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# Investigating the biological carbon pump in the northern Benguela upwelling system oxygen deficient zone

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Chelsey Baker<sup>1</sup>, George Wolff<sup>2</sup>, Kathryn Cook<sup>3</sup>, Sophie Fielding<sup>4</sup>, Calum Preece<sup>2</sup>, Mark Stinchcombe<sup>1</sup>

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<sup>3</sup>University of Exeter, <sup>4</sup>British Antarctic Survey

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**GOCART**



European Research Council  
Established by the European Commission

**IUGC2024**



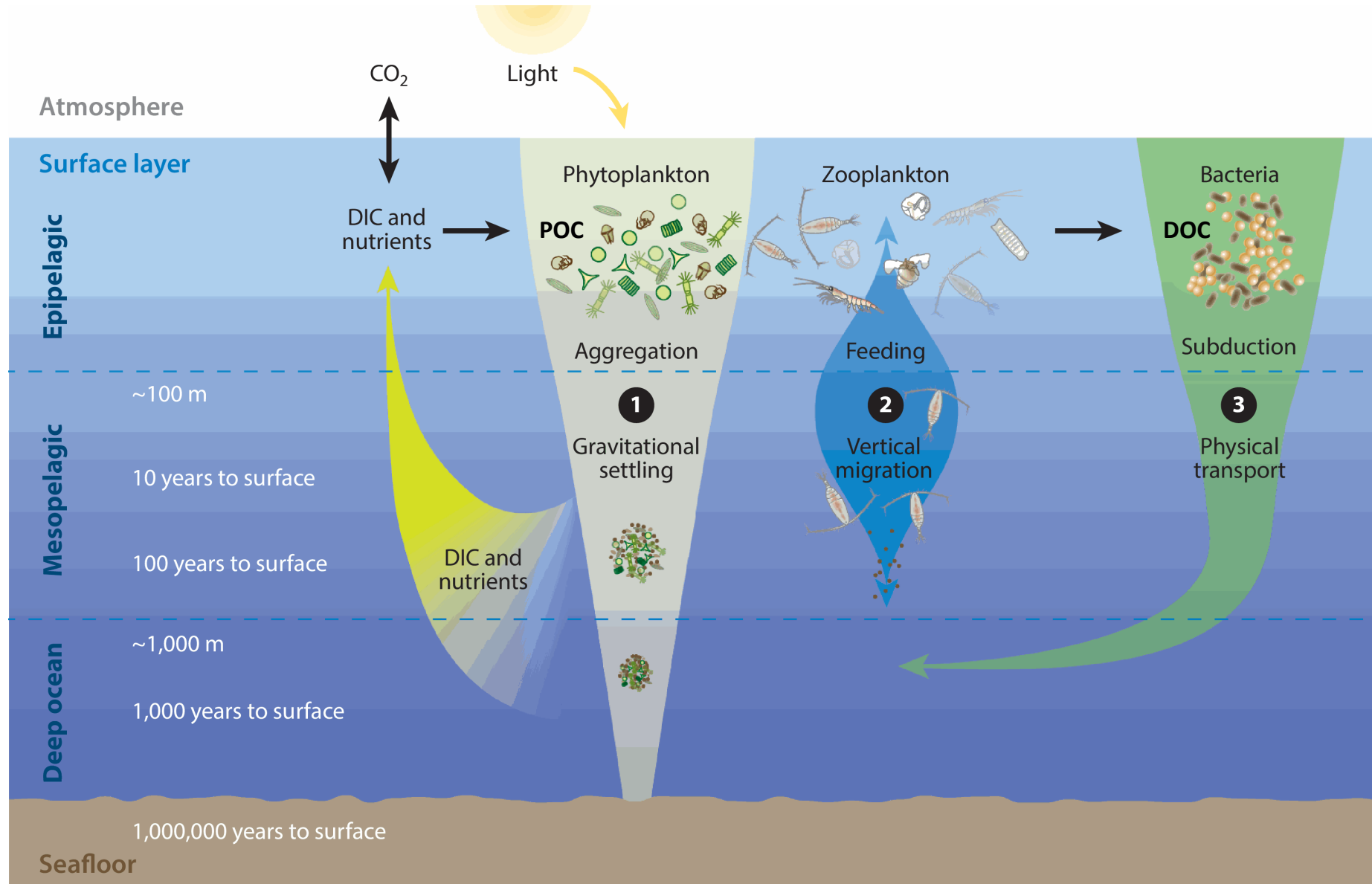
**COMICS**

INVESTIGATING THE TWILIGHT ZONE

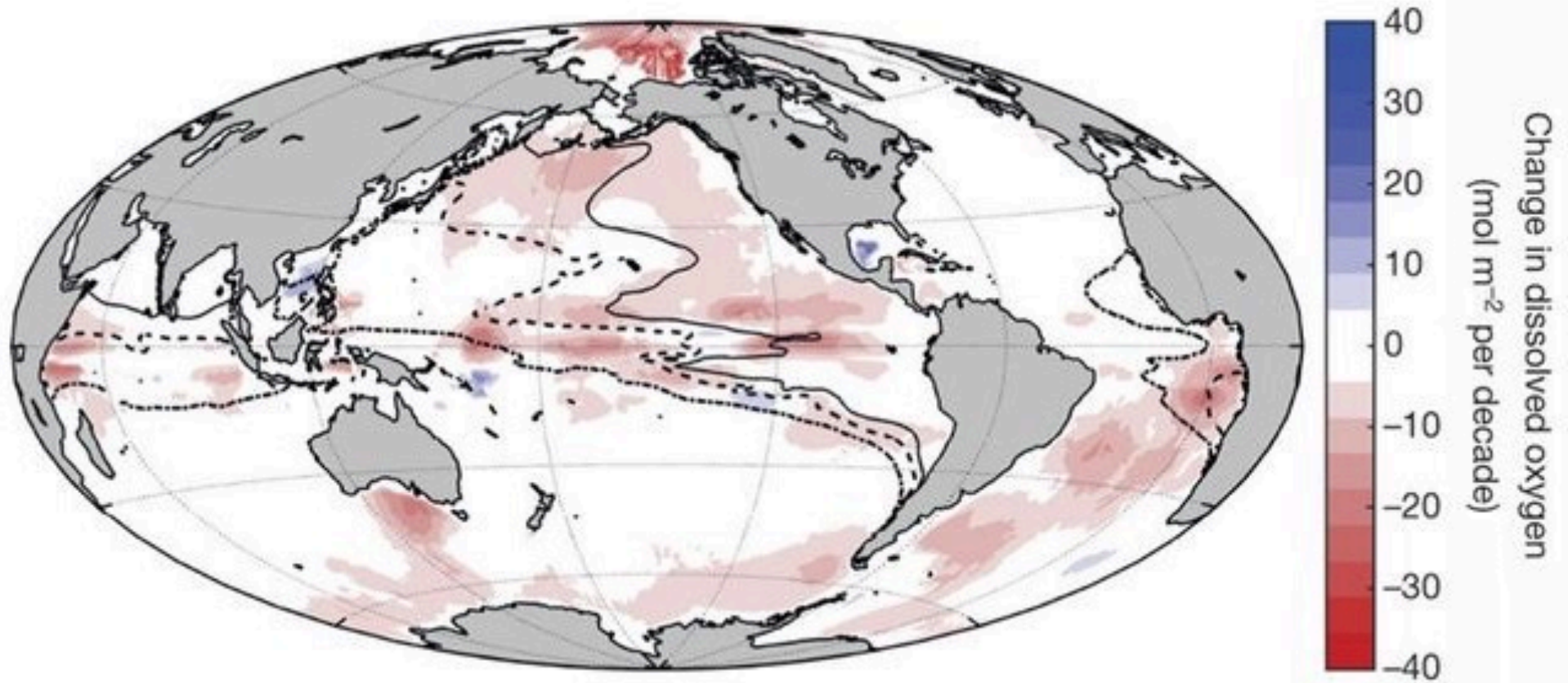


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# The biological carbon pump sequesters carbon on anthropogenic timescales



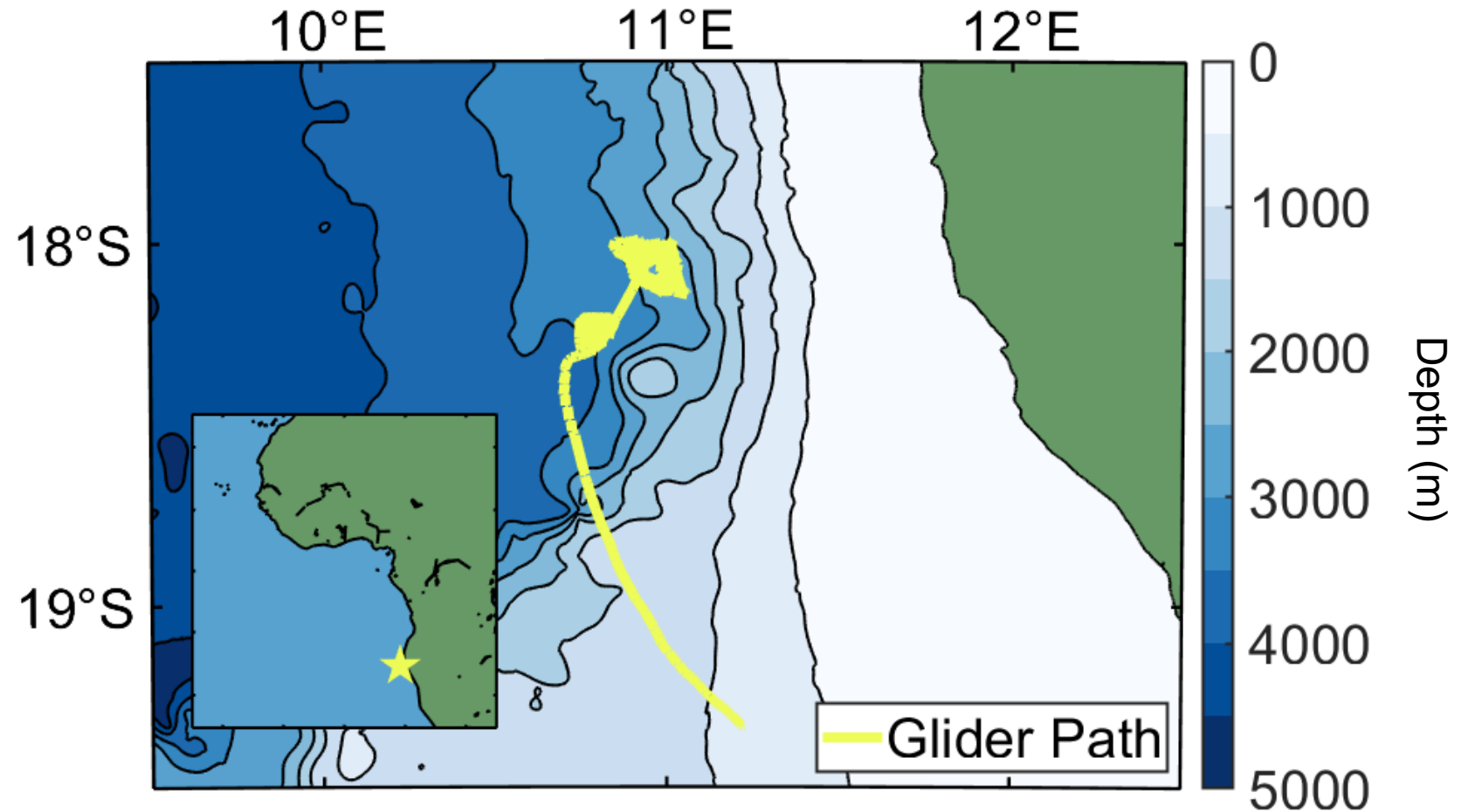
# Globally, ocean oxygen concentrations are decreasing



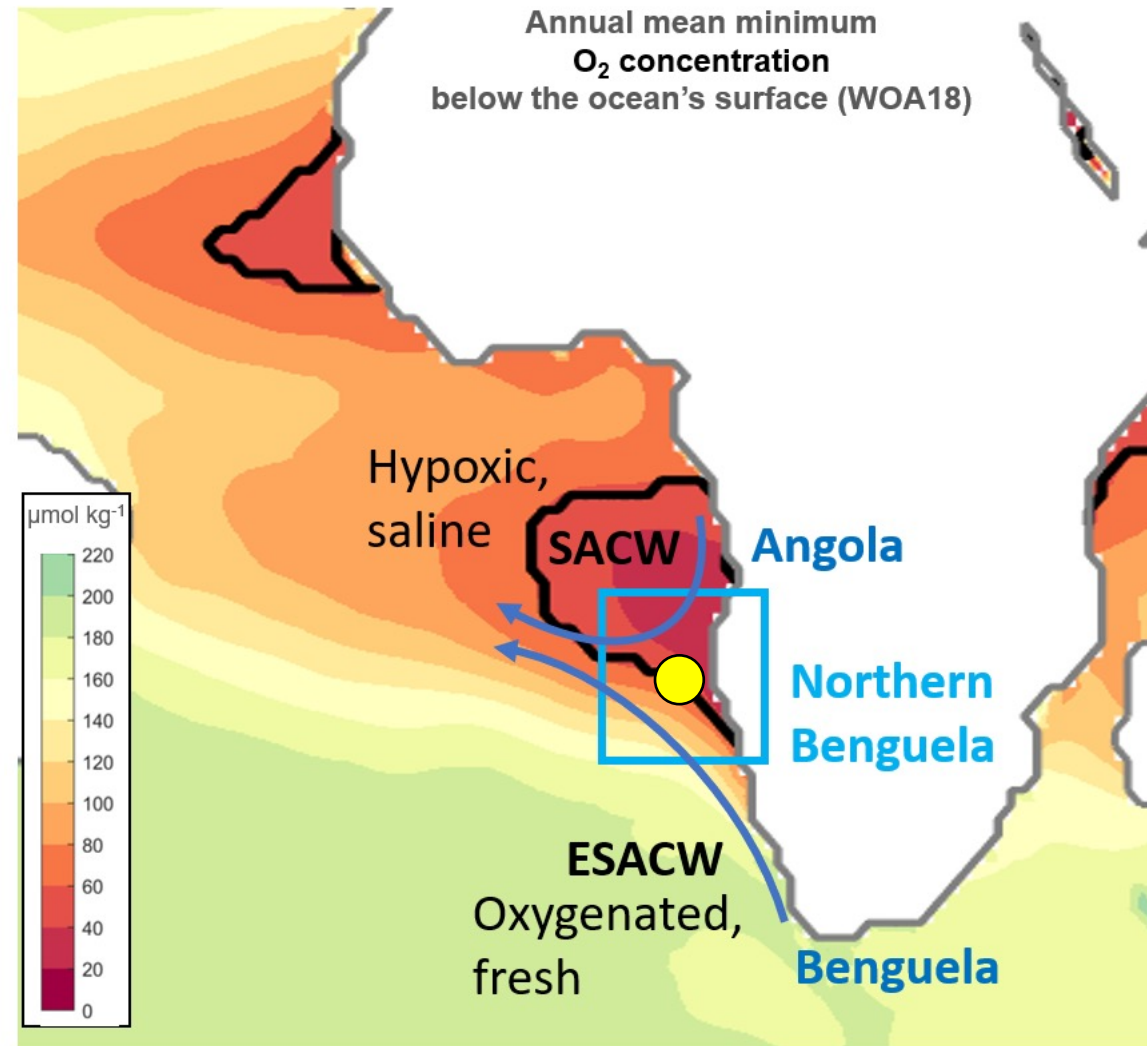


# The northern Benguela Upwelling system is under sampled

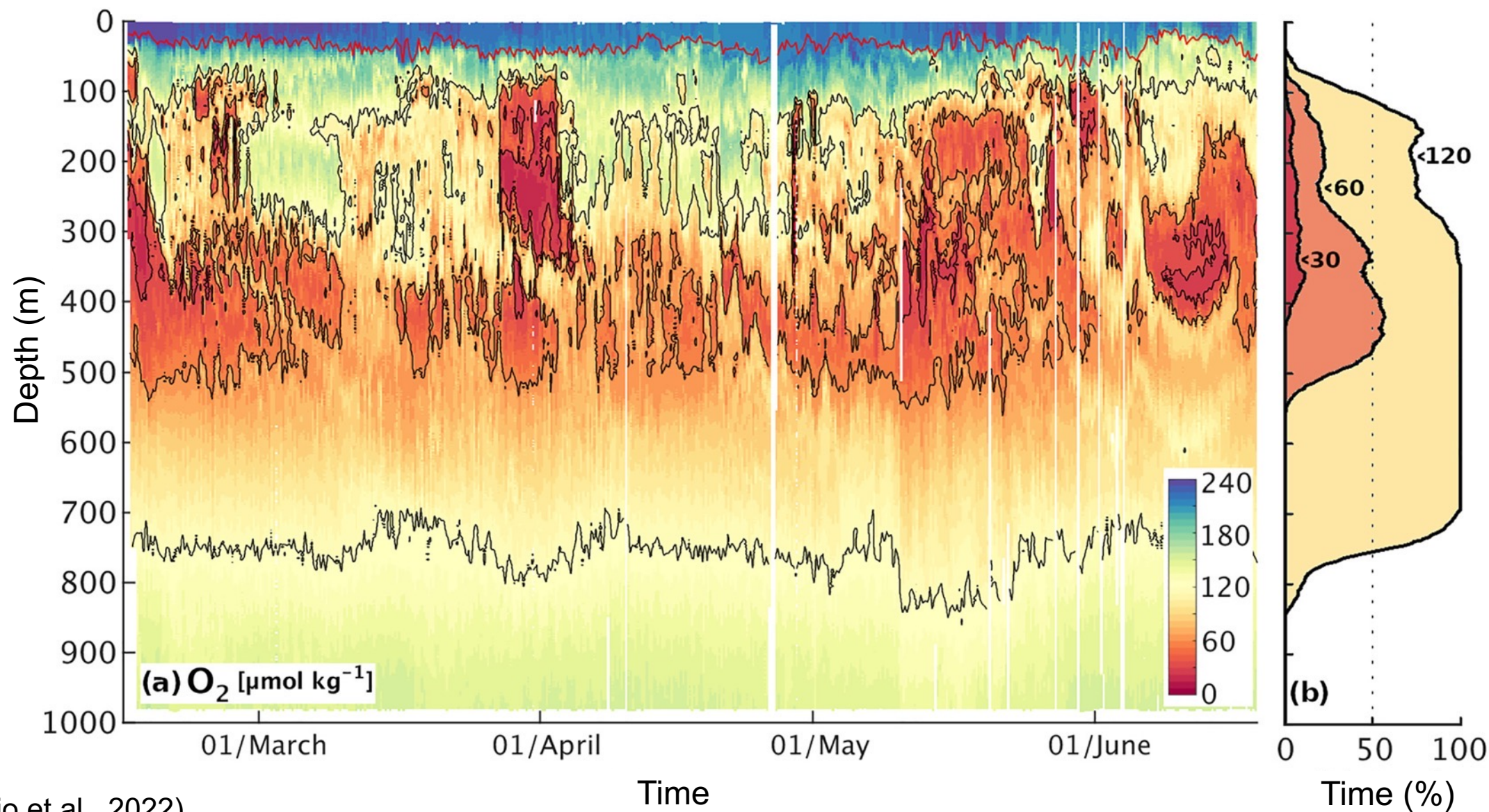
- **4 month** glider deployment
- ~12 km sided triangular path
- ~ 4 profiles per day
- ~100 km offshore



