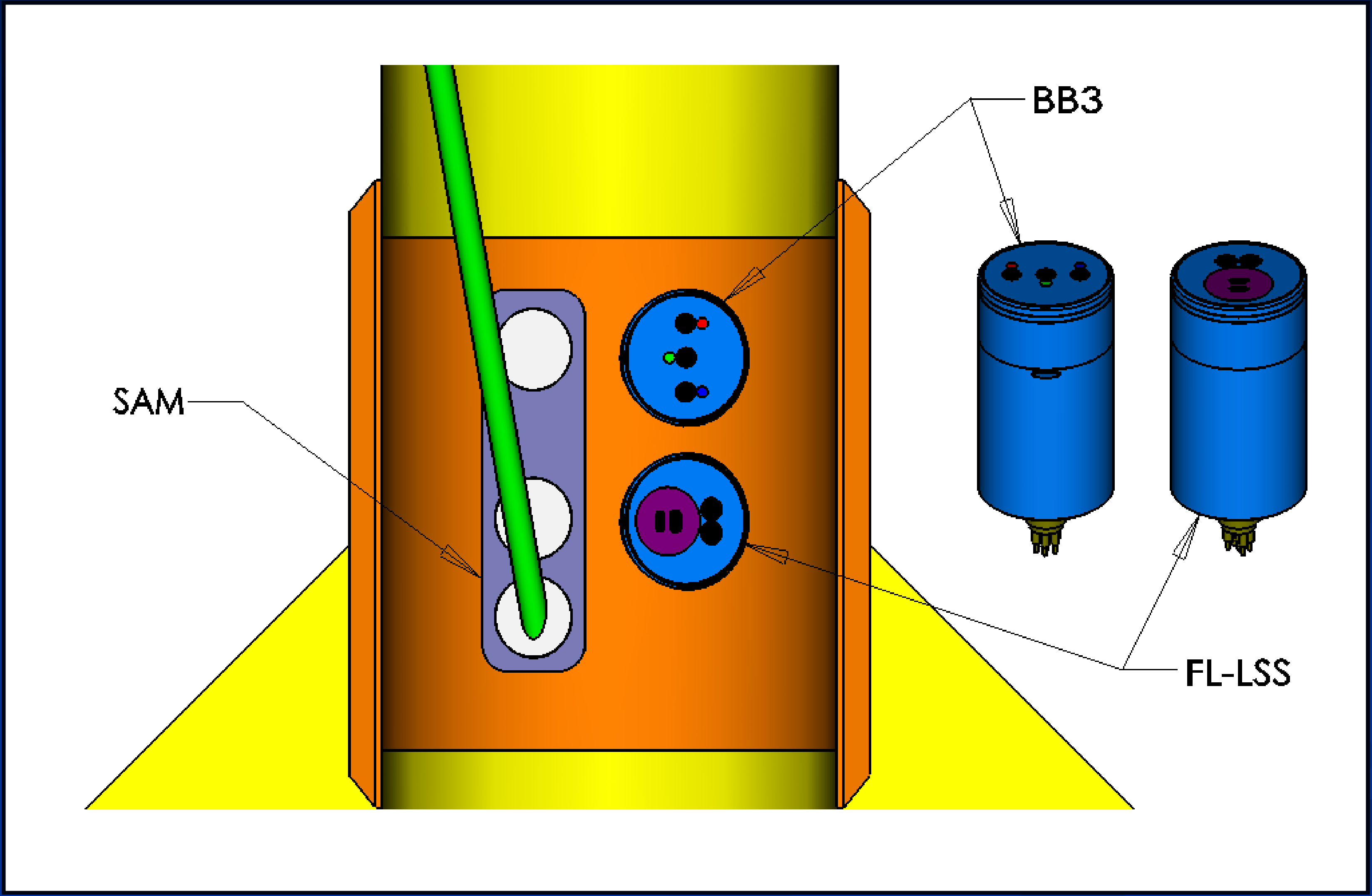




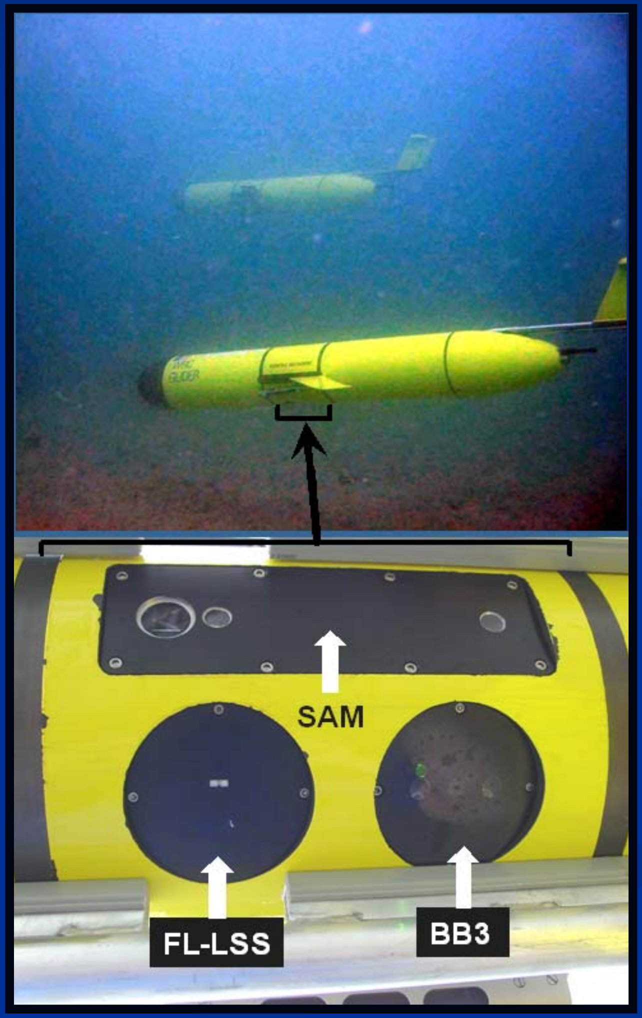







BB3
SAM
FL-LSS

# Attenuation and scattering sensors installed on a glider AUV




**Webb Slocum glider with “eyes”**

Rutgers glider team

# "SAM":
# Attenuation Sensor

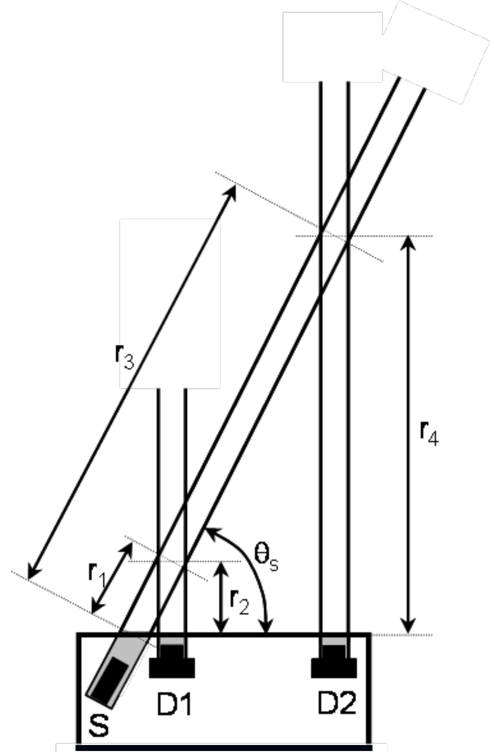
# SAM: How it Works

PROBLEM: To measure attenuation accurately in the ocean, long pathlengths are required.

**How do you do that with a compact sensor?**

- SAM = "Scattering and Attenuation Meter"
- Principle: 2 measurements of scattering are made at the same angle, but over different pathlengths

$$c = P_c \left[ \ln\left(\frac{I_{D1}}{I_{D2}}\right)(l_2 - l_1)^{-1} \right] + O$$

