# Spatiotemporal offsets between production and export need to be incorporated into satellite export products

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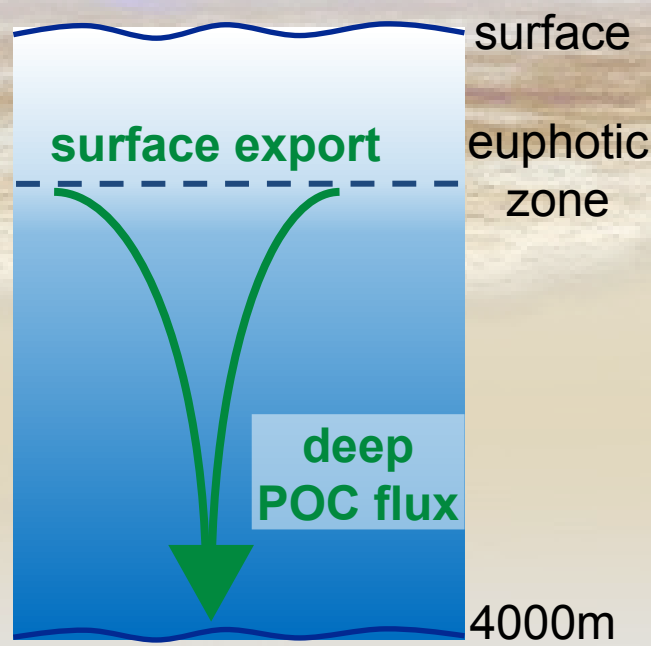
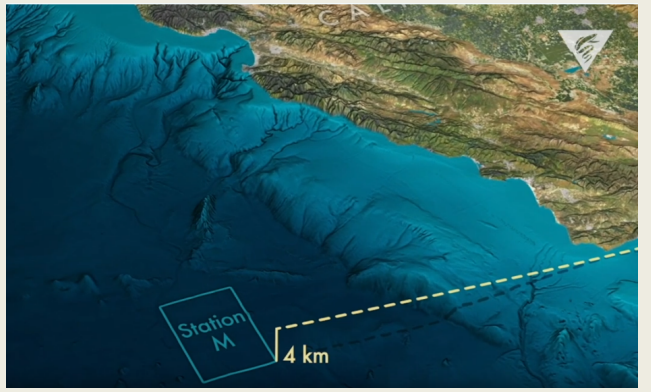


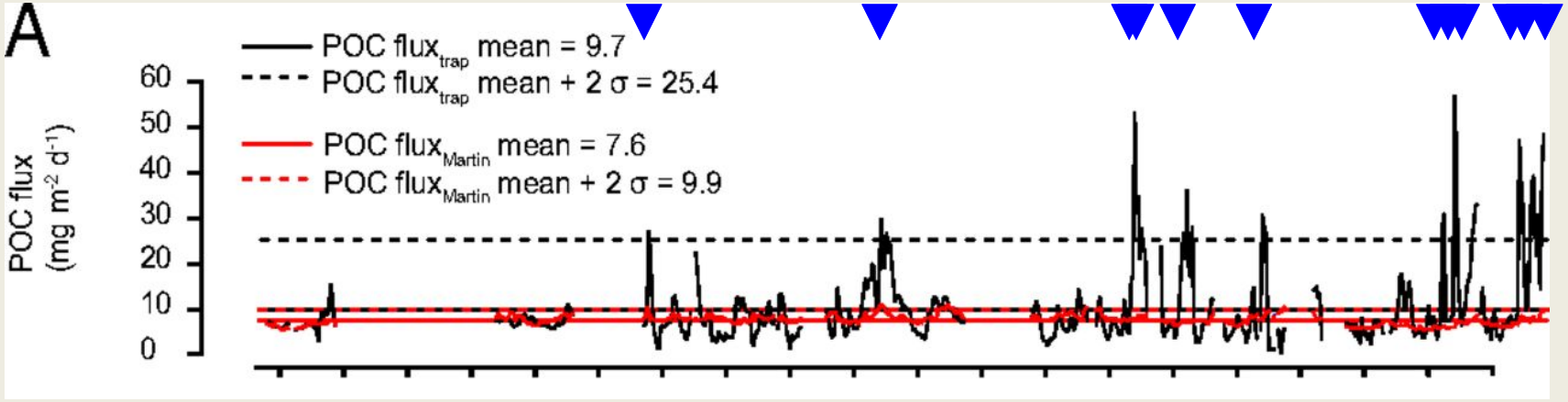
# Station M deep-sea POC fluxes

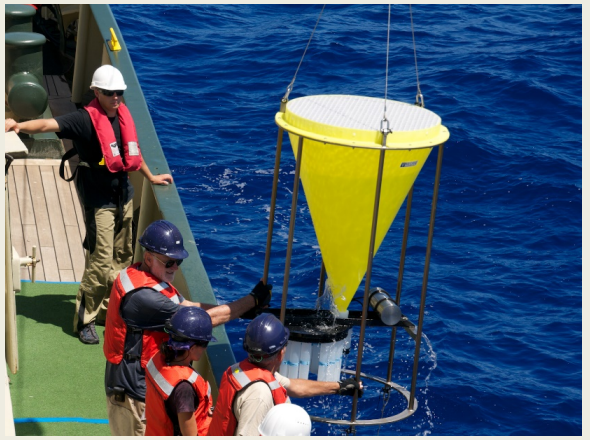



POC flux at 3400m depth

POC flux modeled from attenuated surface export (100km radius circle)

