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

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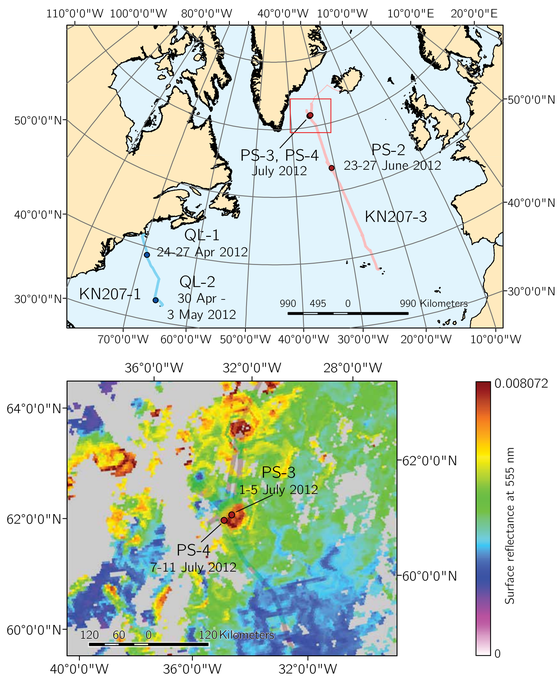
Introduction: Pairing observations and flux attenuation models to constrain carbon export parameters

- 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}

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

F_0: POC flux at overlying reference depth z_0; mgC m^{-2} d^{-1}

L_{remin}: Remineralization length scale; m

W_{avg}: Average particle sinking velocity; m d^{-1}

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

k_{DD}: Activity constant for loss to dissolution & disaggregation; d^{-1}

Model 2

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

F_z: POC flux at depth z

F_0: POC flux at overlying depth z_0

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

BGE: Bacterial growth efficiency

ID: Isotope dilution factor

f_{pa}: Fraction of BP attributable to particle-attached communities

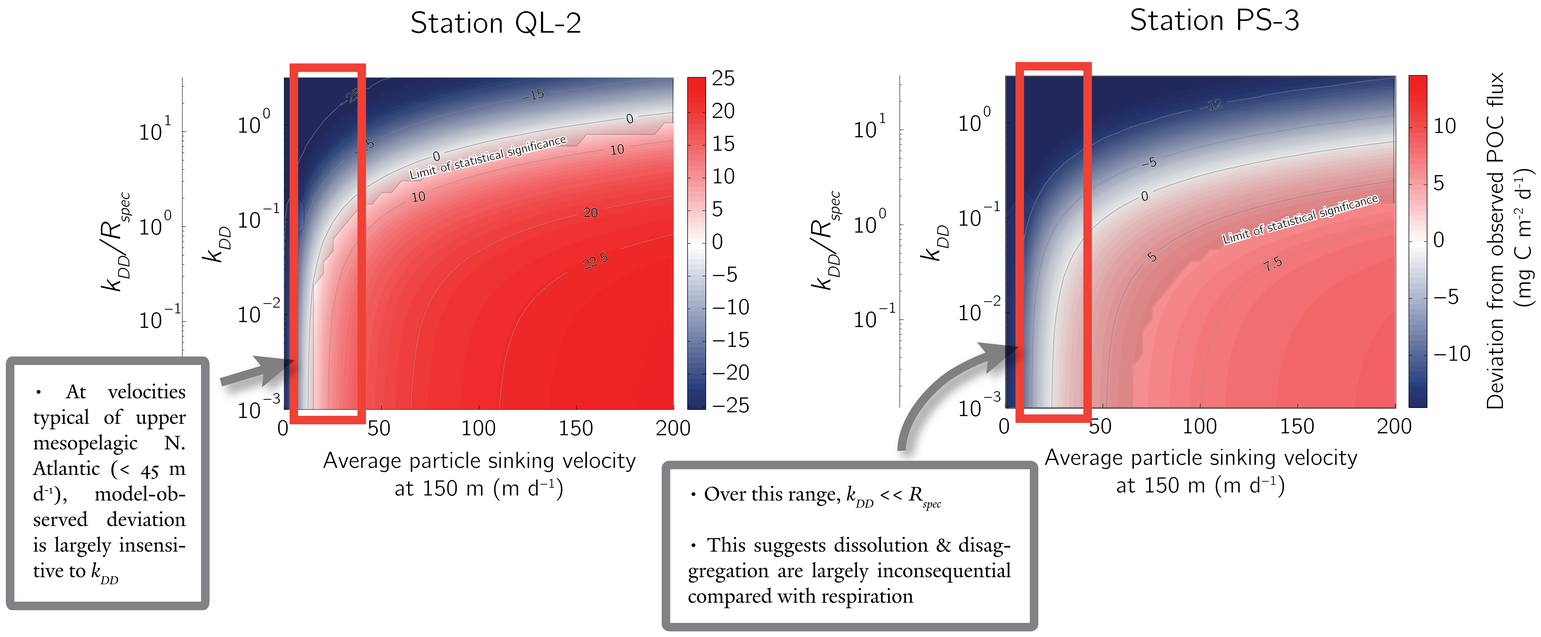
Input ranges for unknown parameters

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

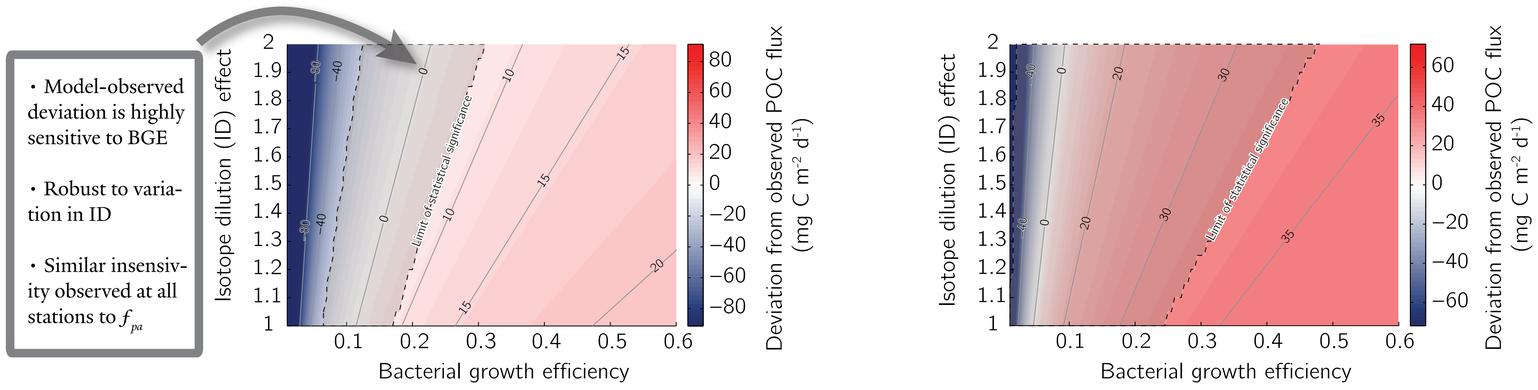
Results from two typical stations

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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