A mini-review of sensor technologies for measuring sinking particle fluxes from ocean iron fertilization

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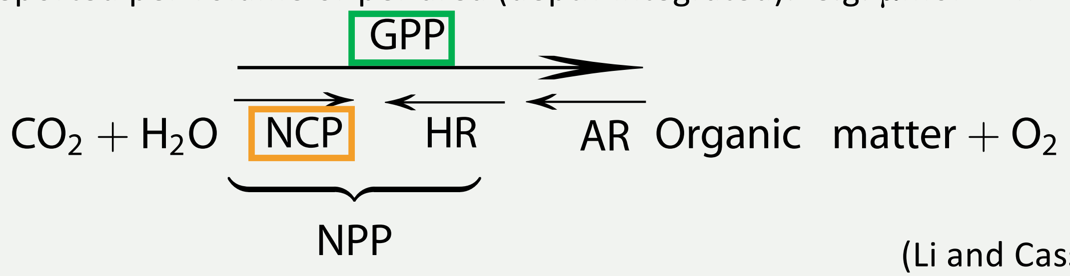
Biological rates & quantifying the biological carbon pump

Can be reported per volume or per area (depth-integrated): e.g. $\mu mol\ L^{-1}\ h^{-1}$ or $mmol\ m^{-2}\ d^{-1}$



(Li and Cassar, 2016)

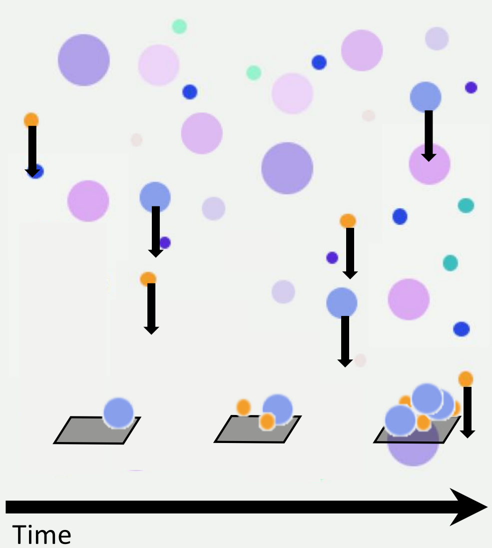
- GPP: Gross primary production
- AR: Autotrophic respiration
- NPP: Net primary production (what is left over for the heterotrophic community)
- HR: Heterotrophic respiration (what the heterotrophic community uses)
- NCP: Net community production (left over for export or OC accumulation)

Export defined here as flux of OC out of the system (e.g. below the euphotic zone)
For a system in steady state, **export should equal NCP**
The majority of OC is exported as **sinking particulate organic carbon** (POC)

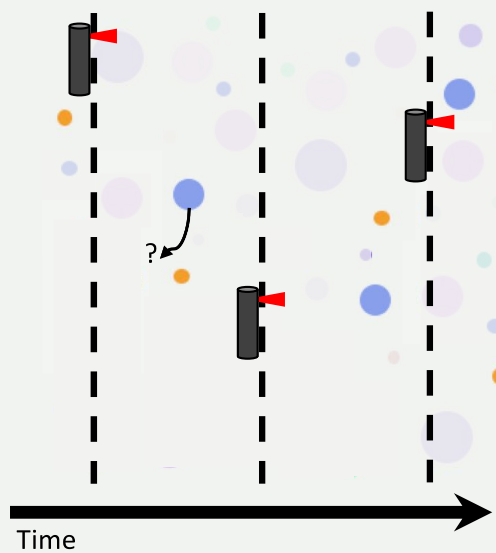
→ This talk: Measure **export** and sinking POC fluxes *below* the productive layer
→ Yibin Huang's talk (next): Measure **NCP** as changes in tracer concentrations

Tools for observing POC flux – a cartoon view

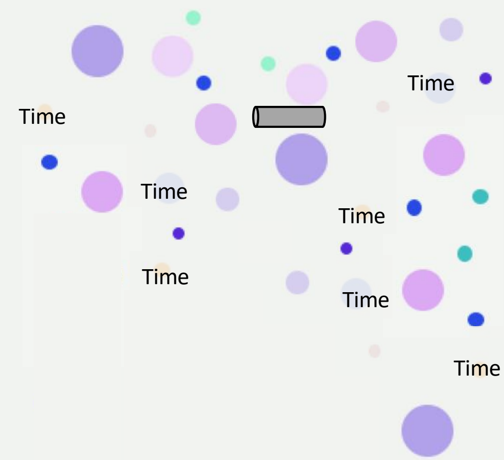
Category 1: "Sinking" particle fluxes
Ship-supported: Sediment traps, Marine Snow Catchers
Sensors: Optical & imaging sediment traps on drifting platforms



Category 2: Stocks of large POC + sinking speed
Sensors: Optical "spikes", underwater cameras on profiling platforms, particle tracking velocimetry



Category 3: Radiotracers of particles removed by sinking (or zooplankton?)
Ship-supported: ^{234}Th deficits
Sensors: In situ ^{234}Th activity sensor?



Technologies for observing POC export

***Category 1*: Fluxes of sinking particles**

- Specific to sinking particles, measures *flux* directly
- Sinking particle capture efficiency can vary, not many off-the-shelf sensors (many prototypes...)

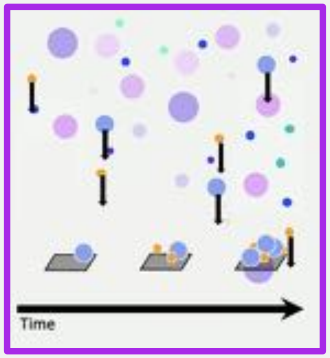
***Category 2*: Stocks of large (sinking?) particles + estimates of sinking speed**

- Several off-the-shelf sensors under widespread use
- Not always straightforward to determine particle sinking speeds

***Category 3*: Radiotracers measuring past flux (^{234}Th)**

- Direct flux measurement, may also capture DVM
- No sensor available, yet...