▼ POC pulses = higher than mean + 2 stddev



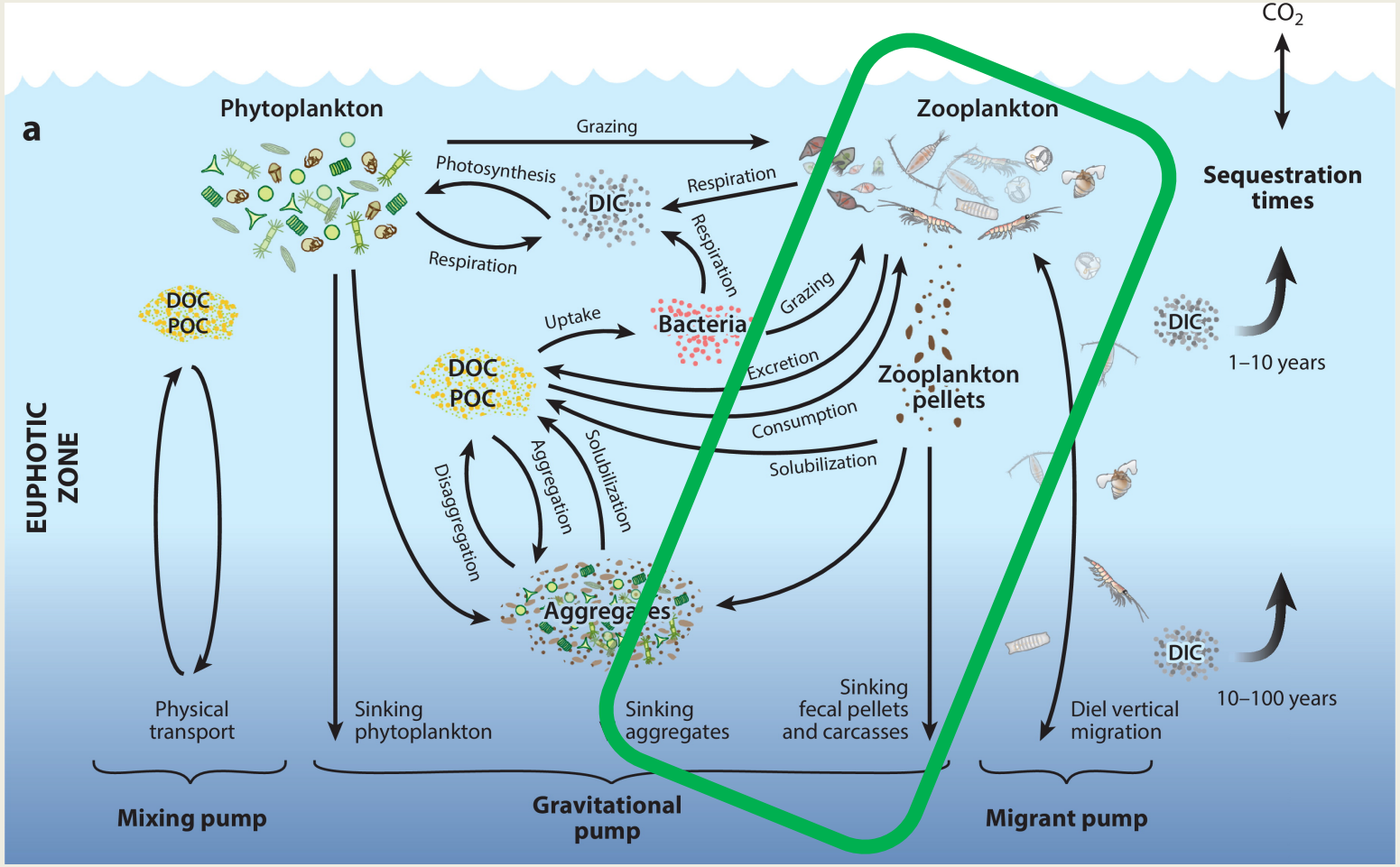



Smith et al., 2018

What creates such high variability in deep-sea POC fluxes?

Are we missing something in surface export products?

# WHAT ABOUT ZOOPLANKTON?




Siegel et al. 2023

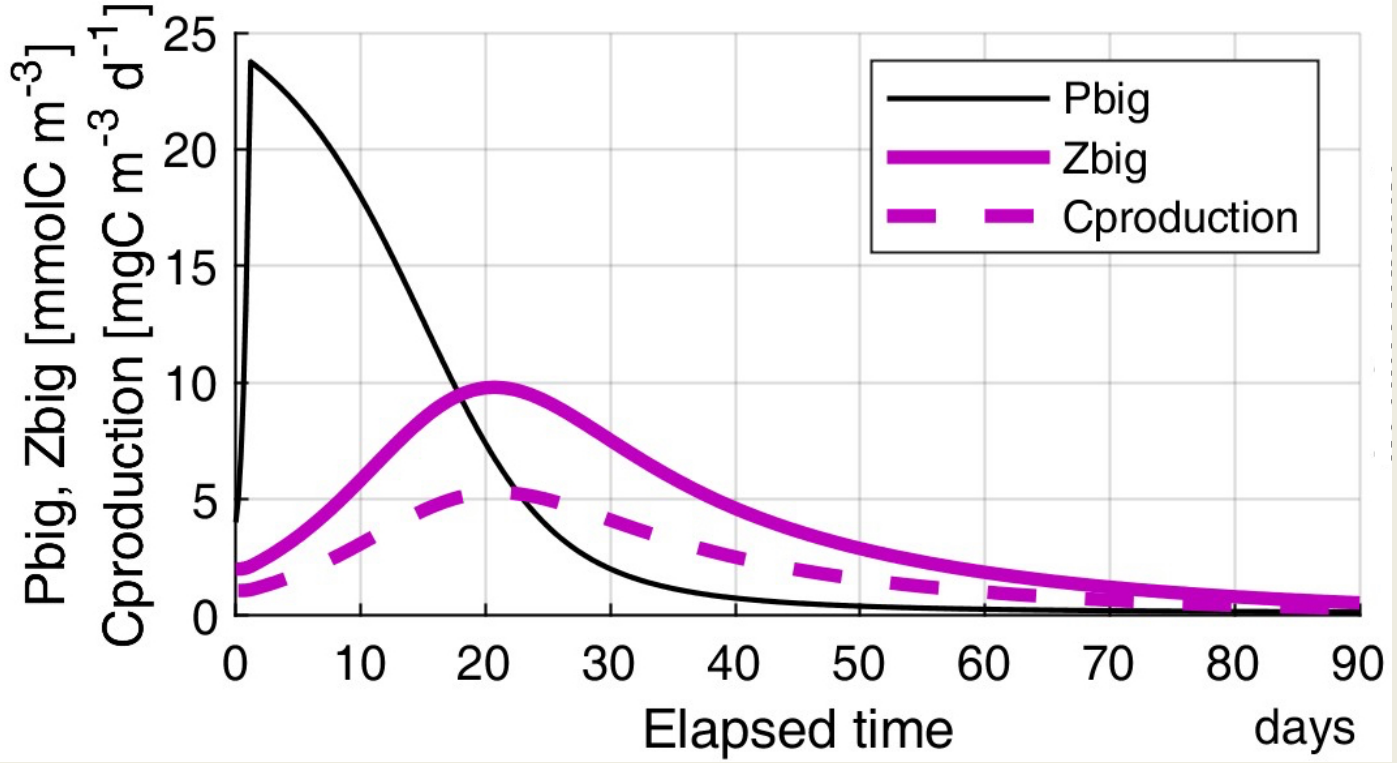
The gravitational pump is dominated by **zooplankton fecal pellets**

(Nowicki et al., 2022 global, Stukel et al., 2013 California)

Phytoplankton and zooplankton are **decoupled in time and space**

→ *ocean color is not enough*

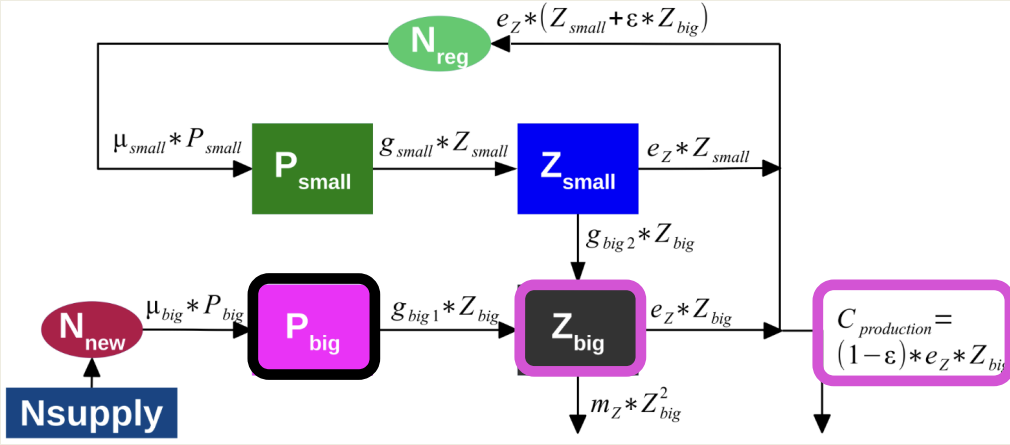
# WHAT ABOUT ZOOPLANKTON?



