Measuring particle fluxes and sinking rates—how can polyacrylamide gel sediment traps help?

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Outline
1. Biological pump—Motivation and current understanding
2. Particle sinking velocities—How do we determine?
3. Gel traps & water column particle studies
4. Future research directions
The Biological Pump & Twilight Zone

Combined processes which transfer organic matter and associated elements to depth

**EZ** = source of fresh sinking particles

**TZ** = layer of net loss of sinking POC

DEPTH MATTERS!

*Buesseler & Boyd 2009*
Motivation behind biological pump & particle studies

Biological pump impacts surface to deep ocean DIC gradients and hence global C cycle and climate. 
*Sarmiento and LeQuere, 1996*

Increase in remineralization depth by 25m will decrease atmos. CO$_2$ by ~20 ppm. 
*Kwon et al. 2009*

>1 °C temp increase in twilight zone with climate change. 
*Levitus et al., 2009*

*Many elements (nutrients, TEI’s) “hitch a ride on the bus”* 
*Gieskes, 1980 lecture SIO; Scavenging concept- Goldberg, 1954*

The biological pump “feeds” the interior ocean and seafloor. 
*Alexander Agassiz, 1888*

The twilight zone carbon budget is unbalanced. 
*Steinberg et al., 2008, Burd et al., 2010*
Current understanding of biological pump & particle cycle

Global models do not adequately represent observed biogenic particle fluxes to the deep ocean
Gehlen et al., 2006

No models have yet incorporated sufficient complexity to capture the observed variability of export fluxes
Boyd and Trull 2007

The reason for this is we have not yet quantified the processes producing or transforming the particle flux
Stemmann and Boss, 2011

The most critical parameter for particle flux is the particle settling speed
in Stemmann and Boss, 2011 & attributed to Fasham et al., 1990
Given that it is so critical, how do we determine particle sinking speeds?

1. Settling columns
2. In-situ observations
3. Sediment trap peak matching
4. Settling velocity traps
5. Gel traps and particle imaging in water and flux
1. Settling columns

An analysis of sinking rates of natural copepod and euphausiid fecal pellets

Paul D. Komar, Alan P. Morse, and Lawrence F. Small
School of Oceanography, Oregon State University, Corvallis 97331

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International Laboratory of Marine Radioactivity, Musée Océanographique, Princess

- lab vs. field vs. in situ?
- works best for large/fast intact particles
pellets 100's-1000 m/d

\[
\omega_s = 0.0790 \frac{1}{\mu} (\rho_s - \rho) g L^2 \left( \frac{L}{D} \right)^{-1.664}
\]
2. In situ observations

The human approach
- limited to large, slow sinking marine snow
- variable human limits

Alldredge and Gotschalk 1988

Progressed to in-situ work with cameras in trap tubes - Asper, Honjo et al.
on ROVs - Silver, Pilskaln et al.
on AUV’s?
3. Sediment trap peak matching

**N. Atlantic - sinking rate & ballast, packaging relationships**

Fisher and Karakas, 2009

Sinking rate increases with depth

see also Berelson 2002
4. In-situ sinking-velocity trap

*Peterson et al., 2003*

IRS collects for 6 hours, dumps to carousel below and repeats cycle for 7 days.

Carousel separates particles into 11 cups/sinking rates

- **8' >142**
- **4' 1'**
- **2' >825**

5hr 59' >2m/day

1' - all clear?

empty hole - deploy/recovery

moored or drifting
Sinking velocity trap - 2 examples
50% of flux > 100 m/d


**Concerns**
- it is still a trap
- changes in situ on rotating ball
- carry over between cups

**VERTIGO** - Trull et al. 2008
5. Particle settling velocity from gel traps

\[ F_i = C_i \times W_{i,\text{avg}} \]

Flux = Concentration × Avg. Sinking Velocity

first used in McDonnell and Buesseler 2010
Measuring the flux size distribution
Measuring the concentration size distribution

Concentration (No. m\(^{-3}\) µm\(^{-1}\))

Equivalent Spherical Diameter (µm)
Calculating the average sinking velocity size distribution

\[ F_i / C_i = W_{i, \text{avg}} \]

\[ \text{Flux (No. m}^{-2} \text{ d}^{-1} \mu \text{m}^{-1}) \]

\[ \text{Concentration (No. m}^{-3} \mu \text{m}^{-1}) \]

\[ \text{Equivalent Spherical Diameter (\mu m)} \]

\[ \text{Average sinking velocity (m d}^{-1}) \]

\[ \text{Equivalent Spherical Diameter (\mu m)} \]

\[ \text{F) McDonnell} \]

\[ \text{and Buesseler 2010} \]
Variability in regional average sinking velocities

**Antarctica**

![Graph showing variability in average sinking velocity for Antarctica.](image)

**Bermuda**

![Graph showing variability in average sinking velocity for Bermuda.](image)
Sinking speed variability linked to differences in the particulate material

* Gel traps quite useful for particle ID work

* See Waite and Nodder, 2001
* Ebserbach et al, 2011
Temporal variability in average sinking velocity

McDonnell and Buesseler 2010
Depth and spatial variability in sinking velocities

- faster in HNLC areas (ballast?)
- slower at depth in this study
- faster at depth in W. Antarctic

Gel traps and water column imaging study in KEOPS
Jouandet et al., 2011
Can we put it all together?

Not very well.....

Gel traps (color)
other methods (B&W)
#7 Stokes ≠ data
No single relationship

Are we even measuring the same parameter?
$w_{\text{individual}}$ vs $w_{\text{average}}$

What are limitations & biases of each method?

Expect variability!

Jouandet et al., 2011
from Stemmann et al. 2004, Guidi et al. 2008 & many more
Grand challenges & future research directions

Need observations!
- multiple methods for flux, particle conc., sources, decomposition and sinking rates
  ✓ gel traps images provide source info
  ✓ gel traps and particle images provide sinking rates

Recognize variability exists on all space & time scales
- moored inst., profilers, gliders can help resolve

BUT also include BIO in biopump PROCESS studies
- need to separate roles of zooplankton & bacteria
- physical controls on aggregation & biota linked
- need to know processes to understand variability & predict changes in biopump due to climate

ASSUMING most critical parameter is sinking speed
why does it vary?