# Confluence of currents leads to dynamic hydrography in the Northern Benguela

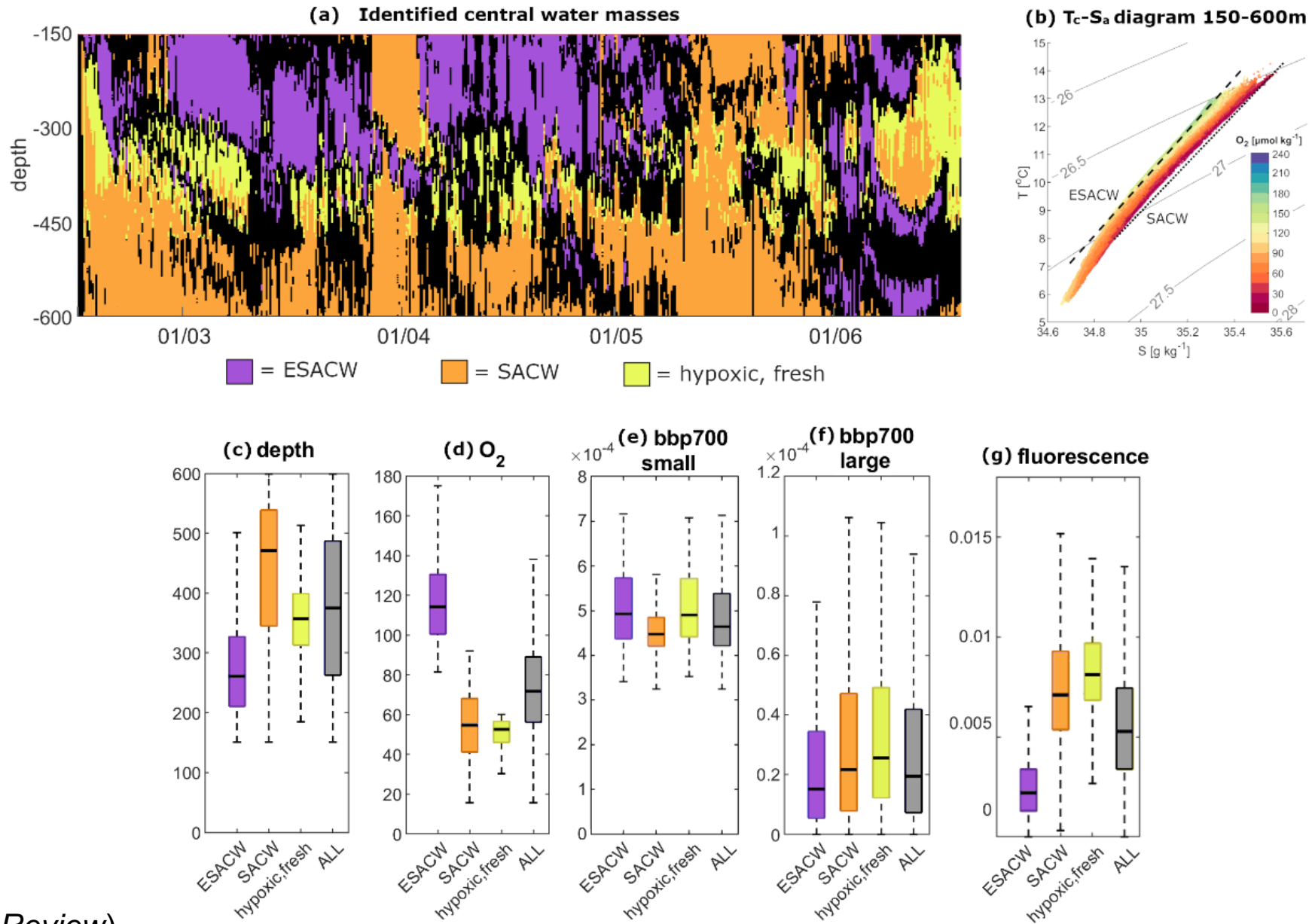


# Highly variable, sub-monthly O<sub>2</sub> fluctuations

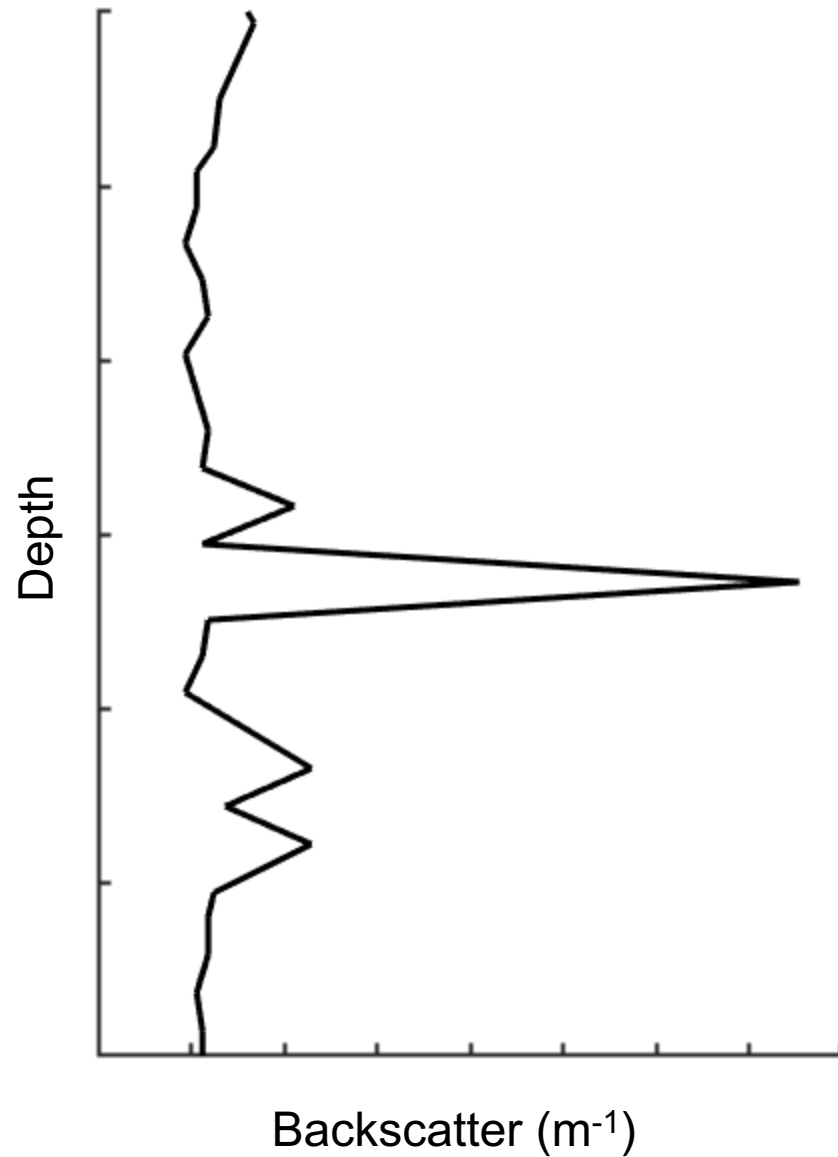




# Backscatter signal is markedly consistent

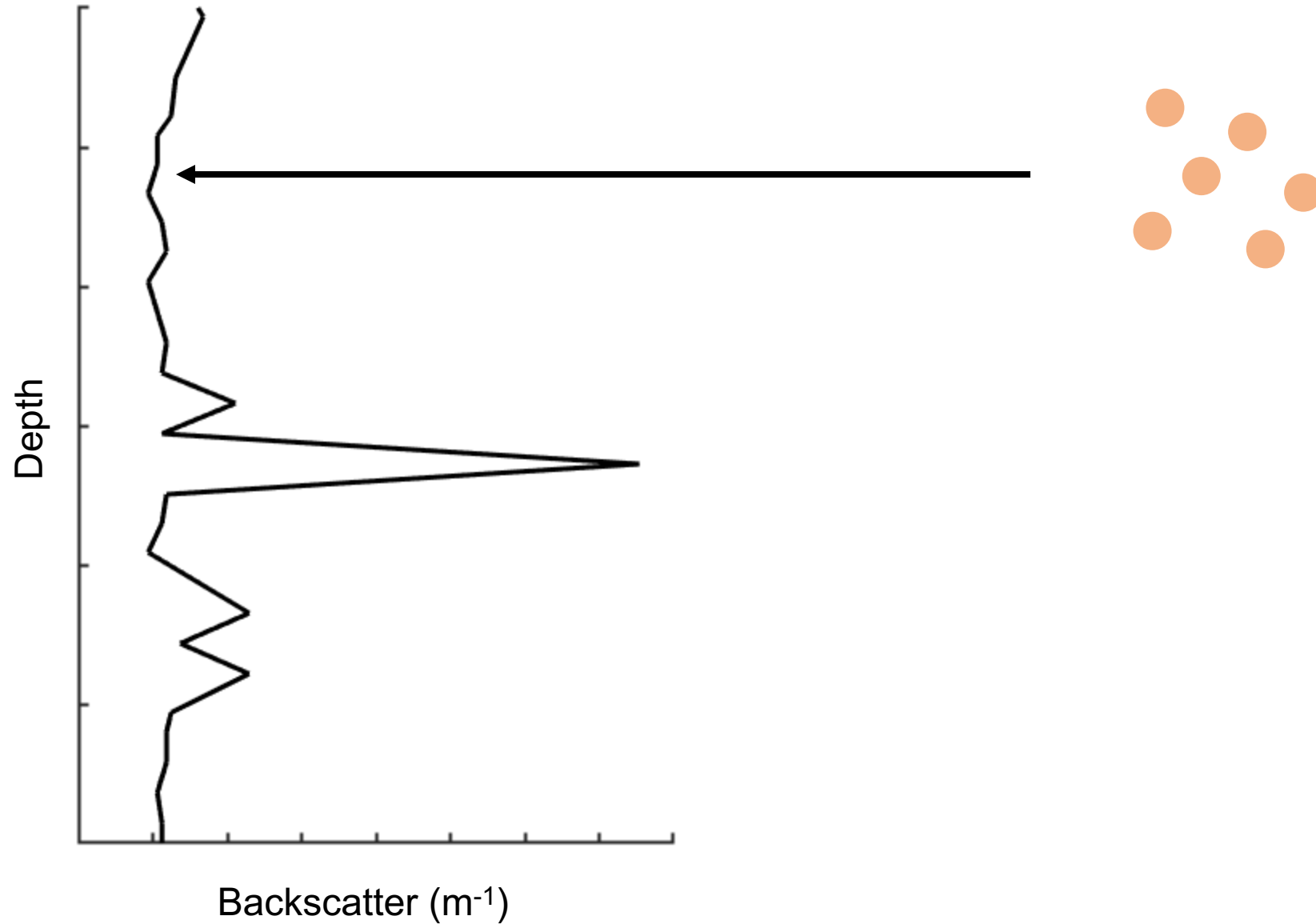


# Backscatter is a proxy for particulate organic carbon

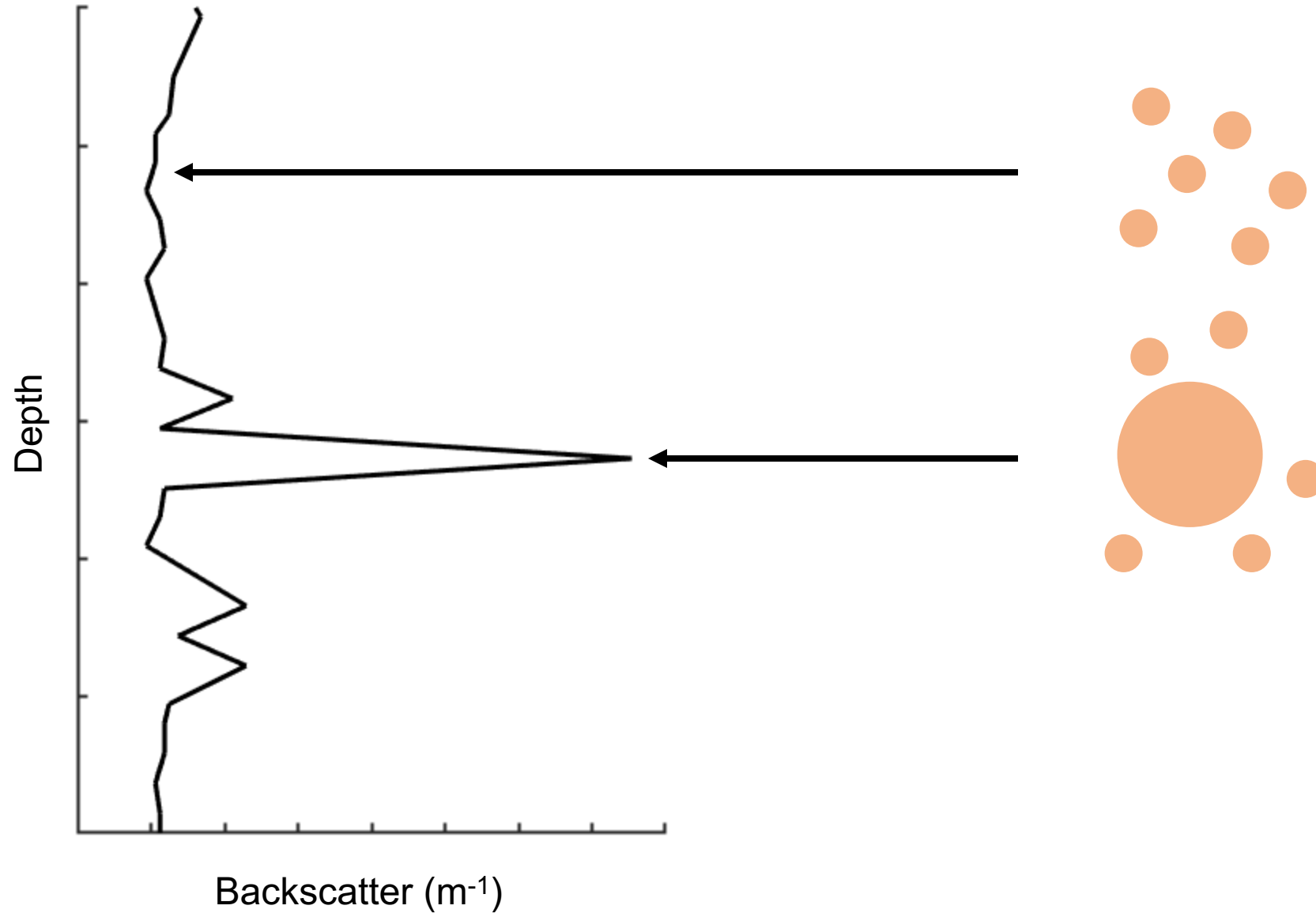




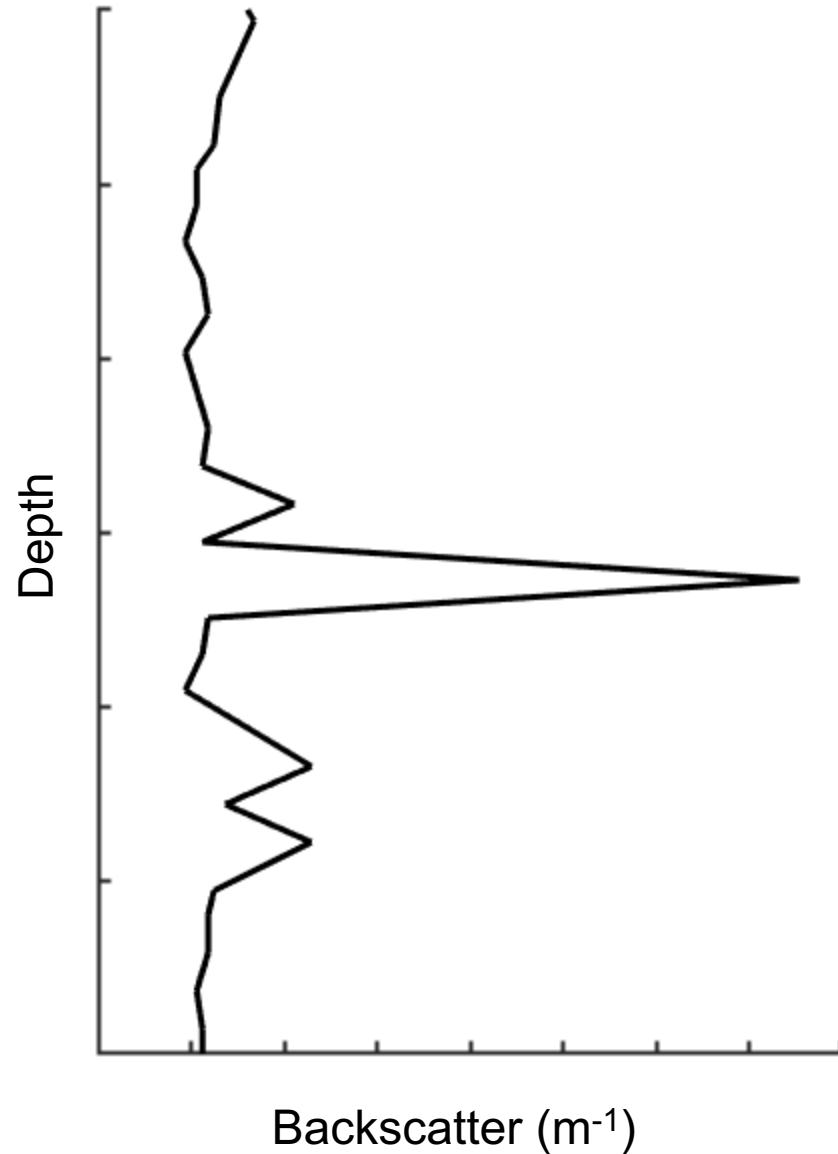
# Backscatter is a proxy for particulate organic carbon



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# Backscatter is a proxy for particulate organic carbon