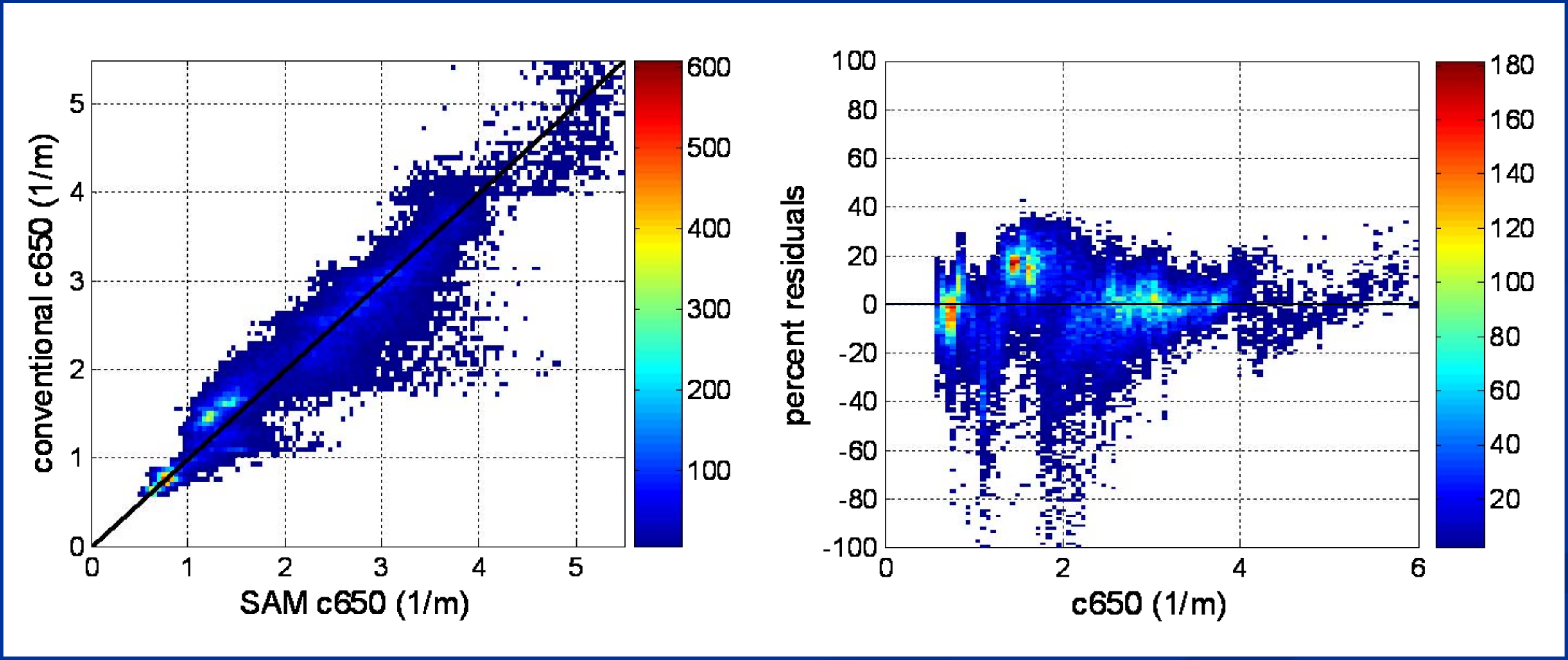



SAM geometry

$$l_1 = r_1 + r_2$$
$$l_2 = r_3 + r_4$$

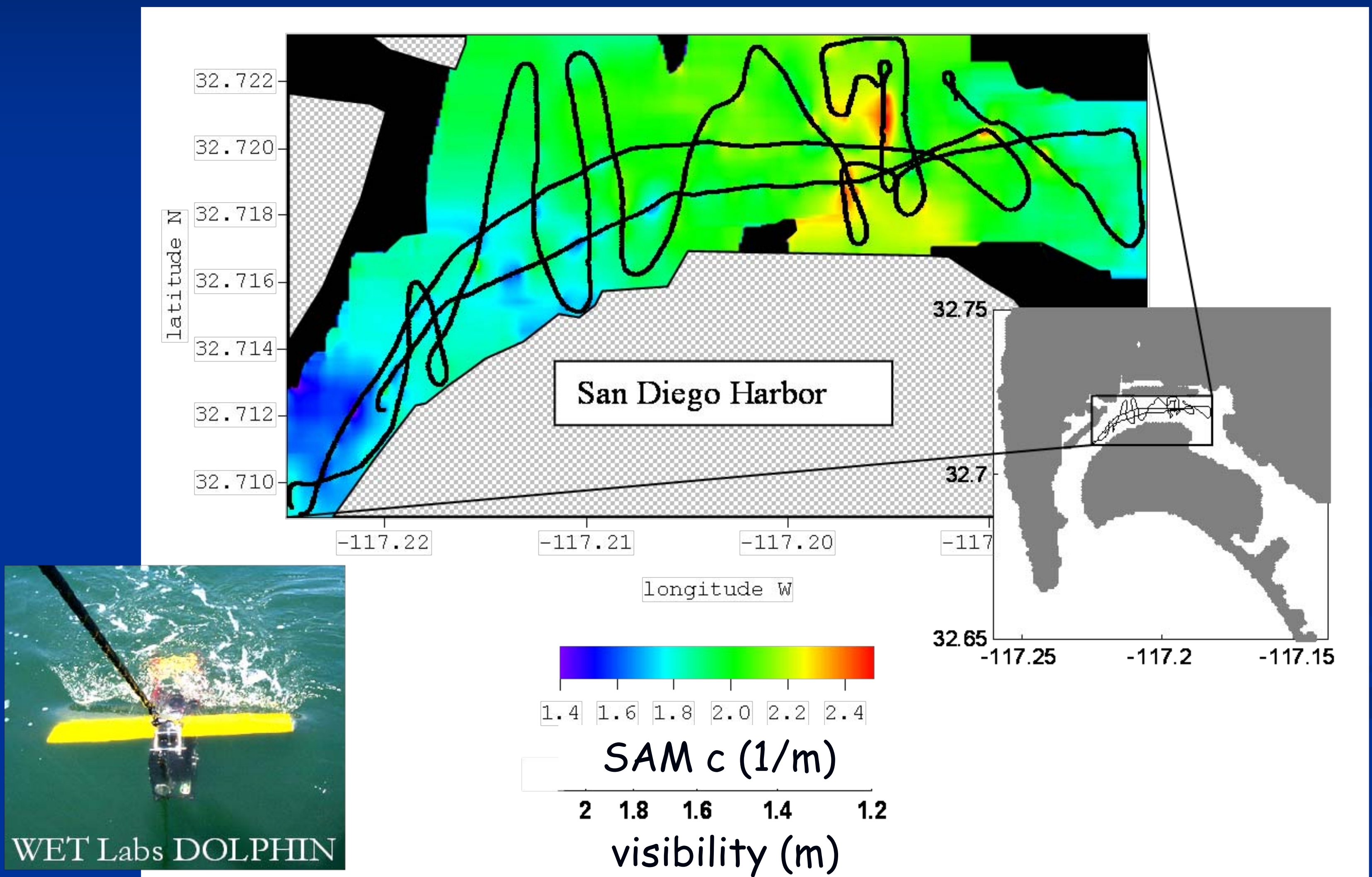
# Comparison with conventional attenuation measurements

## Long Island Sound 2004




59,290 data points, no binning

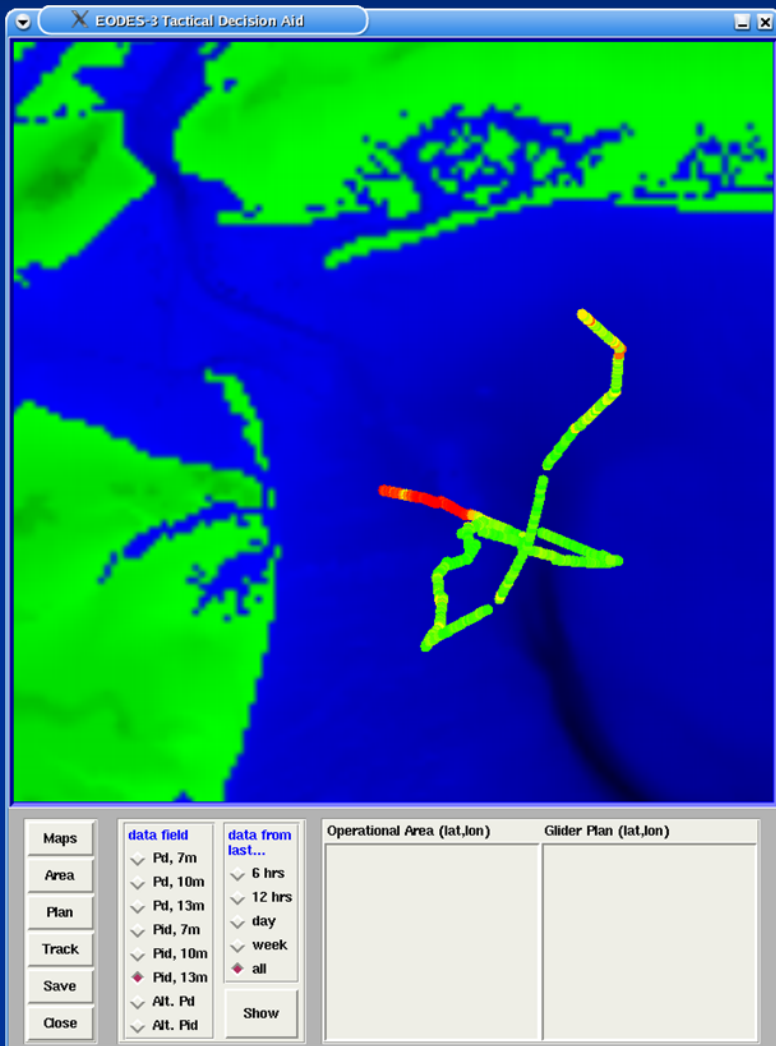
# Visibility and Attenuation in San Diego Harbor



# REMUS Bottom Imaging in San Diego Harbor


# MCM EOID performance prediction

*EODES-3 Tactical Decision Aid*



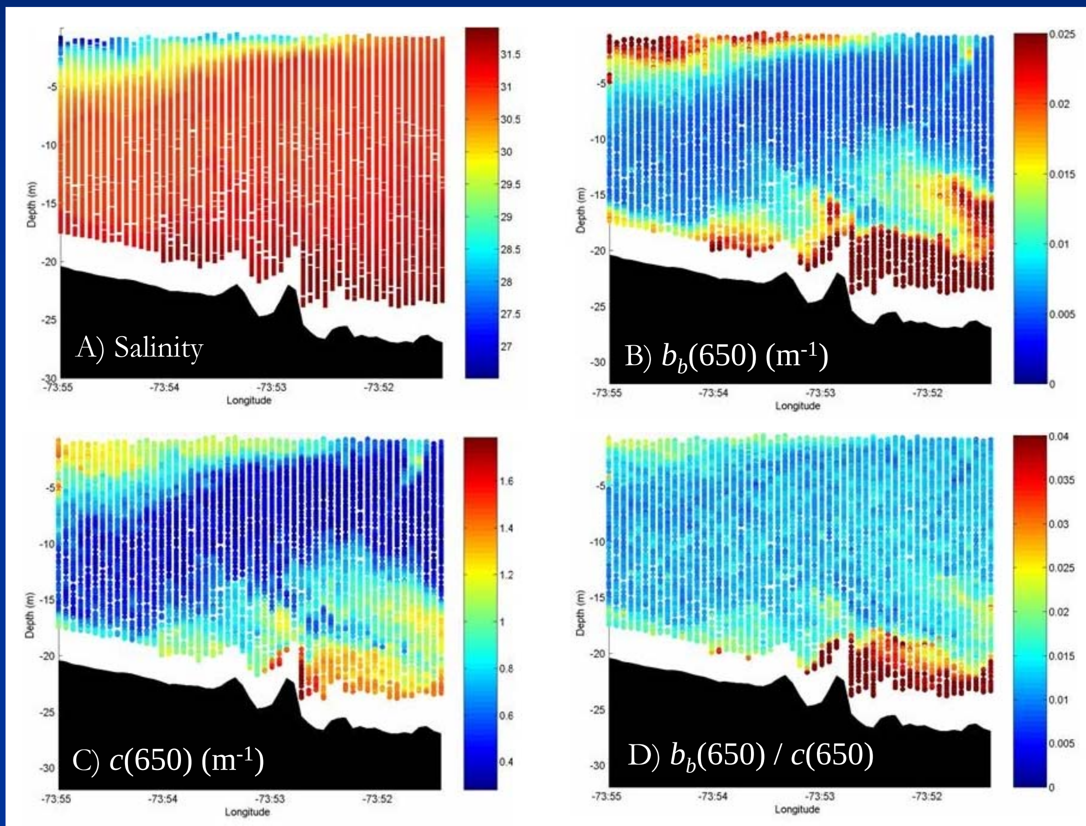

- Model optimized for AN/AQS-24 laser line scan systems
- Model input is SAM attenuation data