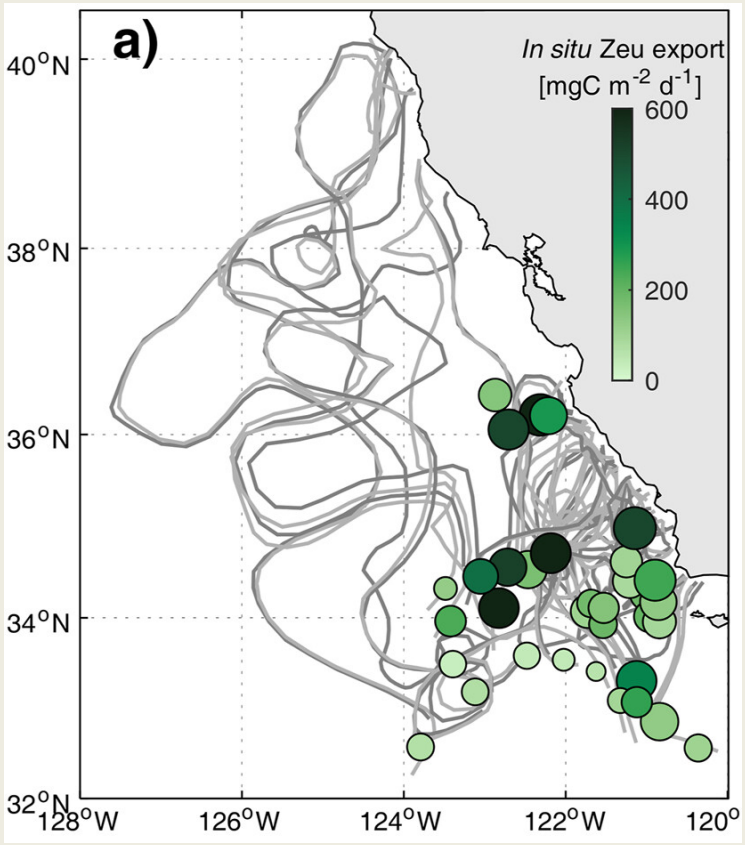

NPZ model output when forced by 1-day initial nutrient pulse

→ 3-week lag between production and export

Messié & Chavez, GRL 2017
Messié et al., F Mar Sci 2022, GRL 2025



# Identifying processes: backward analysis

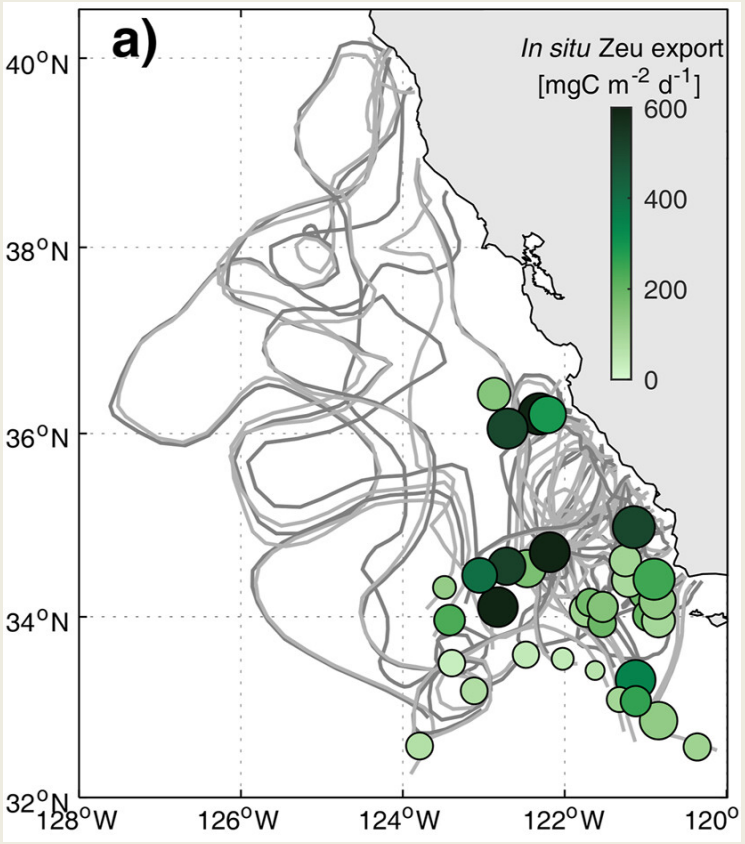



CCE-LTER sediment trap dataset
(carbon export at the base of the euphotic zone)
+ satellite-derived backward current trajectories

Using a **Lagrangian framework** along near-surface current trajectories

Messié et al., GRL 2025

# Identifying processes: backward analysis & NPZ model

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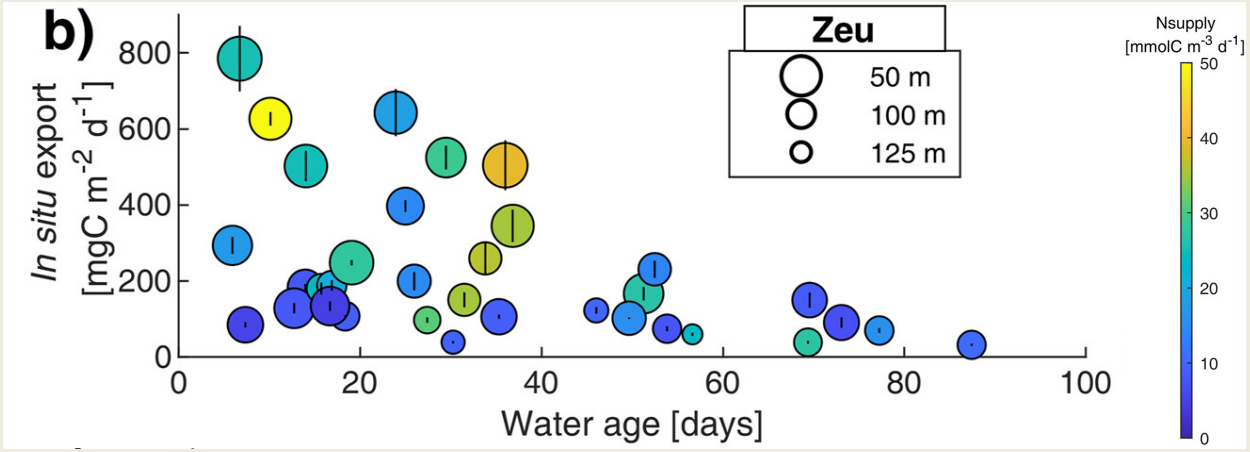
Can we explain export at the base of the euphotic zone?




Messié et al., GRL 2025

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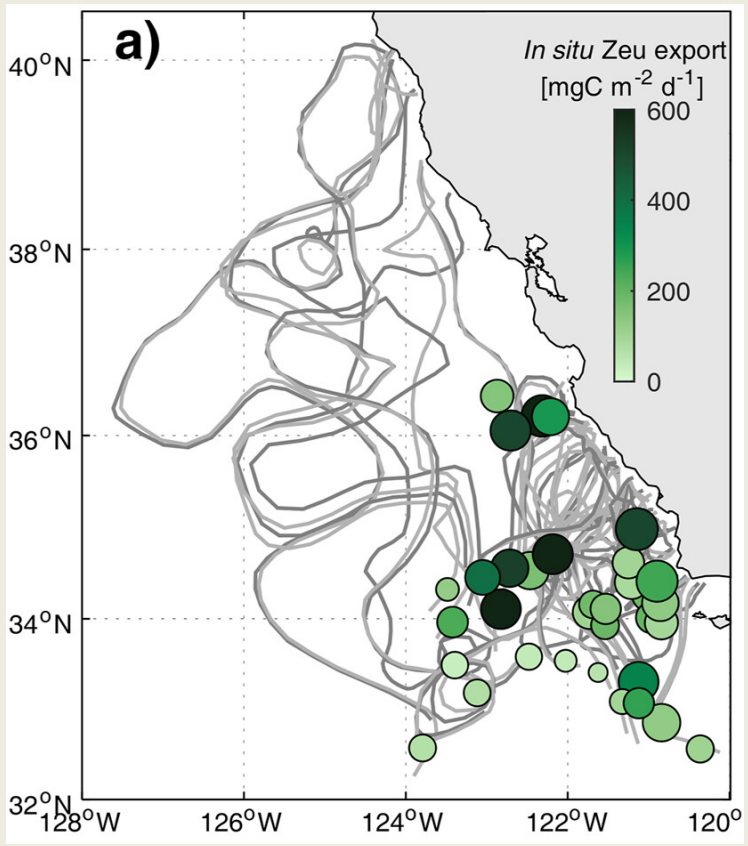