There are no standards for converting images, light scattering/attenuation, or ^{234}Th to moles of carbon!



Technologies for directly observing POC flux

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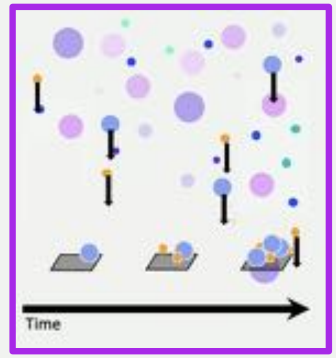
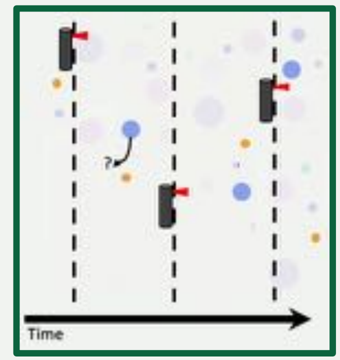
- Thorium-234 sensor





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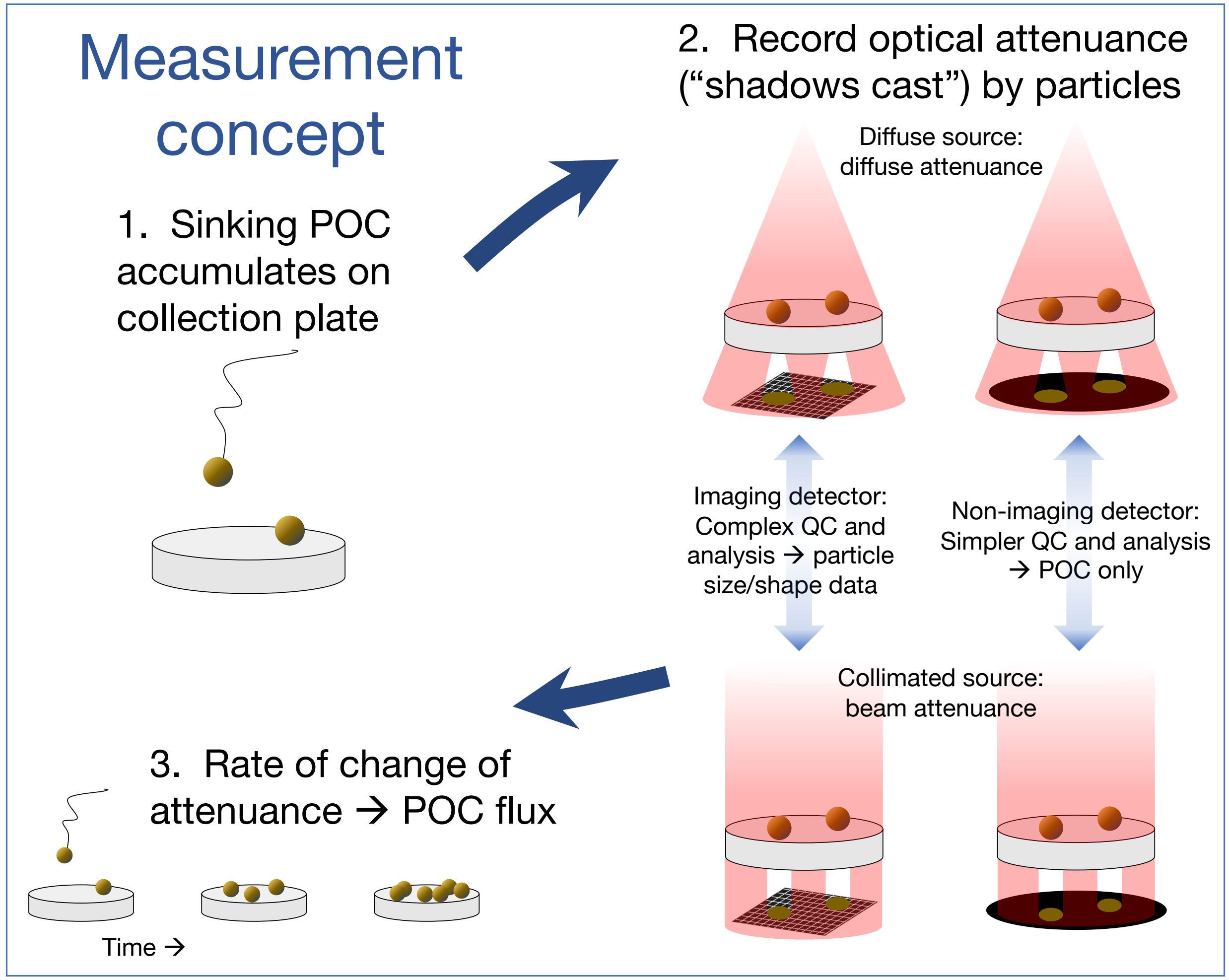
Imaging and non-imaging optical sediment traps

- Imaging: Information on particle size, identity. Expert data interpretation required.
- Non-imaging: Information on POC flux only but simpler data interpretation.