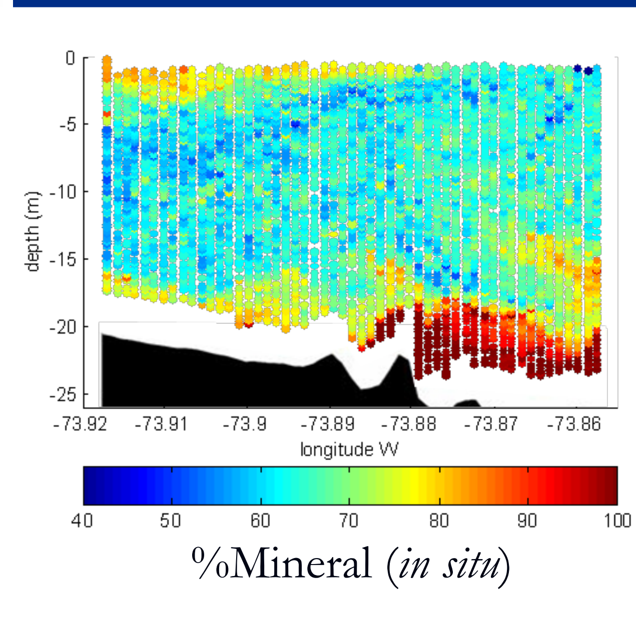

**METRON, Inc.**

**www.metsci.com**

# Particle Composition with Gliders

*Hudson River plume*



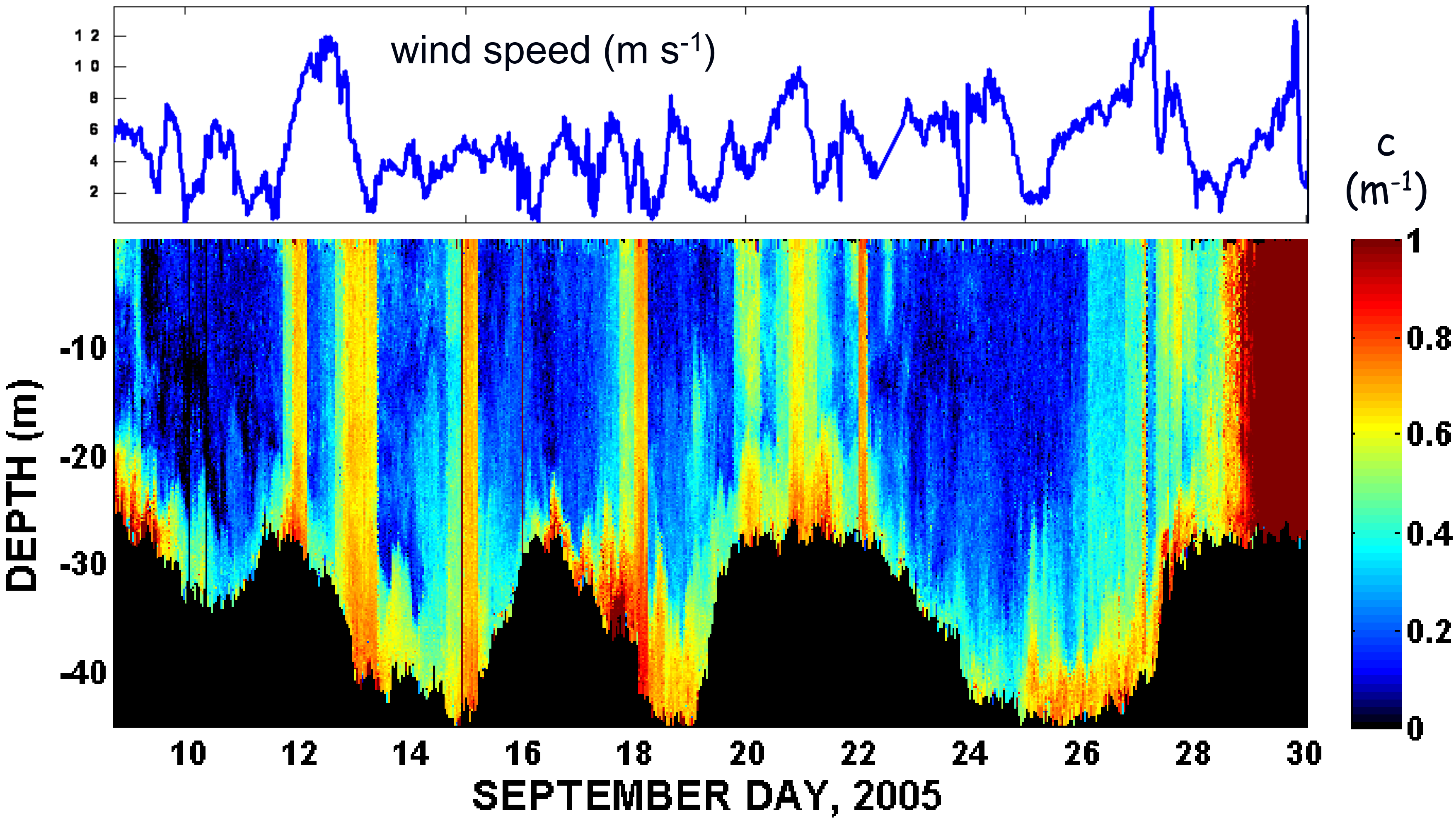




Algorithm based on Twardowski et al. (2001)

http://marine.rutgers.edu/cool/

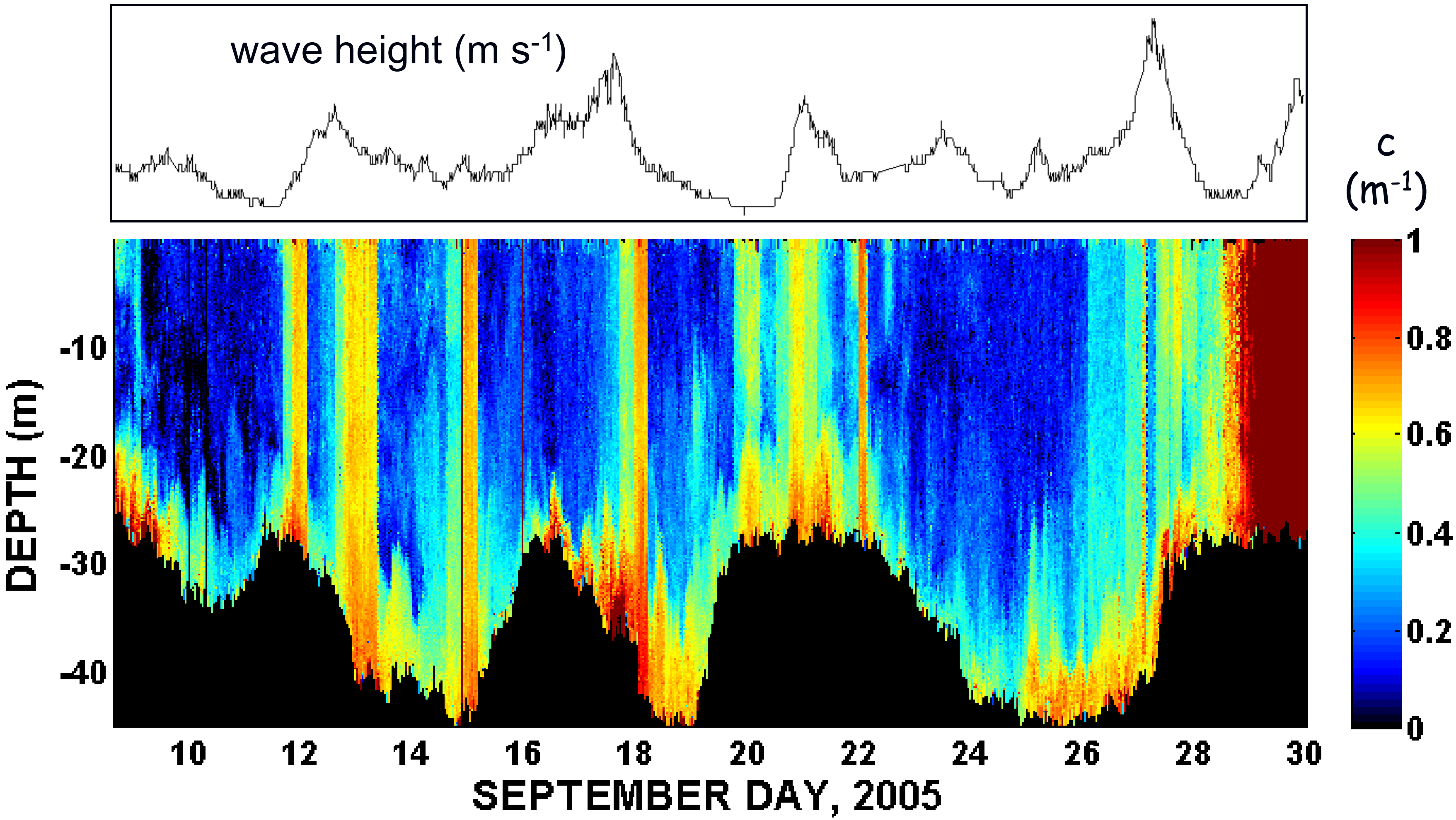
OASIS project, Near Martha's Vineyard Coastal Observatory

# Glider SAM Attenuation



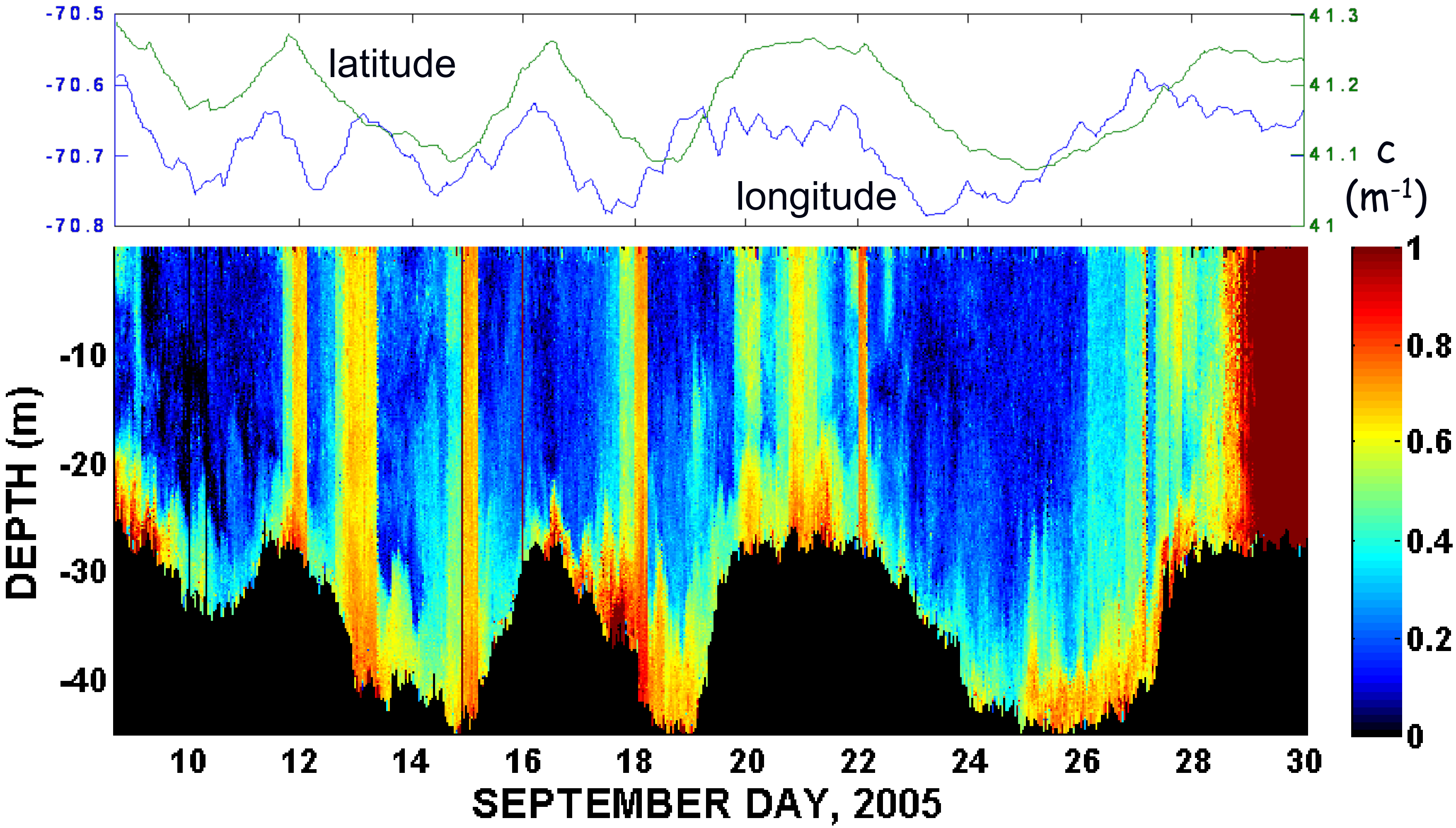
OASIS project, Near Martha's Vineyard Coastal Observatory