Deep Sea Research Part I: Oceanographic  
Research Papers

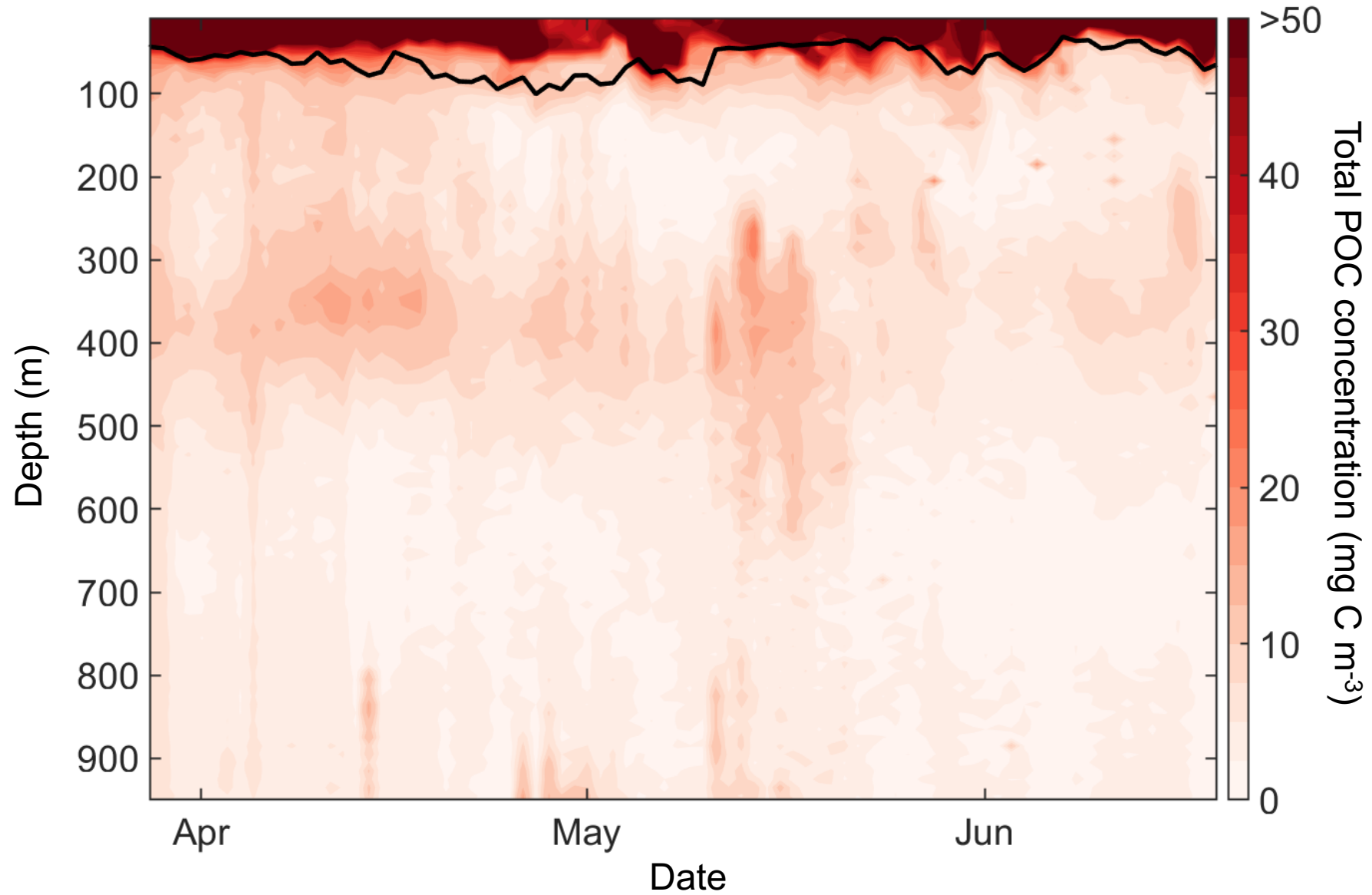
Volume 58, Issue 10, October 2011, Pages 1031-1039



## High-resolution observations of aggregate flux during a sub-polar North Atlantic spring bloom

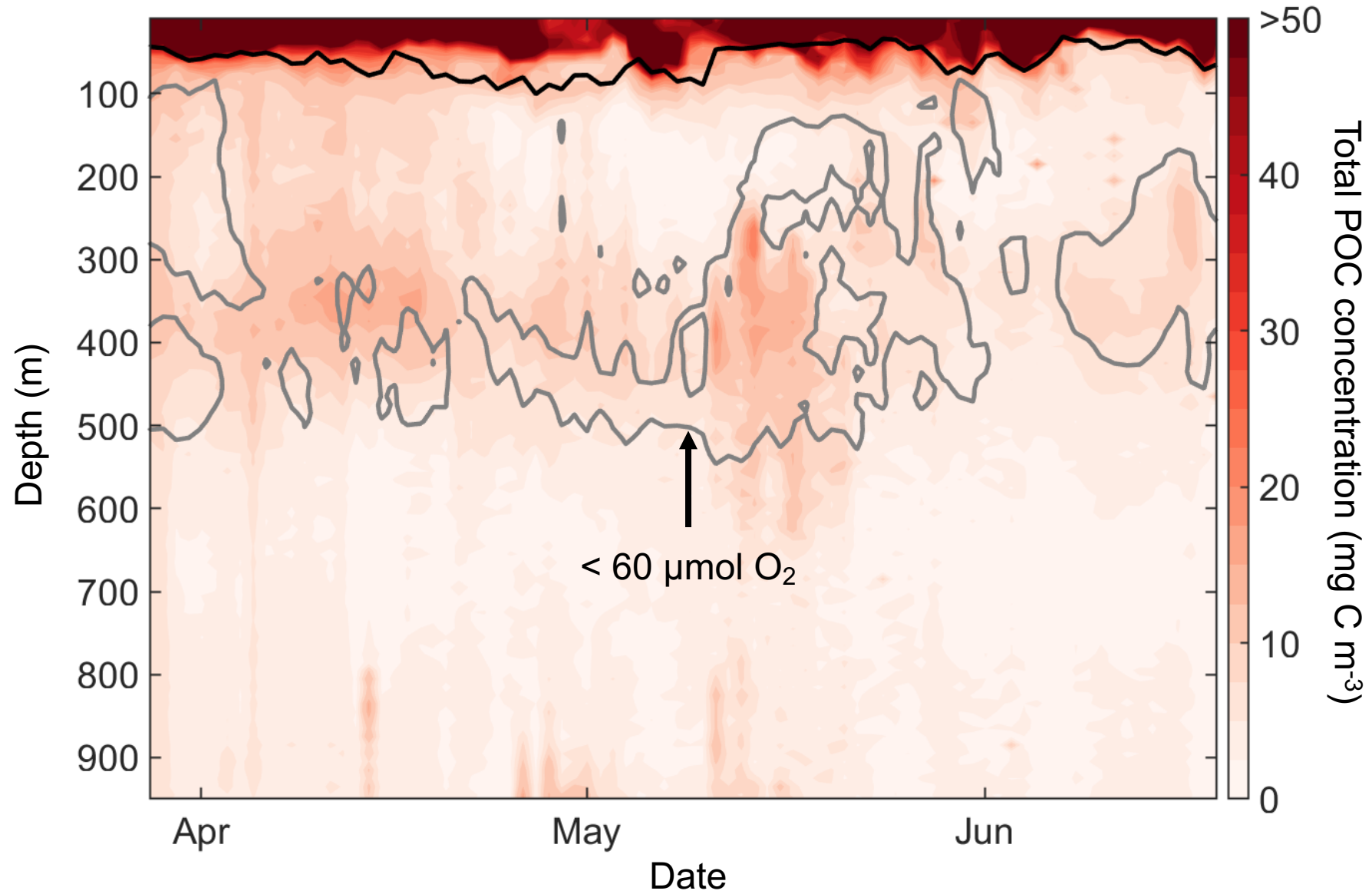
Nathan Briggs<sup>a</sup>  , Mary Jane Perry<sup>a</sup>, Ivona Cetinić<sup>a</sup>, Craig Lee<sup>b</sup>, Eric D'Asaro<sup>b</sup>,  
Amanda M. Gray<sup>b</sup>, Eric Rehm<sup>b</sup>

# An intermediate layer of POC in Benguela

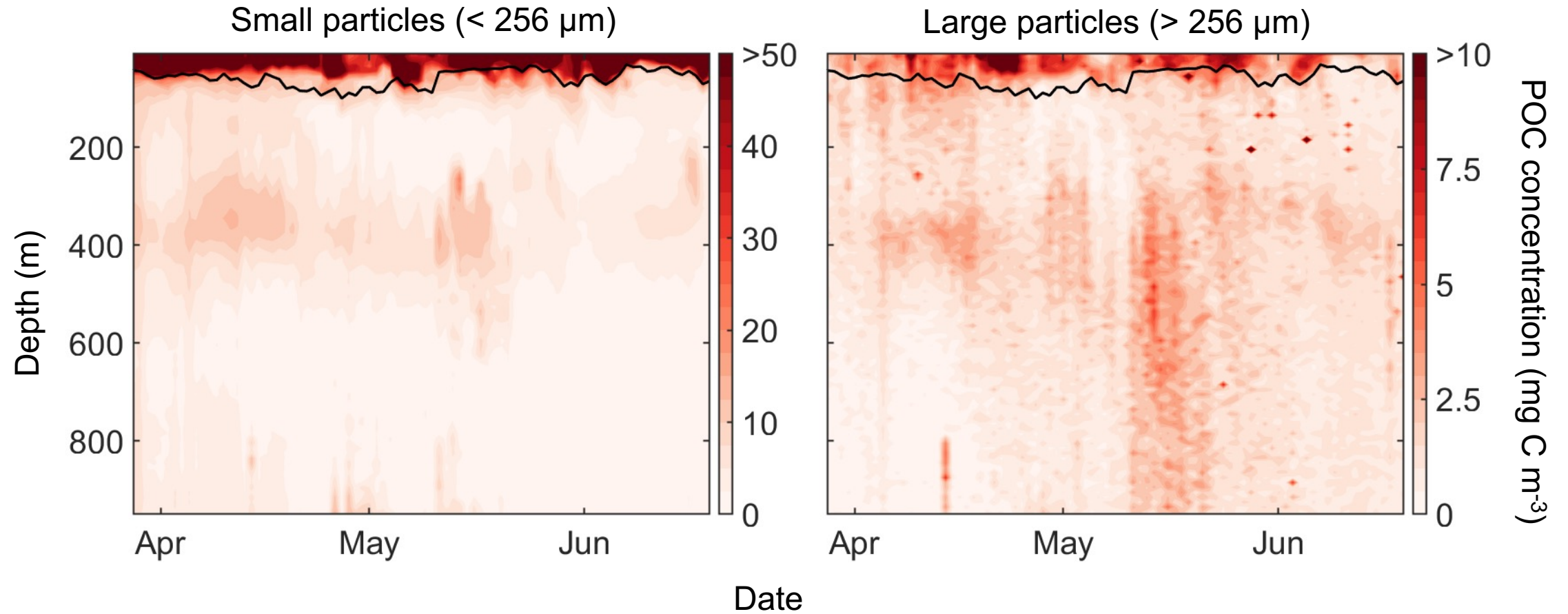




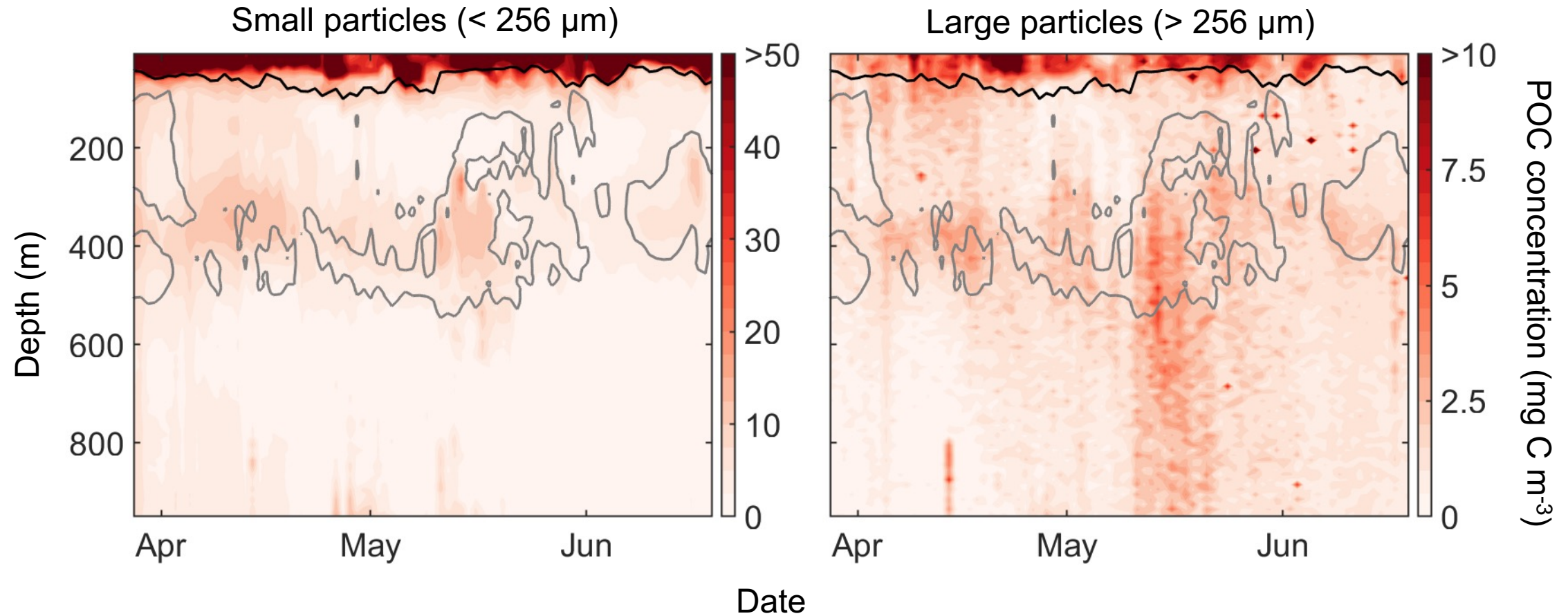
# An intermediate layer of POC in Benguela



# POC contribution from both small and large particles

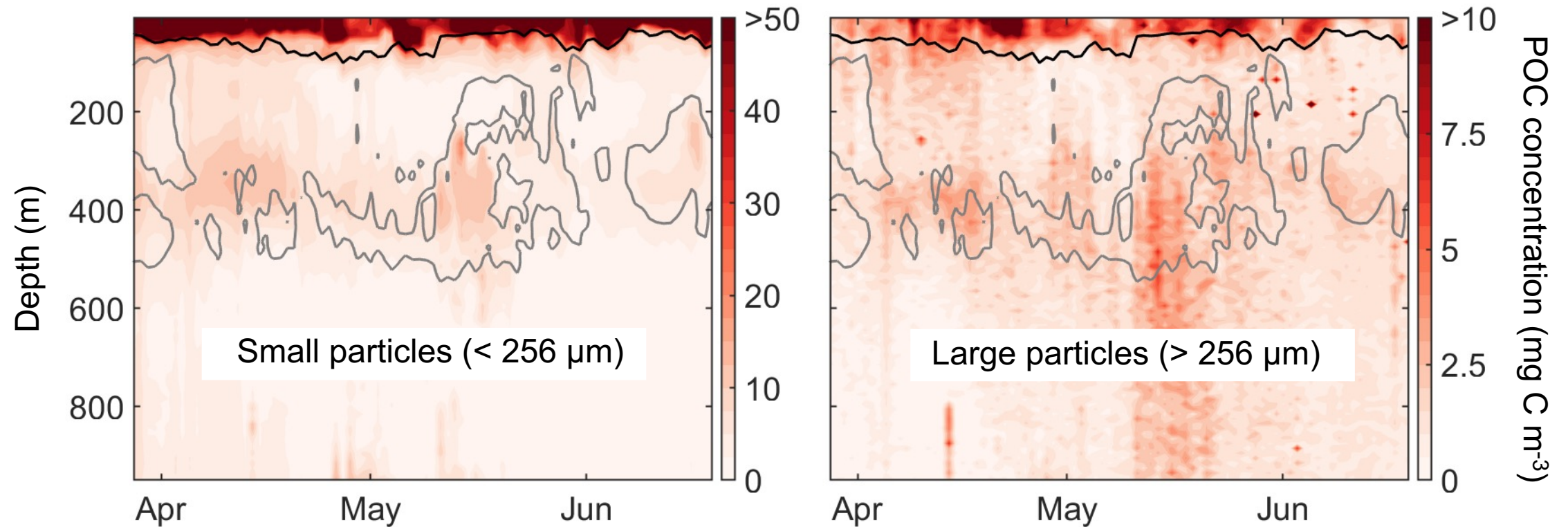


# POC concentrations increase by $4 \text{ mg C m}^{-3}$ in the upper mesopelagic



- Intermediate layer is **present** in **both oxic** and **hypoxic** states, **composed** of **both small** and **large** particles.

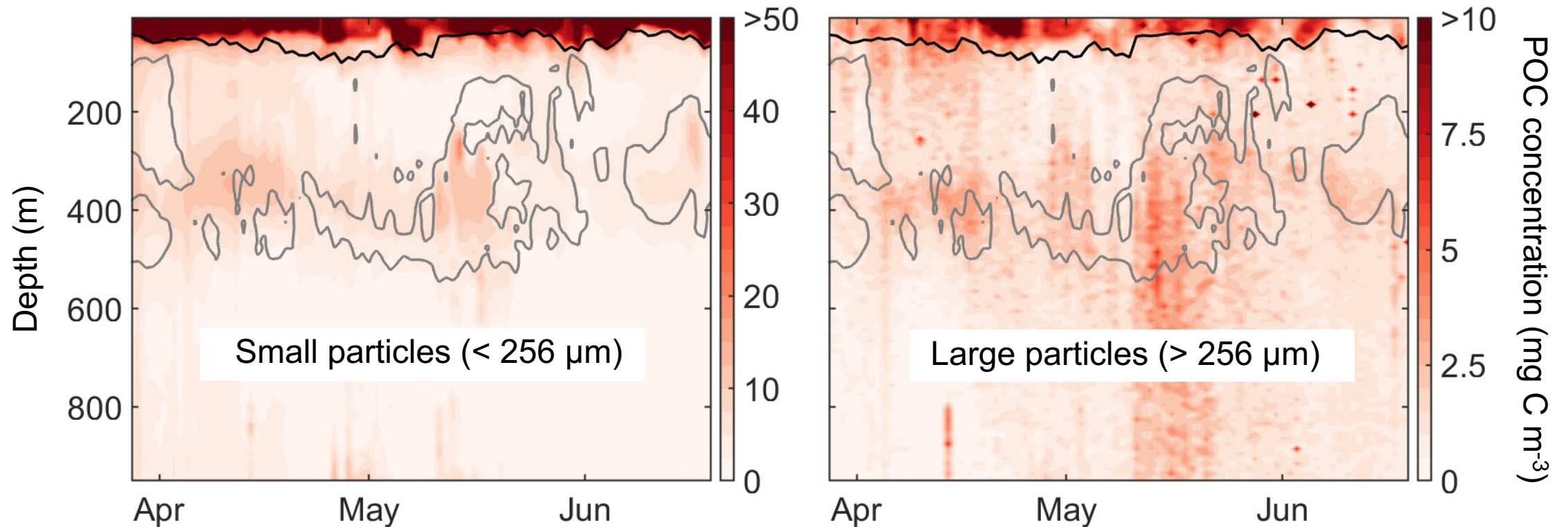
# Explaining an intermediate particle layer





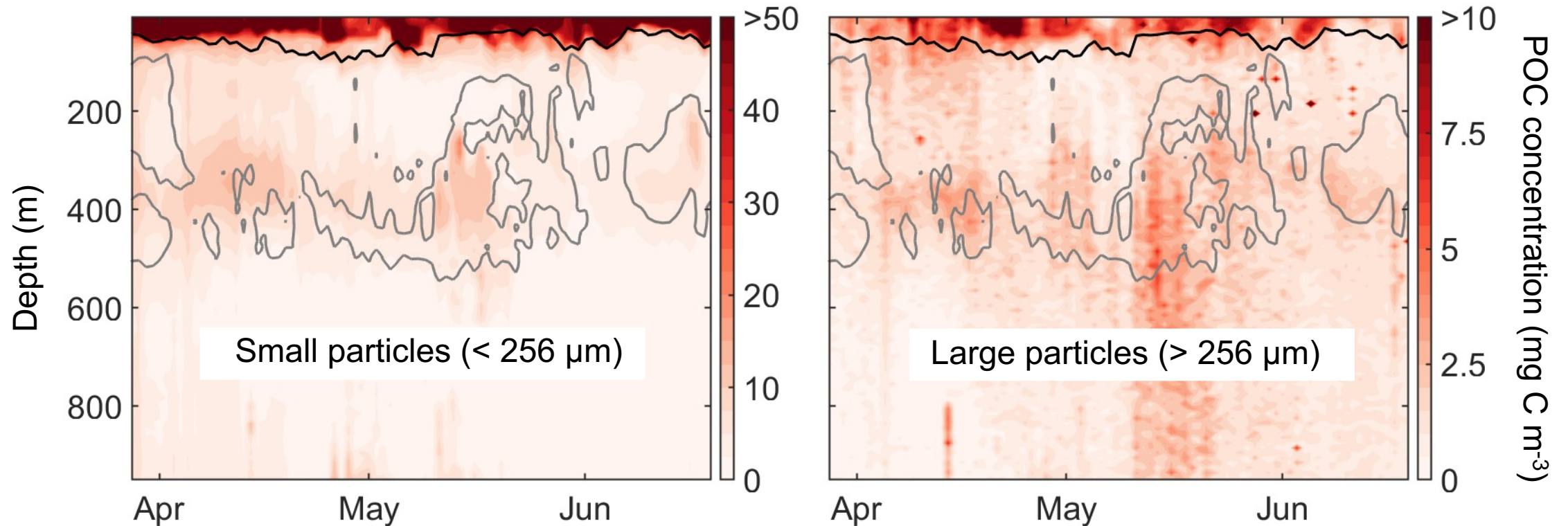
# Explaining an intermediate particle layer

- Lateral **advection/subduction** of sinking POC?



