# Constraining observationally intractable aspects of the mesopelagic carbon cycle: Comparison of direct observations and multi-parameter sensitivity analyses

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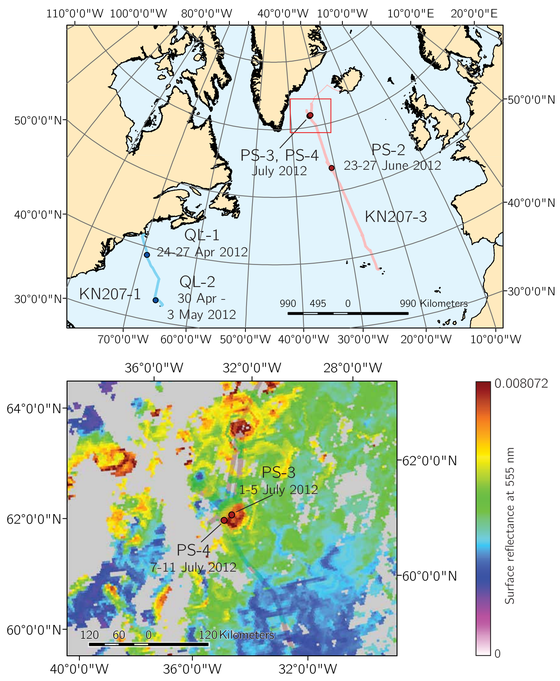
## Introduction: Pairing observations and flux attenuation models to constrain carbon export parameters

- Considerable uncertainities still surround many parameters associated with flux attenuation in the mesopelagic
- We measured particulate carbon fluxes, bacterial production, and respiration by both free-living and particle-attached bacteria at five stations in the North Atlantic
- To constrain several unmeasured parameters, we compared the observed fluxes with the results of sensitivity analyses in two different models
- Using this method, we obtain estimates of bacterial growth efficiency, particle sinking velocity
- We also evaluate the relative contributions of dissolution/disaggregation and respiration to particle flux attenuation

## Deployment locations and cruise tracks




*Upper panel:* Our five quasi-lagrangian stations in the North Atlantic.

*Lower panel:* Stations PS-3 and PS-4 are superimposed over 8-day-average MODIS Aqua surface reflectance at 555 nm, an indicator of biological PIC precipitation.

High export fluxes and very low POC : PIC rain ratios suggest export was driven by coccolithophorids

## Sensitivity analysis in two models of flux attenuation

### Model 1

POC flux at depth $z$; mg C m$^{-2}$ d$^{-1}$

Average particle sinking velocity; m d$^{-1}$

$$F_z = F_0 exp^{-(z-z_0)/L_{remin}} \qquad L_{remin} = \frac{W_{avg}}{R_{spec} + k_{DD}}$$

POC flux at overlying reference depth $z_0$; mgC m$^{-2}$ d$^{-1}$

Remineralization length scale; m

Specific respiration rate from incubations of sinking particle material; d$^{-1}$

Activity constant for loss to dissolution & disaggregation; d$^{-1}$

### Model 2

Depth-integrated bacterial production from $^3$H-leucine incorporation; mg C m$^{-2}$ d$^{-1}$