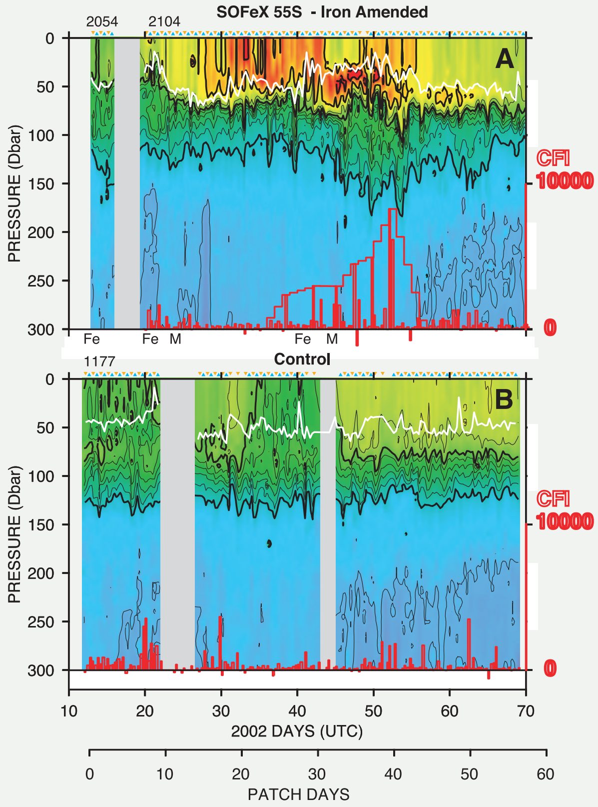


Non-imaging optical sediment traps

Off-the-shelf beam transmissometer used as a sediment trap

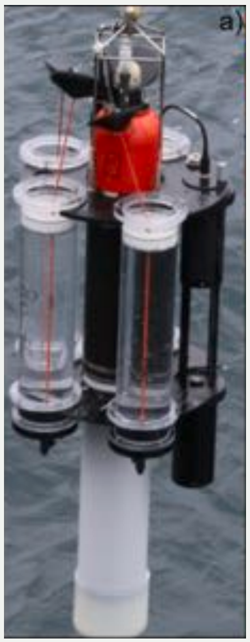
Pioneered during SOFEX…

Bishop and Wood, 2009
10.1029/2008GB003206



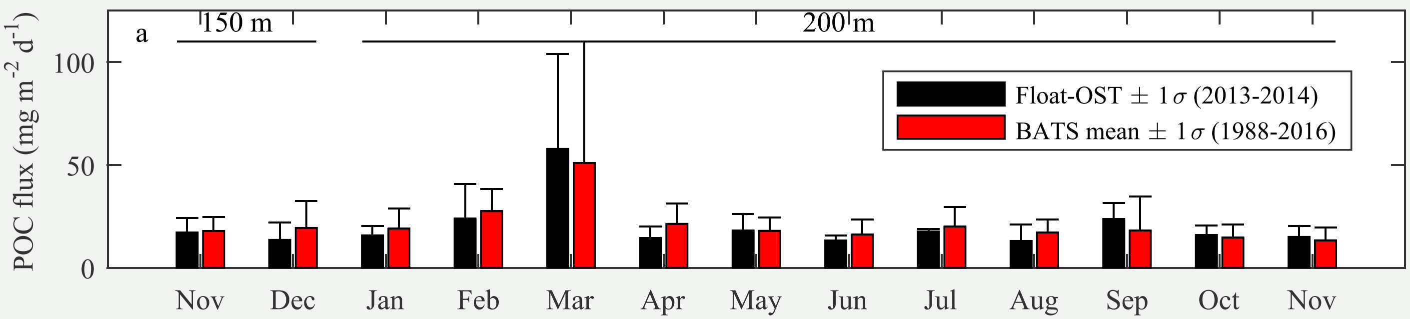
Bishop et al., 2004. 10.1126/science.1087717

Non-imaging optical sediment traps



Baker et al., 2020
10.1016/j.pocean.2020.102317

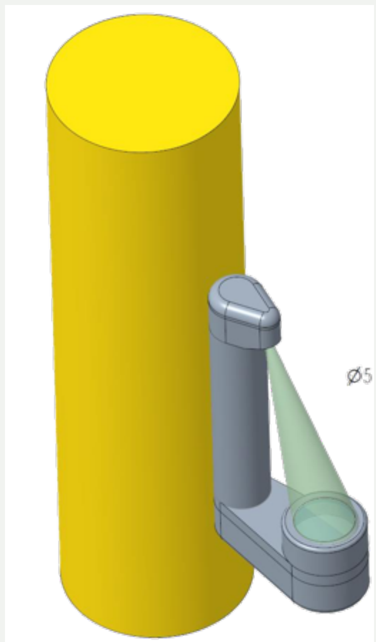
Fast forward ~10 years – *in situ* calibration vs. direct sediment traps



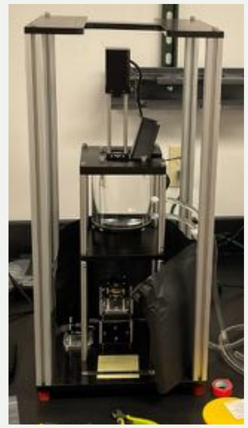
Estapa et al. 2019. 10.1029/2018GB006098

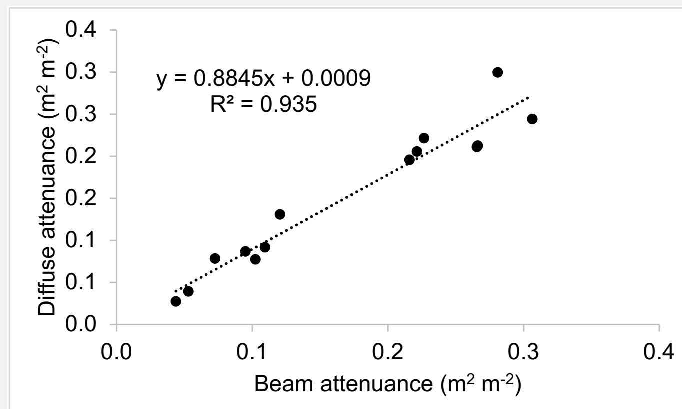
Non-imaging optical sediment traps

Now... prototyping a simple, low-cost sensor that is actually meant to be used as an optical sediment trap