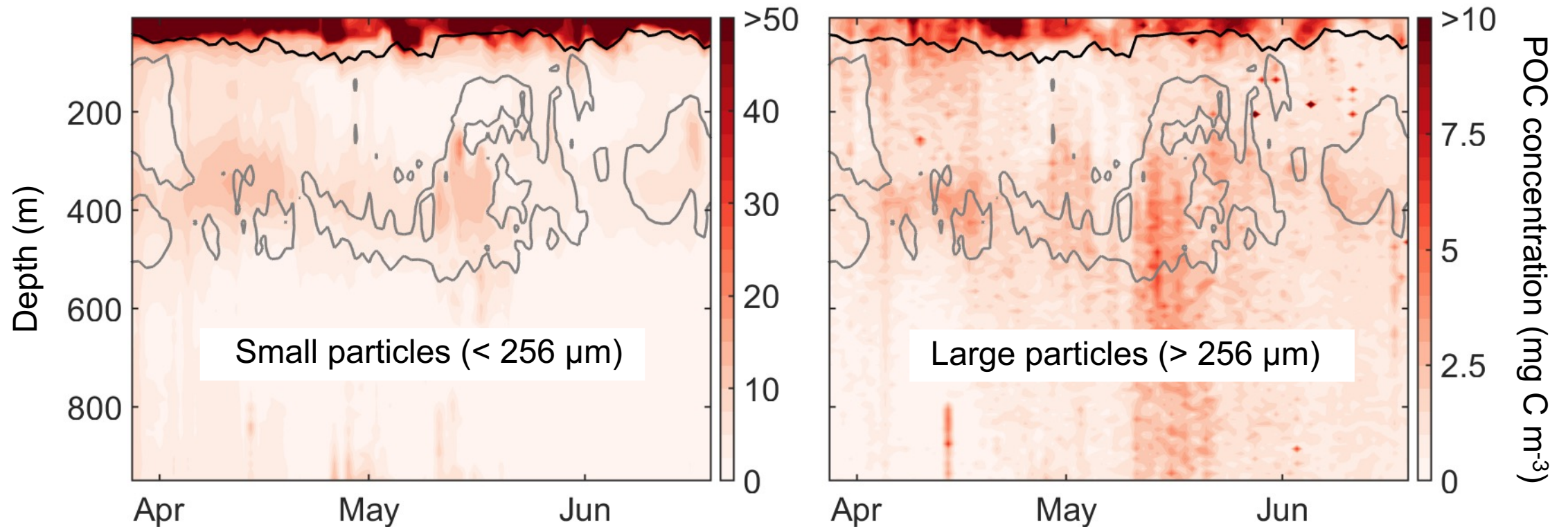
# Explaining an intermediate particle layer

- Lateral advection/subduction of sinking POC?
- **Resuspension** of shelf material?



# Explaining an intermediate particle layer

- Lateral advection/subduction of sinking POC?
- Resuspension of shelf material?
- **Biological activity** in the mesopelagic?



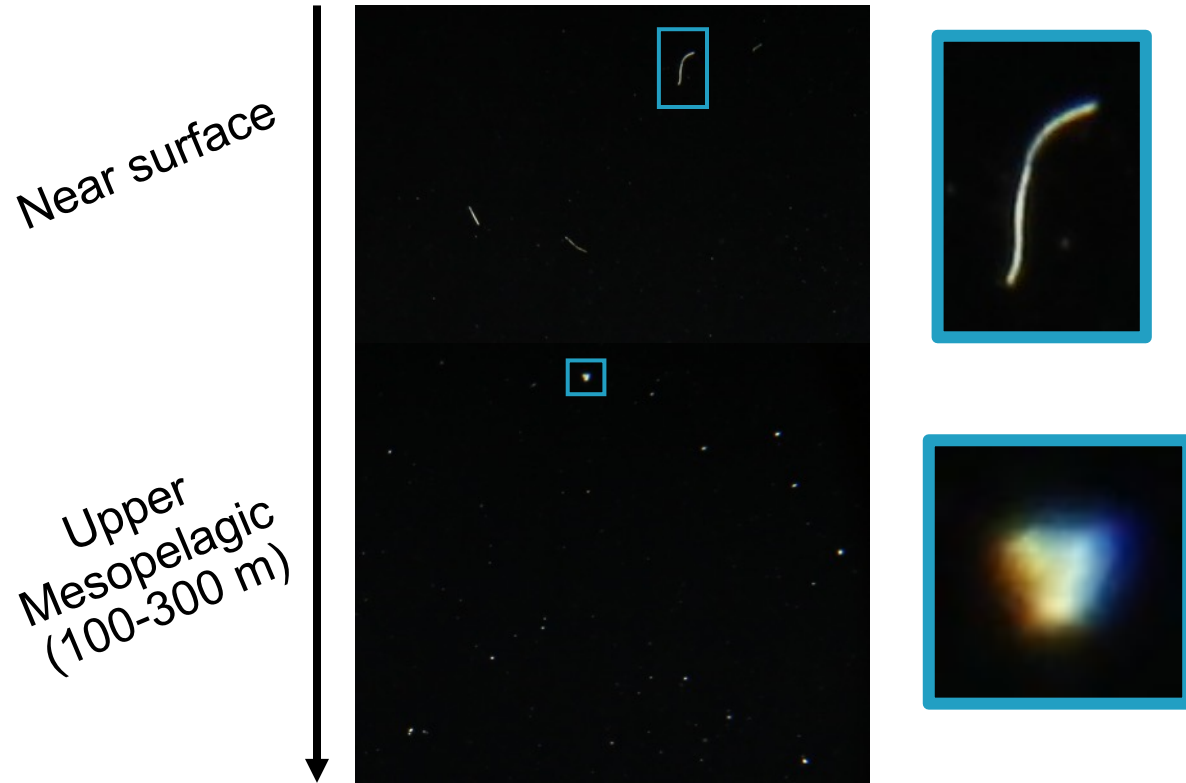
# P-CAM images suggest a biological explanation



- Faecal pellets in near surface

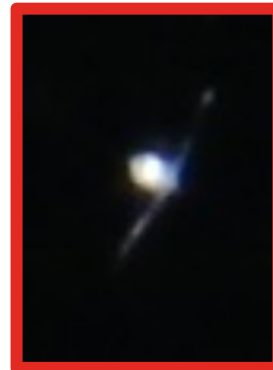
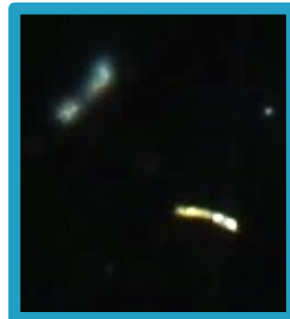
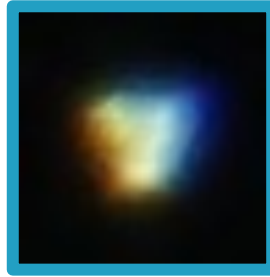
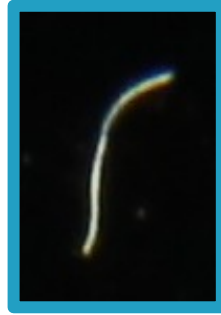
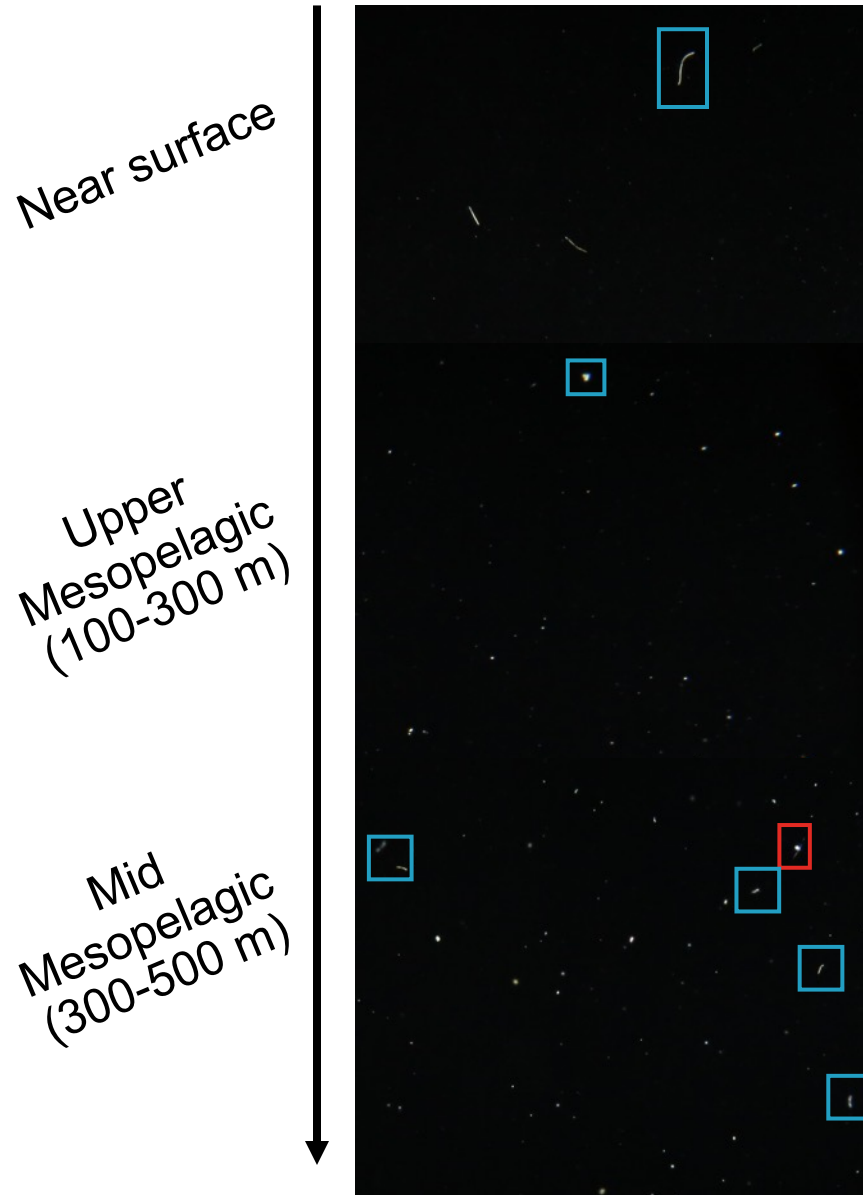


# P-CAM images suggest a biological explanation



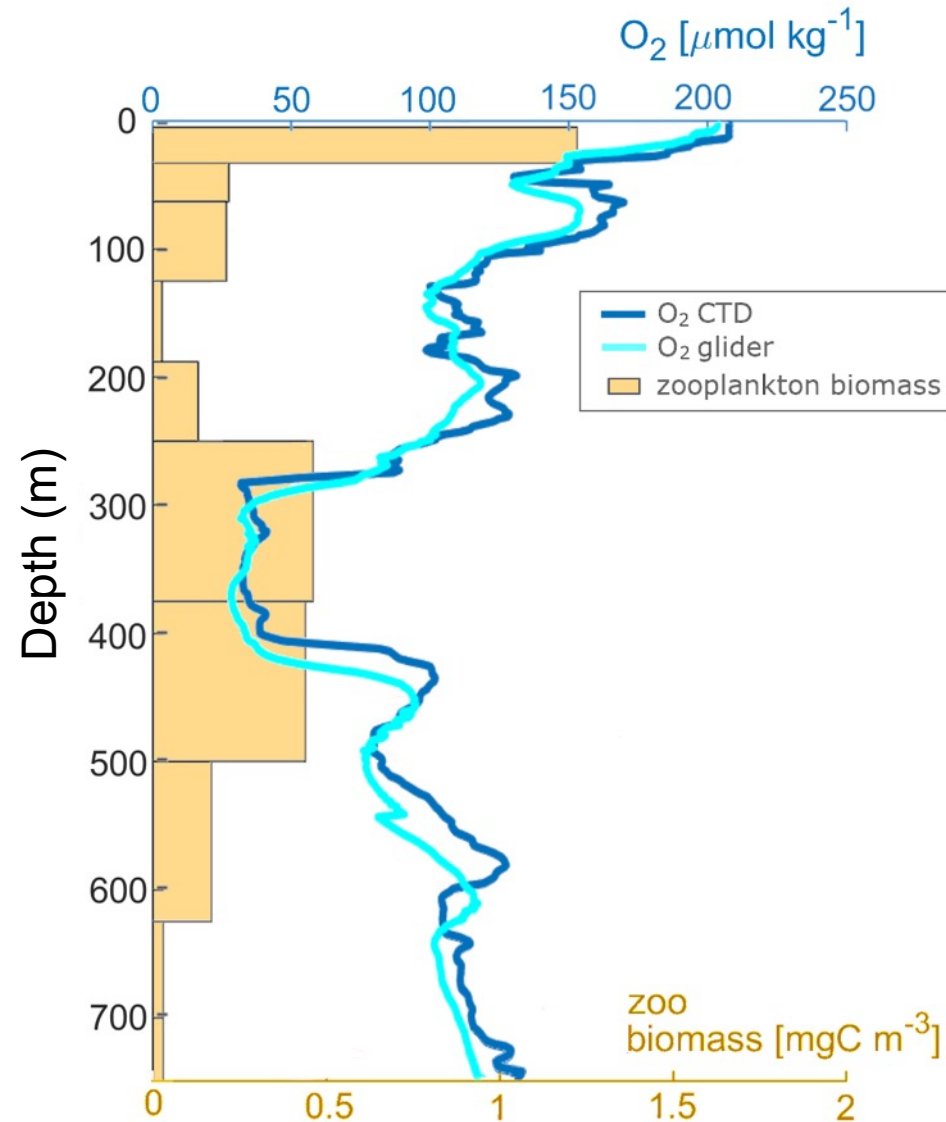
- Faecal pellets in near surface
- Aggregates in upper mesopelagic

# P-CAM images suggest a biological explanation

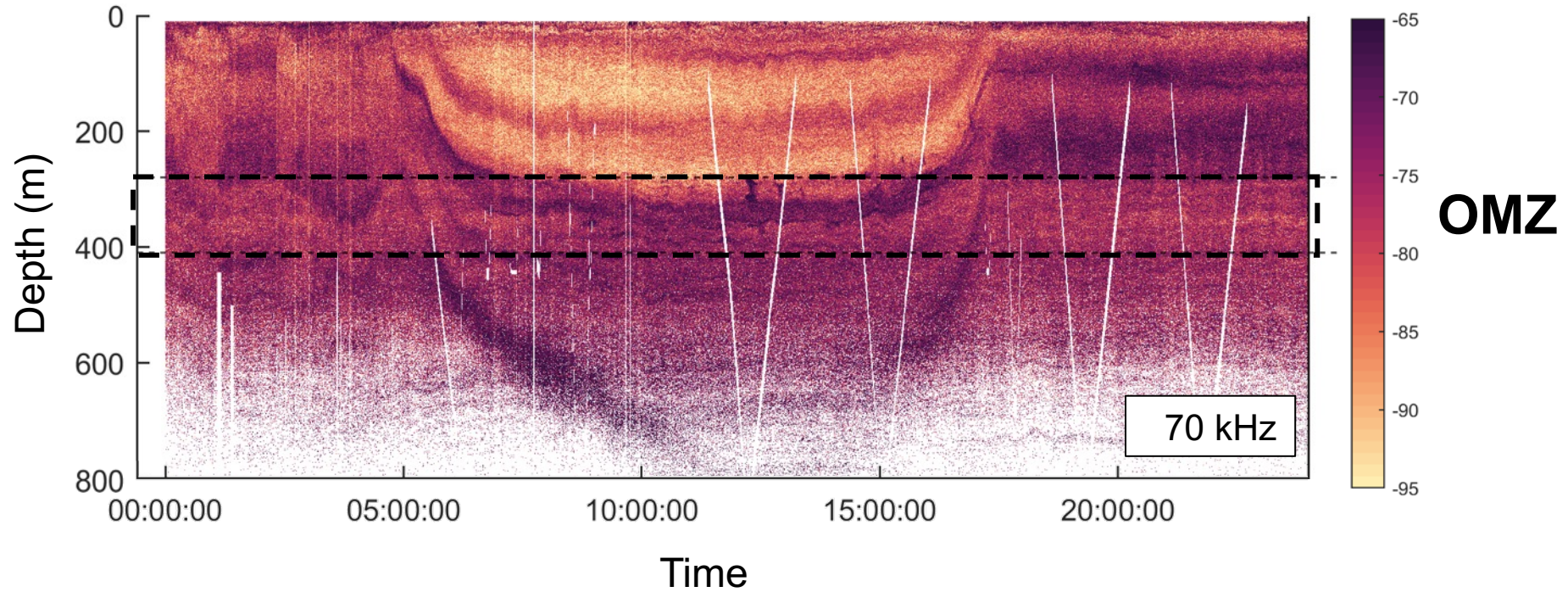


- Faecal pellets in near surface
- Aggregates in upper mesopelagic
- Zooplankton, faecal pellets, and aggregates in mid mesopelagic