# Glider SAM Attenuation



OASIS project, Near Martha's Vineyard Coastal Observatory

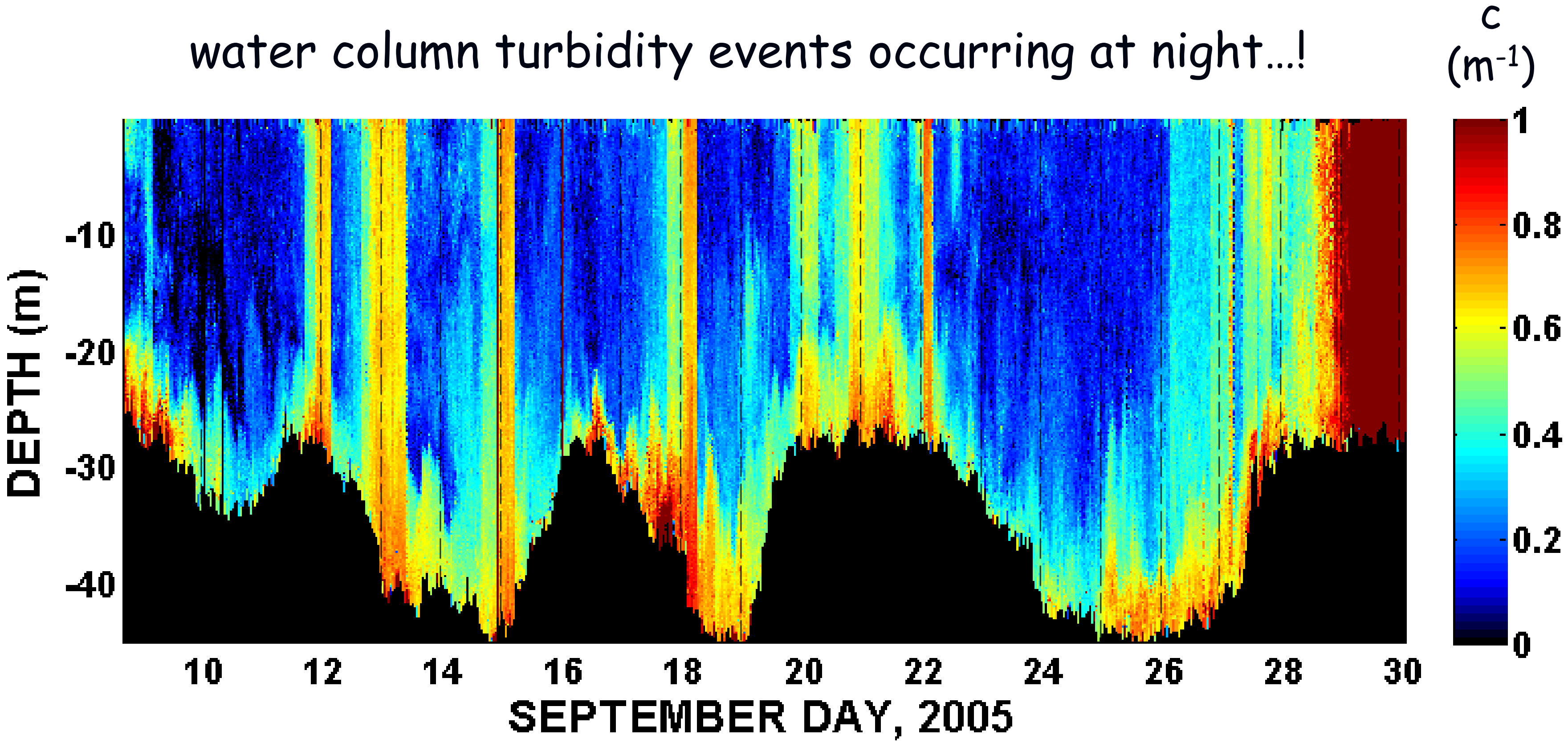
# Glider SAM Attenuation



OASIS project, Near Martha's Vineyard Coastal Observatory

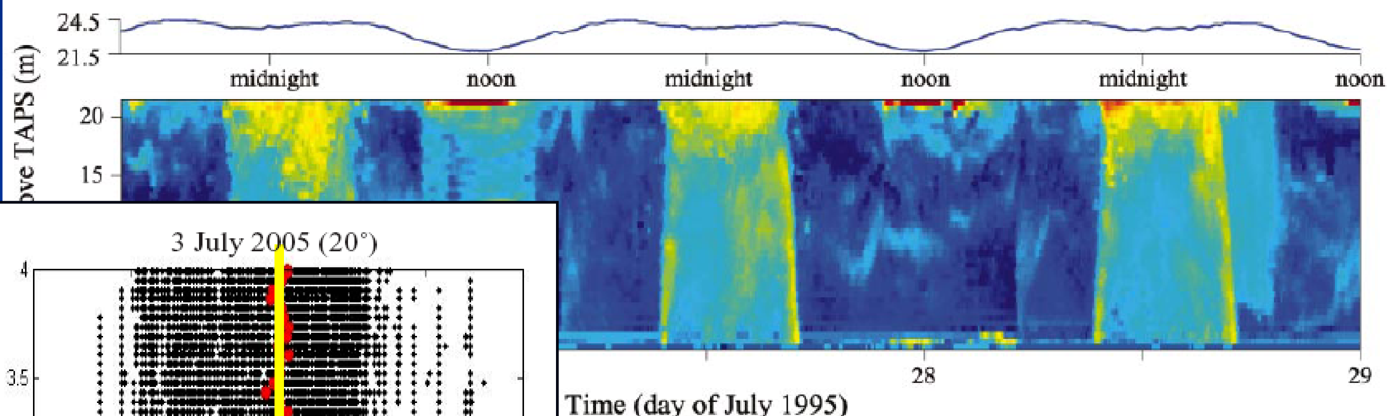
# Glider SAM Attenuation

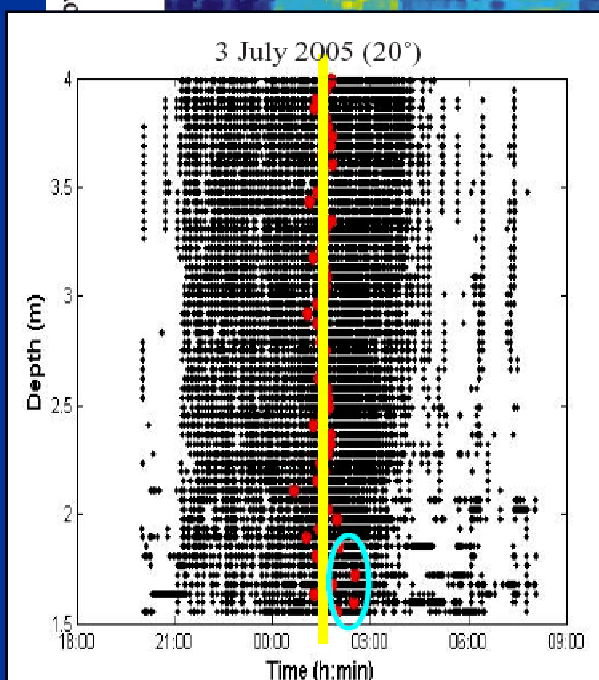
water column turbidity events occurring at night…!



# Vertical migrations: TAPS

Kringel, Jumars, Holliday. 2003. L&O.

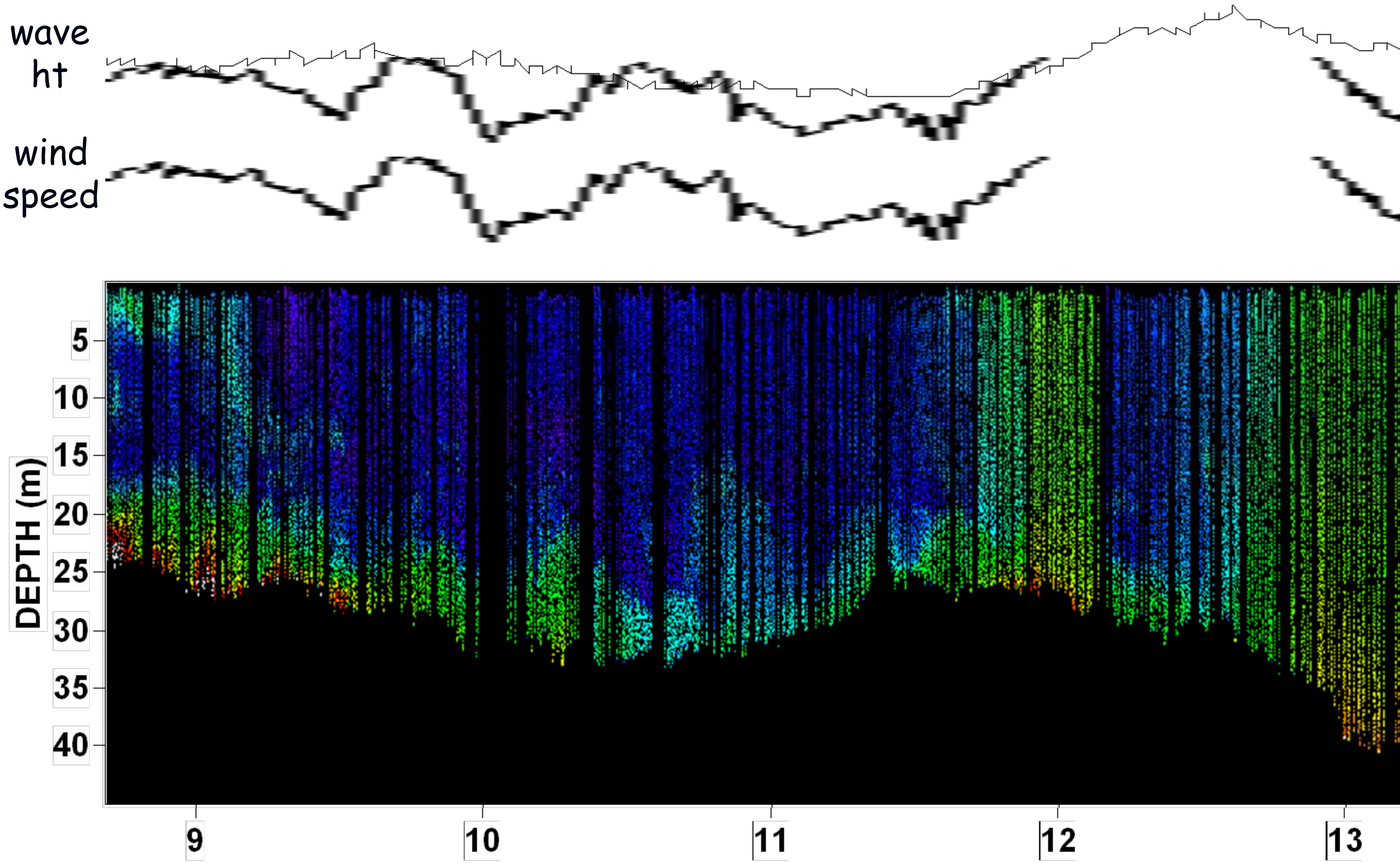



Jumars ONR Report 2005

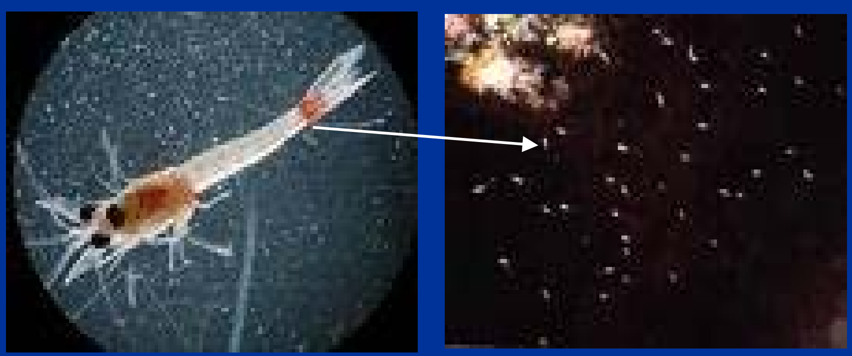
*" the major event of the night is immediate, i.e., that its beginning and emergence speeds are not resolvable with data collected every minute, even with the higher spatial resolution afforded by the low-angle perspective"*

# OASIS 2005: glider SAM attenuation



# Questions

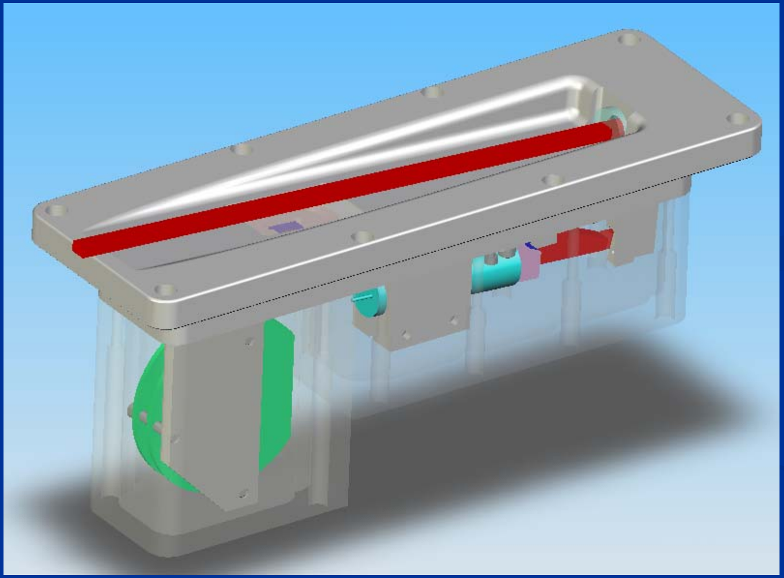
- nocturnal turbidity events: what are we really looking at? Are the optics really resolving mysid shrimp ~1 cm long?