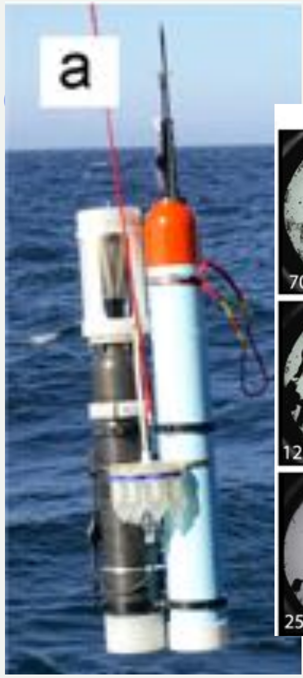
Slade et al., *Ocean Optics* 2022 poster

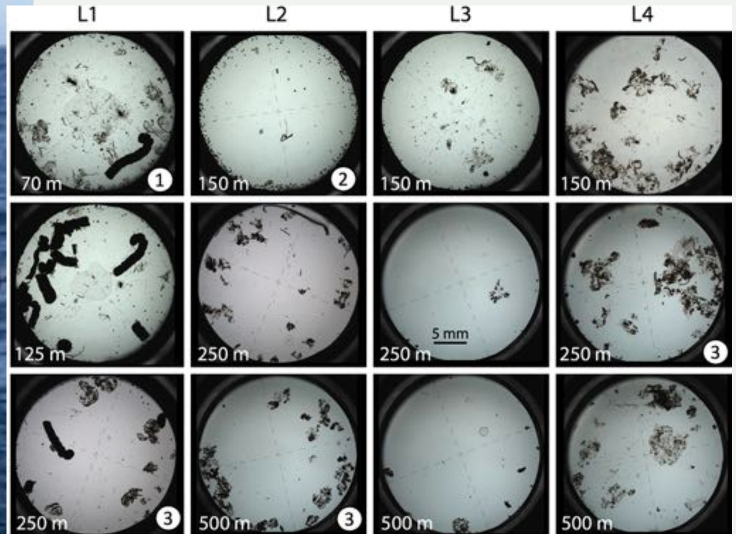




Estapa and Slade, *unpublished.*

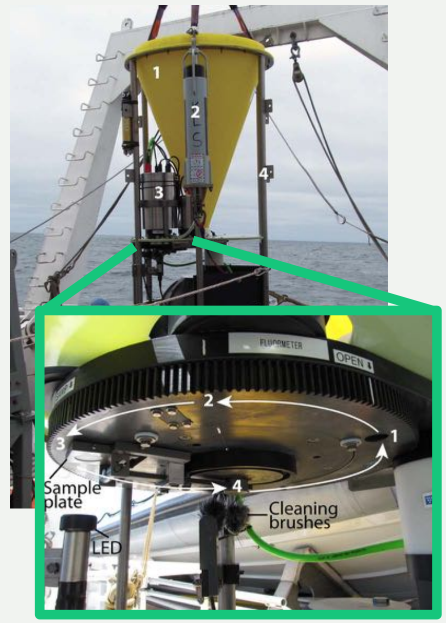
Transmitted-light imaging optical sediment traps





Bourne et al. 2021. 10.5194/bg-18-3053-2021

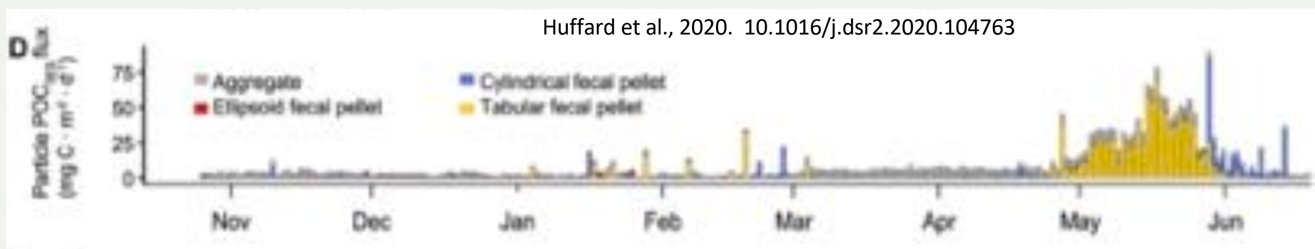
McGill et al. 2016. 10.1002/lom3.10131



Above: Carbon Flux Explorer (Bishop, UCSB)

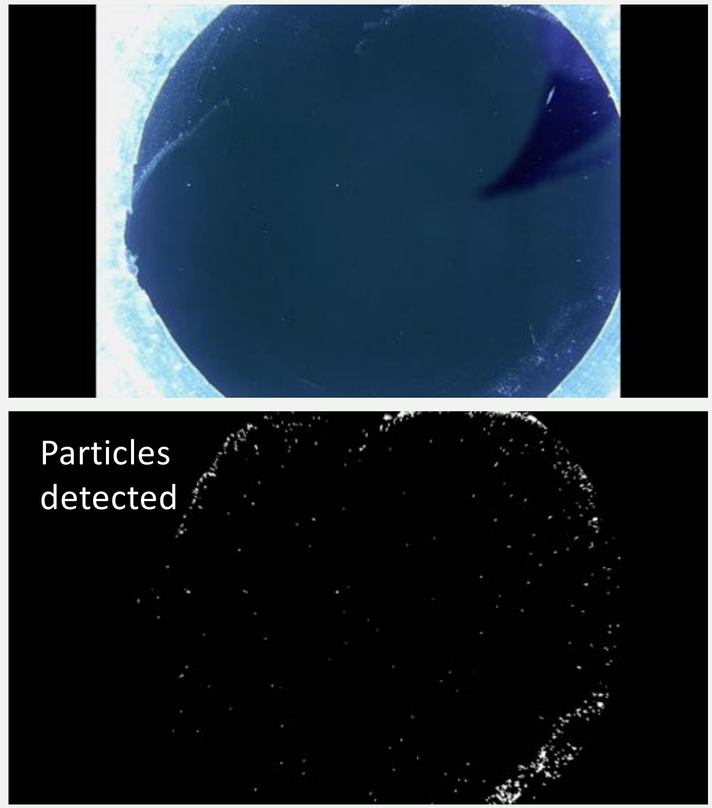
Right: Sedimentation Event Sensor (Smith, Huffard, Durkin, MBARI)