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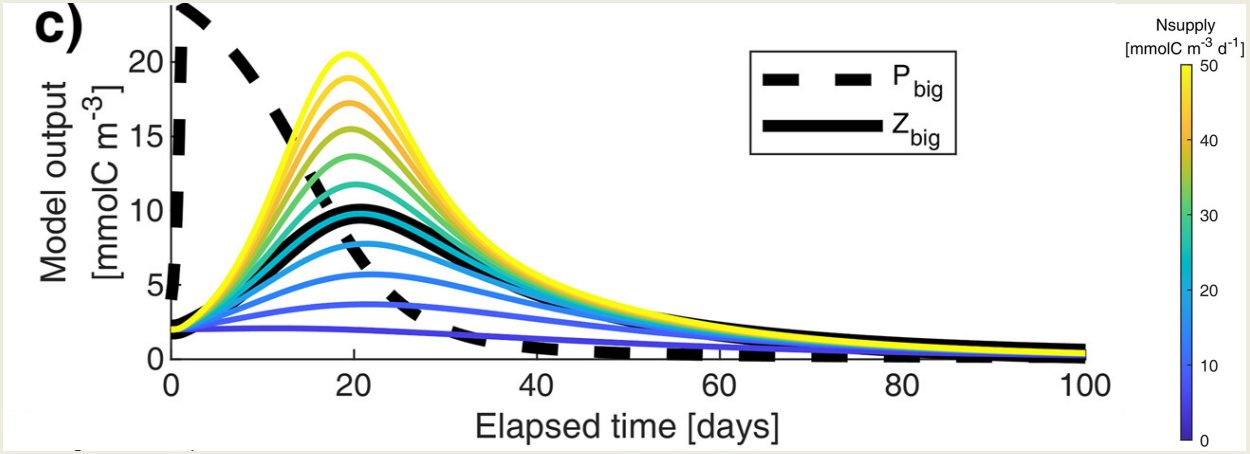
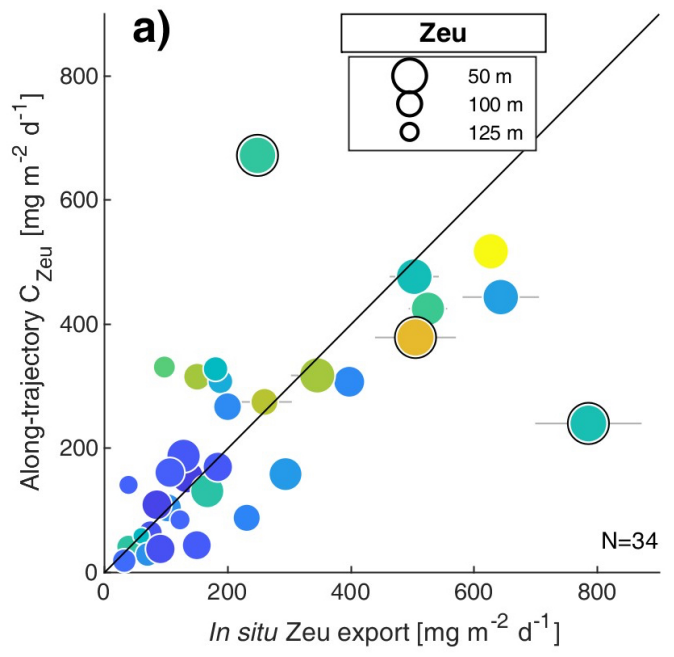



Messié et al., GRL 2025

# Identifying processes: backward analysis & NPZ model

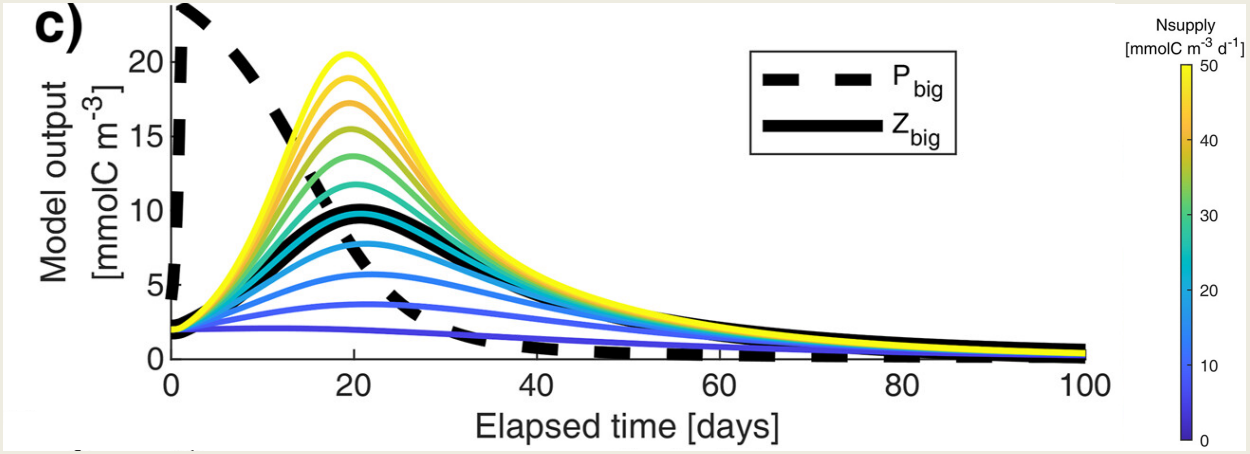
**69% variance explained**

(when excluding 3 points shallower than 30m)




Using a **Lagrangian framework** along near-surface current trajectories

Export can be explained by coastal upwelling, a 3-week lag, and advection

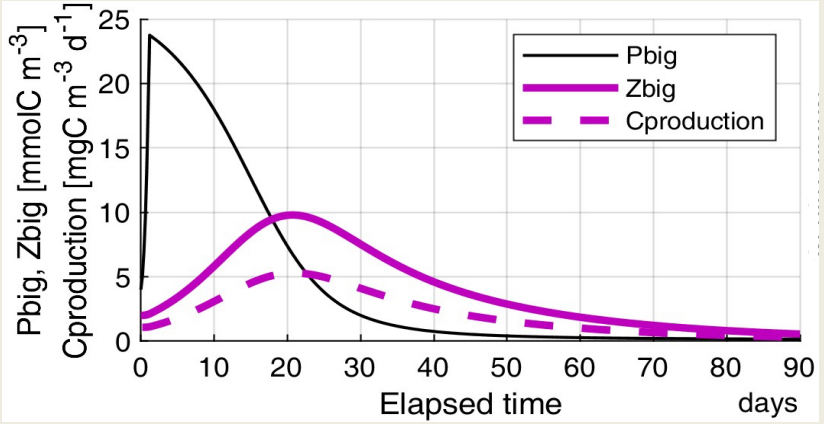



Messié et al., GRL 2025

# Satellite-derived export: forward analysis (GA model)

GA = growth-advection

**(1)**




*plankton model forced by wind-driven nitrate supply at time 0*

(https://www.mbari.org/data/nitrate-supply-estimates-in-upwelling-systems/)