# Resident zooplankton community within intermediate layer



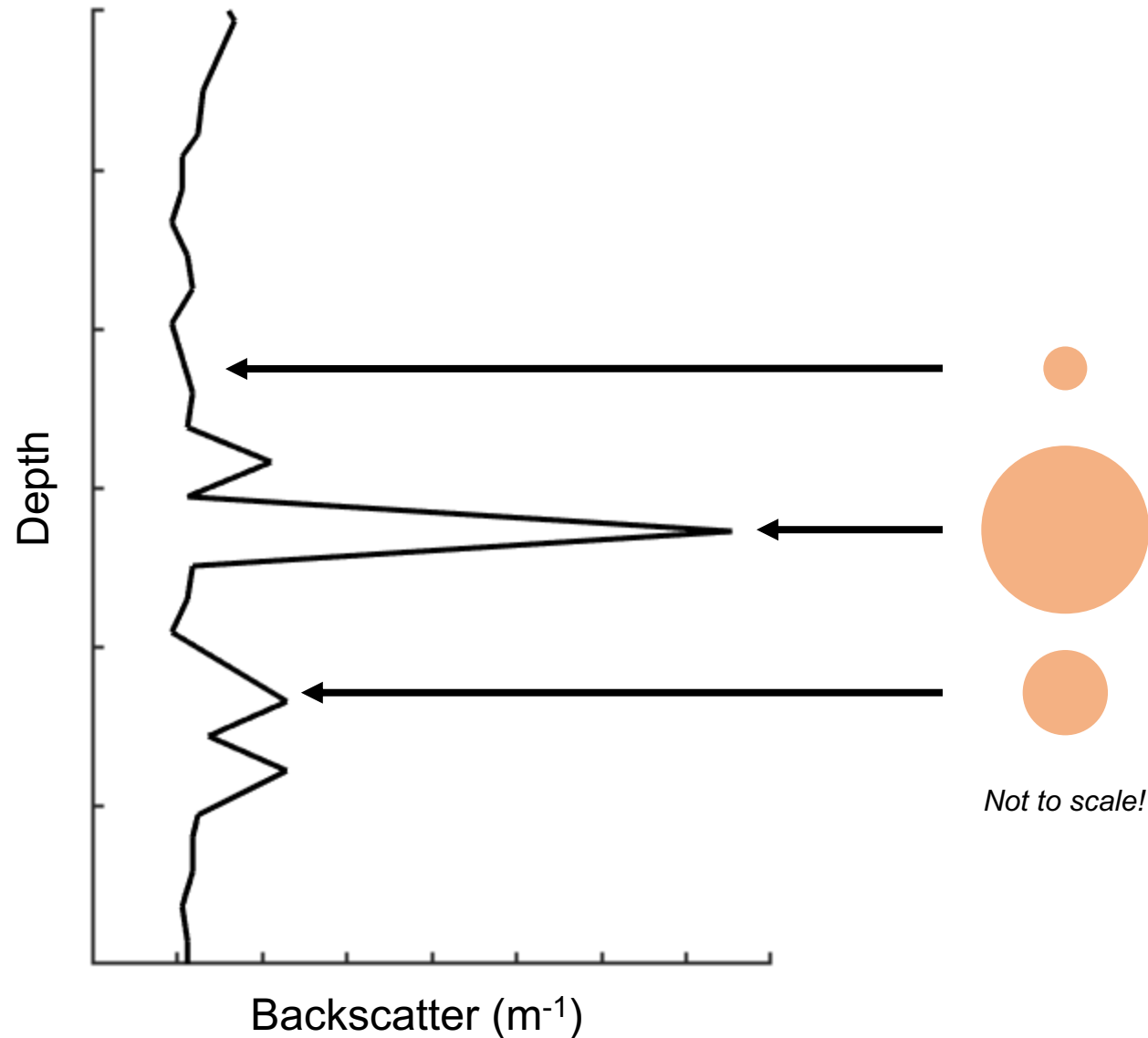
# Sustained by larger diel vertical migrators





**What does this mean for POC flux?**

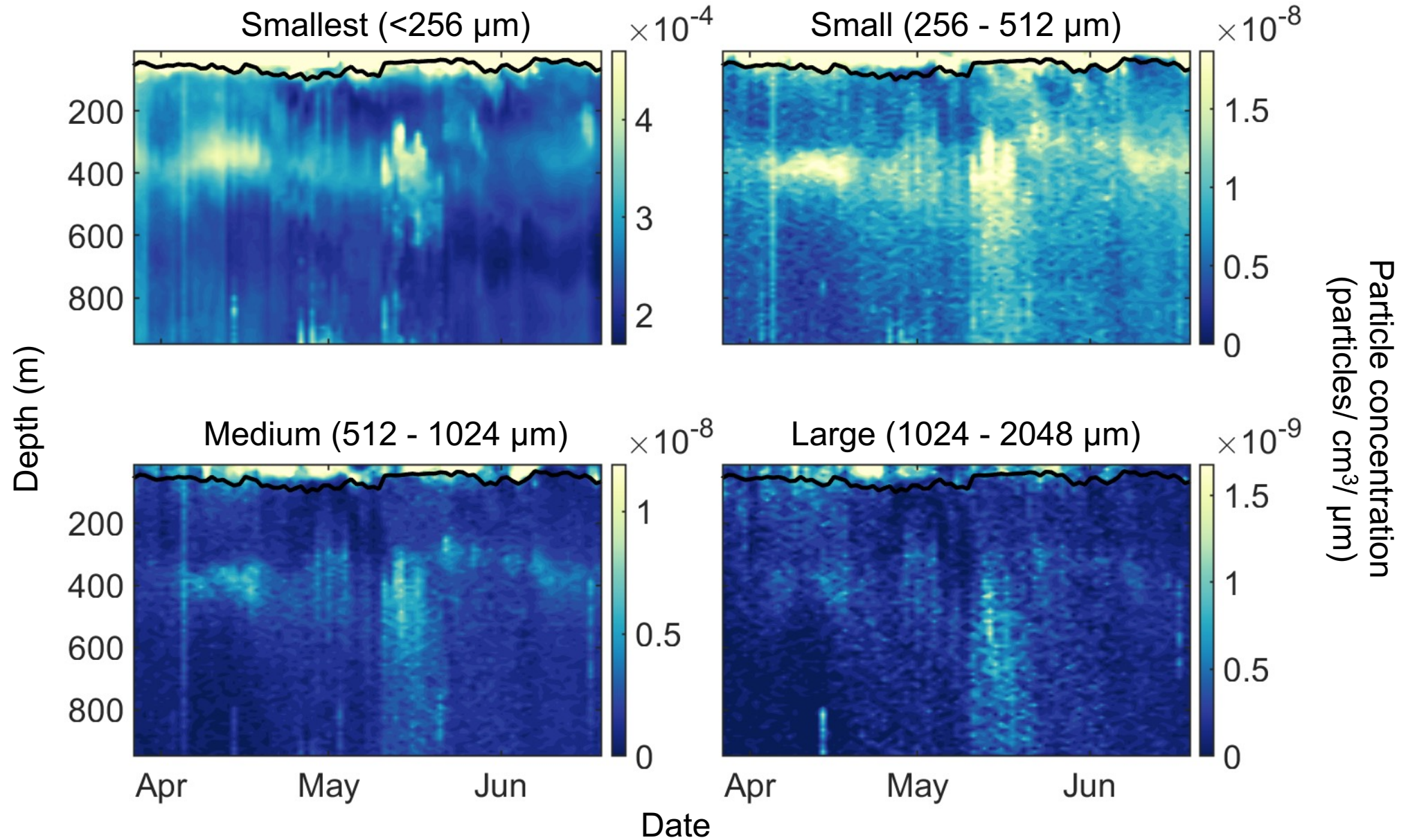
# Additional size classes can be resolved from backscatter signal



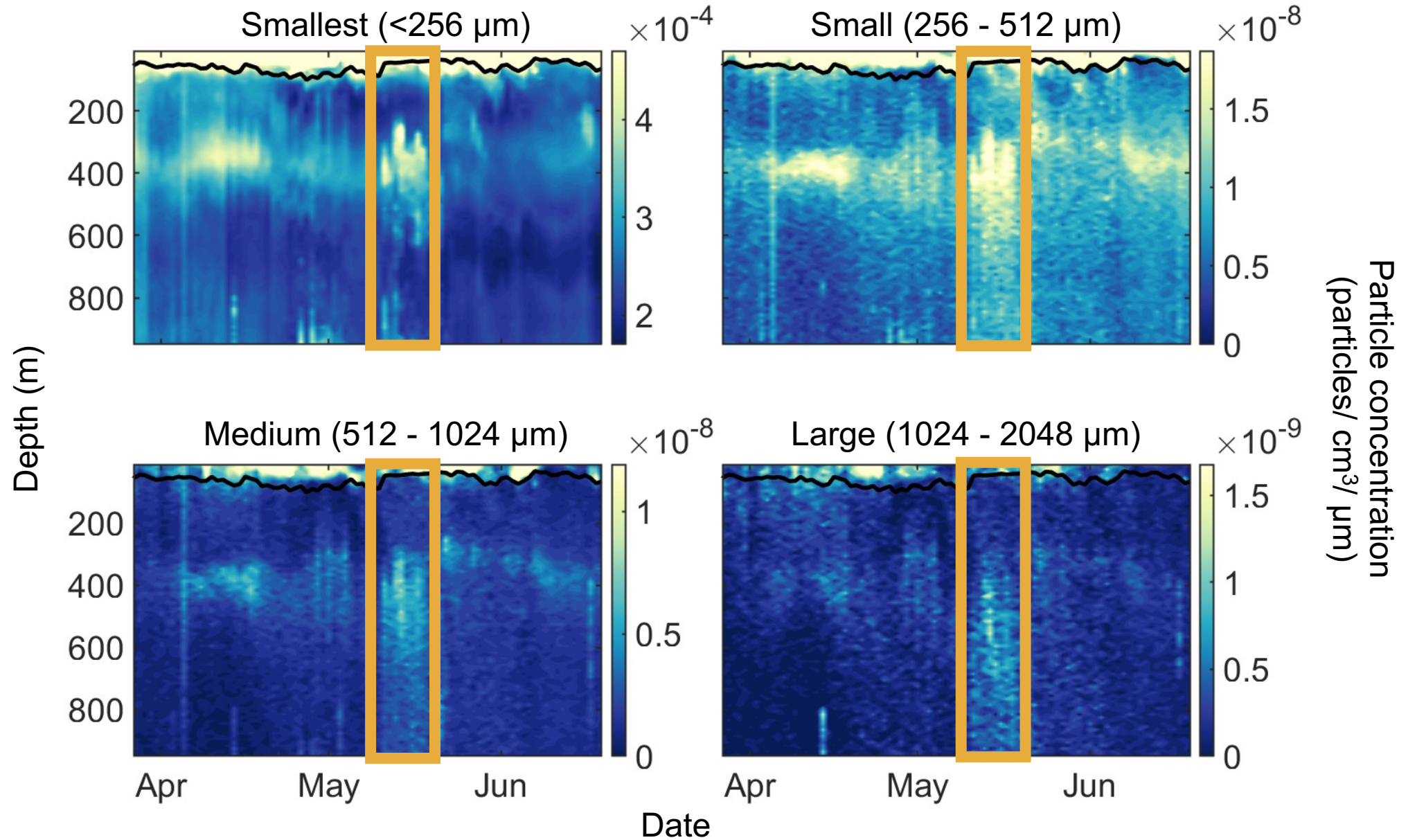
- Relate **spike height**, to **equivalent spherical diameter**

Method in development,  
*Nathan Briggs*

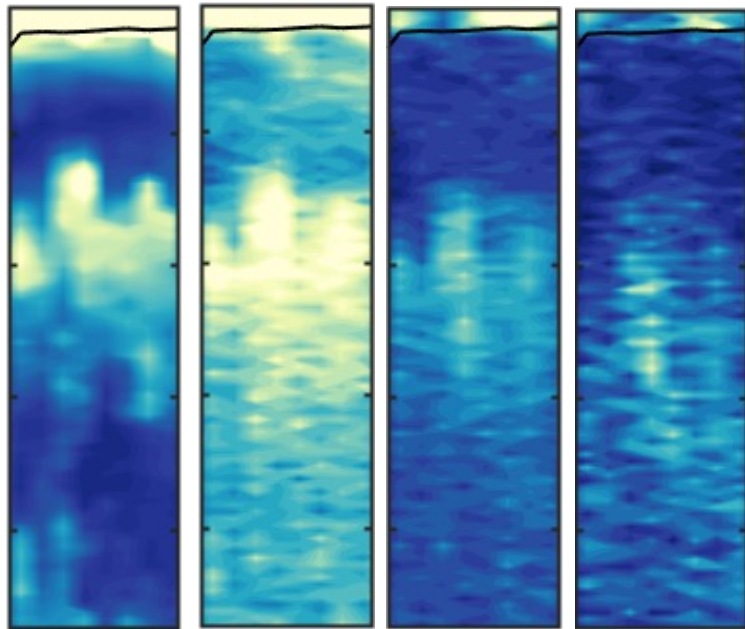
# Splitting backscatter signal reveals structure of the intermediate layer



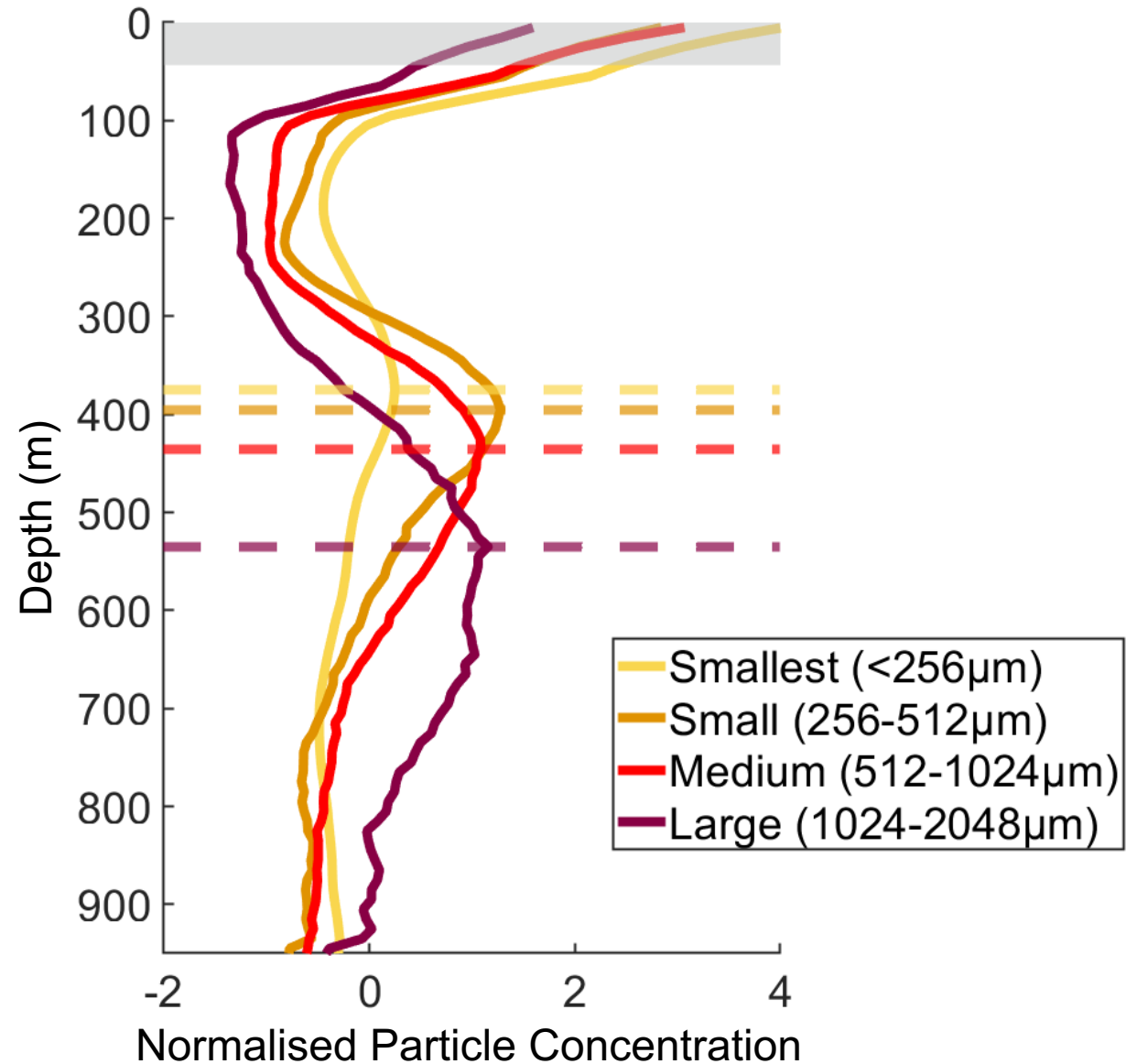
# Splitting backscatter signal reveals structure of the intermediate layer