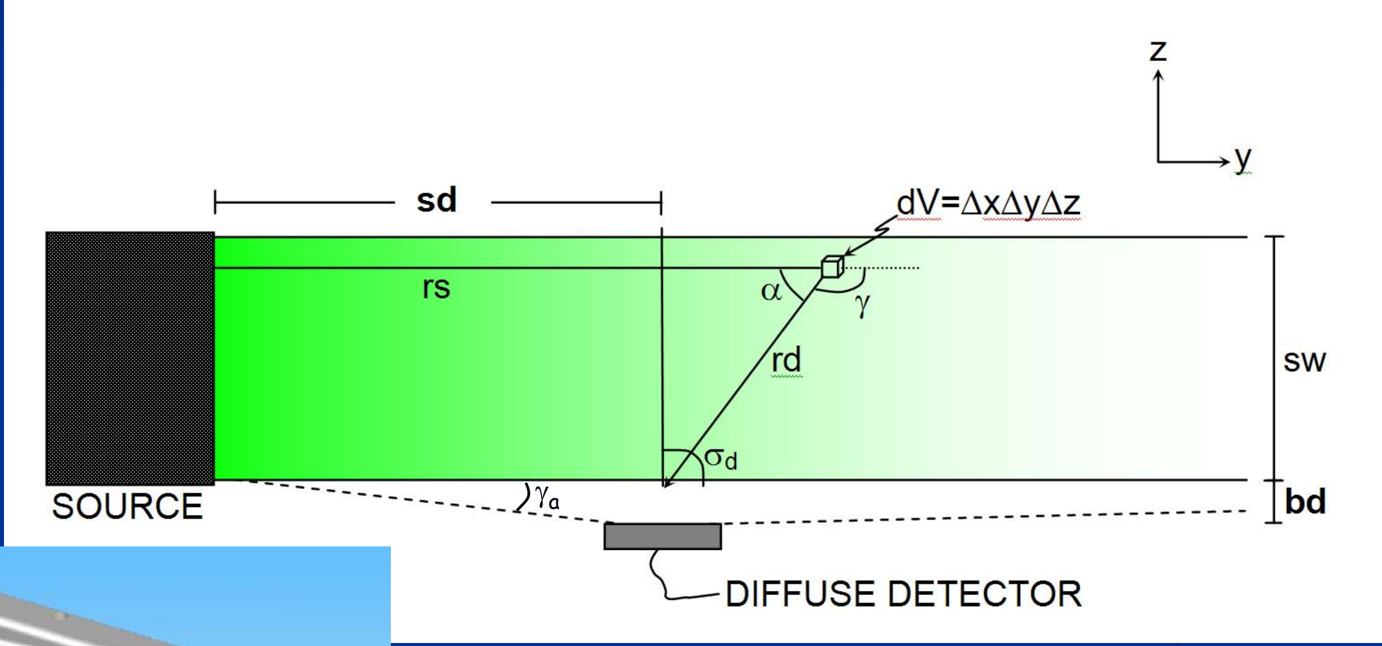
no way…

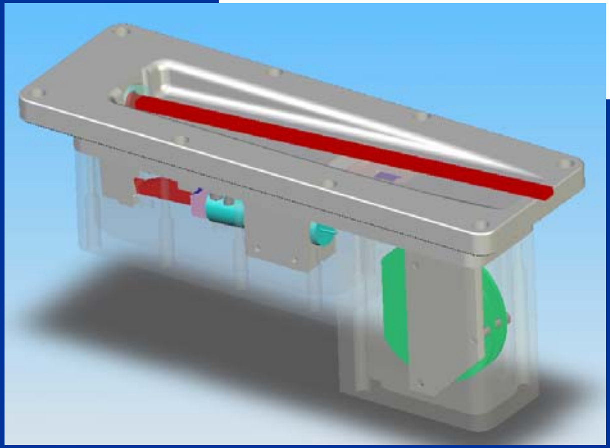
- Are we seeing an influx of smaller (optically significant) particles as a "migration residual"?
- But how does the entire water column clear so fast?
- Aren't mysids attracted to light?

# "AUV-B": Total Scattering Sensor



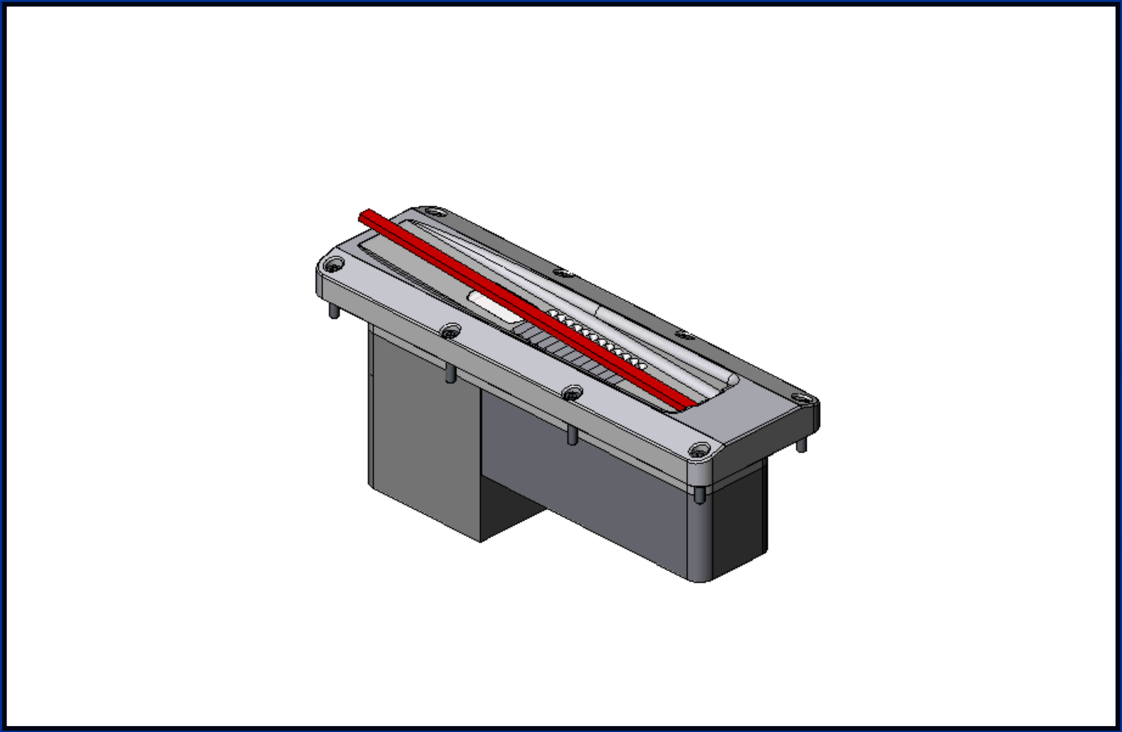
# AUV-B: Theory and Modeling

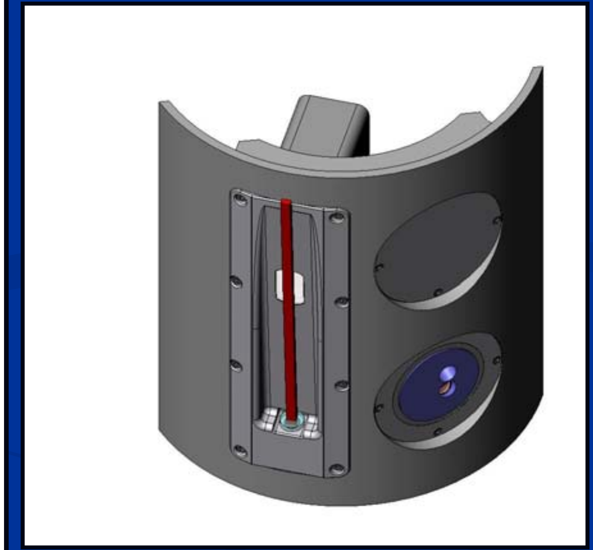


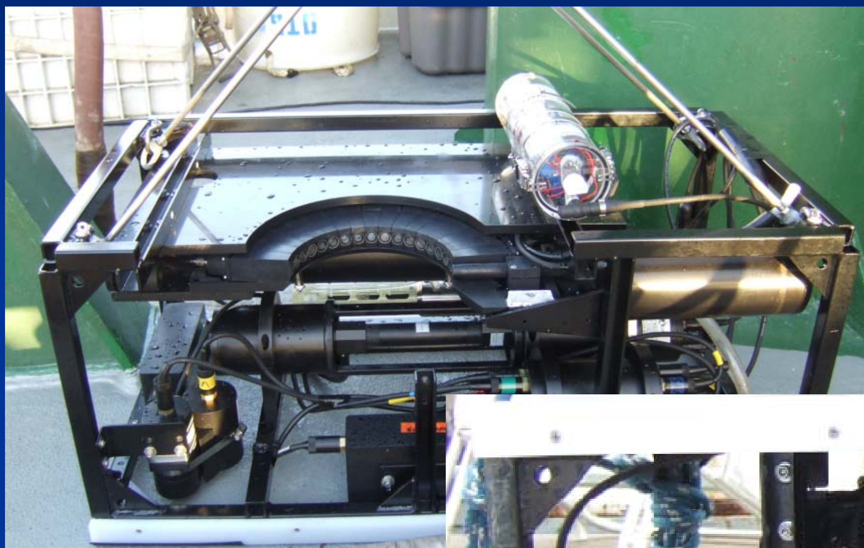
- Teflon diffuser
- Acceptance angle ($\gamma_a$) critical
  - When bd = 1 mm and sd = 10 cm, then $\gamma_a$ is ~0.7°, comparable to that of the WET Labs ac9 meter