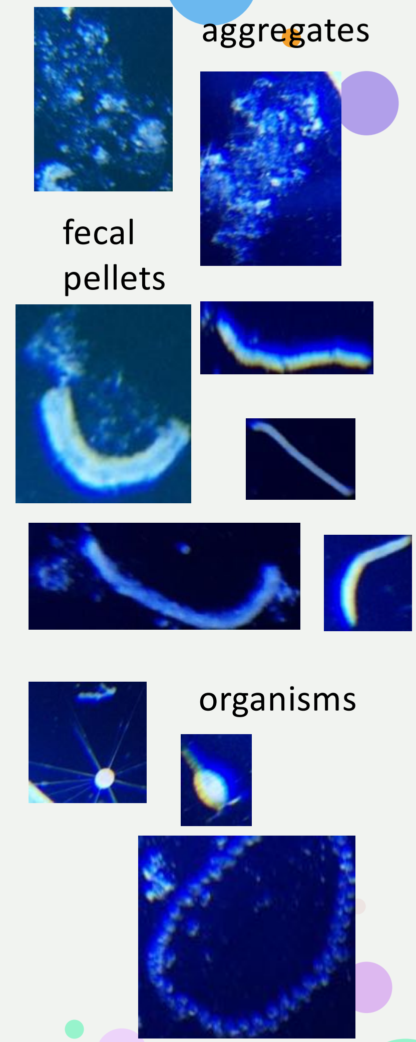
Huffard et al., 2020. 10.1016/j.dsr2.2020.104763



Scattered-light imaging optical sediment traps: SnoCam

SnoCam images

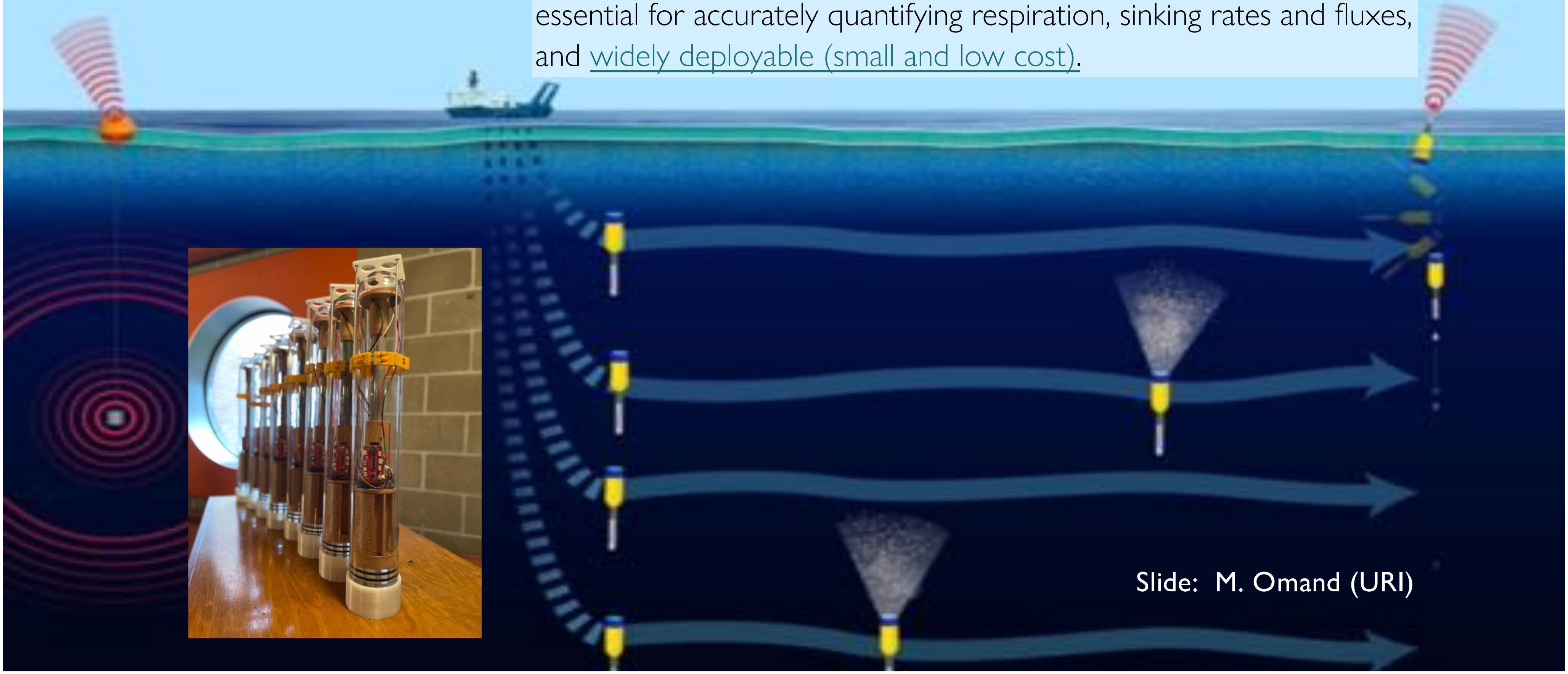




Data: M. Omand, C. Durkin, E. D’Asaro

Scattered-light imaging optical sediment traps: MINIONs (MINiature IsOpycNal floats)

Autonomous, subsurface expendable platforms which are Lagrangian, essential for accurately quantifying respiration, sinking rates and fluxes, and widely deployable (small and low cost).