# Layering of particle sizes inconsistent with particle fragmentation

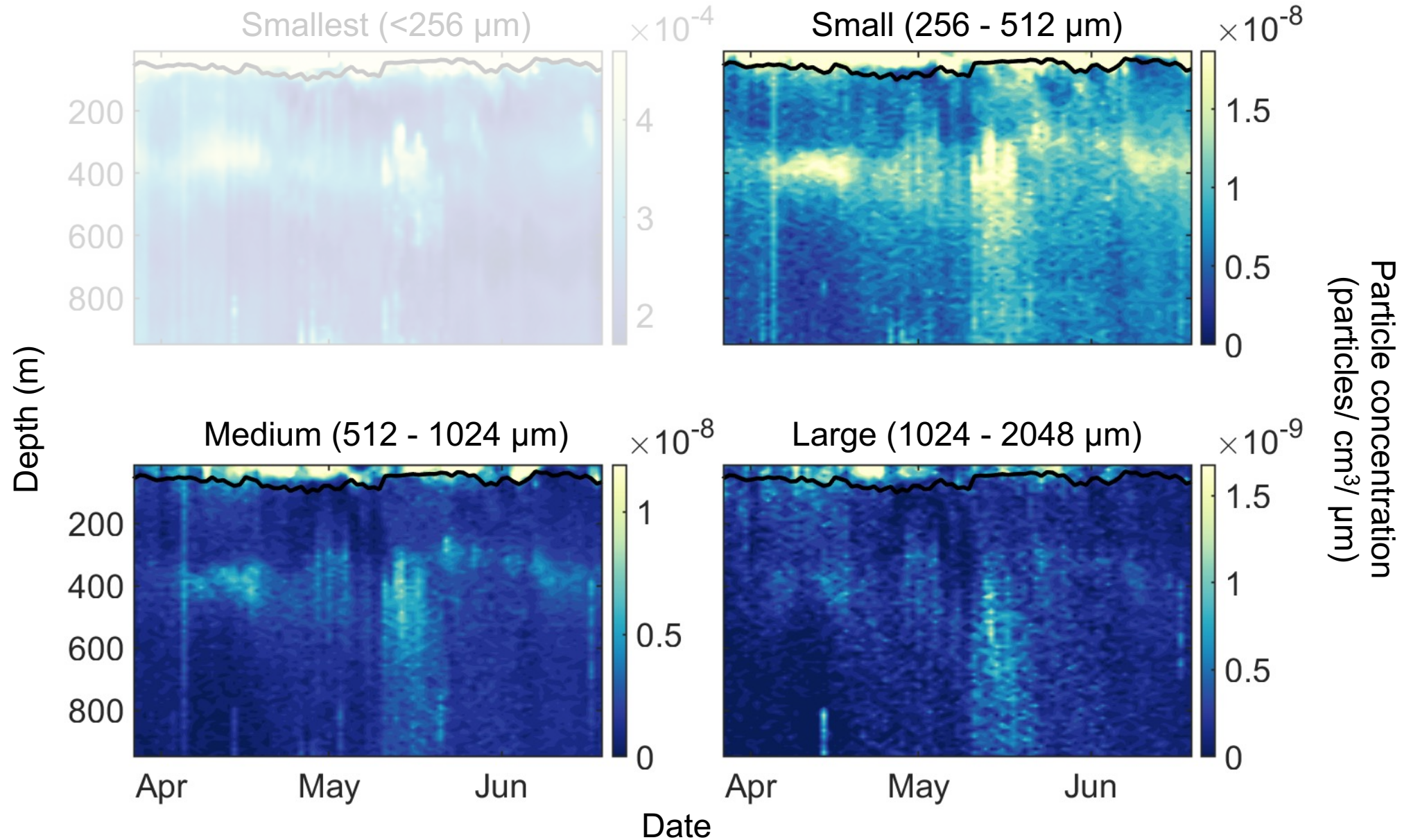


Particle size

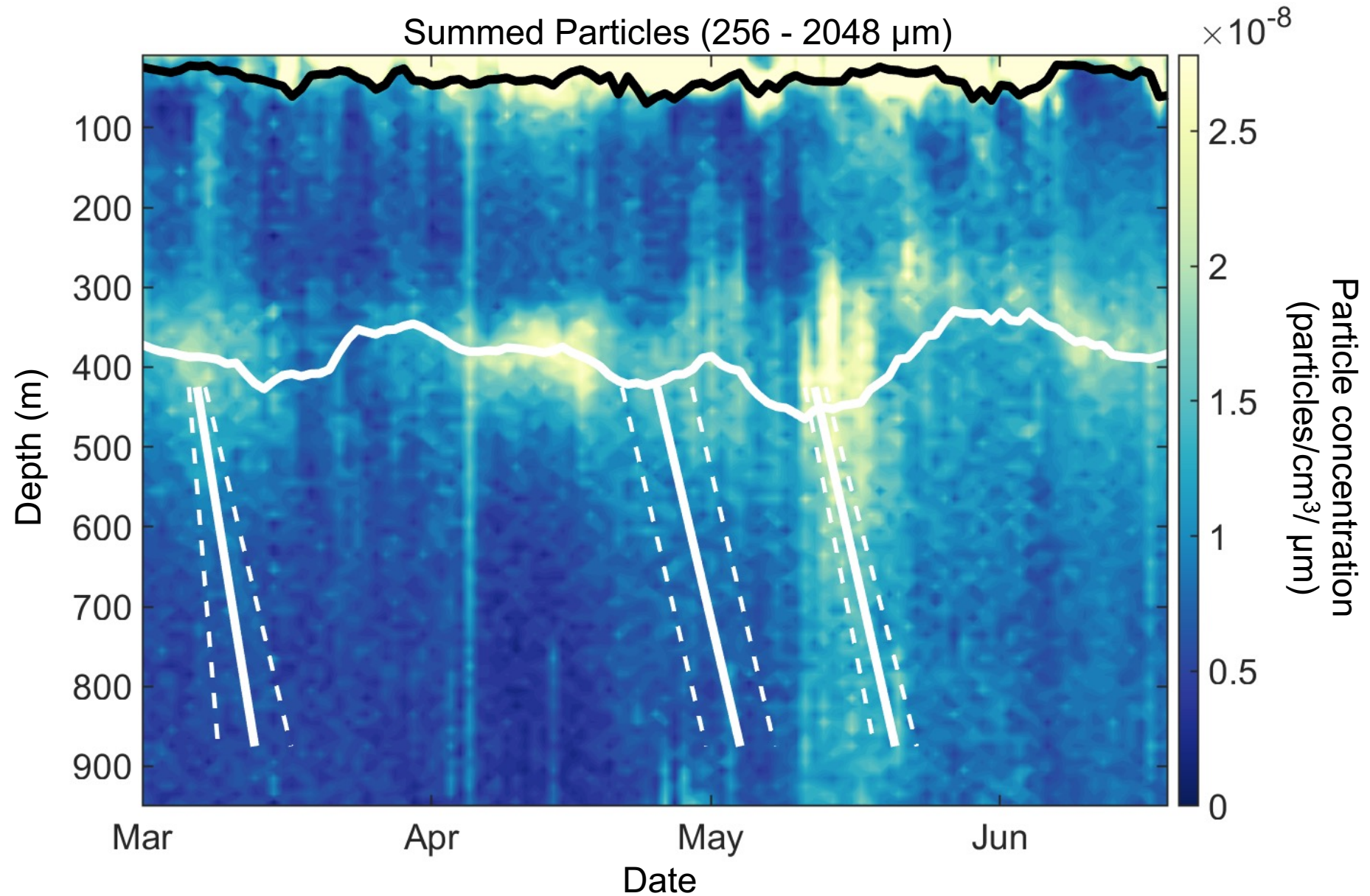




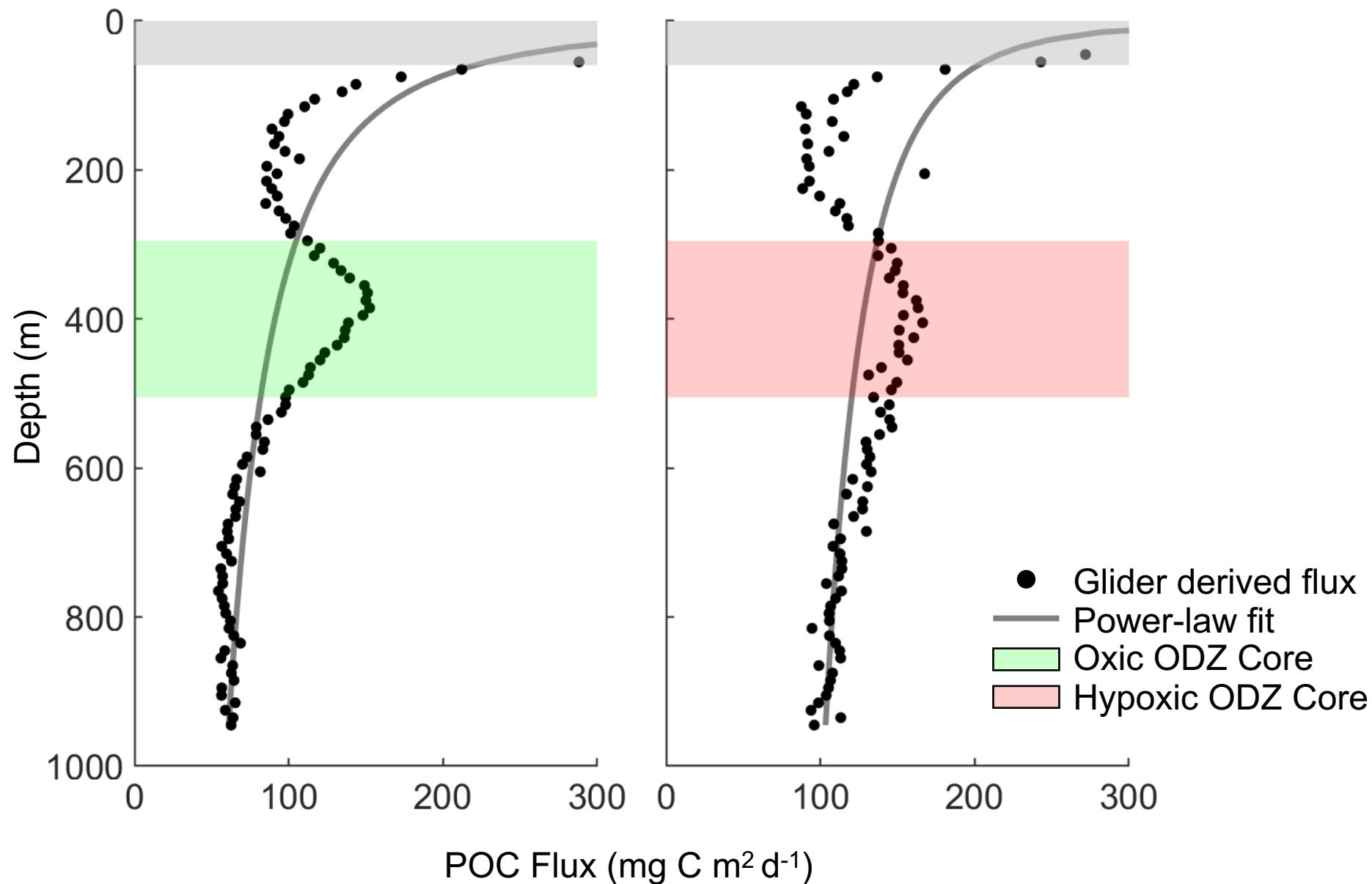
# Three large size classes are summed for plume tracking



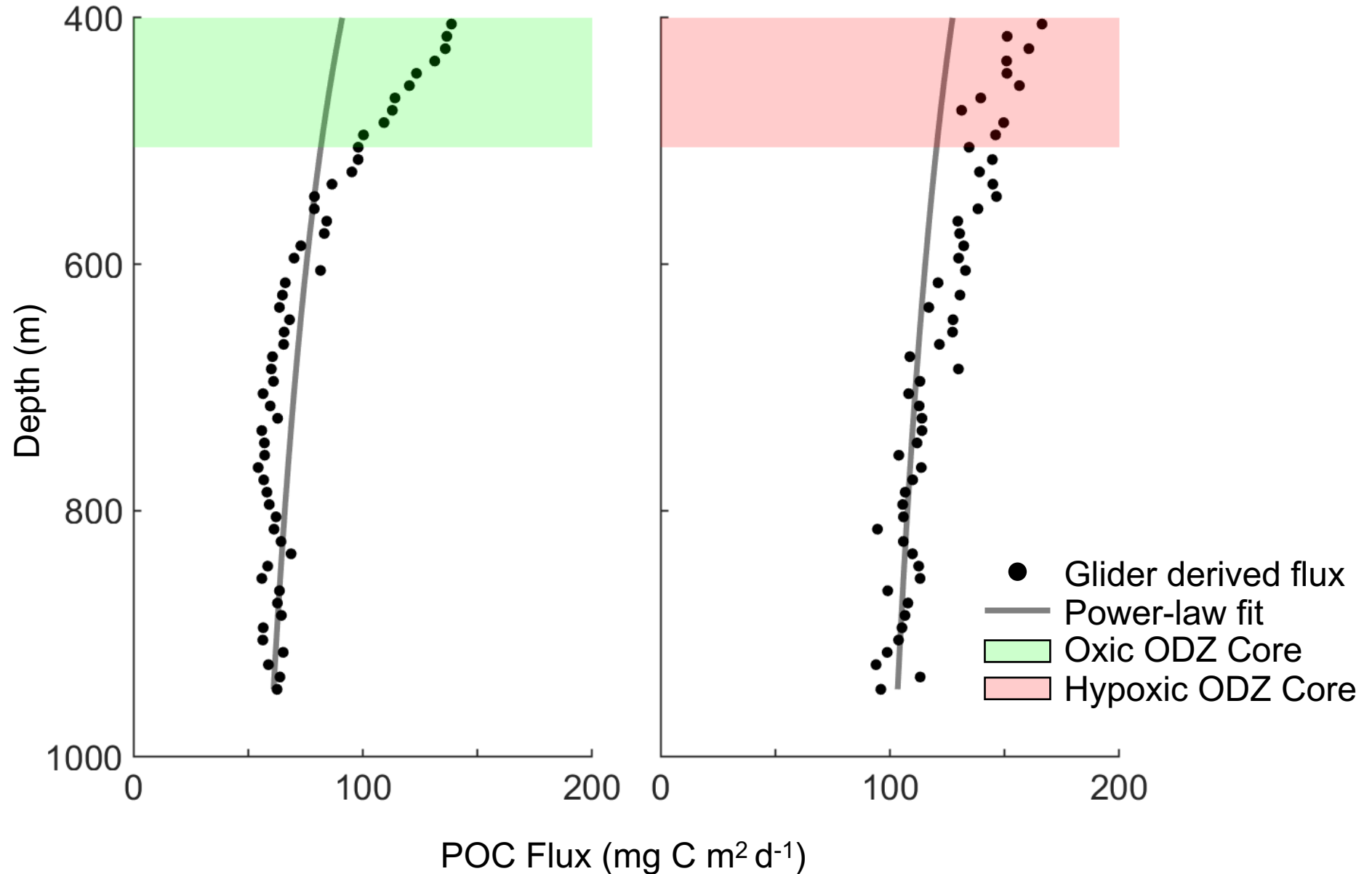
# Large particles sink at ~60 m/d



# Flux attenuation is lower in hypoxic ODZ states

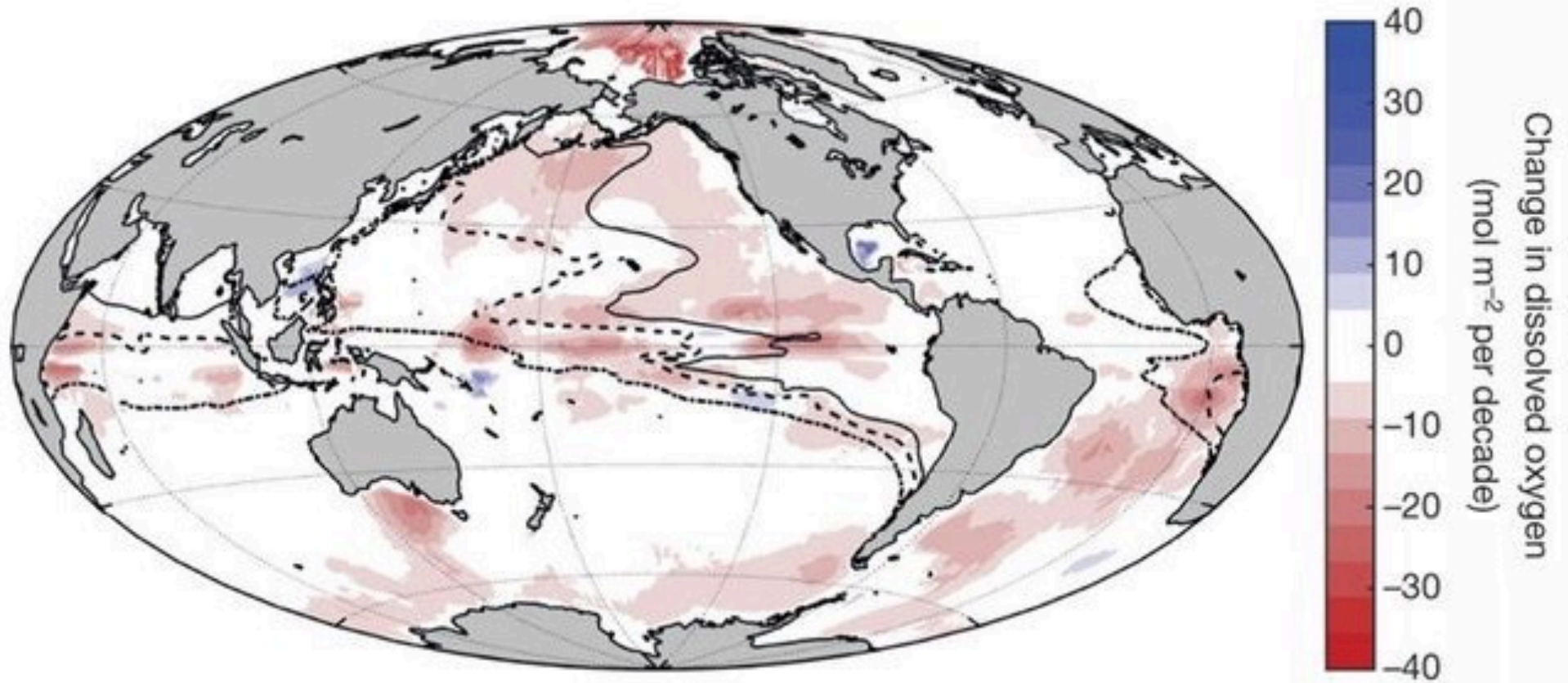


# Total POC flux reaching 1000 m doubles in hypoxic ODZ state





# Will enhanced ODZs see enhanced POC export?



# Summary

- Persistent intermediate nepheloid layer present in the northern Benguela upwelling system
- Difficult to explain through physics alone, mediated by biological community
- Hypoxia in ODZ core associated with an increase in POC flux at depth

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Thank you!

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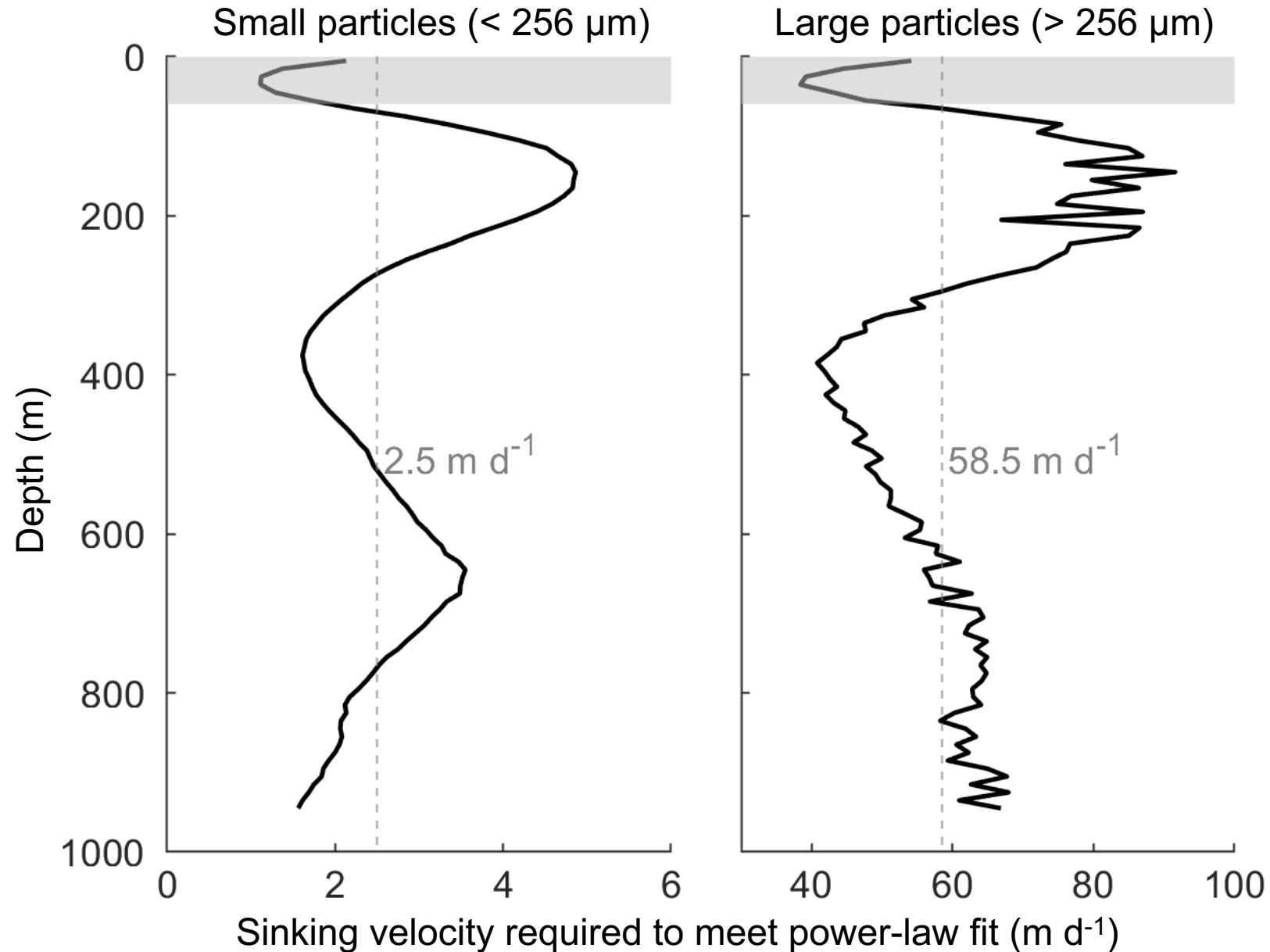