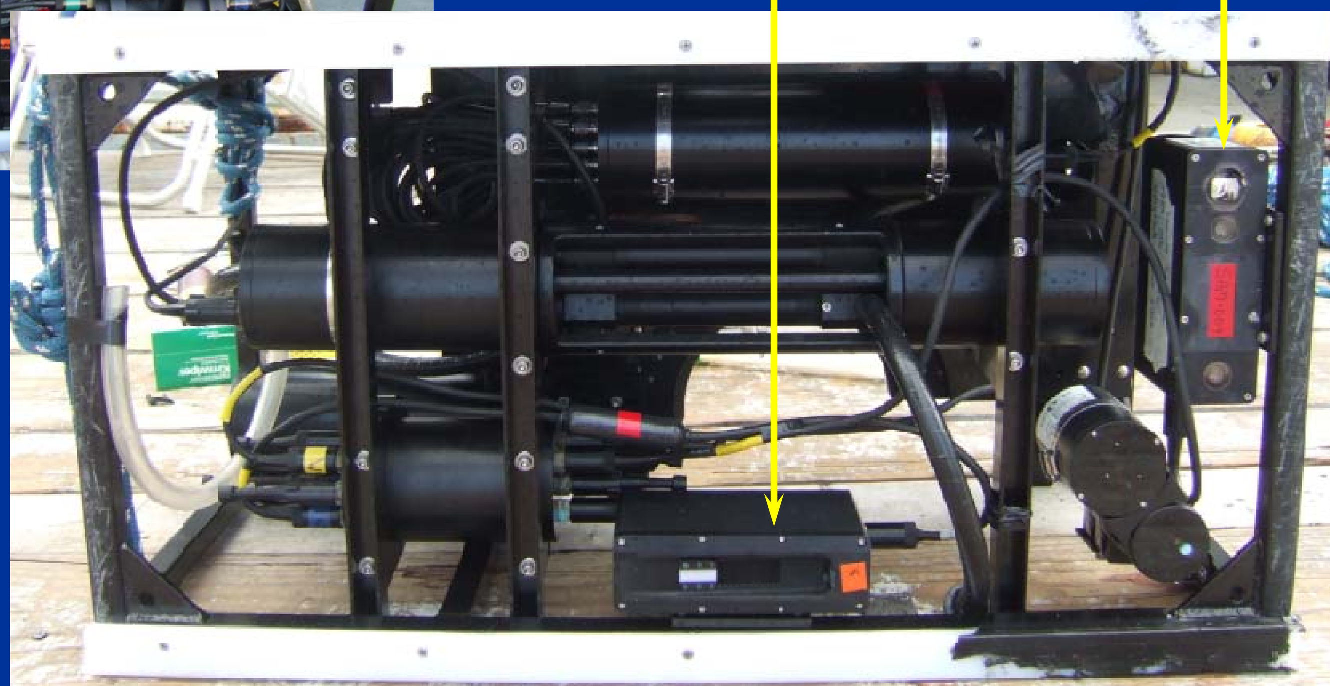
# AUV-B Prototype: Design





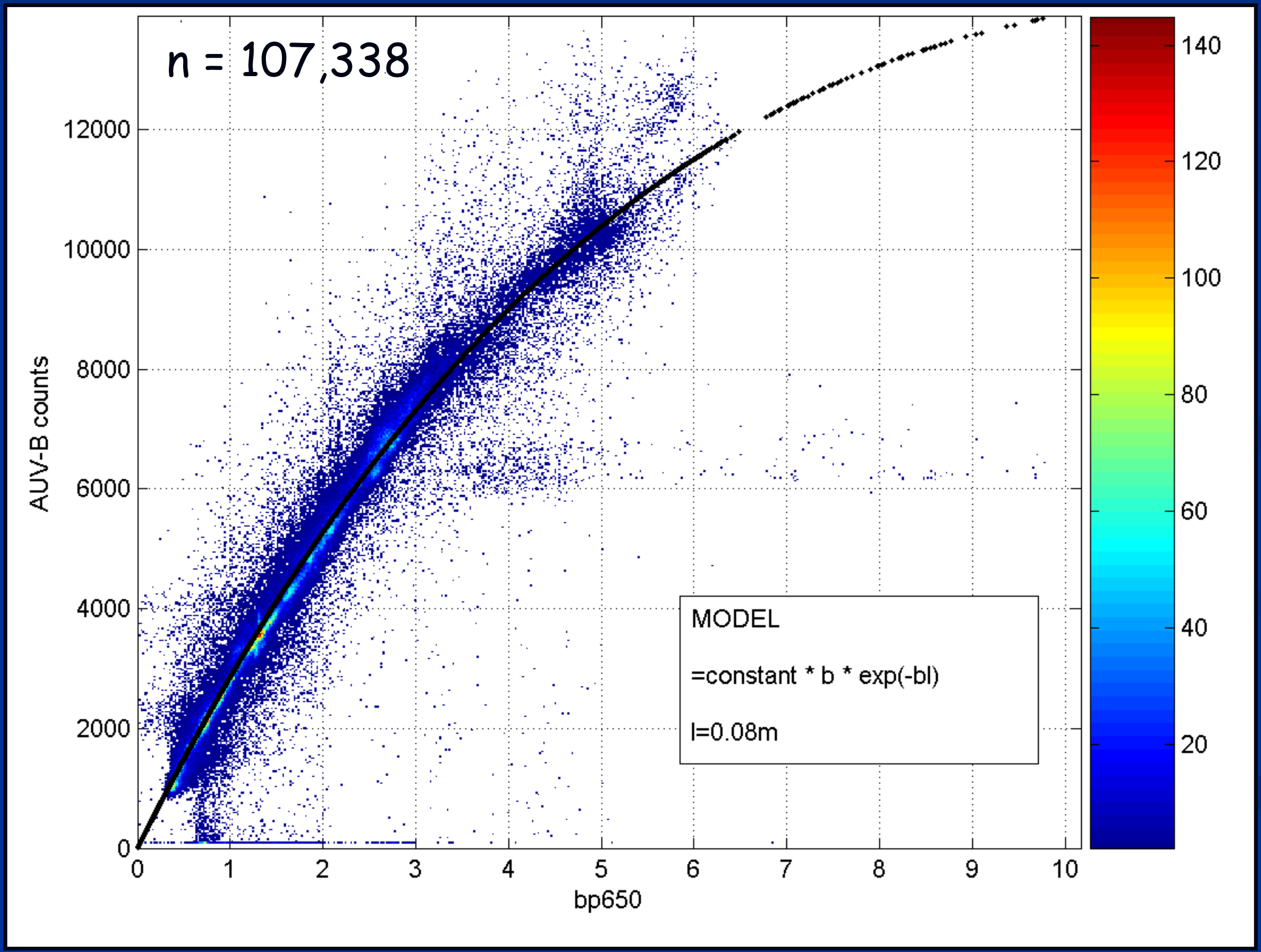
# AUV-B Prototype Testing



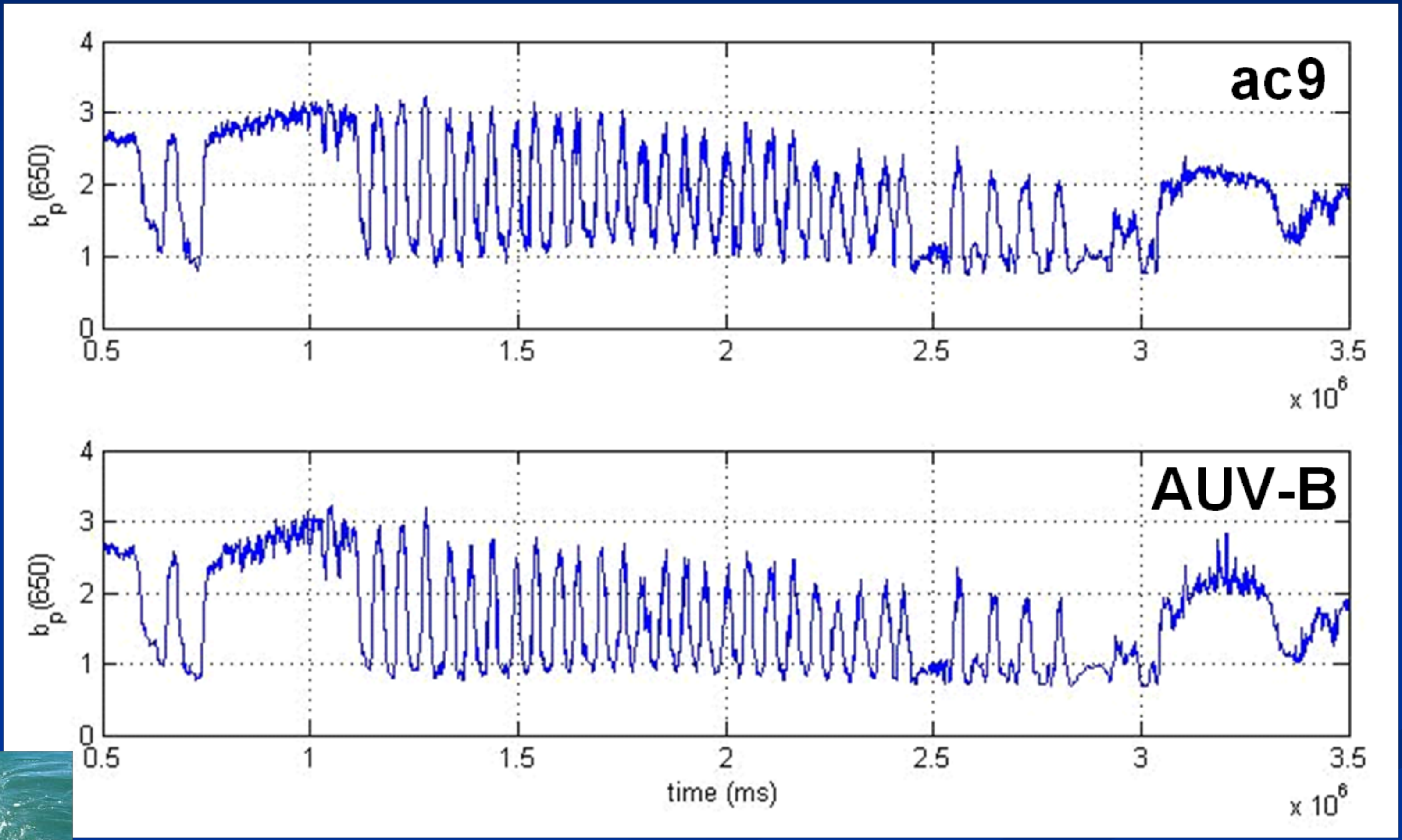


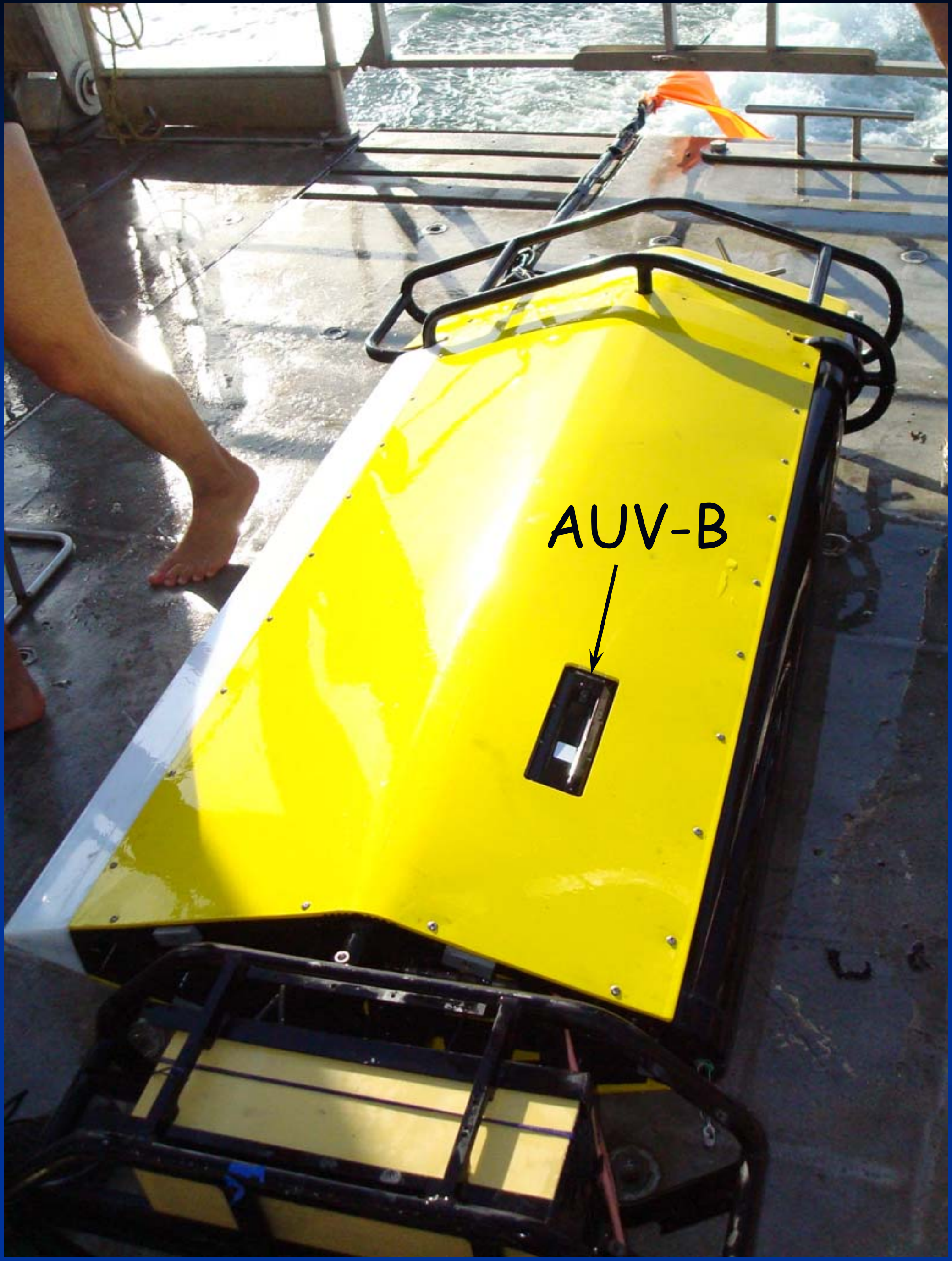
# AUV-B

## Long Island Sound: May, 2005



# Comparison with b from ac9

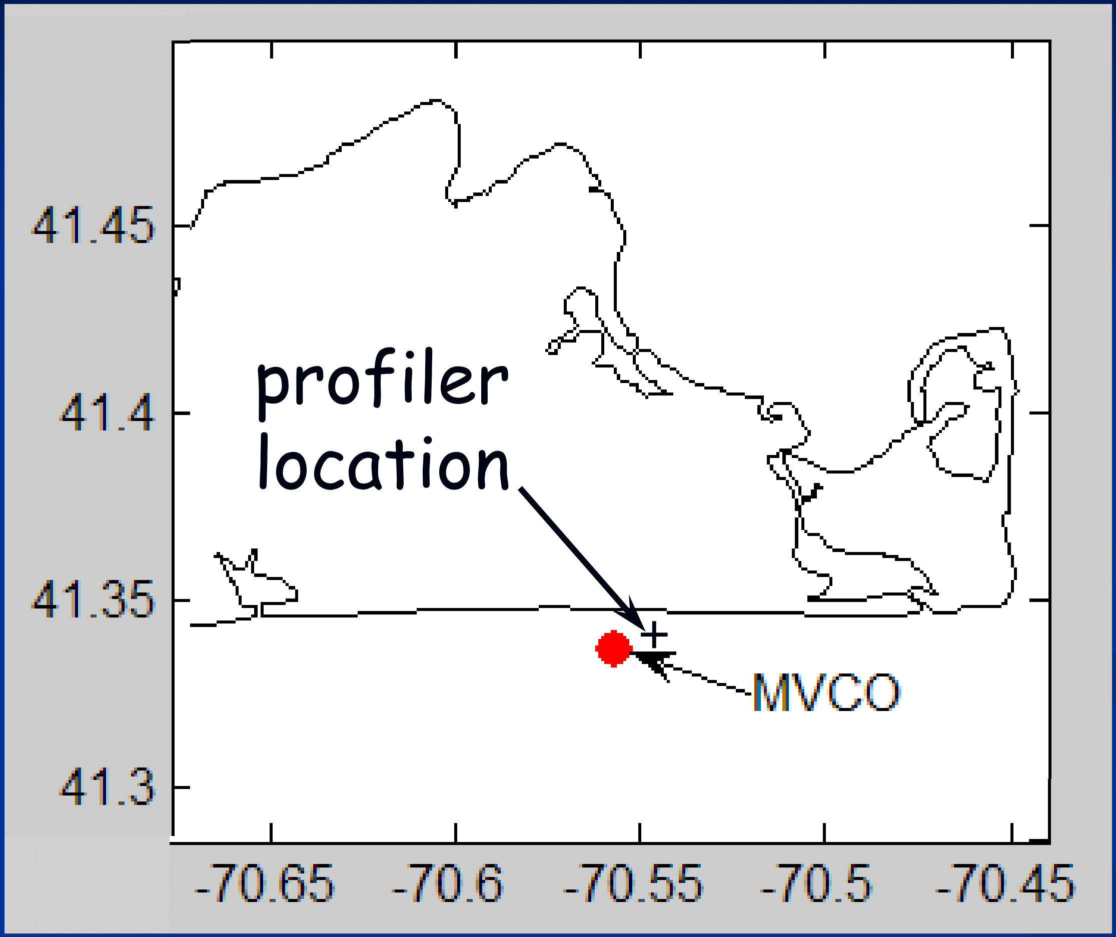



# OASIS 2007: autonomous profiler

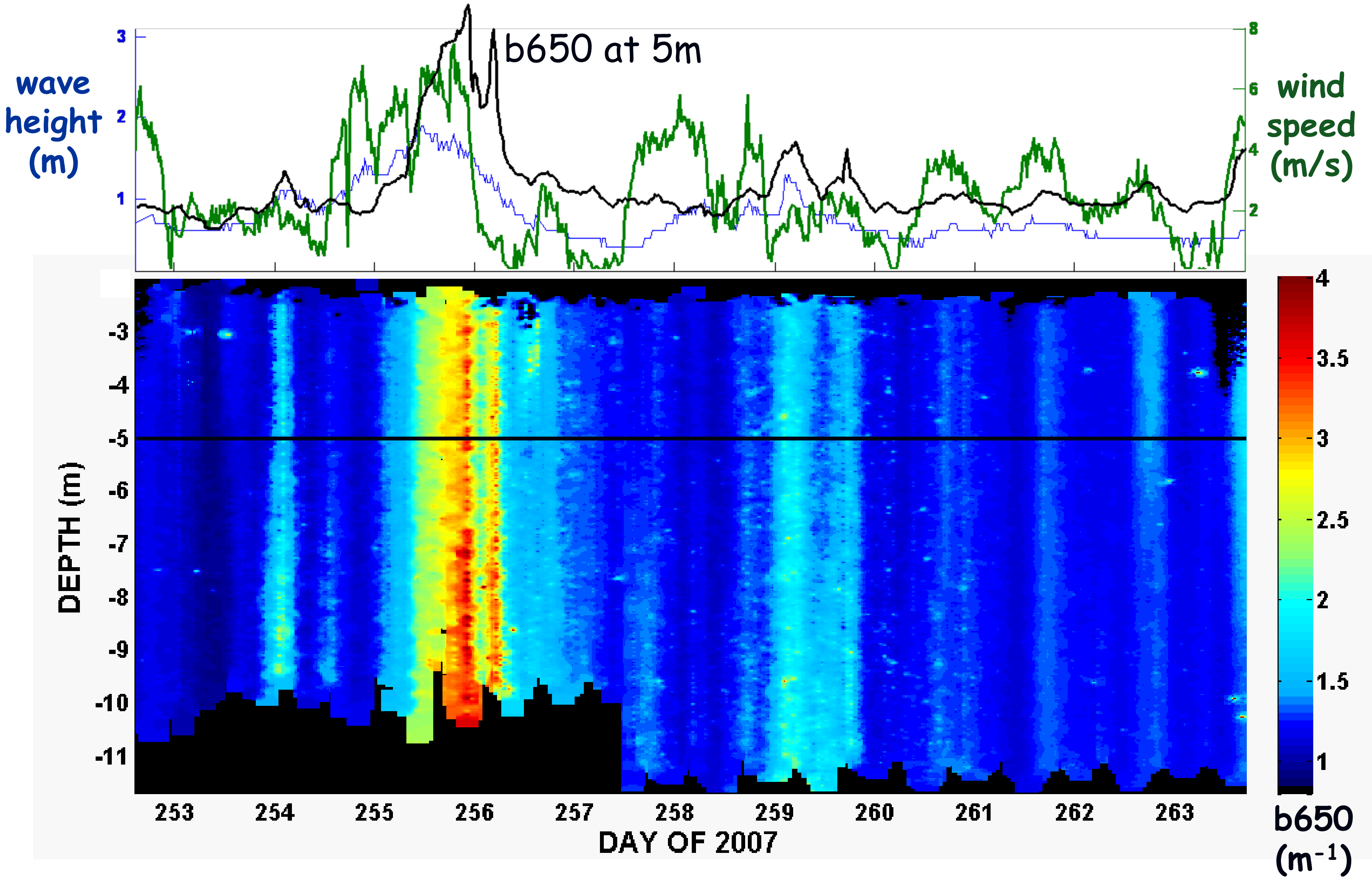