Messié et al.,
F Mar Sci 2022

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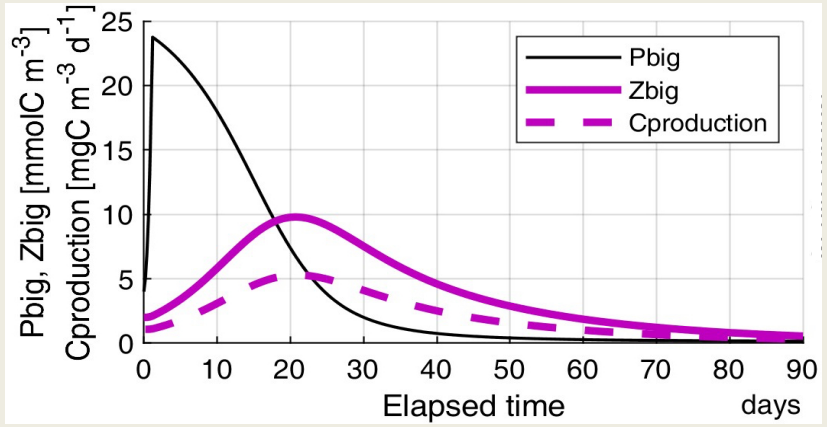


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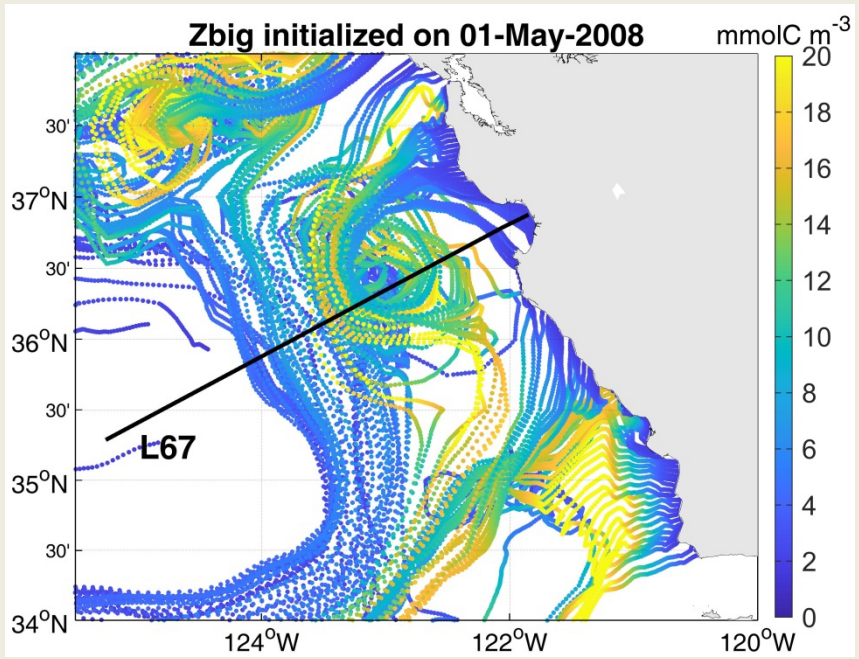


*advection by near-surface currents*

(Copernicus - GlobCurrent)

Messié et al., F Mar Sci 2022

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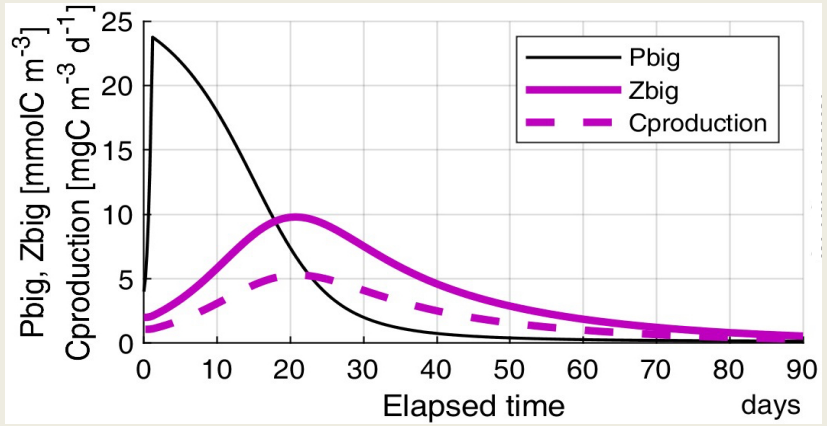


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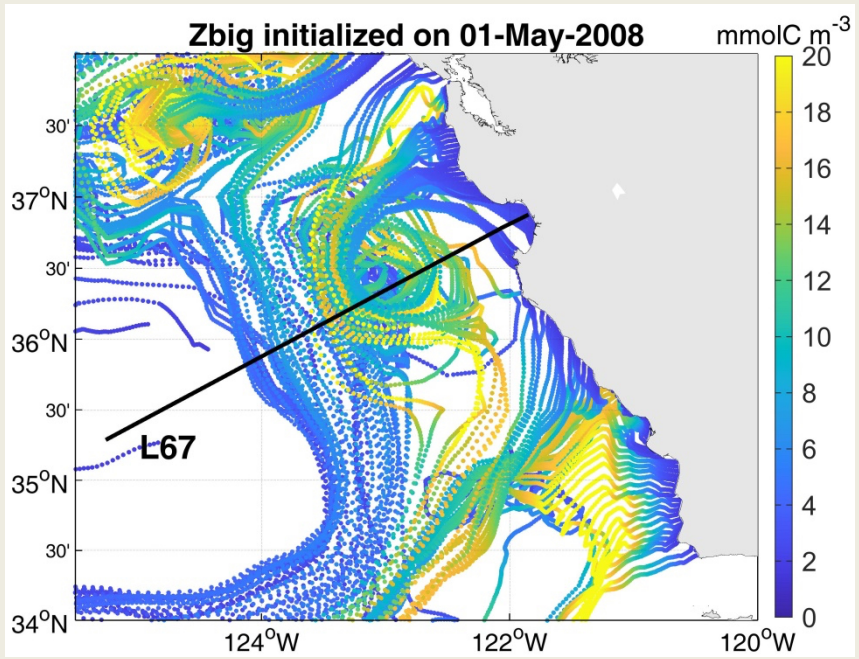


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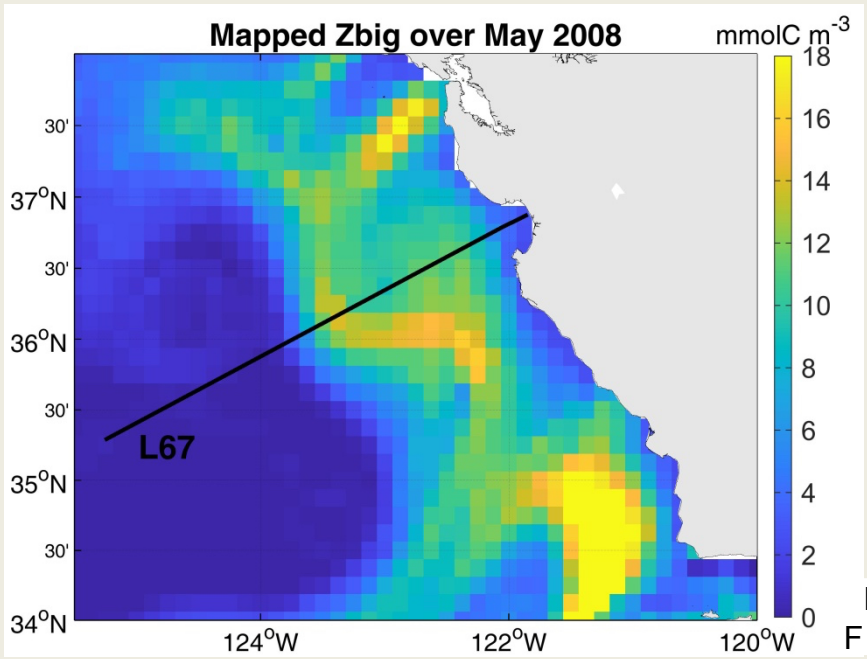