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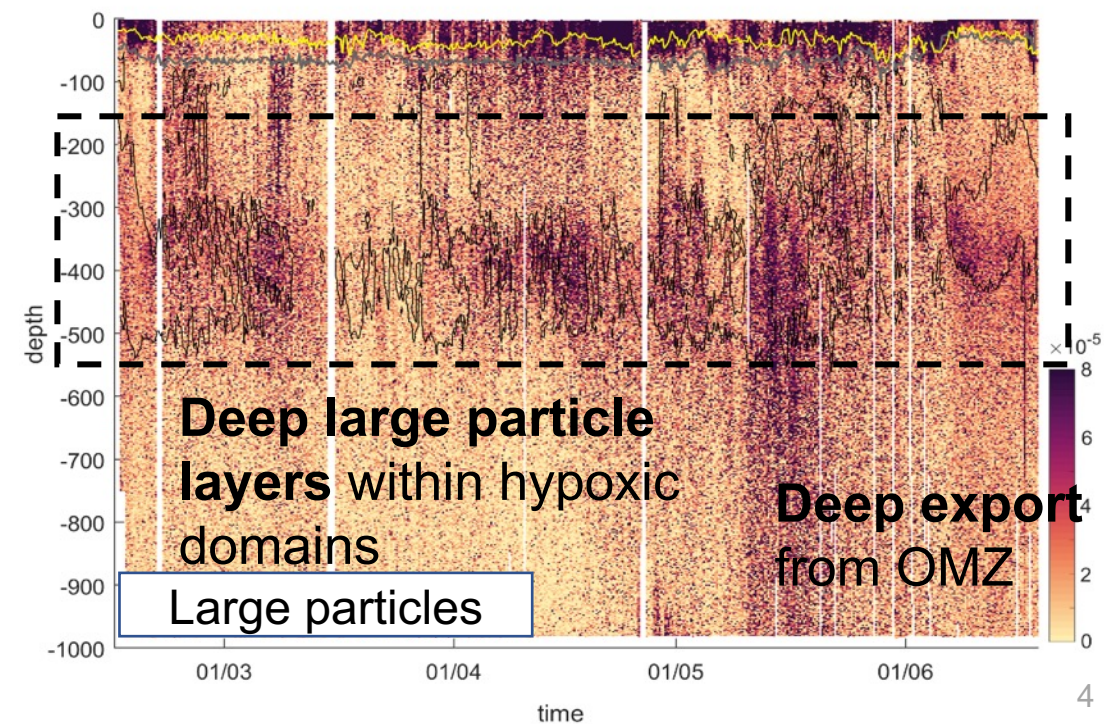
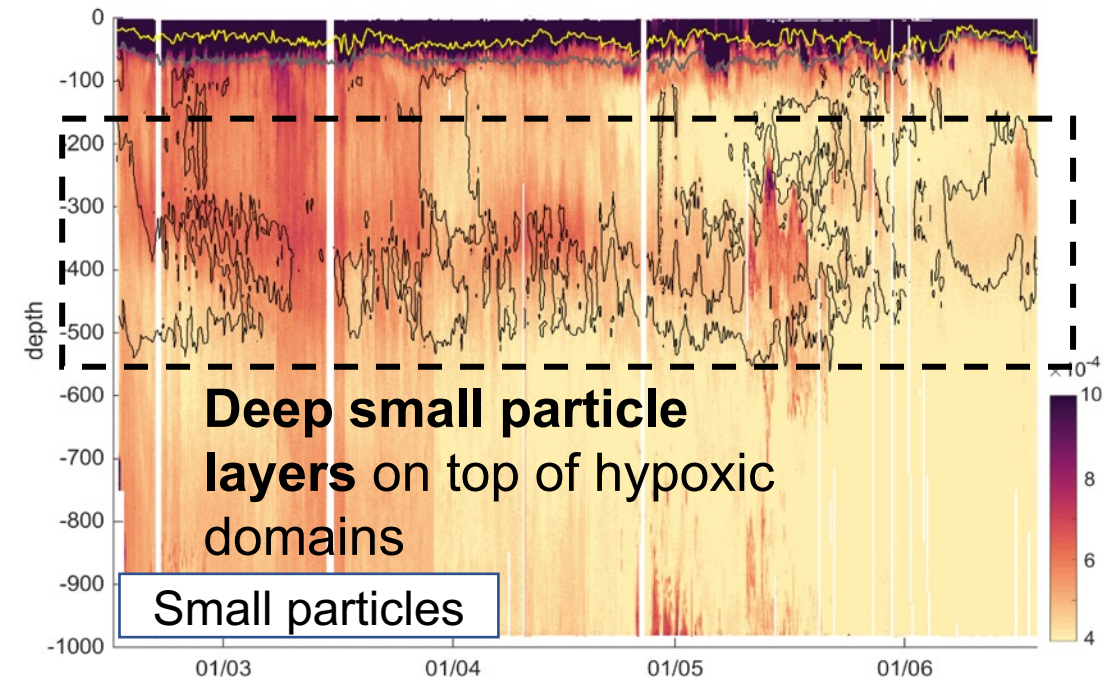
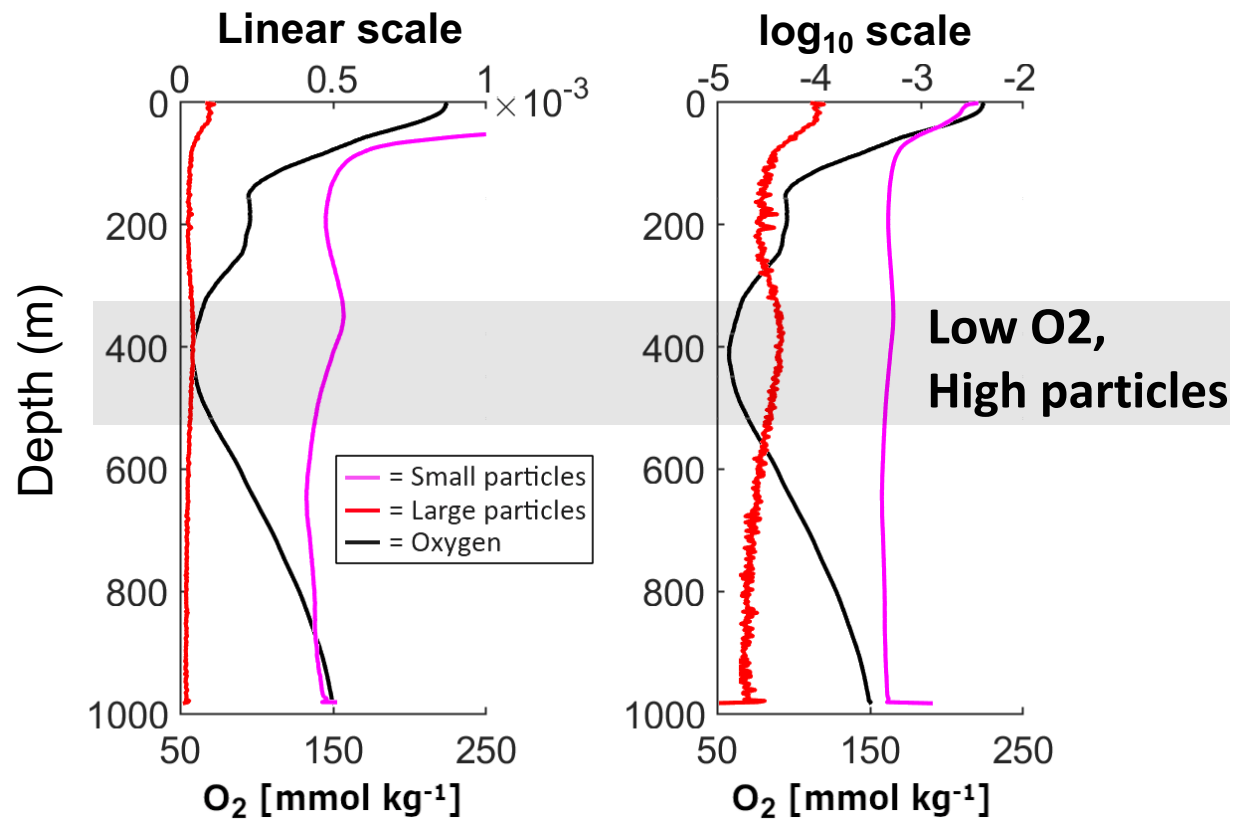
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# Variations in particle sinking speed may explain “increasing” flux



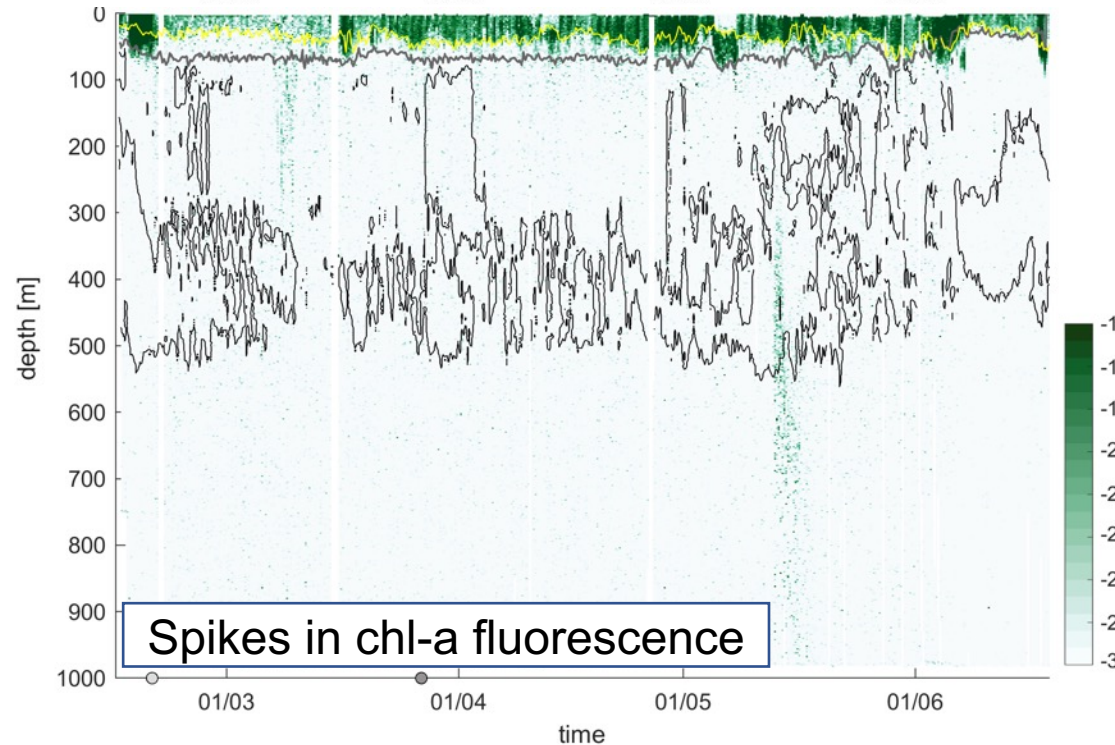
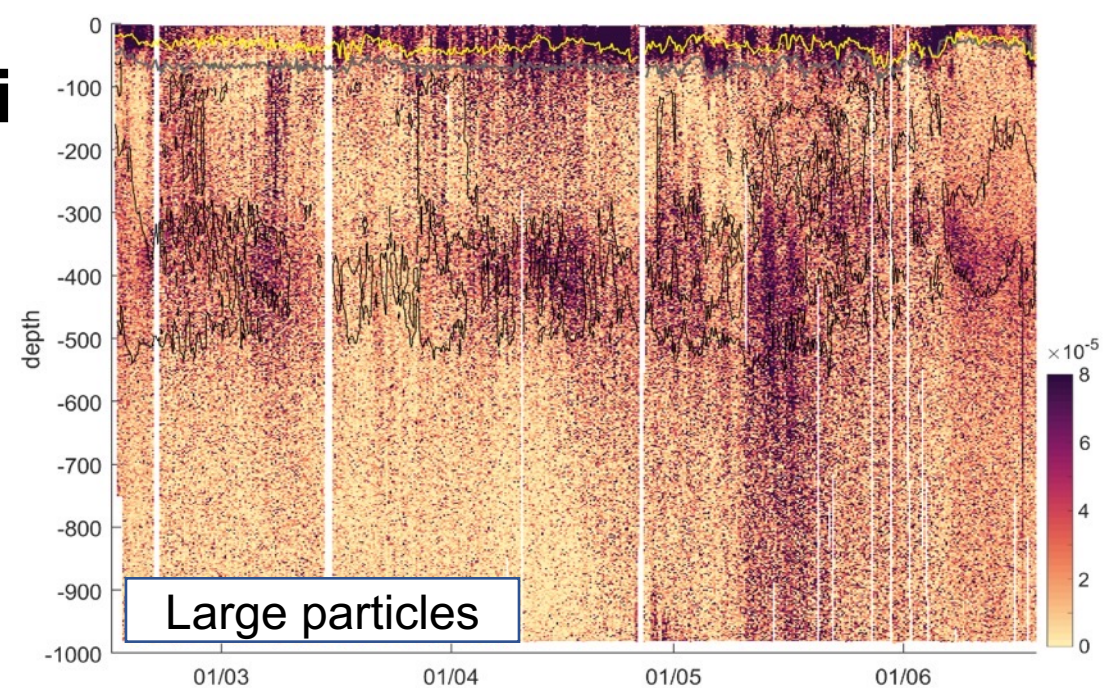
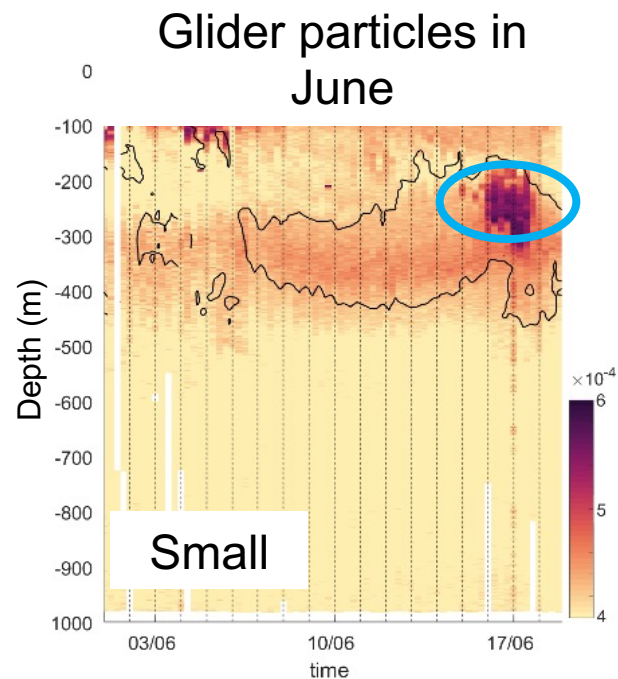
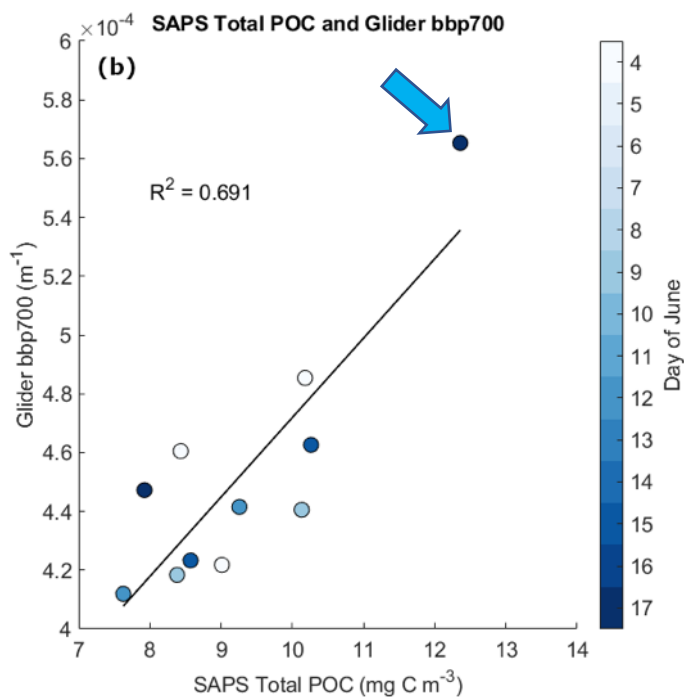