Slide: M. Omand (URI)

Technologies for directly observing POC flux

***Category 1*: Fluxes of sinking particles**

- Non-imaging optical sediment traps: Beam transmissometer, OST "v2"
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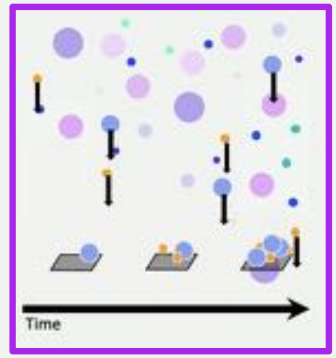
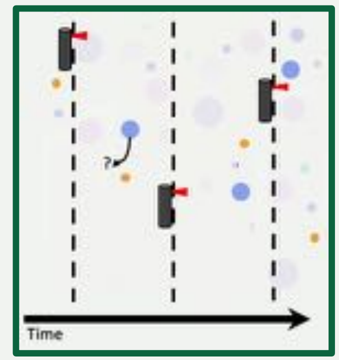
***Category 2*: Stocks of large (sinking?) particles + estimates of sinking speed**

- Optical "spikes"
- Underwater cameras
- In situ particle tracking velocimetry

***Category 3*: Radiotracers measuring past flux (^{234}Th)**

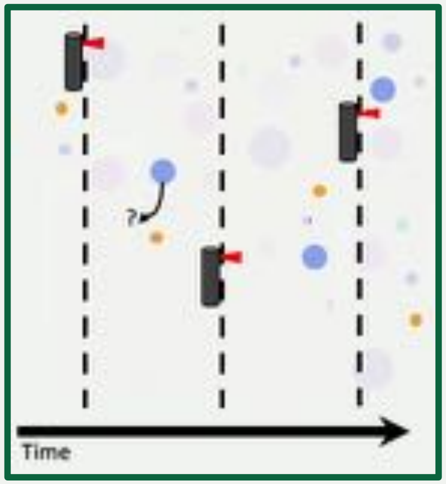
- Thorium-234 sensor

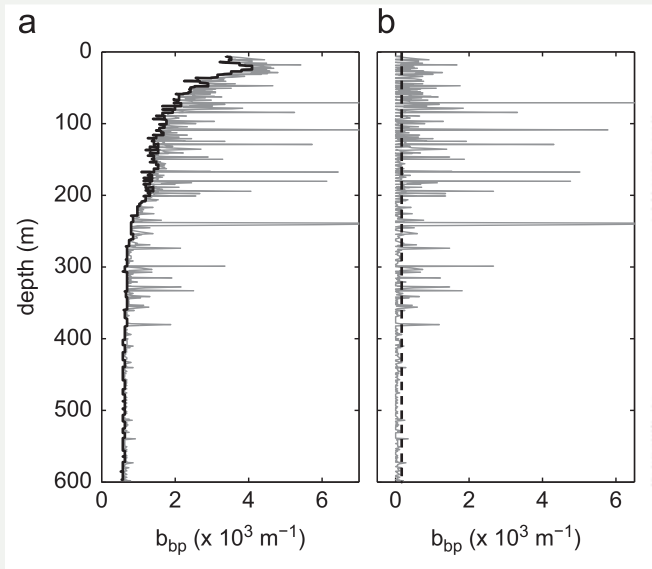




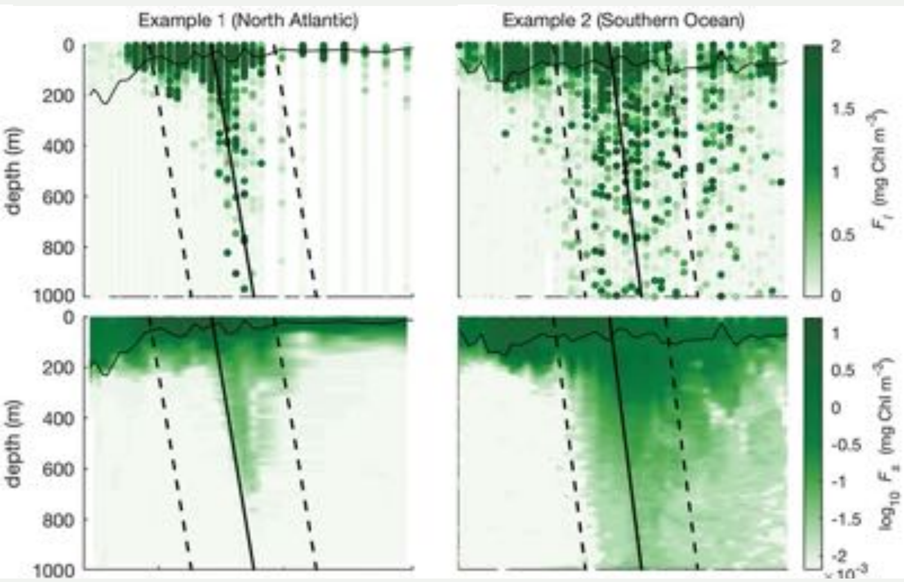
There are no standards for converting images, light scattering/attenuation, or ^{234}Th to moles of carbon!

