Supporting Information for "Modeling Photosynthesis and Exudation of DOM in Subtropical Oceans"

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Text S1. Ecosystem and biogeochemical model equations

The model equations are based on Dutkiewicz et al. (2015) and Dutkiewicz et al. (2020). We consider the cycling of carbon, nitrogen, phosphorus, and iron. We also resolve explicit dynamic Chl-a (Geider et al., 1998). We resolve tow types of phytoplankton, PC_j, which uptake several nutrients, N_i, and are grazed by two types of zooplankton, ZC_k. Mortality and exudation from plankton and sloppy feeding by zooplankton contribute to a dissolved organic matter pool, DOM_i, and a particulate organic matter pool, POM_i. Subscript i refers to a nutrient/element, j to a phytoplankton type, and k to a zooplankton type. All tracers, X, are advected and diffused by three-dimensional flow fields. The complete set of equations are provided below.

$$\frac{\partial X}{\partial t} = -\nabla \cdot (\boldsymbol{u} X) + \nabla \cdot (\boldsymbol{K} \nabla X) + S_X \tag{S1}$$

Where $\boldsymbol{u} = (u, v, w)$, velocity in physical model, $\boldsymbol{K}$ is the mixing coefficient in physical model, and S_X is the source and sink term of tracer X.

Nutrients

$$S_{DIC} = -\sum_j P_{C,j} \cdot c_{P,j} + r_{DOC} \cdot DOC + F_C \tag{S2}$$

$$S_{PO_4} = -\sum_j R_j^{P:C} \cdot BS_{C,j} \cdot c_{P,j} + r_{DOP} \cdot DOP \tag{S3}$$

$$S_{HN_4} = -\sum_j \Gamma_{NH_4,j} \cdot R_j^{N:C} \cdot BS_{C,j} \cdot c_{P,j} + r_{DON} \cdot DON - k_{NH_4} \cdot NH_4 \tag{S4}$$

$$S_{NO_2} = -\sum_j \Gamma_{NO_2,j} \cdot R_j^{N:C} \cdot BS_{C,j} \cdot c_{P,j} + k_{NH_4} \cdot NH_4 - k_{NO_2} \cdot NO_2 \tag{S5}$$

$$S_{NO_3} = -\sum_j \Gamma_{NO_3,j} \cdot R_j^{N:C} \cdot BS_{C,j} \cdot c_{P,j} + k_{NO_2} \cdot NO_2 - k_{NO_3} \cdot NO_3 \tag{S6}$$

$$S_{FeT} = -\sum_j R_j^{Fe:C} \cdot BS_{C,j} \cdot c_{P,j} + r_{DOFe} \cdot DOFe + F_{atmos} + F_{sed} - c_{scav} \cdot Fe' \tag{S7}$$

Plankton

$$S_{c_{P,j}} = BS_{C,j} \cdot c_{P,j} - m_{P,j} \cdot c_{P,j} - \sum_k g_{j,k} \cdot c_{Z,k} - \frac{\partial(w_{P,j} \cdot c_{P,j})}{\partial z} \quad \text{(S8)}$$

$$S_{c_{R,j}} = P_{C,j} \cdot c_{P,j} - BS_{C,j} \cdot c_{P,j} - E_{C,j} \cdot c_{P,j} - m_{P,j} \cdot c_{P,j} \cdot Q_j^{RC} - \sum_k g_{j,k} \cdot c_{Z,k} \cdot Q_j^{RC} - \frac{\partial(w_{P,j} \cdot c_{P,j} \cdot Q_j^{RC})}{\partial z} \quad \text{(S9)}$$

$$S_{Chl_j} = \rho_j \cdot BS_{C,j} \cdot c_{P,j} - m_{P,j} \cdot c_{P,j} \cdot Q_j^{Chl} - g_{j,k} \cdot c_{Z,k} \cdot Q_j^{Chl} - \frac{\partial(w_{P,j} \cdot c_{P,j} \cdot Q_j^{Chl})}{\partial z} \quad \text{(S10)}$$

$$S_{c_{Z,k}} = \sum_j \xi_{j,k} \cdot g_{j,k} \cdot c_{Z,k} \cdot (1 + Q_j^{RC}) - m_{Z,k} \cdot c_{Z,k} \quad \text{(S11)}$$