## Mean profiles

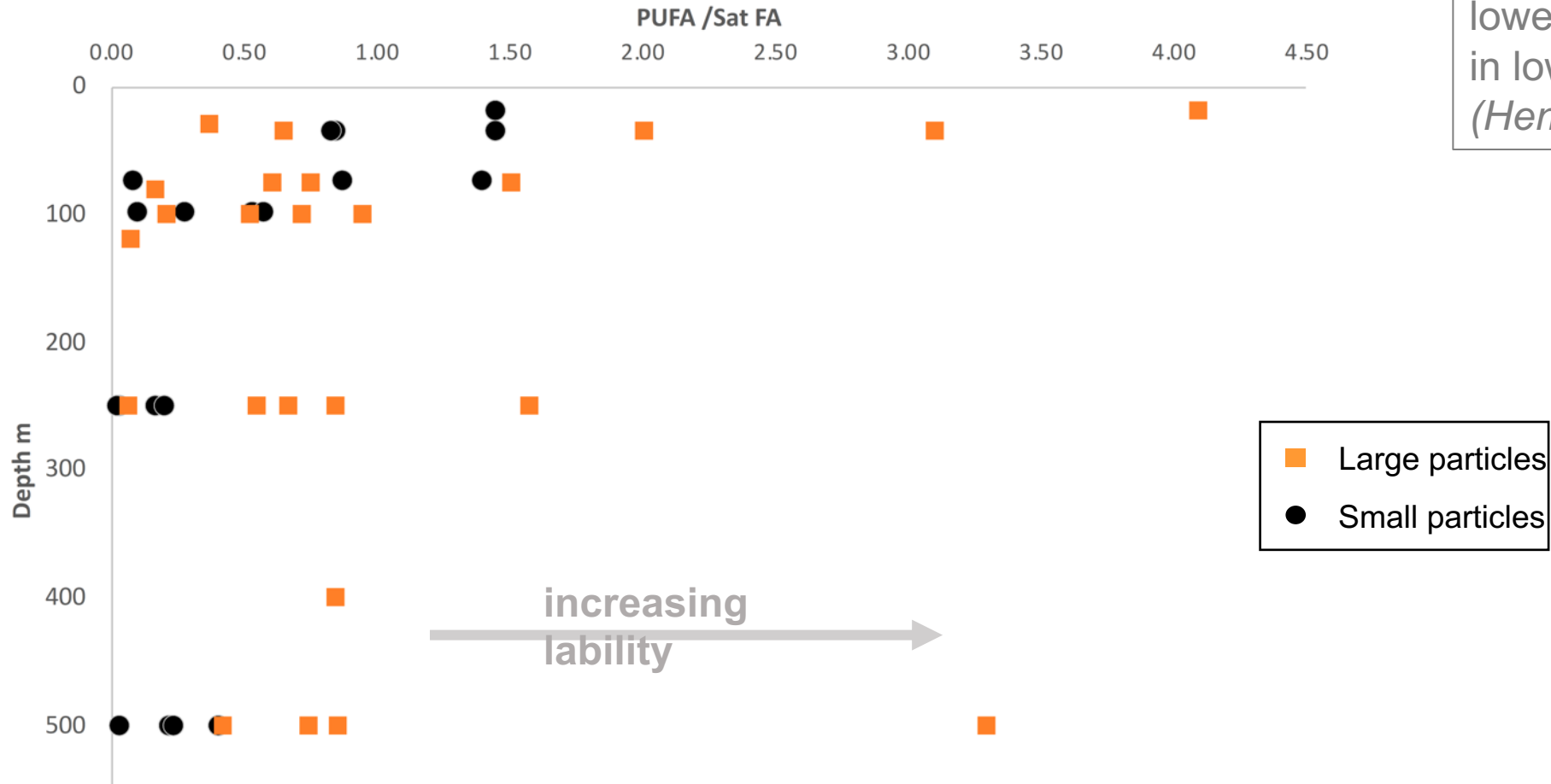




# Organic properties of backscatter parti



# POM properties - organic geochemistry data

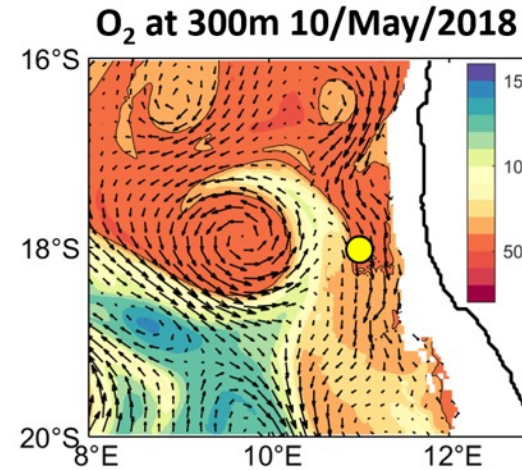
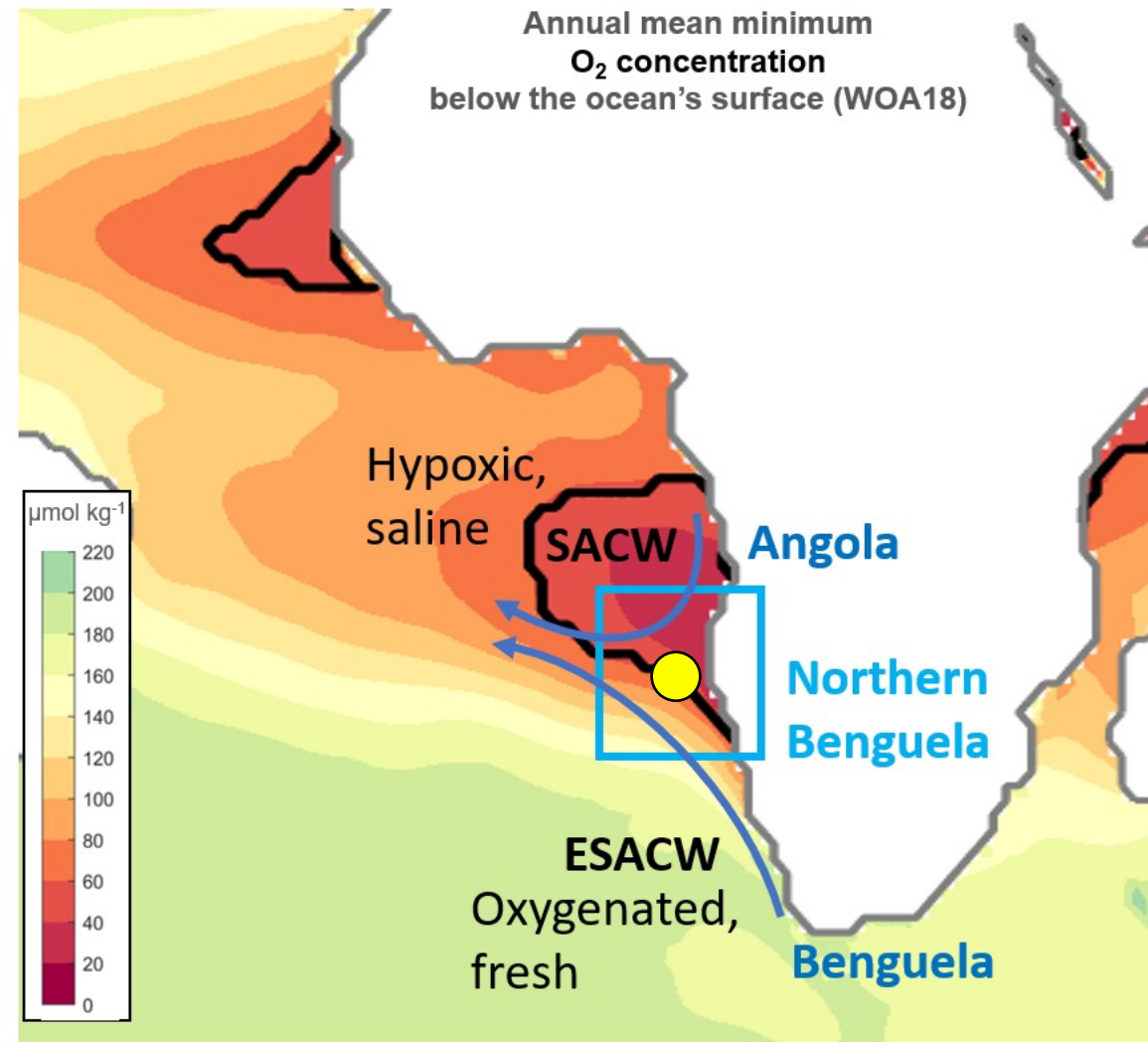


Also:

Incubation experiments during the same cruise: lower respiration rates in lower oxygen waters (*Hemsley et al. 2023*)



# Regional coupled physical-biogeochemical model, 3.2 km resolution

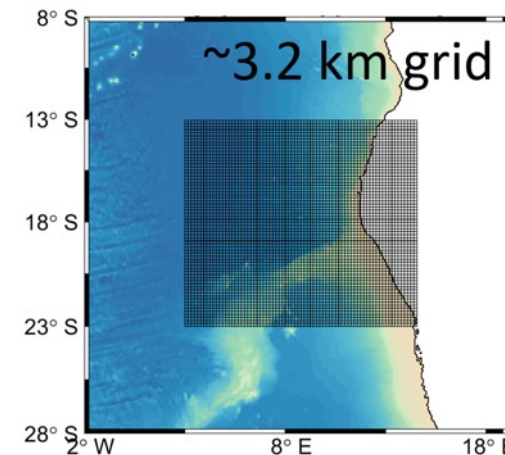


Run Feb-Jun 2018  
(ERA5, GLORYS, ...)

Day mean output

## Physical model: ROMS

Shchepetkin &  
McWilliams 2006



## Biogeochemical model: BEC-ETH

- 3 Phytoplankton (diat, diaz, small phy)
- 1 Zooplankton
- 2 Detritus (explicit sinking)
- BCG cycling:  
C, N, P, Si, Fe,  $O_2$

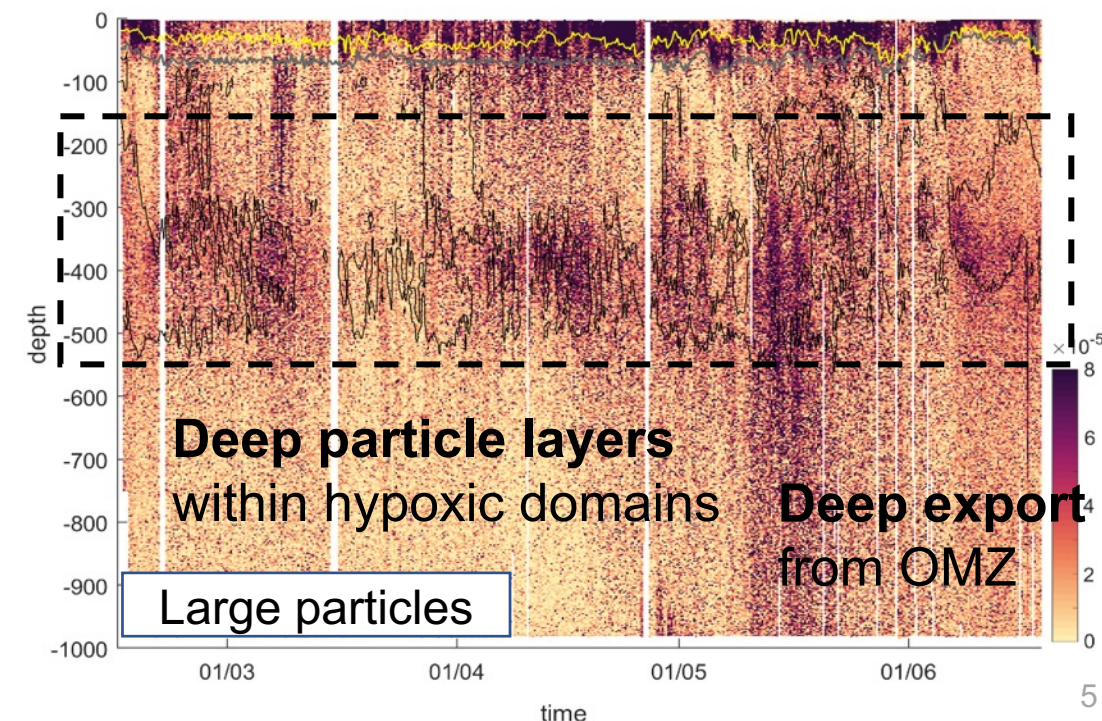
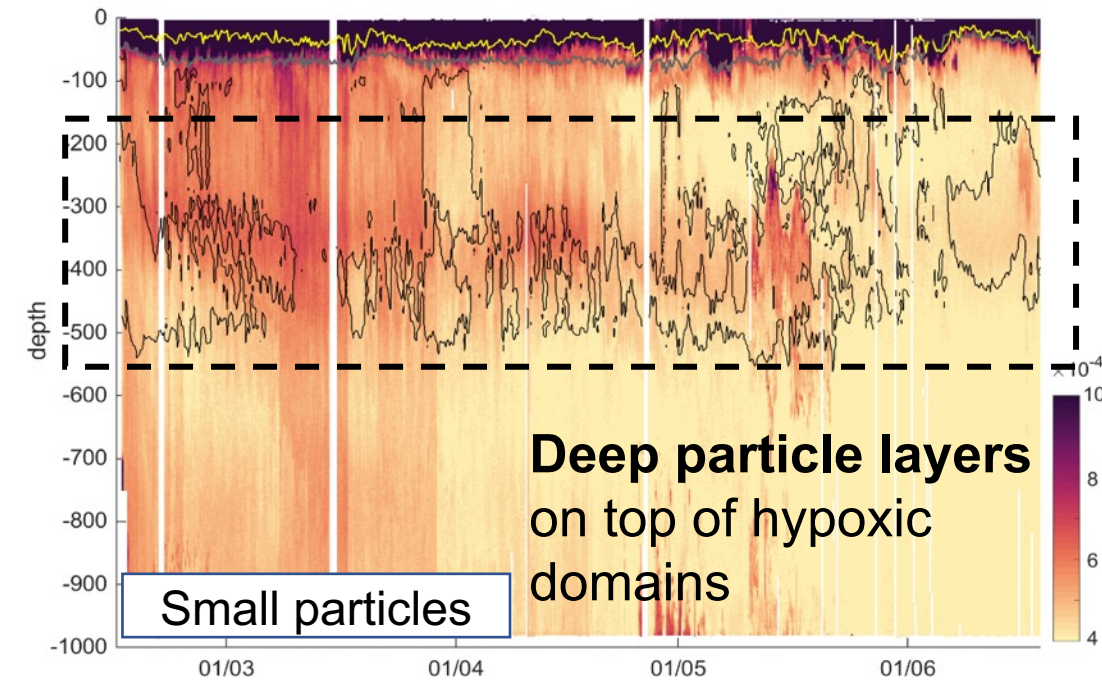
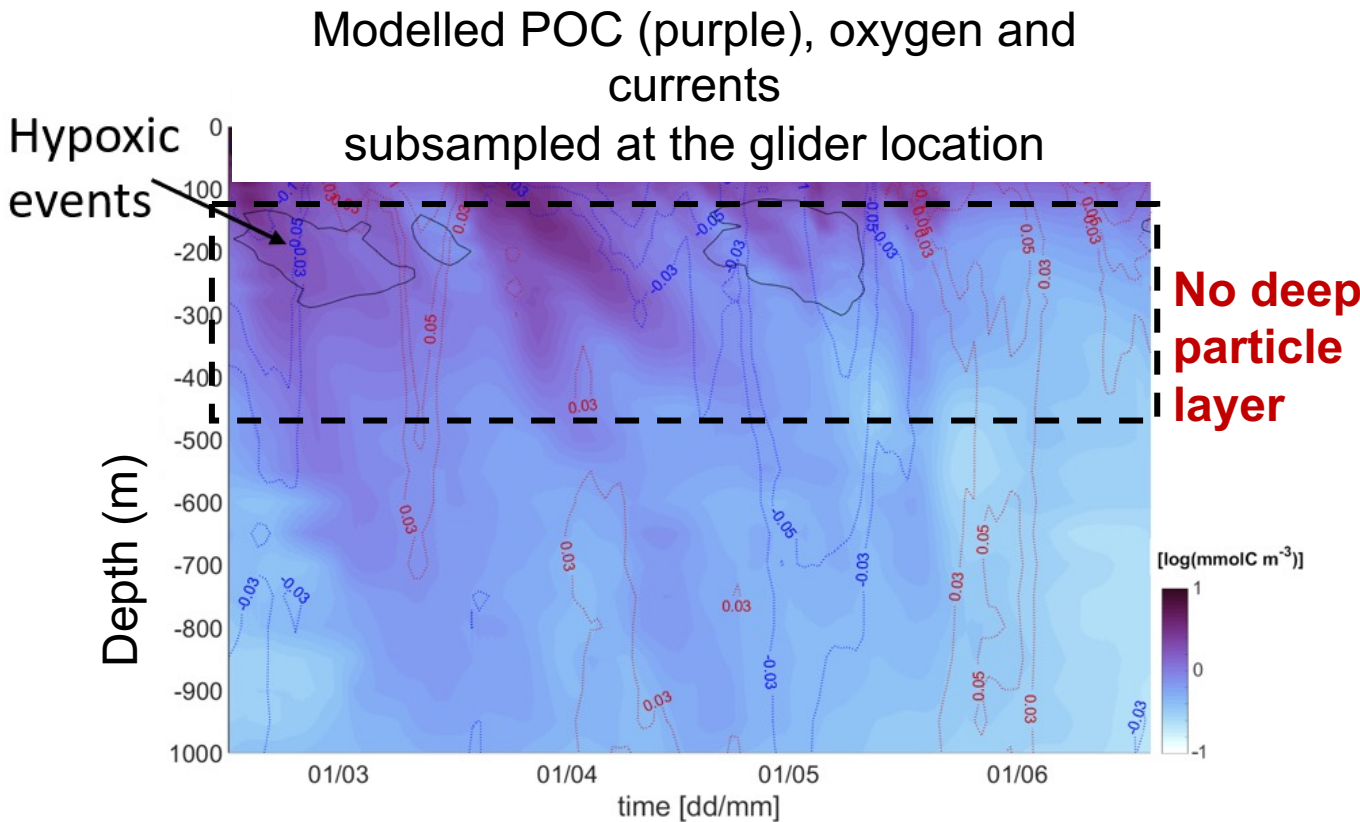
Frischknecht et al. 2018  
Moore et al. 2013

References for the currents scheme:

- [1] Boyer et al., 2000, doi: 10.1016/S0025551-326X(00)00106-5
- [2] Morholtz et al., 2008 doi: 10.1016/j.csr.2007.10.001
- [3] Sigfried et al., 2019, doi: 10.1371/journal.pone.0210083



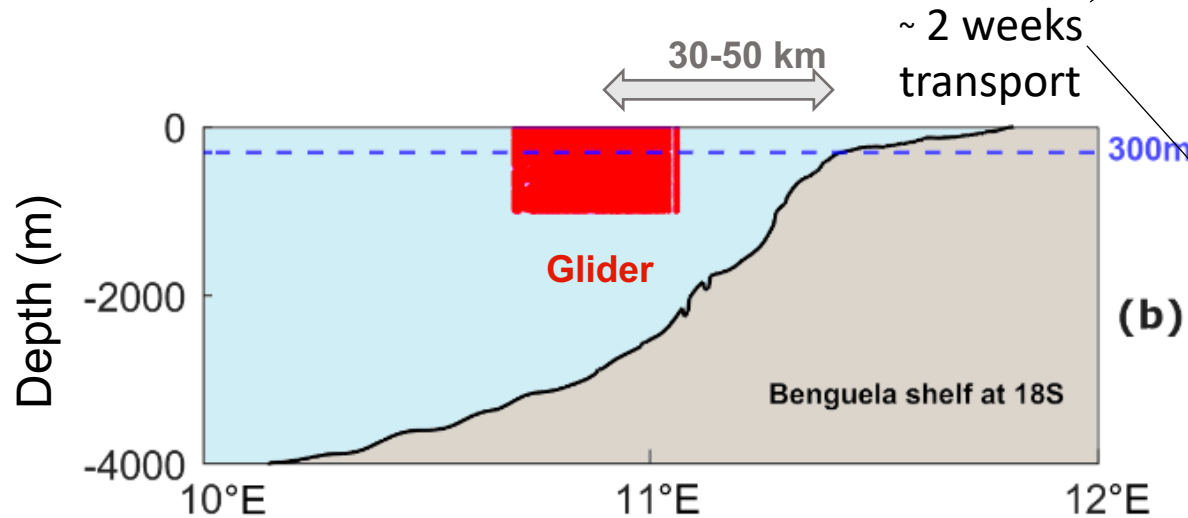
# Lateral advection/subduction of sinking POC



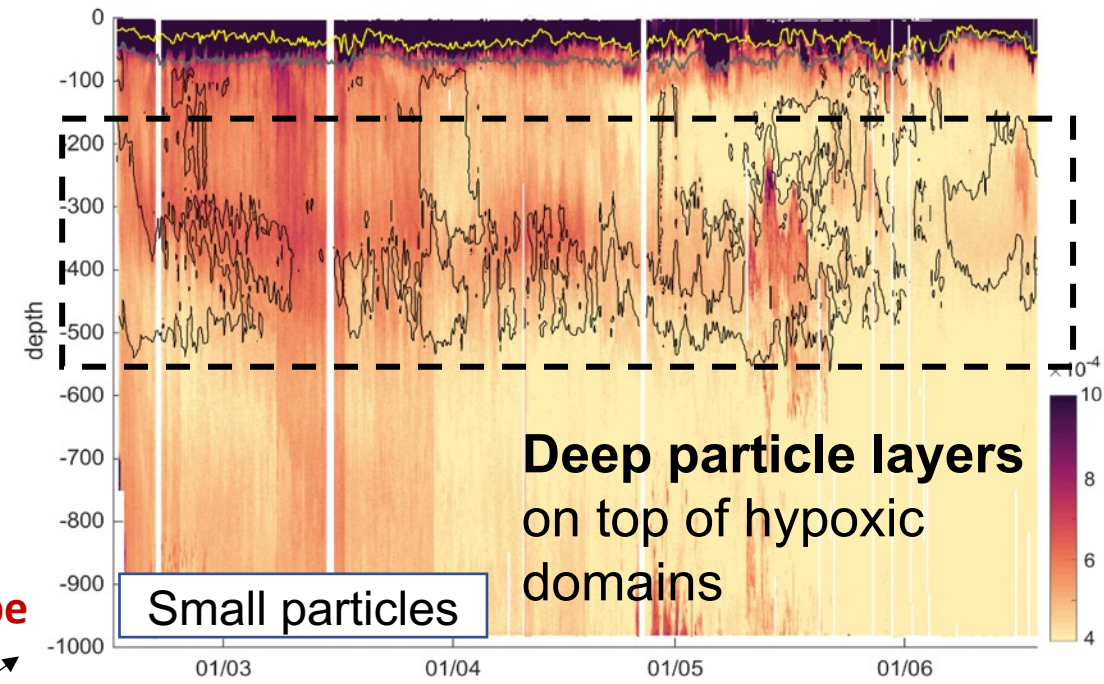


# Drivers of the formation of the deep particle layers & export events

Resuspended sediment from the shelf?



Maybe



NO