POC flux at depth $z$

Isotope dilution factor

$$F_z = F_0 - \frac{BP_{int}}{BGE} f_{pa} ID$$

POC flux at overlying depth $z_0$

Bacterial growth efficiency

Fraction of BP attributable to particle-attached communities

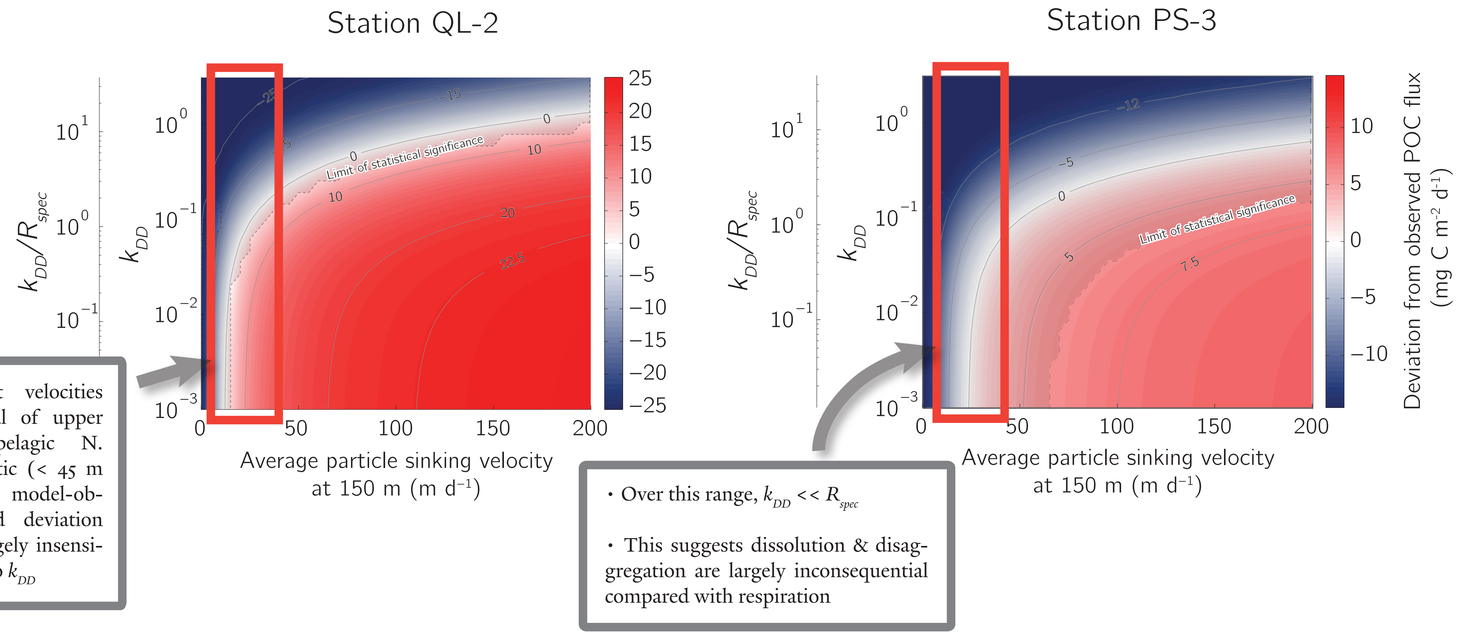
### Input ranges for unknown parameters

| Parameter | Values used |
|---|---|
| $W_{avg}$ | 1 - 400 m d$^{-1}$ |
| $k_{DD}$ | 10$^{-5}$ - 2 d$^{-1}$ |
| $BGE$ | 0.01 - 0.60 |
| $f_{pa}$ | 0.018 - 0.39 |
| $ID$ | 1.00 - 2.00 |

*Observed quantities are in black; unknown parameters varied in sensitivity analyses are in red*

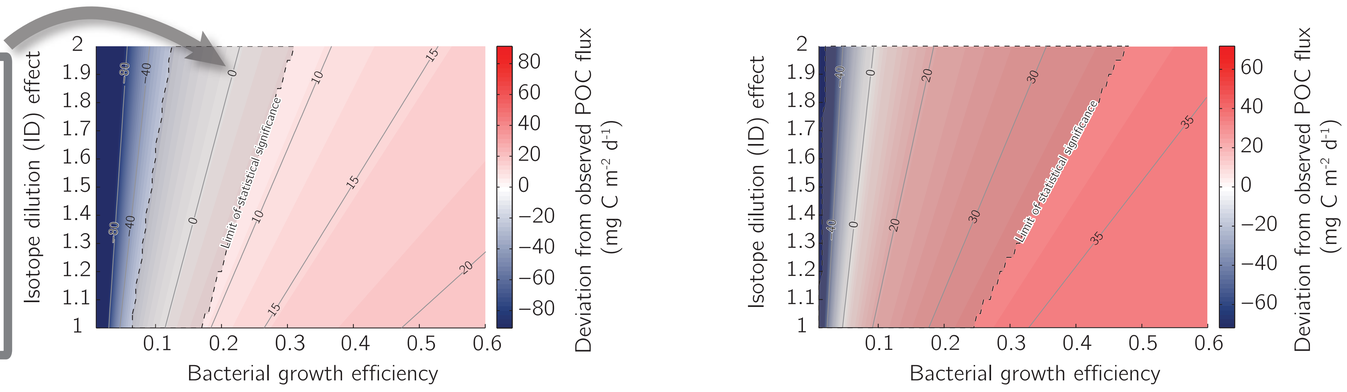
## Results from two typical stations

### Model 1: Dissolution & disaggregation versus sinking velocity




- At velocities typical of upper mesopelagic N. Atlantic (< 45 m d$^{-1}$), model-observed deviation is largely insensitive to $k_{DD}$
- Over this range, $k_{DD}$ << $R_{spec}$
- This suggests dissolution & disaggregation are largely inconsequential compared with respiration

### Model 2: BGE, isotope dilutuon, fraction BP attributable to particle-attached het bact




- Model-observed deviation is highly sensitive to BGE
- Robust to variation in ID
- Similar insensivity observed at all stations to $f_{pa}$

## Key results and conclusions

From direct measurements, we observed:

- Substrate-specific respiration rates from 0.007 ± 0.003 to 0.173 ± 0.105 d$^{-1}$
- Bulk quality of sinking substrate (ratio of POC to PIC) influenced both rate and efficiency of heterotrophic metabolism
- Lower BGEs on PIC-rich material sinking from a coccolithophore bloom

By comparing model sensitivity analyses to observed fluxes, we found:

- BGEs ranging from 0.05 to 0.40
- Average particle sinking velocities ranging from 5 to 50 m d$^{-1}$, with the majority of velocities < 50 m d$^{-1}$
- Disaggregation and dissolution were inconsequential as sinks for particle material relative to microbial respiration
- Choice of BGE had a pronounced effect on POC flux, suggesting heterotrophic activity is the dominant determinant of the strength of the biological pump in the upper mesopelagic
- Variation in $ID$ and $f_{pa}$ did not produce significant changes in model output

## Estimates of BGE & sinking velocity

| Cruise | Station | Average particle sinking velocity (m d$^{-1}$) | | | Bacterial growth efficiency (BGE) | | |
|---|---|---|---|---|---|---|---|
| | | Estimate | Lower bound | Upper bound | Estimate | Lower bound | Upper bound |
| KN207-1 | QL-1 | 57 | 7 | n/c* | 0.40 | 0.05 | n/c |
| | QL-2 | 17 | 10 | 69 | 0.12 | 0.07 | 0.30 |
| KN207-3 | PS-2 | 7 | 2 | n/c | 0.04 | 0.02 | 0.17 |
| | PS-3 | 7 | 2 | 65 | 0.05 | 0 | 0.48 |
| | PS-4 | 21 | 8 | n/c | 0.06 | 0 | n/c |

*n/c: not constrained

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