Particulate and dissolved organic matter

$$S_{DOM_i} = r_{POM_i} \cdot POM_i \sum_j \varphi_{mp_{i,j}} m_{P,j} \cdot c_{P,j} + \sum_k \varphi_{mz_{i,k}} m_{Z,k} \cdot c_{Z,k} + \sum_j \sum_k \varphi_{i,j,k}(1 - \xi_{j,k}) \cdot g_{j,k} \cdot c_{Z,k} - r_{DOM_i} \cdot DOM_i \quad \text{(S12)}$$

$$S_{POM_i} = \sum_j (1 - \varphi_{mp_{i,j}}) m_{P,j} \cdot c_{P,j} + \sum_k (1 - \varphi_{mz_{i,k}}) m_{Z,k} \cdot c_{Z,k} + \sum_j \sum_k (1 - \varphi_{i,j,k})(1 - \xi_{j,k}) \cdot g_{j,k} \cdot c_{Z,k} - r_{POM_i} \cdot POM_i - \frac{\partial(w_{POM_i} \cdot POM_i)}{\partial z} \quad \text{(S13)}$$

Nutrient limitations

$$\gamma_{i,j} = \frac{N_i}{N_i + K_{N_i,j}} \quad i = NH_4, PO_4, FeT \quad \text{(S14)}$$

$$\gamma_{NO_2,j} = \frac{NO_2}{NO_2 + K_{NO_2,j}} e^{-\psi NH_4} \quad \text{(S15)}$$

$$\gamma_{NO_3,j} = \frac{NO_3}{NO_3 + K_{NO_3,j}} e^{-\psi NH_4} \quad \text{(S16)}$$

$$\Gamma_{NH_4,j} = \frac{\gamma_{NH_4,j}}{\gamma_{NH_4,j} + \gamma_{NO_2,j} + \gamma_{NO_3,j}} \quad \text{(S17)}$$

$$\Gamma_{NO_2,j} = \frac{\gamma_{NO_2,j}}{\gamma_{NH_4,j} + \gamma_{NO_2,j} + \gamma_{NO_3,j}} \quad \text{(S18)}$$

$$\Gamma_{NO_3,j} = \frac{\gamma_{NO_3,j}}{\gamma_{NH_4,j} + \gamma_{NO_2,j} + \gamma_{NO_3,j}} \quad \text{(S19)}$$

Chl-a synthesis

$$\rho_j = \theta_j^{max} \frac{P_{C,j}}{\alpha I \theta_{oj}} \tag{S20}$$

$$\theta_{oj} = \frac{\theta_j^{max}}{1 + \frac{\alpha I \ \theta_j^{max}}{2P_{C,j}^{Sat}}} \tag{S21}$$

Where $P_{C,j}$ is the photosynthesis rate of phytoplankton j (function in main text),

$P_{C,j}^{Sat}$ is light saturated photosynthesis rate of phytoplankton j (function in main text),

$BS_{C,j}$ is the biosynthesis rate of phytoplankton j (function in main text),

$E_{C,j}$ is the exduation rate of phytoplankton j (function in main text),

r_{DOM_i} is remineralization rate of DOM for element i, here C, N, P, Fe,

r_{POM_i} is remineralization rate of POM for element i, here C, N, P, Fe,

$R_j^{N_i:C}$ is $N_i : C$ ratio in phytoplankton j, here N, P, Fe,

$k_N H_4$ is oxidation rate of NH_4 to NO_2,

$k_N O_2$ is oxidation rate of NO_2 to NO_3,

$k_N O_3$ is denitrification rate of NO_3,

c_{scav} is scavenging rate for free iorn Fe',

F_{atmos} is atmospheric deposition of iron dust on ocean surface,

F_{sed} is the sedimentray source of iron,

F_C is air-sea flux of carbon dioxide,

Q_j^{RC} is the ratio of carbon reserve to functional carbon pool $c_{P,j}$ in phytoplankton j,

Q_j^{Chl} is the ratio of Chl-a to functional carbon pool $c_{P,j}$ in phytoplankton j,

$m_{P,j}$ is mortality rate for phytoplankton j,

$m_{Z,j}$ is mortality rate for zooplankton k,

$g_{j,k}$ is grazing rate of zooplankton k on phytoplankton j,

$\xi_{j,k}$ is grazing efficiency of zooplankton k on phytoplankton j,

$\varphi_{mp_{i,j}}$ is fraction of dead phytoplankton organic matter that goes to DOM_i,

$\varphi_{mz_{i,j}}$ is fraction of dead zooplankton organic matter that goes to DOM_i,

$\varphi_{m_{i,j,k}}$ is fraction of sloppy grazing that goes to DOM_i,

$w_{P,j}$ is sinking rate of phytoplankton j,

w_{POM_i} is sinking rate of POM_i,

$K_{N_i,j}$ is the half-saturation constant of nutrient i for phytoplankton j, here i = NH_4, NO_2, NO_3, PO_4, FeT,

ψ is the fixed nitrogen uptake inhibition coefficient by ammonia,

θ_j^{max} is the maximum Chl-a:C ratio in phytoplankton ja,

I is the flux of photosynthetically active radiation (PAR),

α is the initial slope of the photosynthesis-irradiance (PI) curve normalized to Chl-a.