SENSORS

- WL AUV-B
- WL ACS
- WL ECO-FLNTU
- SBE49 CTD
- NORTEK ADV

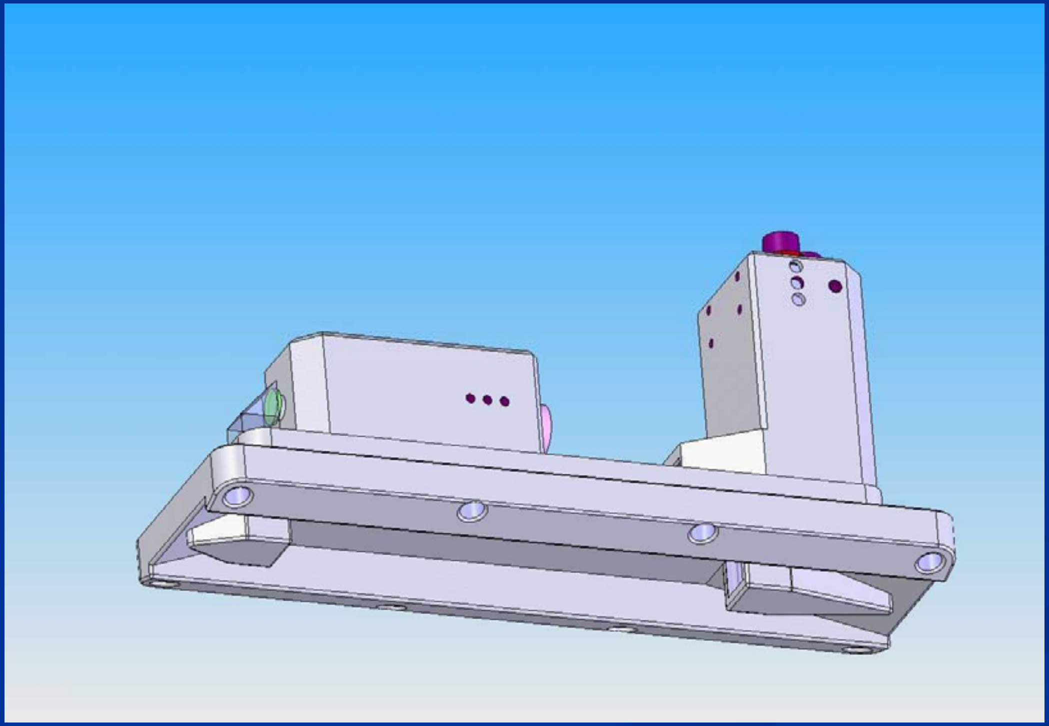



- Deployed Sept 9-21, 2007

# Profiler AUV-B scattering

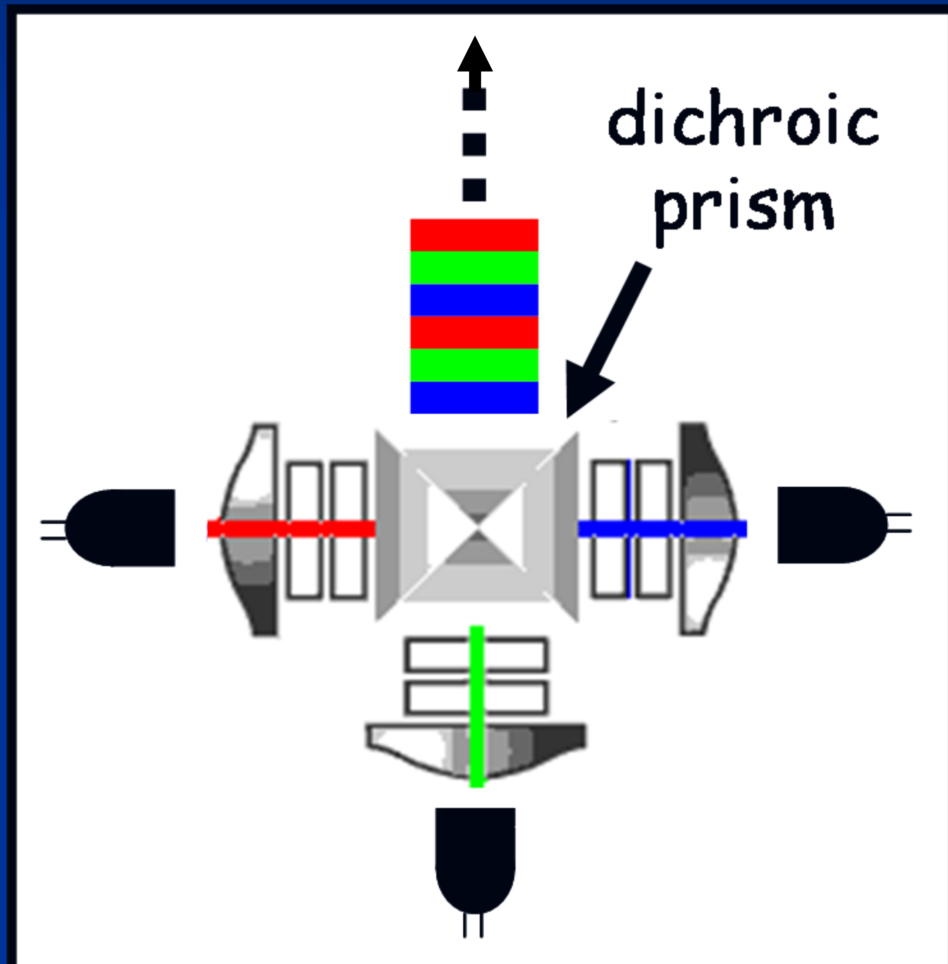


# "BAM3":
# 3λ Beam Attenuation Meter



Currently in design and feasibility demonstration phase…

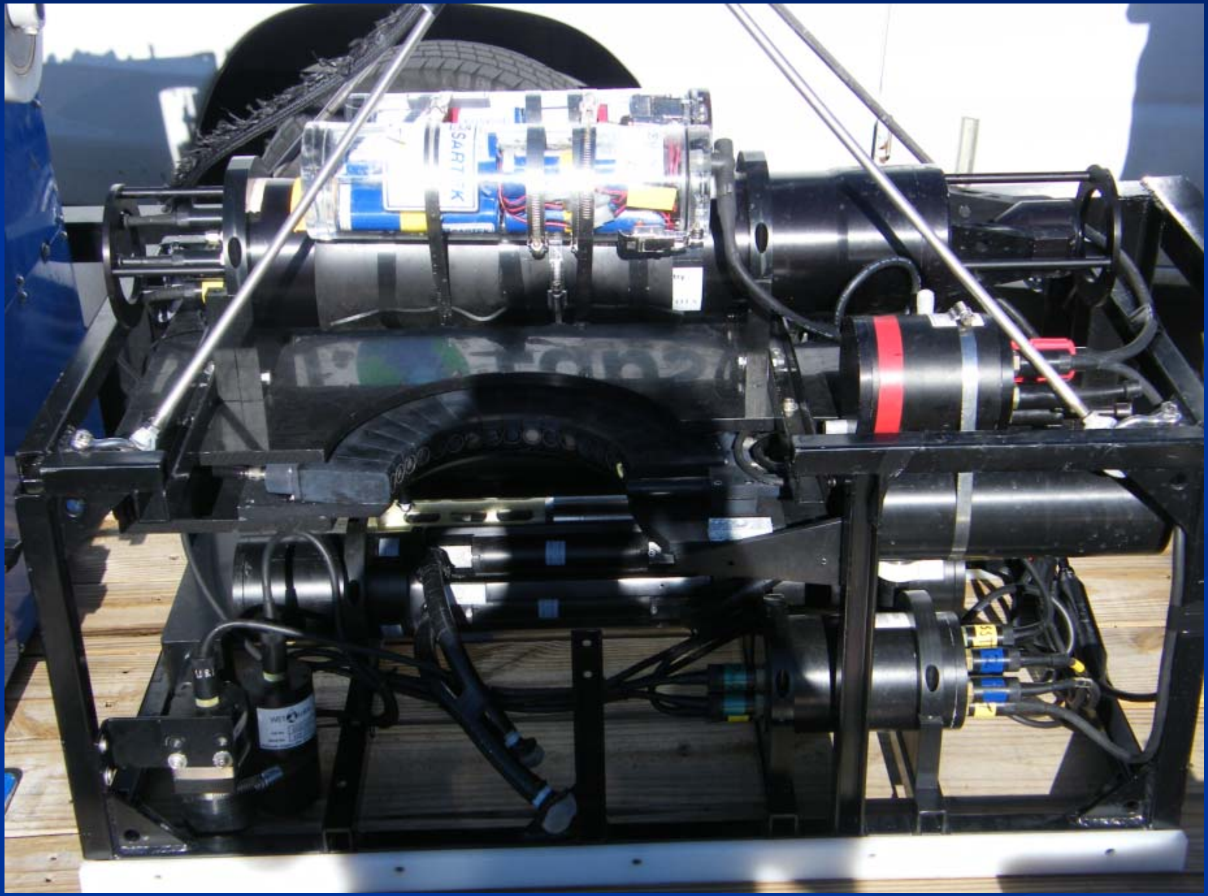