Messié et al., F Mar Sci 2022

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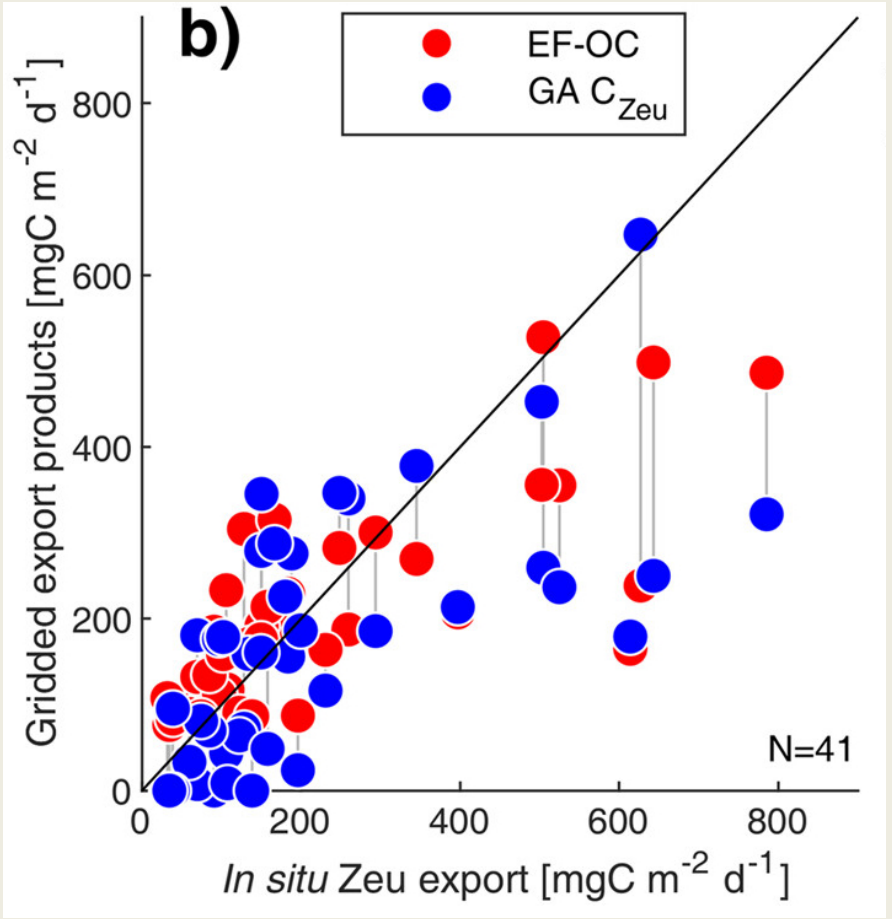



$r^2$ = 0.58 (4km resolution)
$r^2$ = 0.43 (12km resolution)

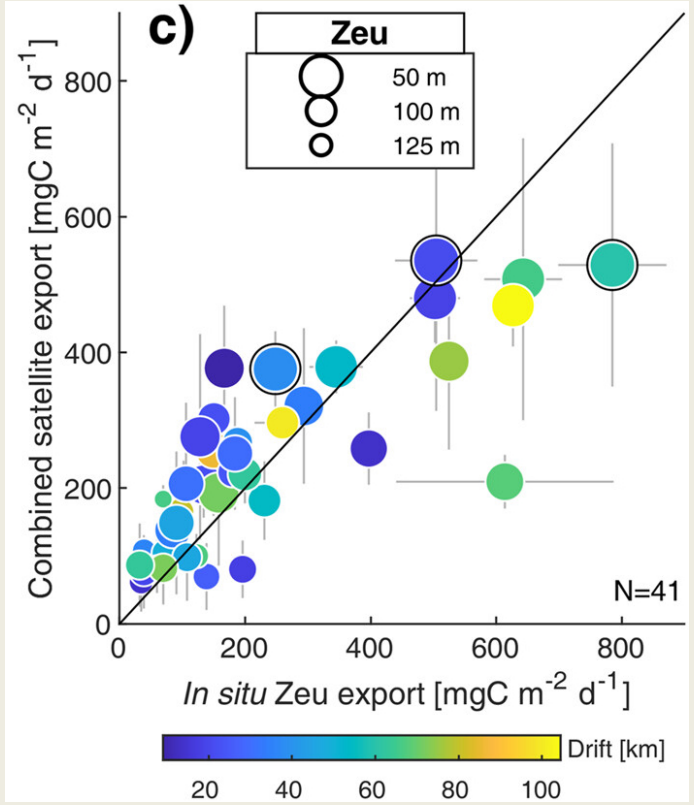
EF-OC (Export Flux - Ocean Color)
= 0.284 * primary production + 9.75
(tuned using CCE-LTER sediment trap dataset)