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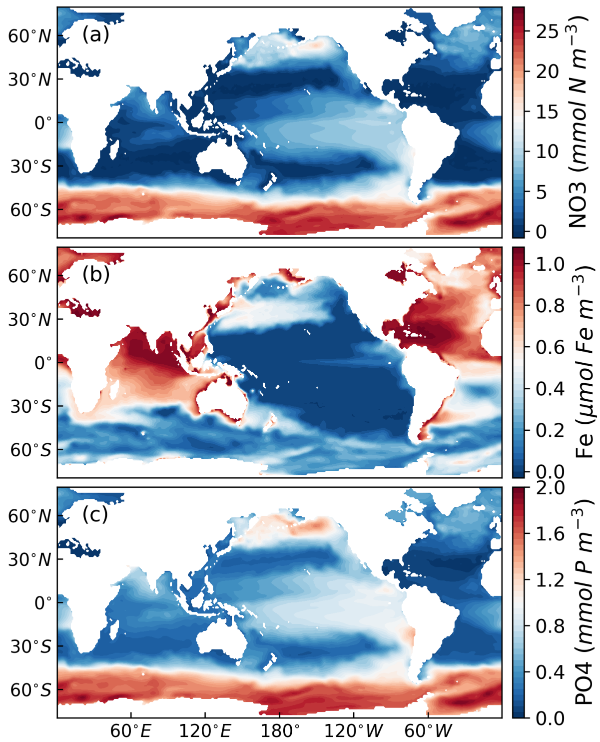

Figure S1. Simulated annual mean of nitrate, iron, and phosphate in decoupled model. (a) modeled nitrate (mean 0-50 m, $mmol\ N\ m^{-3}$), (b) modeled iron (mean 0-50 m, $\mu mol\ Fe\ m^{-3}$), (c) modeled phosphate (mean 0-50 m, $mmol\ P\ m^{-3}$).

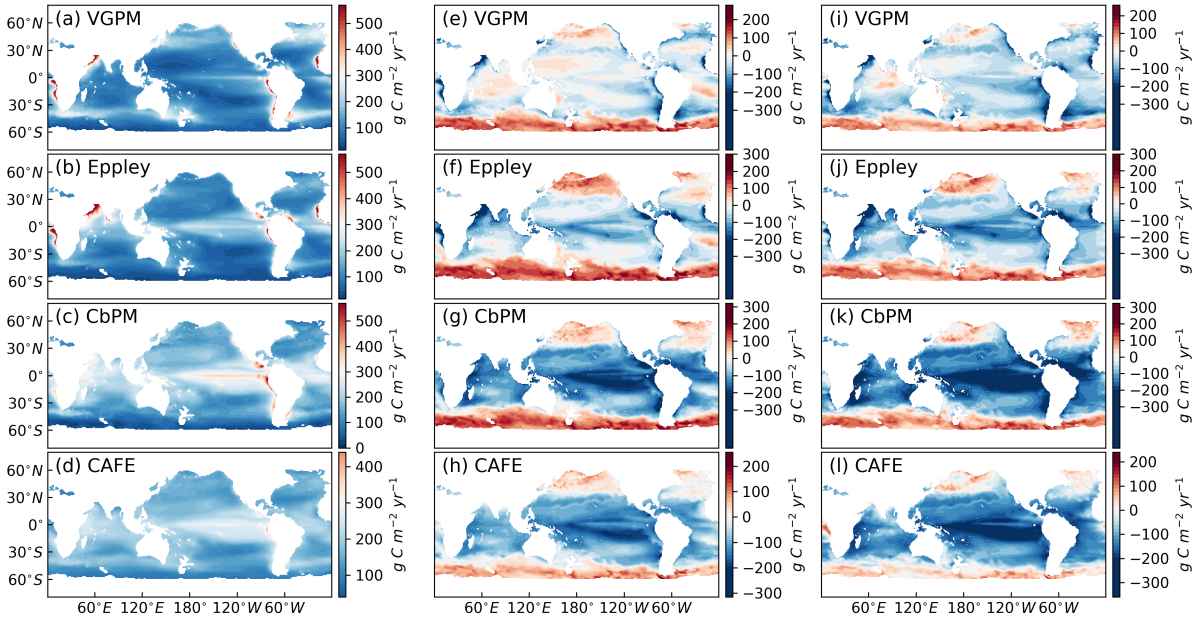

Figure S2. Comparison of model simulations and satellite-derived products of Chl-a and primary production. (a) to (d) are different satellite-derived products, namely VGPM (Vertically Generalized Production Model), Eppley-VGPM, CbPM (Carbon-based Productivity Model), and CAFE (Carbon, Absorption, and Fluorescence Euphotic-resolving model) ($gC\ m^{-2}\ yr^{-1}$), (e) to (h) are differences between primary production in decoupled simulation and satellite-derived products ($gC\ m^{-2}\ yr^{-1}$), (i) to (l) are differences between primary production in standard simulation and satellite-derived products ($gC\ m^{-2}\ yr^{-1}$).