# 3λ source concept



# What have we been doing the last 2 weeks off the pier?

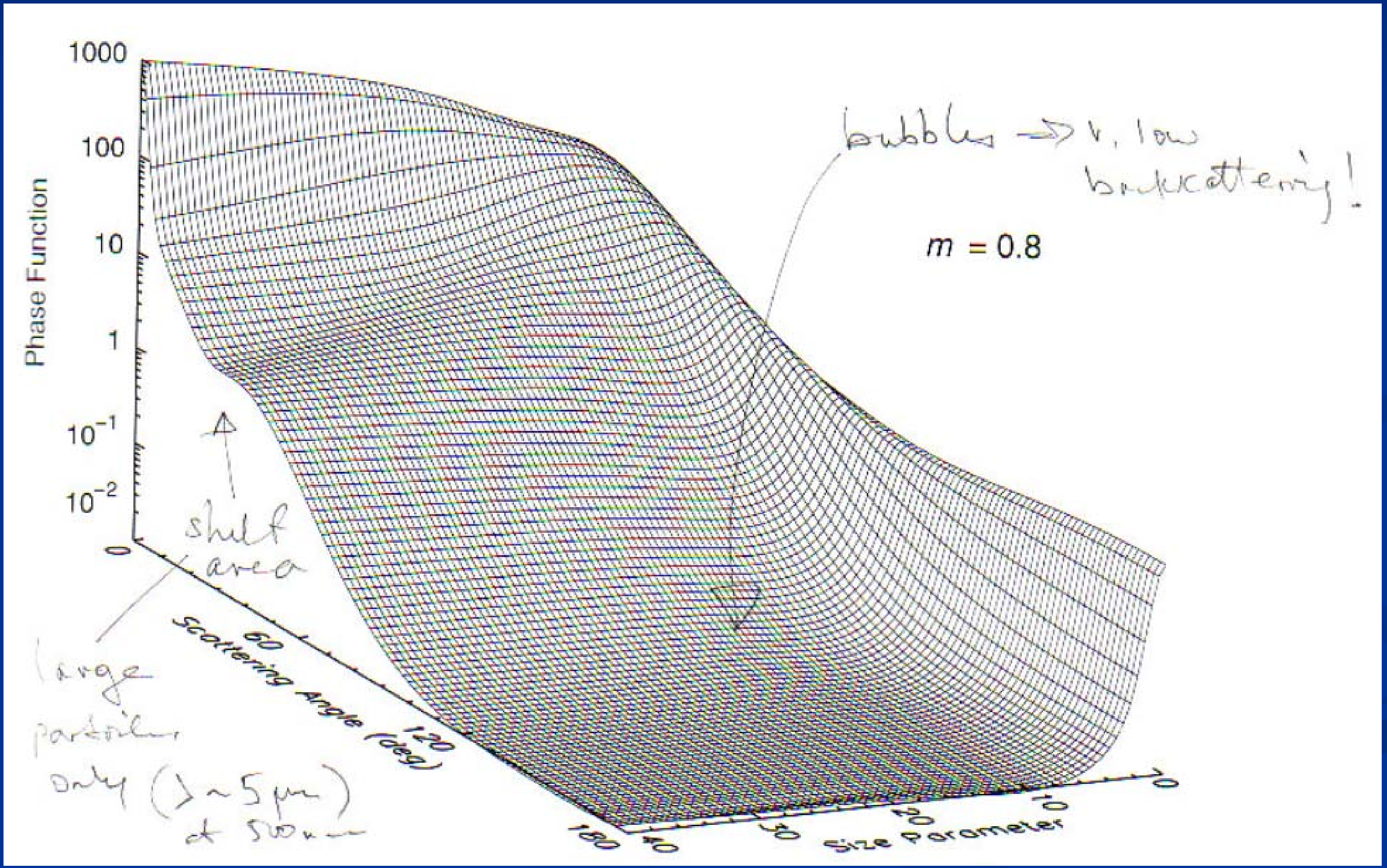

# RaDyO: Radiance in a Dynamic Ocean

# Primary instrument package

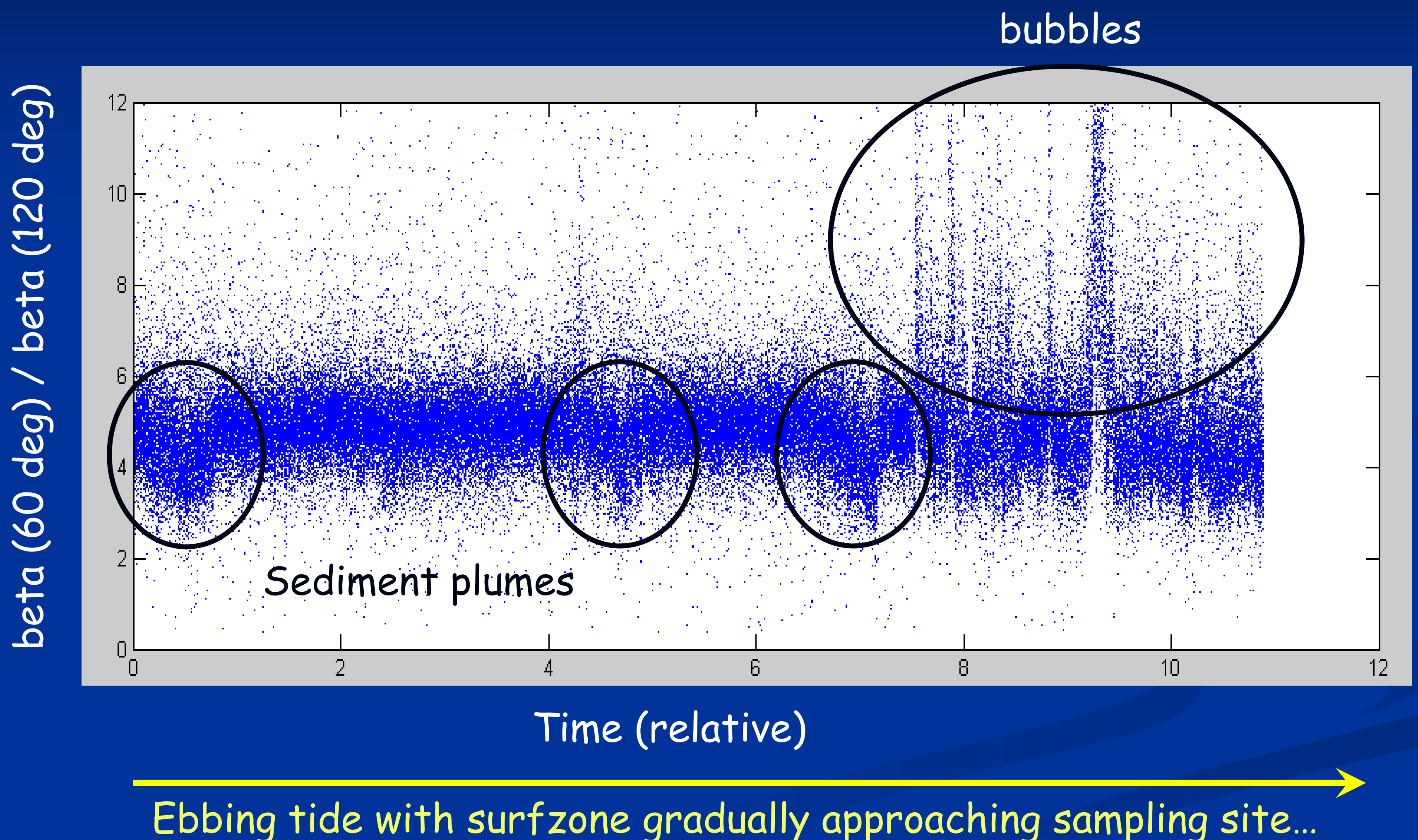


Designed to investigate aspects of the particle population (size distribution, composition, etc.) and bubbles with optical scattering

# Bubble VSFs (monodisperse)



# Preliminary data…




*Thank You*