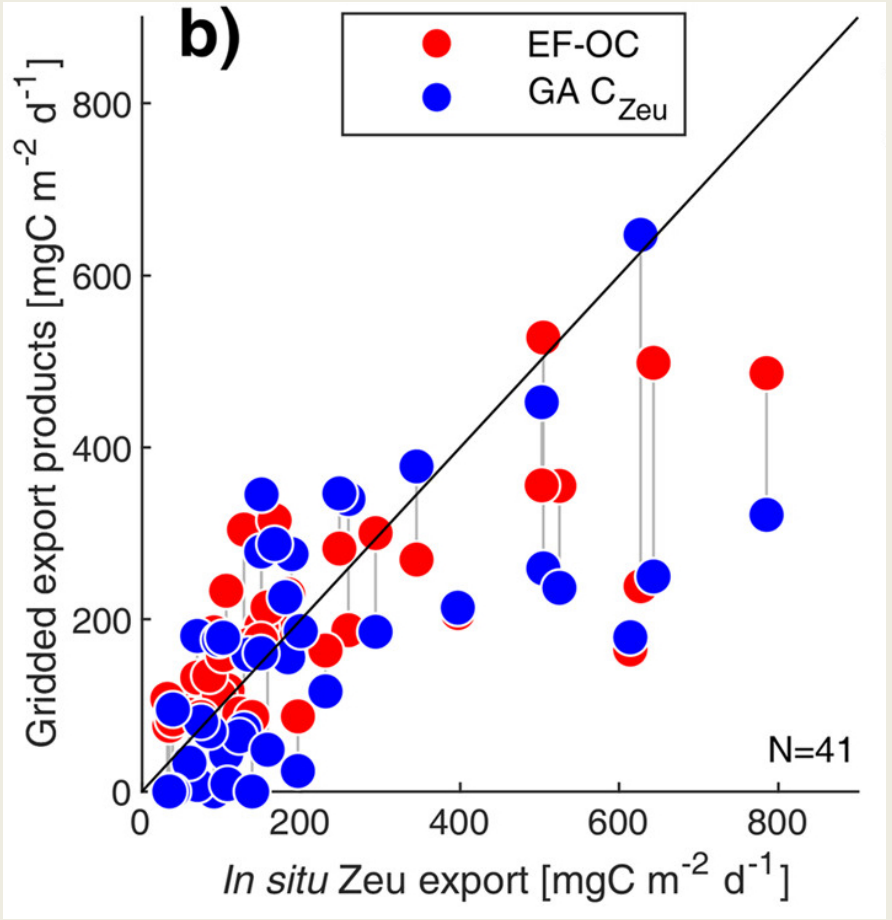
Messié et al., GRL 2025

# Satellite-derived export: forward analysis (GA model)

Export is best represented from satellite when combining ocean color and GA

**combined: $r^2$ = 0.66**
(14% improvement)



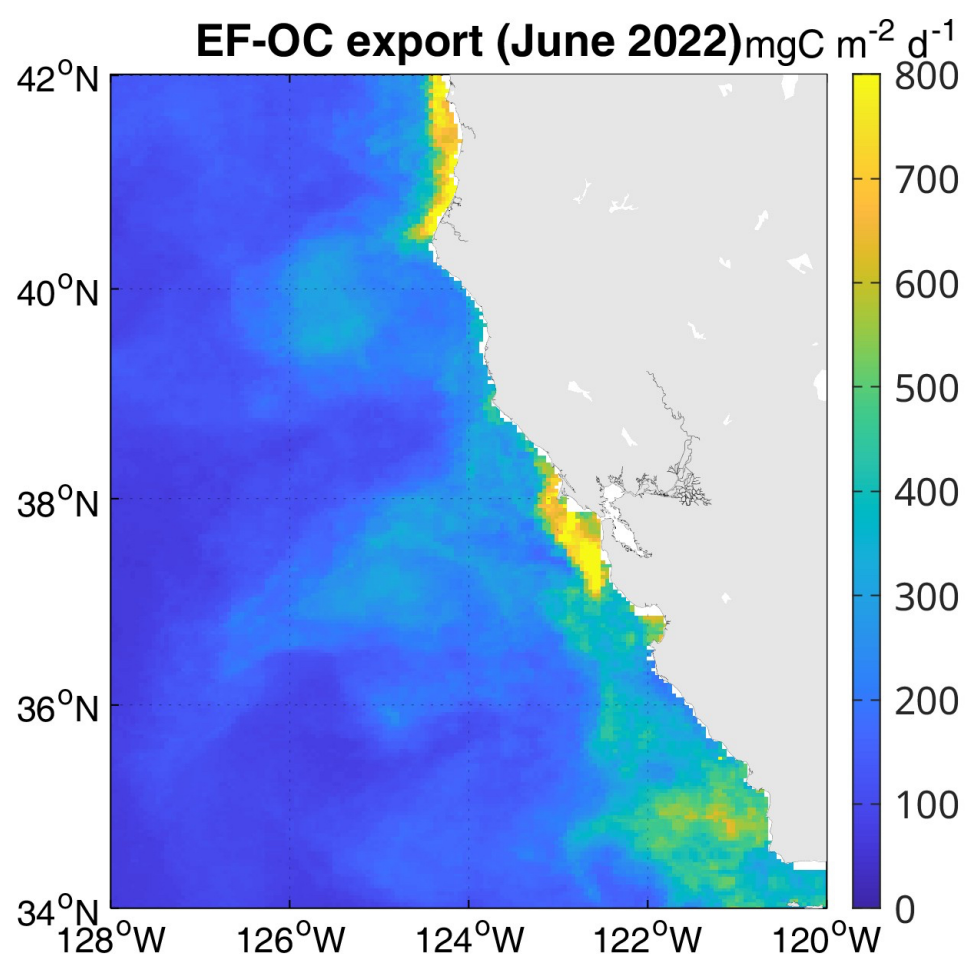

(EF-OC derived from ocean color, Kahru et al., 2020)