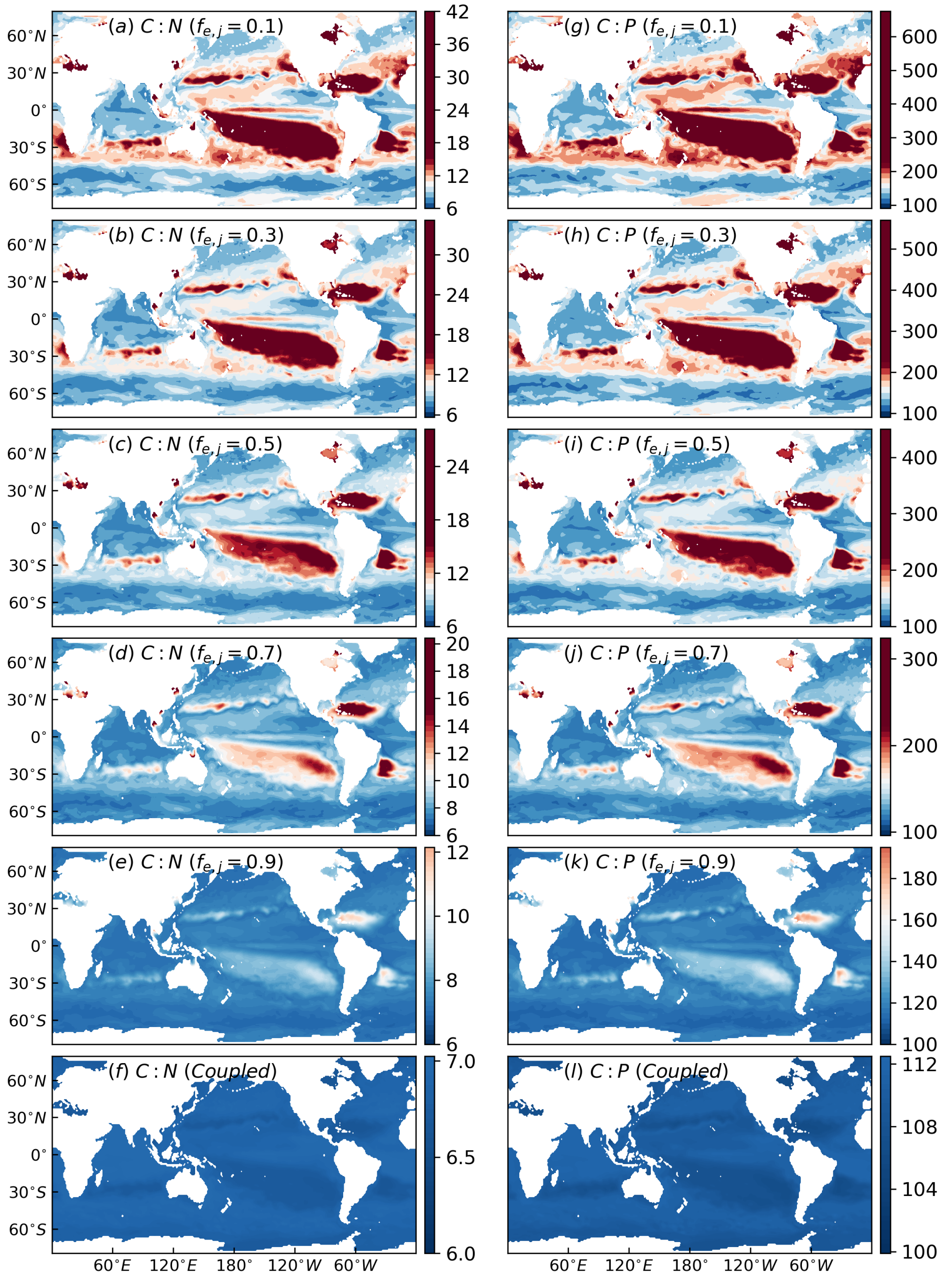

Figure S3. Simulated C:N and C:P ratios with different $f_{e,j}$. (a) to (e) are C:N ratios with $f_{e,j} = 0.1$ to 0.9, (g) to (k) are C:P ratios with $f_{e,j} = 0.1$ to 0.9. (f) and (l) are C:N and C:P ratios in coupled simulation. Opposite patterns of C:N and C:P ratios are observed between decoupled simulations and coupled simulation. In the decoupled simulations, C:N and C:P ratios are also sensitive to $f_{e,j}$.