Sinking particles from optical spikes





Briggs et al. 2011. 10.1016/j.dsr.2011.07.007



Briggs et al. 2020. 10.1126/science.aay1790

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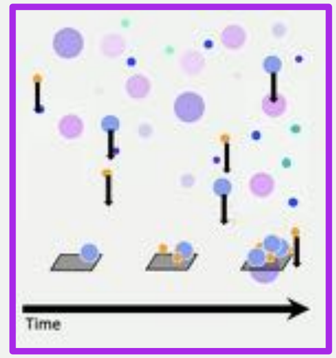

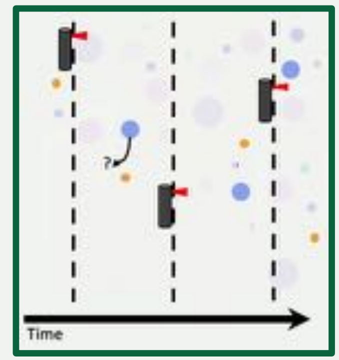

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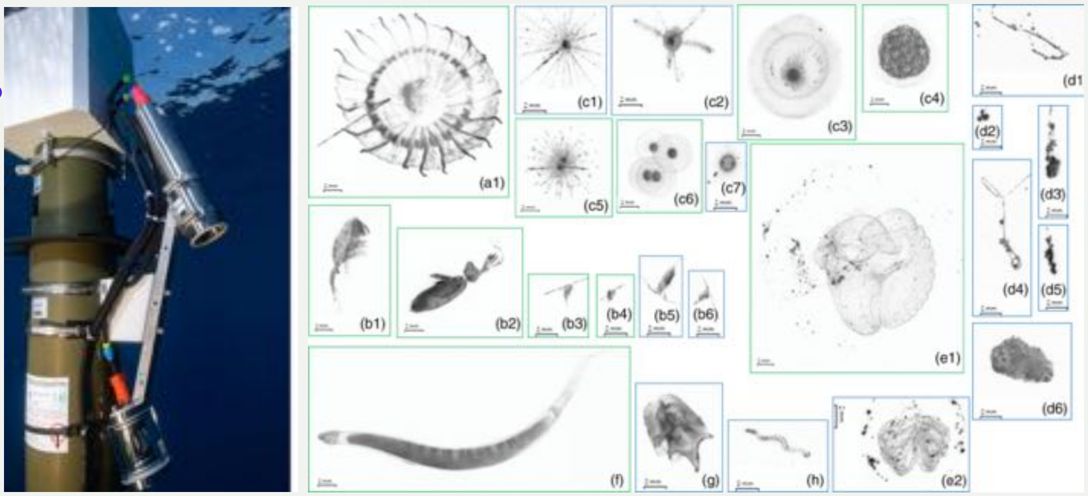
Underwater cameras



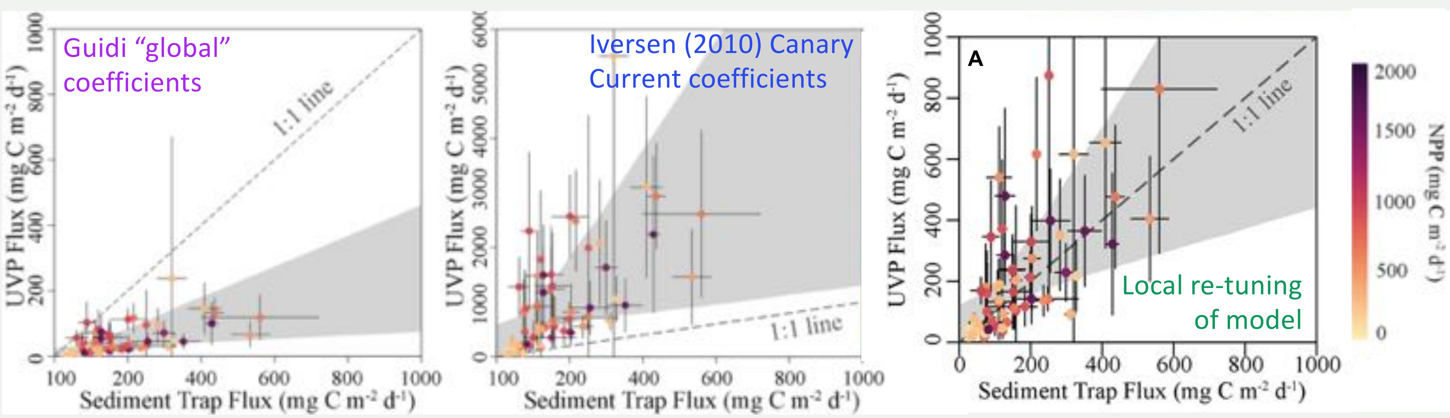
Underwater vision profiler (UVP) 6, Picheral et al. 2022. 10.1002/lom3.10475

How to go from particle number concentration (#/volume) to carbon flux (mass/area/time)?

A commonly-used method: Assume particle carbon content and sinking speed are both power-law functions of diameter (Guidi et al., 2008):

$$F = \Sigma_i N_i A d_i^B \Delta d_i$$

Obtain A and B by fitting particle size spectra (N(d)) to carbon flux measurements (F).



Fender et al. 2019. 10.3389/fmars.2019.00603

L to R: Fit to "global" flux data (Guidi et al. 2008), fit to flux data from a different region (Iversen et al. 2010) and fit to locally collected flux data.

Take home: hard to extrapolate particle size to C flux!

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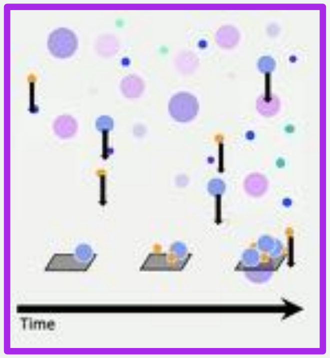