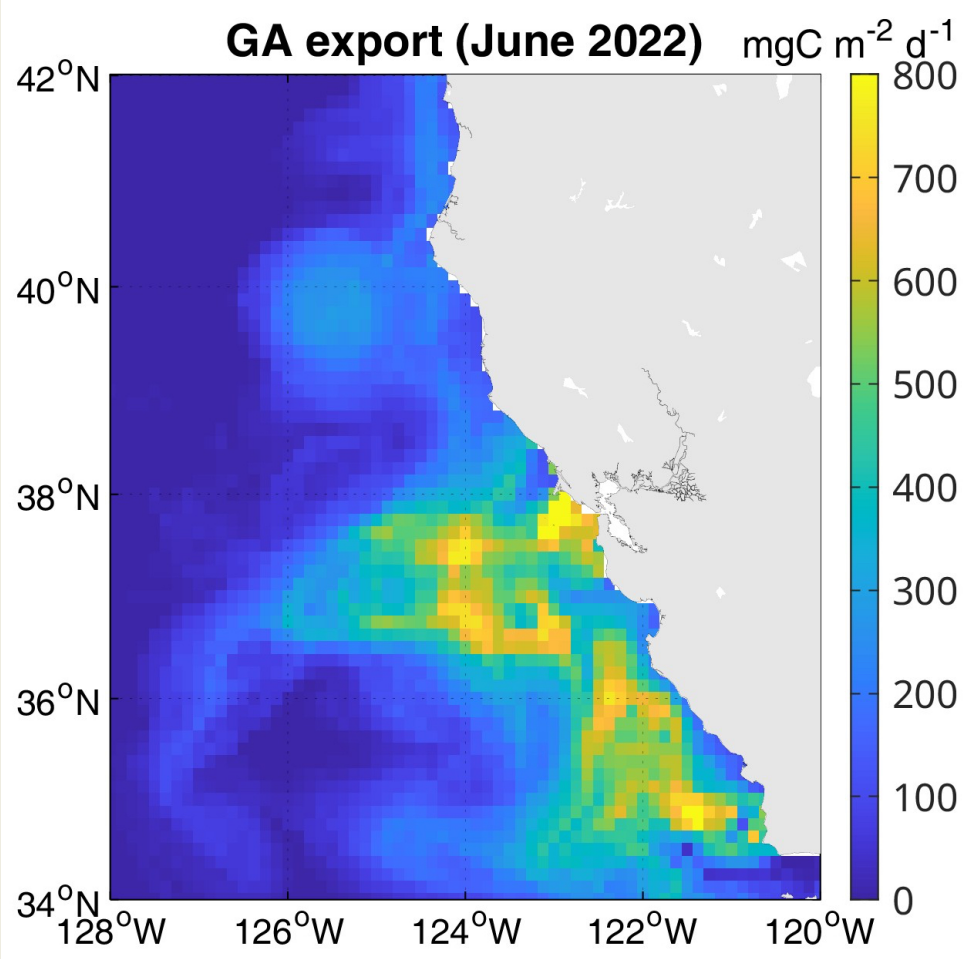
$r^2$ = 0.58
$r^2$ = 0.43

Messié et al., GRL 2025

# Satellite-derived export: forward analysis (GA model)

Export may be more variable than previously recognized



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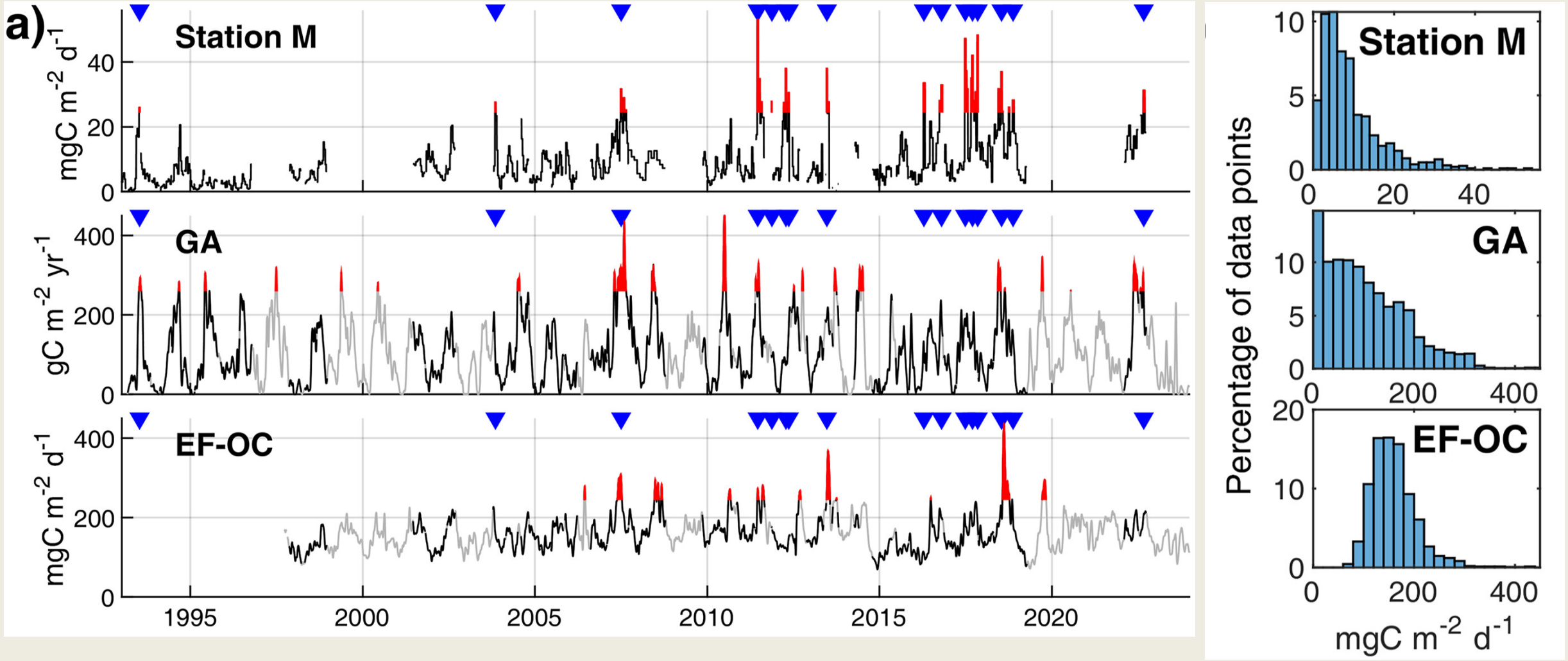


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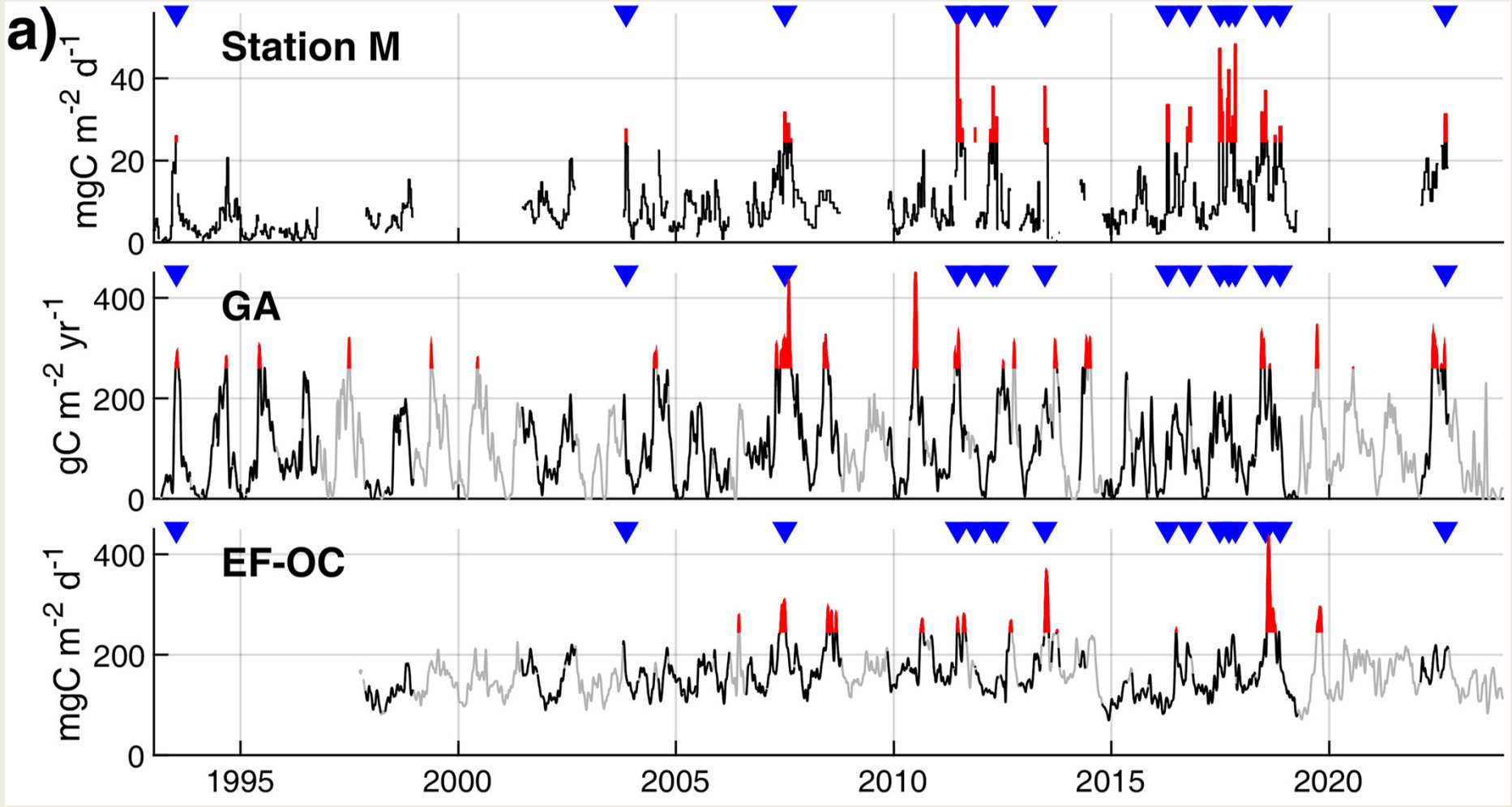


$R^2 = 0.20$

$R^2 = 0.18$

**Combined:**
**$R^2 = 0.24$**
(33% improvement)

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# Conclusions

- Satellite-derived export products are likely hindered by not considering **lags between phytoplankton** (ocean color) **and export**
- **Coastal upwelling, advection, and spatiotemporal lags** can predict surface export and deep-sea POC flux from satellite with similar accuracy as ocean color
- Variable upwelling and oceanic circulation create **patchiness** that can drive abyssal carbon pulses
- There is value in considering phyto and zoo contributions separately

Messié et al., GRL 2025

# Knowledge gaps and priorities

- Gaps:
  - estimates of zooplankton from space
  - inconsistencies in satellite NPP products
  - lags between production and export (may be variable?)
  - role of phytoplankton taxonomy
- Moving forward:
  - global database of intercalibrated export estimates
  - more export measurements coincident with SWOT & PACE
  - improved ocean currents (SWOT, ODYSEA)