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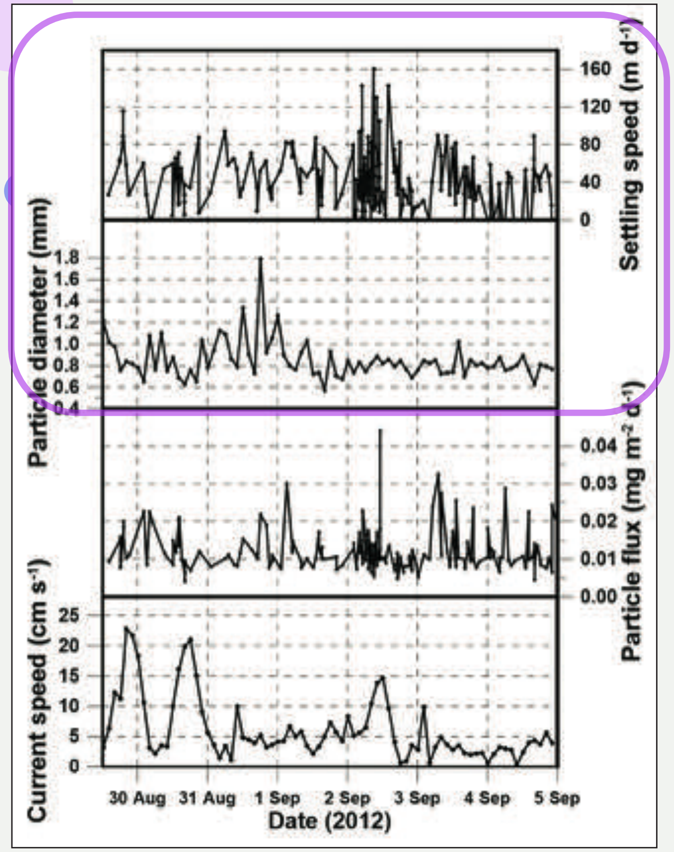
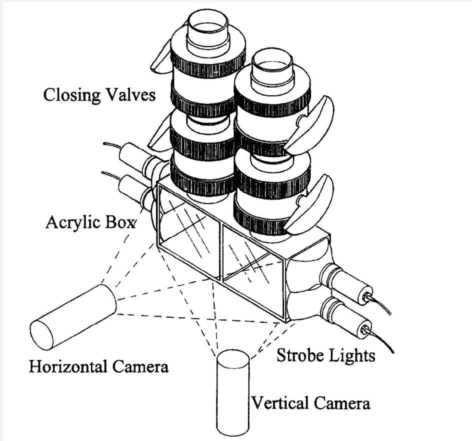
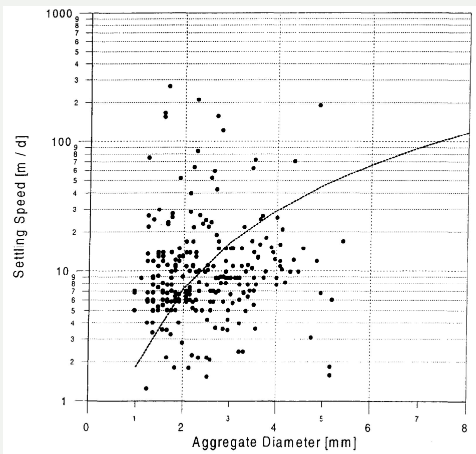
In situ particle tracking velocimetry



Diercks et al. 2018. 10.1525/elementa.285

Diercks and Asper 1997.
10.1016/S0967-0637(96)00104-5





Iversen and Lampitt, 2020. 10.1016/j.pocean.2020.102445

Both studies: No relationship between particle size and sinking speed...

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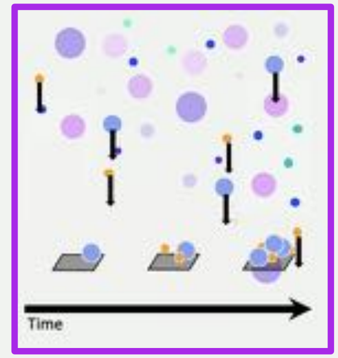

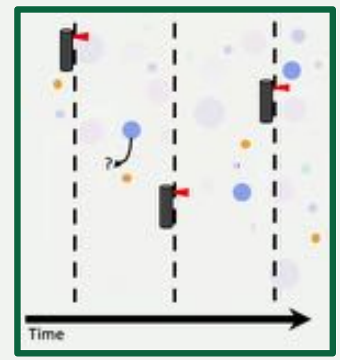

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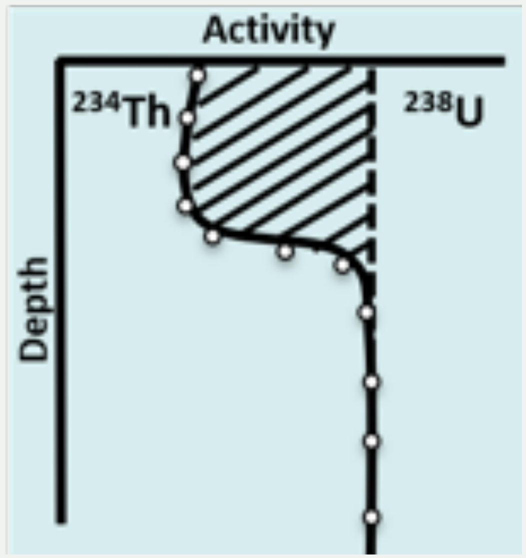
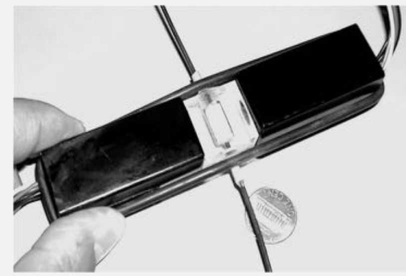
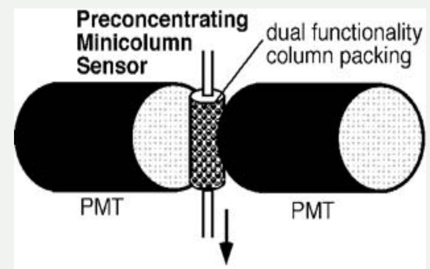
In situ Thorium-234 detector



Multiply depth-integrated ^{234}Th deficit (dpm/area/time) by C:Th ratio (mol/dpm) of sinking particles





Can ^{234}Th be measured *in situ?*

Figures: K. Buesseler, WHOI, *unpublished*

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